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CROPS

Winter Rye as a Cover Crop Following Soybean under Conservation Tillage

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ABSTRACT

Rotation of corn (*Zea mays* L.) with soybean [*Glycine max* (L.) Merr.] provides certain economic and environmental advantages over monoculture corn. Low soybean residue production and persistence, however, promote potentially excessive soil erosion following soybean harvest. An irrigated field experiment was conducted in eastern Nebraska for 4 yr (1990–1993) under various tillage treatments and N rates to evaluate the effects of a winter rye (*Secale cereale* L.) cover crop following soybean on (i) rye dry matter yield, (ii) surface residue cover for erosion protection, and (iii) corn establishment and production. The soil was a Sharpsburg silty clay loam (fine, montmorillonitic, mesic Typic Argiudolls). Treatments were (i) no-tillage and disk tillage; (ii) corn following soybean with a winter rye cover crop (CBR), corn following soybean without rye (CB) and corn following corn (CC); and (iii) 0, 50, 100, 150, and 300 kg N ha^{-1} (applied to corn). Rye aboveground dry matter yield, surface residue cover, and corn yield parameters were estimated. Rye dry matter yield ranged from 0.25 to 2.9 Mg ha^{-1} and was influenced by tillage, N rate, and weather conditions in different years. During the years of high rye dry matter yield, presence of rye in the corn–soybean system gave approximately 16% additional surface residue cover prior to planting through cultivation, compared with soybean residue alone. Surface cover by rye and soybean residues in CBR was equivalent to corn residue in CC under both disk and no-till management. In 1 of the 3 yr, corn plant population and grain yield were reduced following rye (CBR) compared with the no rye system (CB), possibly due to apparent allelopathic effects related to the age of rye. No significant difference in N response was observed between CBR and CB corn yields. In general, rotation of corn with soybean (with and without rye) resulted in an increase of approximately 27% in corn grain yield and N uptake over continuous corn. During the years of high rye dry matter production, rye accumulated approximately 45 kg N ha^{-1} through aboveground dry matter. Overall, including a winter rye cover crop in the corn–soybean rotation system was beneficial.

ROTATION of corn with soybean increases the yield potential of corn and reduces residual soil NO_3–N in the root zone (Franzluebbers, 1994; Olson and Sander, 1982; Peterson and Varvel, 1989; Stecker et al., 1993; Walters and Shapiro, 1988). Low residue production by soybean and its rapid decomposition, however, can increase the risk of soil erosion following soybean. Soil loss following soybean has been observed to be 35% higher than following corn (Laflen and Moldenhauer, 1979; Miller et al., 1988).

Historically, cover crops have played an important role in soil and water conservation. Rye, a nonleguminous crop, has long been recommended as a winter cover crop because of its winter hardiness (Ditsch and Alley, 1991) and has been shown to provide additional mulch for no-till corn (Moschler et al., 1967) and soybean (Eckert, 1988). However, decomposing rye residues exhibit allelopathic effects on other plant species and retard their growth and development (Rice, 1995; Shilling et al., 1986). In Canada, Raimbault et al. (1990) demonstrated that planting a winter rye cover crop following corn harvest in a monoculture corn system provided adequate surface residue cover, but reduced subsequent corn grain yield because of apparent allelopathic effects. Additional research indicates that the adverse effects of rye on succeeding crop plants are not limited to its allelopathic properties. In Ohio, Eckert (1988) reported poor seed–soil contact and seedling rot for no-till corn following corn or soybean, as a result of an altered physical environment in the presence of rye residues. Also, during the decomposition of rye residues large amounts of residual soil NO_3–N and fertilizer N may be immobilized temporarily in the soil organic matter (Hargrove, 1986). Depending on soil conditions and seasonal rainfall distribution, this temporary reduction in N availability may lead to N deficiency in young corn plants affecting their growth and development. Ebelhar et al. (1984) and Blevins et al. (1990) found reductions in corn grain yield following a winter rye cover crop when no fertilizer N was applied to corn, but observed no reduction in corn grain yield if fertilizer N was applied. Possibly, one of the reasons for corn yield reduction was N deficiency caused by the immobilization of inorganic N during rye decomposition.

Although no-till fields are less susceptible to erosion than disk-tilled fields (Langdale et al., 1991; Unger, 1984), no-tillage management may not be a suitable

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Abbreviations: BC, soybean following corn; CB, corn following soybean; CBR, corn following soybean with a winter rye cover crop; CC, corn following corn.

Table 1. General physical and chemical characteristics of the soil at the experimental site (Mead, NE).

Soil characteristics	
Soil textural class	Silty clay loam
Sand, %	6
Silt, %	64
Clay, %	30
pH	5.9
Organic C, g kg^{-1}	17.6
Total N, g kg^{-1}	1.7
Total inorganic N, mg kg^{-1}	8.6
Cation exchange capacity, cmol$_c$ kg^{-1} soil	25.2
Bulk density, Mg m^{-3}	1.3

option under some cropping patterns. Eckert (1988) reported that including a winter rye cover crop in no-till continuous corn and corn–soybean rotation systems resulted in the formation of a thick mulch of rye residue on the soil surface and interfered with corn planting and led to reductions in plant stand and grain yield.

Our objectives were to evaluate under no-tillage, disk tillage, and various N rates (i) the dry matter yield, surface residue cover, and persistence of a winter rye cover crop planted following soybean harvest in a corn–soybean rotation system and (ii) corn establishment and yield as influenced by rotation and rye cover crop.

MATERIALS AND METHODS

An irrigated field study was conducted at the Agricultural Research and Development Center at Mead, NE, between 1990 and 1993 on a corn–soybean rotation plot previously established in 1989. The soil was a Sharpsburg silty clay loam (fine, montmorillonitic, mesic, Typic Argiudolls). Physical and chemical properties of the soil and general weather conditions for the three growing seasons are given in Tables 1 and 2, respectively. The experimental design was a split-split plot arrangement of a randomized complete block with three replications. Main plot treatments were two tillage systems: spring disk and no-till, with a cultivation in both systems for weed control. Subplot treatments were three crop rotations: (i) corn following soybean with a winter rye cover crop (CBR), (ii) corn following soybean without a winter rye cover crop (CB), and (iii) corn following corn (CC). The sub-subplot treatments were five N rates: 0, 50, 100, 150, and 300 kg N ha^{-1}. The size of a sub-subplot under corn following soybean with and without winter rye cover crop (CBR and CB) was 12.2 by 3.05 m (4 rows of corn), but was 12.2 by 6.1 m (8 rows of corn) for corn following corn (CC). All the plots were sprinkler irrigated with a linear move irrigation system based on rainfall and evapotranspiration rates. Additional subplots were included for the cropping sequences soybean following corn with and without winter rye cover crop, so that all crops were grown all years.

Corn (hybrid Pioneer 3189[1]) was planted in 76-cm rows at a rate of 72 000 seeds ha^{-1} using a fluted coulter to ensure good seed–soil contact. In 1990, 1992, and 1993, disking and planting were performed during the second week of May. In 1991, tillage and planting were delayed until 21 May due to heavy spring rainfall. Every year prior to tillage and planting, N was surface broadcast on corn plots under disk and no-till as NH_4NO_3 prills. Fertilizer N in disk treatment was then incorporated into soil through disk tillage. Plots where soybean

[1] Mention of a particular product or company does not imply endorsement or preference over similar products not mentioned.

Table 2. Prevailing weather conditions for the study period (1991–1993) at Mead, NE.

Description	1991	1992	1993
Precipitation, mm			
Annual	739	643	864
30-yr annual norm	737	737	737
Growing season (May–Sept.)	536	409	747
30-yr seasonal norm	475	475	475
Irrigation, mm	152	25	0
Growing degree days (GDD)†			
Rye (April–May)	255	262	287
Corn and soybean (May–Sept.)	1630	1434	1409
Days below 0°C (minimum) (April)			
1–14 April	2	4	5
15–30 April	1	5	0
Solar radiation, J m^{-2} × 10^9 (May–Sept.)	2.60	2.75	2.52

† GDD = $[(T_{max} + T_{min})/2]$ − Base temperature, where base and ceiling temperatures are 4.4 and 25°C, respectively, for rye and 10 and 30°C for corn and soybean.

was planted following corn did not receive N fertilizer. Soybean ('Century 84') was planted at a seed rate of 500 000 plants ha^{-1} in a row spacing of 76 cm before 25 May each year. Soon after planting, a mixture of preemergence herbicides alachlor [2-chloro-*N*-(2,6-diethylphenyl)-*N*-(methoxymethyl) acetamide] at 2.2 kg a.i. ha^{-1} and cyanazine {2-[[4-chloro-6-(ethylamino)-1,3,5-triazin-2-yl]amino]-2-methylpropanenitrile} at 2 kg a.i. ha^{-1} was applied to corn, while soybean received an application of alachlor at 2.2 kg a.i. ha^{-1} for weed control.

Cultivation was done both under disk tillage and no-tillage at the V7 stage for corn and the V5–V6 stage for soybean using a Buffalo till cultivator. The cultivator was driven through the field only once, so that it just loosened the soil without causing much disturbance to residue cover on the soil surface.

In the fall of 1990, 1991, and 1992, immediately after the soybean harvest, winter rye ('Aroostook') was drilled into soybean stubble in 17.8-cm rows at a rate of 62 kg seeds ha^{-1}. In the spring of 1991 (7 May), 1992 (8 May), and 1993 (7 May), prior to tillage and N application, rye was hand-harvested at the vegetative stage from five randomly selected 0.09-m^2 areas per replicate in all tillage × N rate treatments (sub-subplot). Total N content of aboveground rye tissue was determined by the Kjeldahl method (Bremner and Mulvaney, 1982). Subsequently, aboveground dry matter yield and N uptake of rye were estimated per hectare on a dry weight basis. Rye was then killed by spraying glyphosate (*N*-[phosphonomethyl] glycine) at 3 kg a.i. ha^{-1}.

Prior to tillage, after planting, and after cultivation, surface residue cover was estimated in all rotation and tillage treatments by using a 100-point line-transect method (Shelton et al., 1990). Five counts per plot were taken each time with a 20-point line-transect and the cumulative residue count was expressed in percentage. No residue count was taken after cultivation in 1993.

Corn grain was hand-harvested from 12.2 m of row in the middle of the plot at physiological maturity during the first week of October each year. Stover was harvested from 6.1 m of the 12.2 m harvested for grain. Plant and ear numbers were counted to estimate the percent barren stalks at harvest. Total N content in corn grain and stover was determined by the Kjeldahl method. Subsequently, the yield and N uptake of grain and stover were estimated per hectare on a dry weight basis.

Analysis of variance was computed using the general linear models (GLM) procedure (SAS Inst., 1992) to detect differences among treatment means. Probability levels of at least 0.05 or lower were used to test the statistical significance of all treatment effects. Since N rates were unequally spaced, orthogonal contrasts for unequally spaced treatment levels were used to test N effects. Also appropriate contrasts were computed

Table 3. Analysis of variance for tillage and N (applied to corn) effects on rye aboveground dry matter yield and N uptake at Mead, NE (1991-1993).

		Rye dry matter			Rye N uptake		
Source	df	1991	1992	1993	1991	1992	1993
Tillage	1	NS	NS	*	NS	NS	NS
N rate	4	*	NS	NS	NS	NS	NS
Linear	1	*	NS	NS	*	NS	NS
Quadratic	1	NS	NS	NS	NS	NS	NS
Tillage × N rate	4	NS	NS	*	NS	NS	*
(Disk vs. No-till) ×							
Linear	1	*	NS	NS	NS	NS	NS
Quadratic	1	NS	NS	*	NS	NS	NS

, Significant at the 0.05 and 0.01 probability levels, respectively.

to test the effects of crop rotation on residue cover and corn production.

RESULTS AND DISCUSSION

Rye Dry Matter Yield and N Uptake

Excellent rye stands were successfully established in the fall of each year. By spring, however, rye dry matter yield and N uptake were influenced by tillage and/or N applied to corn (Table 3 and Fig. 1). Winter and spring weather conditions also played an important role in determining the rye growth. Overall, rye aboveground dry matter yield averaged 1.62, 0.26, and 1.08 Mg ha^{-1} in 1991, 1992, and 1993, respectively (Fig. 1). In 1992, rye plants were small, with some unevenness in crop stand. Diminished rye dry matter yield in 1992 was due in part, to seedling injury caused by below normal November temperatures in 1991 (November 1991 monthly mean temperature of −1.7°C vs. the 30-yr average for November of 3.9°C), and retarded spring growth caused by unseasonably cold nights in early spring of 1992 (diurnal low temperatures were below 0°C nine times, five of which occurred during the last 10 d of April; Table 2). Research indicates that seedling injury due to cold winter temperatures and/or retarded seedling growth because of low spring temperatures (<15.6°C) would result in a low rye dry matter yield (Nuttonson, 1957, p. 8-25).

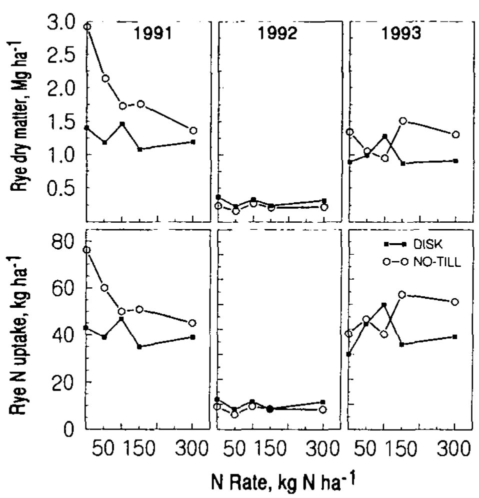

Fig. 1. Rye dry matter yield and N uptake as influenced by tillage and N applied to corn (Mead, NE; 1991-1993).

Tillage and N rate influenced the aboveground rye dry matter yield and N uptake in 1991 and 1993 (Table 3), years with >1 Mg ha^{-1} dry matter yield (Fig. 1). In 1991, an inverse linear relationship was observed between previous-year N rate and rye dry matter yield and N uptake under no-till (Fig. 1). A maximum rye yield of 2.90 Mg ha^{-1} and N uptake of 76 kg N ha^{-1} were obtained under no-till when no N had been applied to corn the previous year. In contrast, in 1993 the rye dry matter yield and N uptake exhibited a positive response to previous-year N rate under no-till. Recently, residual fertilizer N effects on winter rye yield and N uptake following no-till corn (corn/rye system) was demonstrated by Ditsch et al. (1993). The inverse linear trend observed in rye yield and N uptake under no-till management in 1991 could not be explained. Although rye following soybean responded to N rates applied to corn, soybean that immediately succeeded corn did not respond to N applied to corn. We think that this lack of response by soybean is related to its ability to fix atmospheric N. High dry matter yield obtained under no-till may have been due to better soil moisture conditions during fall resulting in good seed germination and crop stand than disk tillage. An average of 48, 9, and 42 kg N ha^{-1} was accumulated in rye residue to the succeeding corn crop in 1991, 1992, and 1993, respectively.

Surface Residue Cover

Surface residue cover serves as a measure of the susceptibility of a field to soil erosion and is a function of the amount and persistence of crop residue present on the soil surface (Shelton et al., 1990). Surface residue cover was influenced by crop rotation and tillage each year, and declined during the growing season (Table 4). During the years of high rye dry matter production (1991 and 1993), an average 1.4 Mg ha^{-1} rye dry matter yield in CBR rotation resulted in surface residue cover comparable to that of corn residue (CC). The combined surface residue cover obtained from soybean and rye residues in the CBR system, under either disk or no-till management exceeded 30% until the development of sufficient corn canopy cover and reduced the potential for soil erosion in this system. This agrees with the findings reported by Triplett (1986) that, under a no-till system, rye planted as a winter cover crop following either monoculture corn or soybean gave persistent mulch and maintained good soil cover.

As expected, tillage played a significant role in surface residue management (Table 4). In all years, disk tillage produced a decline in residue cover relative to no-till because of residue incorporation. In the no-till system, however, rye residue resulted in persistent cover until cultivation. After cultivation in 1991, soybean residue cover was reduced to 12% in disk and 27% in no-till, while soybean/rye cover was reduced to 31% in disk and 76% in no-till. A similar trend was also recorded in 1992, except for the rye effect. Overall, though rotation corn produced on the average 18% (3-yr mean) more

Table 4. Percentage surface residue cover and analysis of variance for tillage and rotation treatments during the study period at Mead, NE (1991-1993).

		1991			1992			1993	
Treatments	df	ResI†	ResII	ResIII	ResI	ResII	ResIII	ResI	ResII
		%							
Tillage									
Disk		93	48	29	82	29	22	88	54
No-till		90	75	59	83	81	43	89	80
Rotation									
CB (soybean residue)		80	34	20	72	45	22	76	51
CBR (soybean + rye residue)		98	81	53	75	49	23	90	66
BC (corn residue)		96	66	52	91	63	45	95	75
CC (corn residue)		92	67	52	91	63	42	95	76
Tillage × Rotation									
Disk									
CB		81	28	12	72	21	15	75	38
CBR		98	63	31	75	23	16	89	51
BC		96	51	38	90	36	30	94	62
CC		96	52	36	91	37	28	96	63
No-till									
CB		78	41	27	73	69	29	77	63
CBR		98	98	76	75	74	29	90	81
BC		96	80	66	93	90	59	95	88
CC		87	82	68	92	89	55	94	89
					Probability				
Source of variation									
Tillage	1	NS	*	*	NS	*	*	NS	*
Rotation‡	3	**	**	**	**	**	**	**	**
CB vs. CBR	1	**	**	**	NS	*	NS	**	**
CBR vs. (BC + CC)	1	NS	**	NS	**	**	NS	**	**
BC vs. CC	1	NS	NS	NS	NS	NS	NS	NS	NS
Tillage × Rotation	3	NS	**	**	NS	NS	**	NS	NS
(Disk vs. No-till) ×									
(CB vs. CBR)	1	NS	**	**	NS	NS	NS	NS	NS
(CBR vs. BC + CC)	1	NS	*	*	NS	NS	*	NS	NS
(BC vs. CC)	1	NS	NS	NS	NS	NS	NS	NS	NS

,,** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.
† ResI, pre-tillage; ResII, post-planting; ResIII, post-cultivation.
‡ CBR, corn following soybean + winter rye cover crop; CB, corn following soybean; BC, soybean following corn; CC, corn following corn.

stover than continuous corn (Table 5), there was no difference in the percentage of surface residue cover between these two systems.

Corn Grain Yield and N Uptake

Average corn grain yields of 6.77, 10.21, and 5.14 Mg ha^{-1} were obtained in 1991, 1992, and 1993, respectively, when corn was grown in rotation with soybean (with and without rye) (Table 5). Average corn yields for this region of Nebraska followed a similar trend during these years. Excessive spring precipitation that delayed planting in 1991 and a below-normal solar radiation and growing degree days in 1993 contributed to lower corn yields in these years (Table 2).

In 1992, corn grain yield for the corn-soybean/rye (CBR) rotation was 9.3% less than for the corn-soybean rotation (CB), but did not differ significantly in 1991 and 1993 (Tables 5 and 6). Reduction in corn total dry matter and grain yield following a winter rye cover crop has been reported by several authors (Eckert, 1988; Rice, 1995; Raimbault et al., 1990; Tollenaar et al., 1992). In Canada, Raimbault et al. (1990) and Tollenaar et al. (1992) attributed the reduction in corn yield following a winter rye to allelopathic effects of rye, as allelochemicals produced by live rye plants and decomposing residues have been shown to affect the growth and development of corn and other plant species (Barnes and Putnum, 1983, 1986; Chase et al., 1991). On the other hand, Eckert (1988) reported that corn yield reduction following winter rye was not due to allelopathic effects of rye but due to rye residues present on the soil surface that interfered with corn planting, leading to reduced crop stand and grain yield.

In our study, however, corn was planted using a planter equipped with fluted coulters to cut through rye residues in order to establish good seed-soil contact and prevent corn yield reduction from improper planting. Therefore, we propose that the grain yield reduction in corn following winter rye cover crop was due to allelopathic effects of rye on corn. In a greenhouse study, Wojcik-Wojtkowiak et al. (1990) reported that tillering-stage rye residue exhibited the greatest level of phytotoxicity to germinating corn seeds during decomposition. This suggests that age of the rye crop at the time of its death in spring may play an important role in determining the degree of its phytotoxicity to corn. In this study, since corn yield reduction occurred only when rye dry matter yield was low due to retarded growth and development of rye, it is likely that relatively young rye tissues at the tillering stage exhibited strong phytotoxicity to corn and caused the significant yield reduction observed in 1992. Final plant population was reduced 6% in the CBR rotation, as compared with the CB rotation in 1992, suggesting poor corn seed germination. In 1991 and

Table 5. Mean corn grain and stover yields and N uptake, plant population and barren stalk as influenced by rye, rotation, tillage, and N rate at Mead, NE (1991-1993).

Variable	Grain yield	Grain N uptake	Stover yield	Stover N uptake	Population	Barren stalk
	Mg ha^{-1}	kg ha^{-1}	Mg ha^{-1}	kg ha^{-1}	plants ha^{-1} × 10^3	%
			1991			
Tillage						
Disk	5.91	82	4.44	31	65.8	14
No-till	6.22	89	5.41	36	69.4	15
Rotation†						
CB	6.79	92	5.31	37	69.8	9
CBR	6.74	93	5.77	38	70.2	13
CC	4.60	72	3.70	26	62.7	22
N rate						
0	5.14	67	4.30	23	64.2	18
50	6.55	88	5.08	31	69.3	12
100	5.98	92	4.83	35	70.0	15
150	6.36	93	5.44	39	68.3	15
300	6.27	88	4.97	40	66.1	12
Tillage × N rate						
Disk						
0	5.85	77	4.03	22	62.3	13
50	6.44	88	4.92	31	69.0	8
100	5.31	78	4.44	33	65.2	15
150	6.03	85	4.34	32	67.8	16
300	5.93	83	4.48	38	64.5	16
No-till						
0	4.44	57	4.57	23	66.2	23
50	6.66	88	5.25	31	69.6	16
100	6.72	106	5.21	37	74.8	14
150	6.70	100	6.55	47	68.3	13
300	6.61	93	5.46	42	67.9	9
			1992			
Tillage						
Disk	9.31	113	6.60	51	67.1	5
No-till	9.18	122	6.92	54	66.5	3
Rotation†						
CB	10.71	130	6.98	54	67.7	2
CBR	9.71	120	7.11	57	63.3	3
CC	7.32	87	6.19	46	69.4	7
N rate						
0	8.21	80	6.08	30	67.2	5
50	9.53	108	6.62	40	67.6	3
100	9.95	128	7.03	58	67.9	4
150	9.77	127	6.99	65	65.7	3
300	8.76	119	7.07	69	65.7	6
Tillage × N rate						
Disk						
0	8.60	82	6.16	31	64.9	5
50	9.61	108	6.86	44	68.5	3
100	9.99	132	6.77	57	68.4	5
150	9.72	127	6.21	55	65.8	3
300	8.60	117	6.97	68	68.0	7
No-till						
0	7.81	78	6.00	29	69.5	5
50	9.45	108	6.39	36	66.7	2
100	9.90	124	7.29	59	67.4	2
150	9.82	127	7.77	75	65.7	3
300	8.92	123	7.18	70	63.5	4

continued

Table 5. cont'd.

Variable	Grain yield	Grain N uptake	Stover yield	Stover N uptake	Population	Barren stalk
			1993			
Tillage						
Disk	4.96	66	5.25	45	66.0	6
No-till	4.59	59	4.92	41	62.6	8
Rotation†						
CB	5.10	67	5.30	46	63.4	7
CBR	5.17	70	5.25	44	66.5	8
CC	4.05	51	4.71	38	63.1	6
N rate						
0	4.45	48	4.86	30	62.2	7
50	5.07	63	5.15	37	66.1	7
100	4.87	66	4.93	43	64.5	9
150	4.69	66	5.32	51	63.3	5
300	4.80	71	5.17	52	65.6	7
Tillage × N rate						
Disk						
0	4.73	51	5.29	34	64.3	6
50	5.26	67	5.20	39	68.8	7
100	5.08	70	5.14	46	67.3	8
150	4.82	68	5.49	52	65.4	5
300	4.91	73	5.16	54	64.3	4
No-till						
0	4.17	44	4.43	27	60.1	7
50	4.87	59	5.11	35	63.4	7
100	4.65	62	4.72	40	61.7	10
150	4.56	63	5.16	50	61.2	5
300	4.68	68	5.18	51	66.8	10

† CB, corn following soybean; CBR, corn following soybean + winter rye cover crop; CC, corn following corn.

1993, no adverse effects of rye were observed on corn population.

Overall, no significant difference in response to N application was observed between the rye and no rye system (Table 6 and Fig. 2). This indicated that rye residue did not affect N availability to corn as it decomposed in soil. Presumably, with a low C:N ratio (15:1) and high soluble C content (59%) rye residue decomposed easily without adversely affecting net N mineralization.

Overall, rotation of corn with soybean (with or without a winter rye cover crop) led to increases of 27% grain yield, 19% stover yield, 26% grain N uptake, and 24% stover N uptake over continuous corn (Table 5). Greater yield potential of rotation corn may be due, in part, to an early and increased N availability from soybean and rye residues, and non-N rotation effects (Baldock et al., 1981; Crookston, 1984). In 1991, late planting of corn resulted in a greater percentage of barren stalks than observed in 1992 and 1993 (Table 5), due to a severe infestation of stem borer [*Ostrinia nubilalis* (Hübner)].

In general, corn grain yield, stover yield, and grain and stover N uptake responses to N application rates were quadratic (Table 6). Overall, grain yield (Table 6 and Fig. 2) and N uptake (Table 6) of rotation corn exhibited a diminished response to N application when compared with continuous corn. Regardless of rotation, however, application of N beyond 50 kg N ha^{-1} did not significantly increase corn grain yield in 1991 and 1993. But in 1992, significant increase in grain yield was observed up to 100 kg N ha^{-1} (Table 5). No-till corn exhibited a better response to N application than disked corn in grain and stover yields in 1991, and stover yield and N uptake in 1992 (Table 5 and Table 6). Prior to planting corn in spring, residual soil NO_3-N in the top 1.5 m was determined in selected N rate plots in a companion study (Kessavalou, 1994). In general, residual soil NO_3-N in the the top 0- to 1.5-m soil layer under no till was relatively low compared with disk tillage across N rates throughout the study period. During the spring of 1992, NO_3-N in the 0- to 1.5-m layer under no-till was 13 to 47% less than disk tillage across N rates. Therefore, we hypothesize that the greater response to N application observed under no-till was due, partly, to low residual soil NO_3-N, greater potential for denitrification loss and net N immobilization than disk tillage (Doran, 1980).

Table 6. Analysis of variance for rye, rotation, N rate, and tillage effects on corn grain and stover yields and N uptake, plant population, and barren stalk at Mead, NE (1991-1993).

		Probability > *F*					
Source	df	Grain yield	Grain N uptake	Stover yield	Stover N uptake	Population	Barren stalk
				1991			
Tillage	1	NS	NS	NS	NS	NS	NS
Rotation†	2	**	NS	**	NS	*	**
CB vs. CBR	1	NS	NS	NS	NS	NS	NS
(CB + CBR) vs. CC	1	**	NS	**	NS	**	**
N rate	4	*	**	*	**	NS	NS
Linear	1	*	**	*	**	NS	NS
Quadratic	1	NS	**	*	NS	*	NS
Tillage × Rotation	2	*	NS	NS	NS	NS	NS
(Disk vs. No-till) ×							
CB vs. CBR	1	*	NS	NS	NS	NS	NS
(CB + CBR vs. CC)	1	NS	NS	NS	NS	NS	NS
Tillage × N rate	4	*	NS	*	NS	NS	NS
(Disk vs. No-till) ×							
Linear	1	*	NS	*	NS	NS	*
Quadratic	1	*	NS	NS	NS	NS	NS
Rotation × N rate	8	NS	NS	NS	NS	NS	NS
(CB vs. CBR) ×							
Linear	1	NS	NS	NS	NS	NS	NS
Quadratic	1	NS	NS	NS	*	NS	NS
(CB + CBR vs. CC) ×							
Linear	1	NS	*	NS	NS	NS	NS
Quadratic	1	NS	NS	NS	NS	NS	NS
Tillage × Rotation × N rate	8	NS	NS	NS	NS	NS	NS
				1992			
Tillage	1	NS	NS	NS	NS	NS	NS
Rotation†	2	**	**	NS	*	NS	NS
CB vs. CBR	1	*	NS	NS	NS	*	NS
(CB + CBR) vs. CC	1	**	**	*	*	*	**
N rate	4	**	**	*	**	NS	NS
Linear	1	NS	**	*	**	NS	NS
Quadratic	1	**	**	*	**	NS	NS
Tillage × Rotation	2	NS	NS	NS	NS	NS	NS
(Disk vs. No-till) ×							
CB vs. CBR	1	NS	NS	NS	NS	NS	NS
(CB + CBR vs. CC)	1	NS	NS	NS	NS	NS	NS
Tillage × N rate	4	NS	NS	*	**	NS	NS
(Disk vs. No-till) ×							
Linear	1	NS	NS	NS	*	NS	NS
Quadratic	1	NS	NS	*	*	*	NS
Rotation × N rate	8	*	NS	NS	NS	NS	NS
(CB vs. CBR) ×							
Linear	1	NS	NS	NS	NS	NS	NS
Quadratic	1	NS	NS	NS	NS	NS	NS
(CB + CBR vs. CC) ×							
Linear	1	NS	NS	NS	NS	NS	NS
Quadratic	1	*	*	NS	NS	NS	*
Tillage × Rotation × N rate	8	NS	NS	NS	NS	NS	NS
				1993			
Tillage	1	NS	NS	NS	NS	NS	NS
Rotation†	2	**	**	NS	*	NS	NS
CB vs. CBR	1	NS	NS	NS	NS	NS	NS
(CB + CBR) vs. CC	1	**	**	*	*	NS	NS
N rate	4	*	**	NS	**	NS	*
Linear	1	NS	**	NS	**	NS	NS
Quadratic	1	NS	**	NS	**	NS	NS
Tillage × Rotation	2	NS	NS	NS	NS	NS	NS
(Disk vs. No-till) ×							
CB vs. CBR	1	NS	NS	NS	NS	NS	NS
(CB + CBR vs. CC)	1	NS	NS	NS	NS	NS	NS
Tillage × N rate	4	NS	NS	NS	NS	NS	NS
(Disk vs. No-till) ×							
Linear	1	NS	NS	NS	NS	*	NS
Quadratic	1	NS	NS	NS	NS	NS	NS
Rotation × N rate	8	NS	*	NS	NS	NS	NS
(CB vs. CBR) ×							
Linear	1	NS	NS	NS	NS	NS	NS
Quadratic	1	NS	NS	NS	*	NS	NS
(CB + CBR vs. CC) ×							
Linear	1	*	*	NS	NS	NS	NS
Quadratic	1	*	NS	NS	NS	NS	NS
Tillage × Rotation × N rate	8	NS	NS	NS	NS	NS	NS

,,** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† CB, corn following soybean; CBR, corn following soybean + winter rye cover crop; CC, corn following corn.

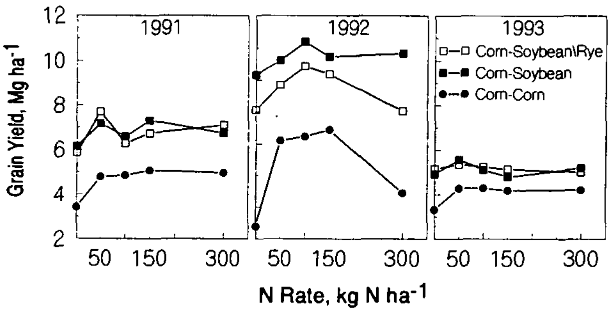

Fig. 2. Corn grain yield as a function of crop rotation and N rate (Mead, NE; 1991-1993).

CONCLUSIONS

Winter rye proved to be a suitable cover crop when planted into soybean stubble. An average of 1.4 Mg ha^{-1} of rye dry matter yield was sufficient to provide a persistent surface cover for erosion protection comparable to that of corn residue. Winter rye establishment for cover was successful in 2 out of 3 yr, but limited cover and a small reduction in grain yield of the succeeding corn resulted when rye development was delayed by successive early spring frosts. Because allelopathic phytotoxicity of rye residue has been reported to be inversely related to age of the plant, we suggest that weather-retarded development of the winter rye crop perhaps caused reduction in 1992 corn yield due to an allelopathic stand reduction. Rye recovered an average of 34 kg N Mg^{-1} aboveground dry matter yield making it an excellent crop for scavenging residual soil NO_3-N present in the root zone.

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