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Hard Red Spring Wheat Response Following the Intercropping of Legumes into Sunflower

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ABSTRACT

Intercropping legumes in sunflower (*Helianthus annuus* L.) may increase soil cover, reduce soil erosion, and increase soil C and N. Subsequent effects of this practice on hard red spring wheat (HRSW) [*Triticum aestivum* (L.) Emend. Thell.] yield and protein content were unknown. Our objective was to quantify effects of intercropping various legumes into sunflower on spring soil nitrate-nitrogen (NO_3^-–N) and grain yield and protein content of a subsequent HRSW crop. Field experiments were conducted near Carrington and Prosper, ND, from 1993 through 1995. Wheat was planted into non-legume plots and those previously intercropped with hairy vetch (*Vicia villosa* Roth), yellow-flowered sweetclover (*Melilotus officinalis* Lam.), alfalfa (*Medicago sativa L.), snail medic* [*Medicago scutellata* (L.) Mill.], or black lentil (*Lens culinaris* Medik.). Soil NO_3^-–N (0–30 cm) in plots previously intercropped with hairy vetch (41 kg ha^{-1}) was greater than control plots (26 kg ha^{-1}). Yield of HRSW was reduced at both Carrington and Prosper in 1993 when grown after a sweetclover intercrop. Yield of HRSW was reduced at Carrington in 1993 when grown after an alfalfa intercrop. Wheat grown after sweetclover intercropped in sunflower had higher protein content (142.0 g kg^{-1}) than HRSW grown after sunflower (140.6 g kg^{-1}) alone. Overall, intercropping hairy vetch at the V4 sunflower growth stage appears superior because it did not reduce sunflower yield, provided soil cover adding between 540 and 2400 kg ha^{-1} above ground dry matter to the system, and increased NO_3^-–N levels at the beginning of the HRSW season in two environments.

Sunflower, when seeded in rows, can result in severe soil erosion during and after the growing season (Deibert, 1987). In a previous study, we evaluated effects of intercropping legumes into sunflower as a technique to increase surface residue cover (Kandel et al., 1997). We reported reduced sunflower yield when hairy vetch, sweetclover, alfalfa, and snail medic were seeded at the same time as sunflower. However, seeding these legumes at the V4 or V10 (Schneiter and Miller, 1981) sunflower growth stages did not reduce sunflower yield. Hairy vetch provided 1593 and 831 kg ha^{-1} dry matter when seeded at the V4 or V10 sunflower growth stages, respectively (Kandel et al., 1997).

Some potential benefits to the farming system of intercropping a legume in sunflower are dinitrogen fixation, soil erosion control, and improvement of the soil structure and organic matter content (Biederbeck and Bouman, 1994). Intercropping may also improve snow trapping and green manure production during the year after legume establishment (Lilleboe, 1991).

Shading by sunflower may decrease growth and dinitrogen fixing ability of the intercropped legumes (Morris and Garrity, 1993). Application of N to legume-based intercrops will usually favor the growth of the nonlegume and further reduce dinitrogen fixation of the legume (Midmore, 1993; Davis and Woolley, 1993). Most legume-fixed dinitrogen will usually benefit only subsequent crops as opposed to the intercrop (Stern, 1993). For example, Jordan et al. (1993) reported that 8 wk after alfalfa was incorporated into the soil, corn (*Zea mays* L.) had recovered 8 to 10% of N fixed by alfalfa, the rest remained in the soil fraction.

Biederbeck et al. (1993) reported that under dry soil conditions legume growth and nodule number were reduced, limiting dinitrogen fixation. Brown et al. (1993) reported that hairy vetch intercropped into corn in August and chemically burned down the following spring, significantly increased soil NO_3^-–N in the top 15 cm, when measured 50 and 78 d after planting the subsequent crop.

Soil NO_3^-–N tests measure the amount of plant available NO_3^- but do not account for N in the unavailable organic form. Ladd et al. (1981) reported that wheat took up between 11 and 17% of labeled ^{15}N from legume material that had been decomposing for 8 mo. They concluded that increased soil organic N was the main benefit derived from planting a legume.

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Abbreviation: HRSW, hard red spring wheat.

Table 1. Dates of seeding and harvesting of sunflower, legumes, and wheat. Mean experiment yields of sunflower and wheat. Dates of soil sampling and fertilizer applied at Carrington and Prosper, ND, 1992 to 1995.

	Environment				
	Carrington		Prosper		
Event	1992–1993	1993–1994	1992–1993	1993–1994	1994–1995
	1992	1993	1992	1993	1994
Seeding sunflower	28 May	19 May	27 May	18 May	18 May
Seeding legumes PLT†	28 May	19 May	27 May	18 May	18 May
Seeding legumes V4	23 June	21 June	22 June	18 June	13 June
Seeding legumes V10	16 July	8 July	10 July	9 July	23 June
Harvest sunflower SW101‡	30 Sept	29 Sept	5 Oct	23 Sept	19 Sept
Harvest sunflower IS3311	7 Oct	14 Oct	9 Oct	4 Oct	29 Sept
Sampling legumes	21 Oct	16 Oct	14 Oct	20 Oct	14 Oct
Mean sunflower yield kg ha^{-1}	1312	686	2349	2042	2456
Mean legumes biomass kg ha^{-1}	357	1622	788	1436	1573
	1993	1994	1993	1994	1995
Soil sampling before seeding wheat	15 Apr	29 Apr	19 Apr	14 Apr	12 May
N fertilizer applied kg ha^{-1}§	46	99	88	44	35
Seeding wheat	22 Apr	5 May	27 Apr	21 Apr	22 May
Control regrowth of sweetclover and alfalfa	13 May	12 May	12 May	3 May	24 May
Soil sampling in legume plots	7 June	1 June	4 June	26 May	22 Jun
Harvesting wheat	19 Aug	15 Aug	16 Aug	11 Aug	23 Aug
Mean wheat yield kg ha^{-1}	2972	2981	2767	2812	2308
Mean protein content g kg^{-1}	136	134	139	151	145

† Legume sown at the same time as sunflower (PLT) and the V4 and V10 growth stages of sunflower, respectively.
‡ SW101, IS3311 are sunflower hybrids Sunwheat 101 and Interstate 3311, respectively.
§ N applied to half of each block. Soil NO_3^-–N plus fertilizer N provided 112 kg N ha^{-1} for a yield goal of 2688 kg HRSW ha^{-1}.

The objective of this experiment was to determine the effect of selected legumes intercropped into sunflower on spring soil NO_3^-–N level, subsequent HRSW grain yield and protein content. Because of the beneficial effects of surface residues and the ability to fix N, we hypothesized that previous grown legumes would increase HRSW yield whether or not HRSW would be fertilized with N.

Our main questions for this research were (i) would increased HRSW yield (with or without fertilizer N) offset decreased sunflower yield (legumes seeded at sunflower planting reduced yield), (ii) which legume(s), if any, seeded at which sunflower growth stage would provide soil cover without negative impacts on sunflower and HRSW yields, and (iii) would legumes increase soil NO_3^-–N levels at the beginning of the HRSW season?

This information is needed because producers are exploring intercropping legumes in sunflower but there is little data available concerning the effects of this practice on subsequent HRSW yield and protein content.

Table 2. Precipitation and average monthly temperature at Carrington, ND, 1993 to 1994 and Prosper, ND, 1993 to 1995.

	Precipitation				Average monthly temperature†			
Month	1993	1994	1995	Average 1961–1990	1993	1994	1995	1961–1990
	mm				°C			
				Carrington				
May	97	34		56	12.2	14.8		11.8
June	190	77		88	15.1	17.7		17.3
July	224	68		70	17.1	18.1		20.4
Aug	76	36		51	18.3	17.6		18.9
Total	587	215		265				
				Prosper				
May	90	24	40	62	14.3	15.9	12.2	11.5
June	146	72	40	72	16.3	19.3	21.1	18.6
July	211	168	133	69	18.2	18.9	19.9	21.7
Aug	34	78	69	62	19.1	18.6	20.7	20.5
Total	481	342	282	265				

† Monthly average of (daily max. temperature + daily min. temperature)/2.

METHODS AND MATERIALS

This study was conducted at Carrington (47°30′ N, 99°08′ W) (1993 and 1994) and Prosper (47°00′ N, 97°07′ W) (1993, 1994, and 1995), ND, following directly an evaluation of legume intercropping into sunflower (Kandel et al., 1997). Soil at Carrington is a complex of Heimdahl loam (coarse-loamy, mixed Udic Haploborolls) and Emrick loam (coarse-loamy, mixed Pachic Udic Haploborolls). Soils at Prosper are mostly Perella silty-clay loam (fine-silty, mixed frigid Typic Haploquoll) and Bearden silt loam (fine-silty, mixed, frigid Aeric Calciaquolls). Precipitation and temperature records were obtained from field weather stations at Carrington and Prosper (Enz et al., 1993).

Plot History

Design of the previous experiment was a split-split plot arrangement in a randomized complete block, with four replicates. Main plots were two oilseed sunflower hybrids: 'Interstate 3311' (Interstate Payco, West Fargo, ND)[1], a standard-height and -maturity hybrid, and the earlier-maturing dwarf hybrid 'Sunwheat 101' (Agripro Biosciences Inc., Brookings, SD). Subplots were three legume seeding dates: at sunflower planting (PLT), when sunflower reached growth stage V4, and when sunflower reached growth stage V10. Sub-subplots were interseeded treatments of common hairy vetch (32.2 kg ha^{-1}), common sweetclover (10.7 kg ha^{-1}), 'Nitro' alfalfa (17.9 kg ha^{-1}), 'Indianhead' black lentil (25 kg ha^{-1}), 'Sava' snail medic (25 kg ha^{-1}), and a non interseeded control.

Table 1 provides seeding and harvest dates and other man-

[1] Mention of trade names, proprietary products, or vendors does not constitute a guarantee or warranty for the product by North Dakota State University and does not imply its approval to the exclusion of other products or vendors that may be suitable.

Table 3. Significance level for the combined analysis of variance of five North Dakota environments, for wheat yield and protein content.

Sources of variation	df†	Wheat yield	Protein content
Nitrogen (N)	1	NS	NS
Environment (E) × N	4	**	**
Hybrids (H)	1	NS	NS
E × H	4	NS	NS
Date (D)	2	NS	NS
E × D	8	**	**
H × D	2	NS	NS
E × H × D	8	NS	*
Legumes (L)	5	NS	*
E × L	20	**	NS
H × L	5	NS	**
E × H × L	20	*	NS
D × L	10	NS	NS
E × D × L	40	**	*
H × D × L	10	NS	*
E × H × D × L	40	*	NS
N × H	1	*	NS
E × N × H	4	NS	NS
N × D	2	*	NS
E × N × D	8	NS	NS
N × H × D	2	NS	*
E × H × H × D	8	NS	NS
N × L	5	NS	NS
E × N × L	20	**	NS
N × H × L	5	NS	NS
E × N × H × L	20	NS	NS
N × D × L	10	NS	NS
E × N × D × L	40	NS	NS
N × H × D × L	10	NS	NS
E × N × H × D × L	40	NS	NS
CV(%)		10.5	2.9

*,** Significant at the 0.05 and 0.01 probability levels, respectively.
† Degrees of freedom. NS, not significant.

agement information about each environment. The sub-subplot size was 6.1 m long and about 3.05 m wide with four rows of sunflower spaced 76 cm apart. Sunflower seeding rates were 60 000 plants ha^{-1}. Legume seeds were hand-broadcast between the sunflower rows and harrowed into the soil.

Near the end of the legume growing season, visual covering of the soil by the legume was observed and a legume biomass sample was taken from a 1-m^2 area between the sunflower rows of all sub-subplots that had legumes. Legumes were cut just above the soil surface with hand clippers. After drying and weighing, the legume biomass was returned to its harvested area and evenly spread on the soil surface.

HRSW Evaluations

The spring following sunflower legume intercropping, soil samples were taken (0-30 cm and 30-60 cm) (Table 1) in all non-legume sub-subplots from the previous season. A composite sample for each block was analyzed to determine soil NO_3^-–N.

The whole block was evenly divided in half, creating units of experiment of (3.05 by 3.05 m). The design for this experiment was a randomized complete block, consisting of a split-split plot within a split-block arrangement. Treatments were replicated four times.

Half of each block was fertilized with N, using dry granular commercial fertilizer urea, at rates (Table 1) based on preseeding soil analysis for a HRSW yield goal of 2688 kg ha^{-1} (Dahnke et al., 1992). Just after broadcasting urea, cover crop legumes were disked into the soil and 'Pioneer 2375' HRSW was seeded in 15-cm rows at a rate of 2.5 million seeds ha^{-1}, with a Kirschmann double-disk-opener drill (Table 1). Regrowth of sweetclover and alfalfa was controlled (Table 1) in the spring of 1993 and 1994, by applying 2,4-D [(2,4-dichlorophenoxy)acetic acid], and in 1995 with glyphosate [*N*-(phosphonomethyl)glycine]. Weeds were chemically controlled in HRSW.

Table 4. Mean wheat yield after legumes intercropped in sunflower at five North Dakota environments, averaged across two nitrogen levels and two sunflower hybrids.

Intercropped legume	PLT†	V4	V10	Mean
	Carrington 1993 (kg ha^{-1})			
Hairy vetch	3304a‡	2899a	3271ab	3158a§
Sweetclover	1779c	2232c	3030c	2347c
Alfalfa	2268b	2573b	3381a	2741b
Snail medic	3300a	3108a	3147bc	3185a
Black lentil	3363a	3006a	3132bc	3167a
Control	3319a	2950a	3440a	3237a
Mean¶	2889y	2795y	3234x	
	Carrington 1994 (kg ha^{-1})			
Hairy vetch	3324ab	3122a	2895a	3114a
Sweetclover	3433a	2993ab	2784a	3070a
Alfalfa	3103bc	3049ab	2868a	3007ab
Snail medic	2932cd	2835b	2953a	2907b
Black lentil	2871d	2965ab	2840a	2892b
Control	2870d	2900ab	2917a	2896b
Mean	3089x	2977xy	2876y	
	Prosper 1993 (kg ha^{-1})			
Hair vetch	2859a	2796a	3087a	2914a
Sweetclover	2029c	2186b	2945ab	2387c
Alfalfa	2359b	2834a	2938ab	2710b
Snail medic	2943a	2940a	2908ab	2931a
Black lentil	2918a	2767a	2824b	2836ab
Control	2803a	2844a	2825b	2824ab
Mean	2652y	2728y	2921x	
	Prosper 1994 (kg ha^{-1})			
Hairy vetch	2973a	2949a	2854a	2925a
Sweetclover	2593b	2687b	2714a	2664c
Alfalfa	2904a	2831ab	2881a	2872ab
Snail medic	2850a	2936a	2778a	2855ab
Black lentil	2786ab	2798a	2766a	2784bc
Control	2753ab	2766a	2789a	2769bc
Mean	2810x	2828x	2797x	
	Prosper 1995 (kg ha^{-1})			
Hairy vetch	2343a	2297a	2290a	2310a
Sweetclover	2323a	2188a	2325a	2279a
Alfalfa	2349a	2283a	2317a	2316a
Snail medic	2253a	2230a	2385a	2289a
Black lentil	2378a	2336a	2307a	2340a
Control	2335a	2232a	2368a	2312a
Mean	2330x	2261x	2332x	

† Legume sown the same time as sunflower (PLT) and at the V4 and V10 growth stages of sunflower, respectively.
‡ Legume sowing date × legume values in a column in each environment followed by the same letter are not significantly different at $P \leq 0.05$ (*F*-protected LSD).
§ Legume means in a column in each environment followed by the same letter are not significantly different at $P \leq 0.05$ (*F*-protected LSD).
¶ For each environment, the legume sowing date means in a row followed by the same letter (x or y) are not significantly different at $P \leq 0.05$ (*F*-protected LSD).

Soil samples (0–30 cm) were taken about one month after seeding HRSW (Table 1) to determine soil NO_3^-–N content in sub-subplots of hairy vetch, sweetclover, black lentil, and the non-legume control that did not receive an urea application in the spring.

After discarding border rows, a 3-m^2 area was harvested (Table 1) with a plot combine. The grain was weighed. Subsamples were ground, and grain protein was determined, corrected to 140 g kg^{-1} moisture, with near-infrared reflectance spectrography (Technicon InfraAlyzer 300, Technicon Instruments Corp., Tarrytown, NY).

Data from all studies were analyzed by the Statistical Analysis System (SAS Institute, 1985). For analysis of variance, locations and years were termed environments. The *F*-pro-

Table 5. Mean wheat protein content after legumes intercropped in sunflower at five North Dakota environments, averaged across two nitrogen levels and two sunflower hybrids.

Intercropped legume	PLT†	V4	V10	Mean
	Carrington 1993 (g kg^{-1})			
Hairy vetch	136b‡	132b	137a	135a§
Sweetclover	142a	136a	131b	136a
Alfalfa	138b	135ab	138a	137a
Snail medic	137b	135ab	132b	134a
Black lentil	137b	133ab	133b	134a
Control	138b	132b	138a	136a
Mean¶	138x	134y	135y	
	Cararington 1994 (g kg^{-1})			
Hairy vetch	140a	134ab	133ab	136a
Sweetclover	140a	134ab	134a	136a
Alfalfa	137ab	136a	134a	135a
Snail medic	135bc	132b	130b	132a
Black lentil	135bc	133ab	133ab	133a
Control	133c	132b	133ab	132a
Mean	137x	134y	133y	
	Prosper 1993 (g kg^{-1})			
Hairy vetch	139a	138ab	142a	140a
Sweetclover	140a	139a	142a	140a
Alfalfa	138a	139a	141a	139a
Snail medic	138a	140a	140a	139a
Black lentil	141a	135b	139a	139a
Control	138a	138ab	142a	139a
Mean	139xy	138y	141x	
	Prosper 1994 (g kg^{-1})			
Hairy vetch	151ab	151ab	150a	151a
Sweetclover	153a	154a	152a	153a
Alfalfa	151ab	151ab	150a	150a
Snail medic	149b	149b	151a	150a
Black lentil	150ab	151ab	151a	151a
Control	149b	149b	150a	149a
Mean	151x	151x	151x	
	Prosper 1995 (g kg^{-1})			
Hairy vetch	145a	143a	145a	144a
Sweetclover	144a	144a	144a	144a
Alfalfa	145a	145a	146a	145a
Snail medic	139b	146a	146a	144a
Black lentil	145a	146a	146a	146a
Control	145a	145a	146a	145a
Mean	144x	145x	146x	

† Legume sown the same time as sunflower (PLT) and at the V4 and V10 growth stages of sunflower, respectively.
‡ Legume sowing date × legume values in a column in each environment followed by the same letter are not significantly different at $P \leq 0.05$ (*F*-protected LSD).
§ Legume means in a column in each environment followed by the same letter are not significantly different at $P \leq 0.05$ (*F*-protected LSD).
¶ For each environment, the legume sowing date means in a row followed by the same letter (x or y) are not significantly different at $P \leq 0.05$ (*F*-protected LSD).

tected least significant difference (LSD) was calculated at the 0.05 level of probability, according to Steel and Torrie (1980).

RESULTS AND DISCUSSION

Carrington in 1993 and Prosper in 1993, 1994, and 1995 received 222, 182, 129, and 106% more precipitation than the 30-yr average, respectively, whereas Carrington in 1994 received only 81% of its long-term average (Table 2). In 1993, the average temperature during the growing season was below the 30-yr average. Plants at all locations except Carrington in 1994 showed low levels (< 15% of heads infected) of head blight (*Fusarium graminearum* Schwabe).

The environment × date (seeding date of the legumes), environment × legumes, and environment × date × legumes interactions are used in answering the main research objectives in this study (Table 3) as seeding date of the legumes and legume main effects (except for protein content) were not significant.

Table 6. Significance level for the combined analysis of variance of five North Dakota environments, for NO_3^-–N content in the soil at the beginning of the HRSW production season.

Sources of variation	df†	NO_3^-–N
Hybrids (H)	1	*
Environment (E) × H	4	NS
Date (D)	2	NS
E × D	8	**
H × D	2	NS
E × H × D	8	NS
Legumes (L)	3	*
E × L	12	**
H × L	3	*
E × H × L	12	NS
D × L	6	NS
E × D × L	24	**
H × D × L	6	NS
E × H × D × L	24	NS
CV (%)		39.8

*,** Significant at the 0.05 and 0.01 probability levels, respectively.
† Degrees of freedom. NS, not significant.

HRSW Yield

Wheat after hairy vetch yielded higher than the control at Carrington and Prosper in 1994 (environment × legumes interaction; Table 4). Badaruddin and Meyer (1990) reported increased HRSW yield after hairy vetch. In 1993, HRSW yield after vetch or the control were similar. We attribute this to the lower amount of legume biomass produced during the 1992 sunflower season (Table 1). In 1995, HRSW was seeded later than in 1993 and 1994, resulting in a HRSW yield 80% of the mean yield from 1993–1994 with no HRSW yield differences after a legume or without a legume intercropped in sunflower (Table 4).

At Carrington 1993, HRSW seeded on plots where sunflower intercropped with sweetclover or alfalfa seeded at PLT or V4, the yield was lower than the control (environment × date × legumes interaction) (Table 4). At Prosper 1993, HRSW seeded on plots where sunflower was intercropped with sweetclover or alfalfa seeded at PLT, the average yield was lower than the control. At Carrington 1994, HRSW seeded into PLT plots with sweetclover or alfalfa yielded more than the control.

Nitro alfalfa, considered an annual, survived each winter, but was less hardy than sweetclover. Both legumes had established extensive root systems when seeded at PLT or V4 in sunflower and grew vigorously the following spring. Disking the legumes before seeding HRSW and chemical applications to control the growth of the legume did not completely prevent legume regrowth and competition with the HRSW. The HRSW yield reduction in 1993 was caused by the aggressive growth of surviving sweetclover and alfalfa plants. We attribute this to the excessive rainfall during the growing season (Table 2). In 1994 conditions at Carrington, with below average rainfall, provided HRSW the competitive advantage.

The N × sunflower hybrid interaction was significant

Table 7. Mean legume biomass worked into the soil before seeding wheat and soil NO_3^-–N content in the top 30 cm at the beginning of the wheat production season after legumes intercropped in sunflower at five North Dakota environments. Values are averaged across two sunflower hybrids.

Intercropped legume	PLT†		V4		V10		Mean	
	leg‡	N	leg	N	leg	N	leg	N
				Carrington 1993 (kg ha^{-1})				
Hairy vetch	1048a§	14.3b	539a	31.4a	100a	28.1a	562a	24.6ab¶
Sweetclover	710b	15.3b	255a	34.2a	22a	26.9a	329b	25.4ab
Black lentil	803b	29.5a	215a	32.8a	61a	26.9a	360b	29.7a
Control		9.5b		26.3a		27.0a		21.0b
Mean#		17.2y		31.2x		27.2x		
				Carrington 1994 (kg ha^{-1})				
Hairy vetch	5692a	73.9a	2113a	30.0a	946a	19.0a	2917a	41.0a
Sweetclover	3393b	53.5b	1025b	22.7ab	366b	16.0a	1573b	30.7b
Black lentil	2415c	17.6c	887b	12.0b	429b	14.8a	1244c	14.8c
Control		16.0c		12.9b		10.4a		13.1c
Mean		40.3x		19.4y		15.1y		
				Prosper 1993 (kg ha^{-1})				
Hairy vetch	3033a	30.8a	1014a	12.6a	289a	9.5a	1445a	17.6a
Sweetclover	1641b	28.3a	610b	12.9a	167a	10.4a	806b	17.2ab
Black lentil	1127c	10.9b	144c	10.4a	103a	6.2a	458c	9.1c
Control		12.9b		8.7a		8.4a		10.0bc
Mean		20.7x		11.1y		8.6y		
				Prosper 1994 (kg ha^{-1})				
Hairy vetch	5805a	82.0a	1897a	68.0a	830a	48.4a	2844a	66.2a
Sweetclover	3293b	56.8b	766b	38.4b	364b	33.3b	1474b	42.8b
Black lentil	1329c	44.2bc	398b	35.3b	282b	32.5b	670c	37.3bc
Control		37.0c		32.2b		36.1ab		35.1c
Mean		55.0x		43.5y		37.6y		
				Prosper 1995 (kg ha^{-1})				
Hairy vetch	4912a	58.2ab	2400a	52.9a	1990a	61.6ab	3100a	57.6a
Sweetclover	2512b	63.3a	1429b	47.3a	976b	66.9a	1639b	59.2a
Black lentil	1249c	46.5b	828c	44.2a	651b	52.9bc	909c	47.9b
Control		54.9ab		50.4a		41.2c		48.8b
Mean		55.7x		48.7x		55.7x		

† Legumes sown the same time as sunflower (PLT) and at the V4 and V10 growth stages of sunflower, respectively.
‡ Legume biomass (dry weight).
§ Legume sowing date × legume values in a column in each environment followed by the same letter are not significantly different at $P \leq 0.05$ (*F*-protected LSD).
¶ Legume means in a column in each environment followed by the same letter are not significantly different at $P \leq 0.05$ (*F*-protected LSD).
# For each environment, the legume sowing date means in a row followed by the same letter (x or y) are not significantly different at $P \leq 0.05$ (*F*-protected LSD).

(Table 3). Averaged across legumes and legume seeding dates, N applied after Sunwheat 101 produced similar HRSW yields as after Interstate 3311, 2989, and 2978 kg ha^{-1}, respectively. Without supplemental N, HRSW after Sunwheat 101 and Interstate 3311 yielded 2627 and 2476 kg ha^{-1}, respectively.

Wheat with N applied, following sunflower intercropped with legumes, yielded 2914, 2951, and 3087 kg ha^{-1} at PLT, V4, and V10 growth stages, respectively (N × date interaction).

HRSW without N applied, following sunflower intercropped with legumes, yielded 2594, 2485, and 2577 kg ha^{-1} at PLT and growth stages V4, and V10, respectively.

Protein

The HRSW protein content after hairy vetch, sweetclover, alfalfa, snail medic, black lentil, and control was 141.2, 142.0, 141.5, 140.0, 140.6, and 140.6 g kg^{-1}, respectively, and protein after sweetclover was significantly higher than the prote content in HRSW without a previous legume. The hybrid × legumes interaction was significant ($P \leq 0.01$) (Table 3) mainly because of the slightly higher HRSW protein content after the sunflower hybrid Sunwheat 101, which we attribute to more legume biomass produced in the dwarf hybrid compared with the standard-height hybrid Interstate 3311.

Wheat grown after sweetclover intercropped in sunflower had higher protein content than HRSW grown after sunflower alone at Carrington 1993 (PLT and V4), Carrington 1994 (PLT), and Prosper 1994 (PLT and V4) (environment × date × legumes interaction: Table 5). We believe that the higher protein in 1993 and Prosper 1994 (V4) can partly be explained by the inverse relationship between HRSW yield and protein content (Deckard et al., 1984). The HRSW yield of intercropped sweetclover was lower than the control.

In 1994 at the beginning of the HRSW, season sweetclover plots (PLT) had significantly more NO_3^-–N than the control (see next section) this may explain the higher protein content.

Soil NO_3^-–N Levels in Growing HRSW after Intercropped Sunflower

The ANOVA for soil NO_3^-–N levels is provided in Table 6. Amount of legume dry matter incorporated and soil NO_3^-–N is presented in Table 7. Snail medic and alfalfa biomass are not included. Average soil NO_3^-–N content (41.4 kg ha^{-1}) at the beginning of the HRSW production season in plots where hairy vetch was intercropped in sunflower was higher than in plots where sunflower was grown alone (25.6 kg ha^{-1}) (legumes main effect).

When hairy vetch was seeded at the V4 sunflower growth stage, a higher soil NO_3^-–N content was recorded in subsequent HRSW plots at Carrington 1994 and at Prosper 1994. When legumes were seeded at the V10 sunflower growth stage, no differences were observed in soil NO_3^-–N content at Carrington 1993 and 1994 and Prosper 1993. At Prosper in 1995, both hairy vetch and sweetclover, when seeded at the V10 sunflower growth stage, showed higher NO_3^-–N levels than the control plot.

Fertilizer was applied to sunflower for a yield goal of 2800 kg ha^{-1}. Averaged across all environments, the mean sunflower yield was 1769 kg ha^{-1}. As fertilizer NO_3^-–N was available to legumes, and legumes grew under shaded conditions for most of the growing season, it was assumed that this limited dinitrogen fixation (Morris and Garrity, 1993; Stern, 1993). Mandal et al. (1991) reported reduced legume nodule number and nodule dry weight for an intercropped legume compared with a pure legume crop.

Soil tests measured only the amount of available NO_3^-, but did not account for the N in organic form. Brown et al. (1993) reported that hairy vetch intercropped in corn the previous growing season increased soil NO_3^-–N in the surface 7.5 cm between 50 and 64 d after corn planting.

We expected increased HRSW yields after legumes because of anticipated higher soil NO_3^-–N levels. However, higher yields were only recorded after hairy vetch and sweetclover at Carrington 1994 and for hairy vetch at Prosper 1994 (Table 4). This seems to correspond with the significantly higher NO_3^-–N levels in these legume plots compared with the control (Table 7).

Once worked into the soil, legumes may decompose slowly (Wagger, 1989). We speculate that some of the legume biomass disked into the soil may have decomposed after the HRSW had already taken up its maximum NO_3^-–N, although we did not measure this. Meyer (1987) reported increased barley (*Hordeum vulgare* L.) grain yield 2 yr after hairy vetch was incorporated as a green manure crop.

CONCLUSION

None of HRSW grown after legumes consistently yielded higher than HRSW grown without legumes. Relative to HRSW grown with no previous legume, protein content was higher in HRSW only when grown after sweetclover.

In previous reported research (Kandel et al., 1997), we concluded that all legumes tested except black lentil decreased sunflower yield if legumes were seeded at the same time as sunflower. Black lentil did not show any negative effects on the following HRSW crop.

When seeded at the V4 growth stage of sunflower sweetclover and alfalfa might reduce HRSW yield and an extra cost is involved in controlling the legume growth in the spring.

Hairy vetch intercropped at V4 did not reduce sunflower yield (Kandel et al., 1997). This legume yielded between 540 and 2400 kg ha^{-1} biomass (Table 7), visually had about a 90% soil cover going into the winter and contributed in two environments to increased NO_3^-–N levels at the beginning of the HRSW season. Therefore hairy vetch could be used in intercropping at the V4 growth stage of sunflower.

Legumes seeded at the V10 growth stage of sunflower did not negatively affect sunflower yield but neither did they increase subsequent HRSW yields. Hairy vetch yielded 831 kg ha^{-1} biomass (average from Table 7) to provide a 75% soil cover going into the winter and therefore could be used in intercropping with sunflower.

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