Sugarbeet Nematode-Resistant Trap Crops for Recovery of Residual Soil Nitrates

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ABSTRACT

Residual soil nitrates following the main crop harvest, if not recovered, can result in environmental problems, loss of nutrients, and reduced efficiency of irrigated sugarbeet (*Beta vulgaris* L.) rotations. Sugarbeet nematode (SBN)-resistant crops, also known as trap crops, grown in sugarbeet rotations to control sugarbeet cyst nematode (*Heterodera schachtii* Schmidt) were evaluated as cover crops (CC) for soil nitrate recovery. Cultivars of the trap crops, oil radish (*Raphanus sativus* L. spp. oleifera) and yellow mustard (*Sinapis alba* L.), as well as winter wheat (*Triticum aestivum* L.), were planted in early August 1996 and late July 1997 following a previous crop of winter wheat. Five nitrogen fertilizer rates were applied following soil sampling to 0.9 m. Soil samples were taken in late fall after active CC growth had ceased. Radish and mustard quickly established and produced as much as 5 to 8 Mg dry matter ha^{-1}. Radish and mustard above-ground biomass accumulated greater amounts of N, leaving less residual soil nitrate-N, particularly at the 0.6- to 0.9-m soil depth, than winter wheat, the standard cover crop in the region. Both trap crops winter-killed, reducing need for herbicide and lessening the likelihood of N immobilization and negative impact on the following crop.

Additional key words: Oil seed radish, *Raphanus sativus* L. spp. oleifera, yellow mustard, *Sinapis alba* L., wheat, *Triticum aestivum* L., sugarbeet, nitrate-N recovery, N fertilization, soil nitrate-N, plant N uptake, cover crops, *Beta vulgaris* L.

Fertilizing for optimum crop production, while minimizing loss of nitrate-nitrogen (NO_3-N) to ground and surface water, is a challenge. Increasing cost of fertilizer and the need for groundwater protection has stimulated interest in growing cover crops after rotational main crops for capturing and recycling residual soil nitrogen.

Soil NO_3-N accumulation can result from over-fertilization, reduced crop yield due to limiting environmental conditions and/or N mineralization after the main crop is harvested. Large amounts of soil NO_3-N have the potential for loss through over-winter leaching and/or erosion (Meisinger et al., 1991; Thorup-Kristensen et al., 2003). Rotations with high-N requiring crops grown on highly permeable soils under irrigation need to be carefully managed to avoid leaching of nitrate below the soil rooting zone.

Nitrate-N concentrations greater than 10 mg L^{-1} in drinking water can pose health problems for humans and livestock (USEPA, 1973). In many communities this level has been exceeded, leading to expensive removal and/or development of alternative water sources (Magette et al., 1989; Tyson et al., 1992; USDA, 1991).

To be effective in reducing residual soil NO_3-N, cover crops (CCs) need to establish quickly, grow vigorously under cool conditions, and possess extensive roots. Cover crops with frost tolerance actively grow later into the season, improving their ability to immobilize NO_3-N. Cover crops reduce NO_3-N leaching by plant N uptake and water uptake and transpiration.

Most work on cover crop recovery of soil nitrate-N has been with grasses in humid and sub-humid regions. Soil NO_3-N has been a concern, however, in areas with irrigated intensive production. Ludwick et al. (1976) in eastern Colorado showed that soil NO_3-N can accumulate even when fertilizer N is applied at rates less than needed for maximum production. They reported an average soil profile of 170 kg ha^{-1} of NO_3-N on 270 commercial fields. In the irrigated production area in which our study was conducted in eastern Wyoming, 5 of 13 wells sampled had water NO_3-N concentrations in excess of the EPA recommended limit, when sampled before and during the crop-growing season (Reddy, K.J., pers. comm., 2005).

Cover crops have effectively reduced NO_3-N content of gravitational water (Karlen and Doran, 1991). Other benefits of CCs have been summarized by Lal et al., 1991. These include improved soil physical conditions, reduced soil erosion, increased soil organic matter and soil fertility, recycling of nutrients and weed suppression.

Long-term availability of N following CCs is influenced by the amount and composition of above- and below-ground biomass, and degradation rate (Kuo et al., 1997). Legumes generally stimulate growth of succeeding crops (Hargrove, 1986; Meisinger et al., 1991). With non-legume CCs, mineralization and availability of N to following crops has been more variable (Karlen and Doran, 1991; Thorup-Kristensen, et al., 2003; and Weinhert et al. 2002).

Annual cereal crops have been studied extensively for soil N recovery. Rye (*Secale cereale* L.) has been used successfully as a winter cover crop in the northern Corn Belt (Dinnes et al., 2002), although wheat (*Triticum aestivum* L.) is preferred in wheat-growing areas. McCracken et al. (1994), reported that rye, compared with winter fallow, reduced NO_3-N leaching 94%. They found that rye was better able to recover soil NO_3-N and to reduce leachate NO_3-N concentration to a greater extent than hairy vetch (*Vicia villosa* Roth). Rye cover crop reduced mass of N leached from 66 to 77%, compared with no cover crop (Meisinger et al. (1991).

Cruciferae (mustard) family consists of cool-season crops that are frost tolerant and relatively high in nitrogen concentration; therefore, they have potential as a second crop. Although widely adapted and successfully grown from Washington to Florida, there have been few studies in the U.S. on the use of crucifers as cover crops. In an early lysimeter study, compared with fallow, mustard (*Brassica* spp.) reduced the amount of NO_3-N leaching, measured at 122 cm soil depth, from 52 to 10 kg ha^{-1} and soil NO_3-N concentration from 75 to 15 mg kg^{-1} (Chapman et al., 1949). In a study in which unfertilized cover crops followed wheat, radish (*Raphanus sativus* L. spp. oleifera) reduced soil NO_3-N, measured at 99 cm soil depth, from 96 to 54, while rye reduced NO_3-N to 39 kg ha^{-1} (Muller et al., 1989).

Varieties of radish and yellow mustard (*Sinapis alba* L.), developed and used as trap crops, effectively control the sugarbeet nematode (*Heterodera schachtii* Schmidt) (Koch and Gray, 1997). Their use as an alternative to nematicides would be enhanced if, as cover crops, they recovered significant amounts of soil nitrate.

The objective of this study was to evaluate sugarbeet (*Beta vulgaris* L.) nematode-resistant trap crop radish and mustard, compared with wheat, for the recovery of N with various levels of initial soil nitrate-N.

MATERIALS AND METHODS

The study was conducted at the University of Wyoming Research and Extension Center near Torrington, WY (42°05’ N, 104°13’ W), a semi-arid cool-temperate region at elevation 1250 m. The average frost-free

(0°C) growing season is 18 May to 20 September (125 days). About half the 34 cm annual precipitation occurs during this period. Mean monthly air temperature for August, September and October is 21.1°C, 15.6°C and 10.0°C, respectively (Becker and Alyea, 1964; Becker et al., 1977; Martner, 1986). Average GDD accumulation (base 4.4°C), using 30-year temperature averages, for August, September and October is 911, 554 and 258, respectively (Pochop, 1977).

The main crop, winter wheat, was harvested 19 July 1996 and 13 July 1997. A 25-cm stubble was left and loose straw was baled and removed. Three soil cores (5-cm diameter x 0.9 m depth) were taken from all 3.6- x 6.0-m plots with a hydraulic sampler before treatments were imposed and at the end of active cover crop growth in the fall. Soil samples for NO_3-N analysis were stored at -10°C.

To ensure a range in soil N levels, nitrogen fertilizer (NF) rates of 0 to 269 kg N ha^{-1}, were surface broadcast as ammonium nitrate. The same CC and NF treatments were established a second year on an adjacent area of the same field under similar conditions.

The experimental design was a split-plot with randomized complete blocks and four replications. Main plots were the three CCs and an unseeded (fallow) control, which was hand-weeded and treated as bare fallow. Unseeded plots following fertilization and initial irrigation were covered to prevent further irrigation and nitrate leaching. They were uncovered following irrigation to admit rainfall. Sub-plots were NF rates of 0, 67, 134, 202 and 269 kg N ha^{-1}.

The sugarbeet nematode (SBN)-resistant cultivars 'Adagio' radish and 'Metex' mustard and 'Buckskin' hard red winter wheat were planted into stubble with a no-till drill at 22, 17, and 100 kg ha^{-1}, respectively, on 7 August 1996 and 30 July 1997.

The soil was a Dunday loamy sand, sandy, mixed, mesic Entic Haplustoll. The soil was loamy sand to 1.8 m with bulk density of 1.29 to 1.35 and a pH of 7.8. This soil is excessively drained, has a high percolation capacity, and a low water-holding capacity (140 to 190 g water kg^{-1} soil). The field was nearly level (<1% slope). Cover crops were sprinkle irrigated to 90% of field capacity biweekly starting with CC planting through September, and again in mid-October. Irrigation and precipitation totaled 10.3 and 11.9 cm during the CC growing season in 1996 and 1997. Irrigation water contained 3.9 and 3.7 mg L^{-1} NO_3-N in 1996 and 1997.

Soil cores collected before NF application and those collected after active CC growth ceased were sectioned into 0- to 0.3-, 0.3- to 0.6- and 0.6- to 0.9-m and NO_3-N extracted with Ca $(OH)_2$ (Sims and Jackson, 1971).

Crop assessment and soil sampling was completed on 10 October 1996 and 20 November 1997. Plants from a 1 m^2 area per plot were clipped at 1-cm above the soil surface, dried at 65°C and weighed to determine above-ground biomass. Samples were ground in a Wiley mill to pass a 0.5-mm screen and later used to determine plant N content. Plant tissue was analyzed for total C and N (Leco CHN analyzer, Leco, St Joseph, MI). Nitrogen uptake was calculated as the multiple of above-ground biomass and biomass N content.

Growing degree days (GDDs) were calculated as the accumulated heat above the threshold of 4.4°C from the date of planting until final evaluation after termination of growth. Maximum and minimum daily air temperatures, from which GDDs were calculated, were from an Agricultural Experiment Station weather station within 100 m of the study site.

Analysis of variance for treatment effects was performed with the GLM procedure of SAS (Version 4.1, release 7.0, 1998, SAS Inst., Cary, NC). When treatment effects were significant ($P<0.05$) and there were no CC x NF rate interactions, treatment means were compared using LSD at $P= 0.05$. Initial soil nitrate levels were used as a covariant in the statistical analysis of subsequent soil NO_3-N data in order to reduce experimental error. Values reported as kg ha^{-1} NO_3-N were obtained by multiplying concentration (mg kg^{-1}) in each 30-cm soil depth by 4.03, assuming a mean bulk density of 1.32 g cm^{-3}.

RESULTS AND DISCUSSION

Averaged over all 80 plots each year and before CC or NF were established, 60 and 52% of profile soil NO_3-N in 1996 and 1997 was found in the upper 30 cm (Table 1). Sixteen and 24% of NO_3-N was found in the 60-90 cm zone in 1996 and 1997. Total profile (0-90 cm) NO_3-N levels were similar both years (79.4 and 74.1 kg ha^{-1}). Profile distribution changes over time with CCs and selected NF rates are shown in Fig. 1a-c and Fig. 2a-c.

Residual soil NO_3-N concentrations increased at all depths of the profile with the unseeded, unfertilized treatment, compared to original concentrations of NO_3-N, indicating that conditions following the main crop were favorable for mineralization (Fig. 1d and 2d). In 1996, NO_3-N in the total soil profile (0-90 cm) of unseeded (no cover crop) plots that received no NF increased ($P<0.05$) from 79 prior to treatment application to 96 kg ha^{-1} at the end of study on 10 October (Table 2). In 1997, NO_3-N increased ($P<0.05$) from 55 initially to 131 kg ha^{-1} on

Table 1. Soil nitrate-N amounts before cover crop (CC) establishment and nitrogen fertilizer (NF) application, Torrington, WY.

Soil depth	1996	1997
cm	---------- $kg\ ha^{-1}$ ----------	
0-30	47.6	38.3
30-60	18.9	18.1
60-90	12.9	17.7
0-90	79.4	74.1

N = 80.

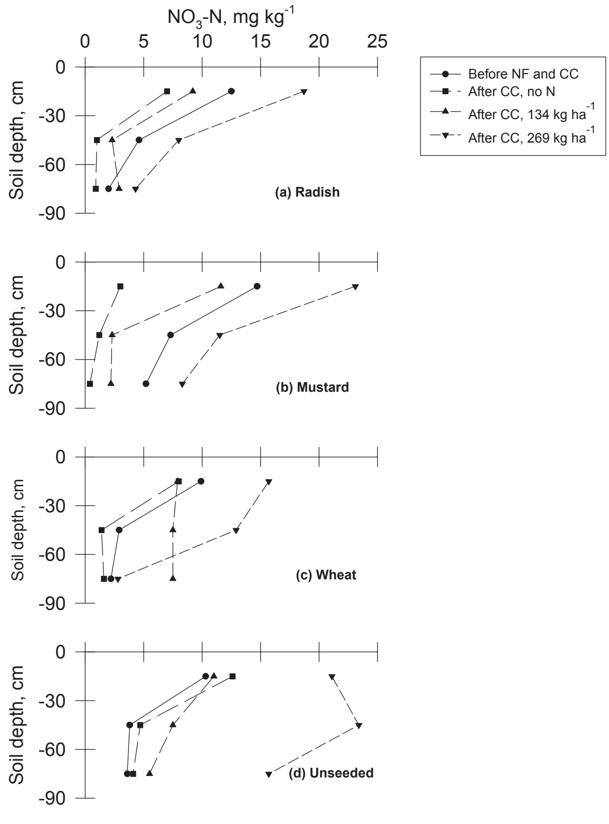

Fig. 1. Soil nitrogen profile before and after growing nitrogen fertilized (NF) cover crops (CC) in 1996.

Table 2. Soil nitrate-N content initially† and following cover crops (CC) grown with five nitrogen fertilizer (NF) rates at three soil depths and total soil profile, Torrington, WY, 1996.

Cover crop	Initial soil $N0_3$-N†	Nitrogen fertilizer (NF) rate, kg ha^{-1}					CC mean
		0	67	134	202	269	
				kg ha^{-1}			
				0-30 cm			
Radish	56.4	31.4	26.9	41.2	42.6	83.8	45.2bc
Mustard	65.9	13.4	55.1	52.0	73.0	103.5	59.6ab
Wheat	44.4	35.8	45.2	35.4	81.1	70.3	53.8abc
Unseeded	46.1	56.4	51.5	49.3	73.0	94.5	65.0a
NF Mean		34.5c	44.8c	44.4c	67.6b	88.3a	
				30-60 cm			
Radish	20.6	4.5	4.9	10.3	9.9	35.8	13.0b
Mustard	32.7	5.4	12.5	10.3	33.6	51.5	22.4b
Wheat	13.0	6.3	10.8	33.6	28.2	57.8	27.3b
Unseeded	17.0	21.1	32.7	33.6	60.9	104.8	50.6a
NF Mean		9.4c	15.2c	22.0bc	33.2b	62.7a	
				60-90 cm			
Radish	9.0	4.0	4.5	13.0	5.8	19.3	9.4b
Mustard	23.3	1.8	3.6	9.9	16.6	37.2	13.8b
Wheat	9.9	7.2	8.1	29.1	12.5	19.3	15.2b
Unseeded	16.1	18.4	17.0	19.3	43.9	70.4	33.8a
NF Mean		8.1bc	8.5bc	20.2ab	19.7ab	37.2a	
				Total soil profile (0-90 cm)			
Radish	86.0	39.9*	36.3*	64.5*	58.3*	138.9*	67.6c
Mustard	121.9	20.6*	71.2*	72.2*	123.2	192.2*	95.9b
Wheat	67.3	49.3*	64.1	98.1*	121.8*	147.4*	96.1b
Unseeded	79.2	96.2*	101.2*	102.2*	177.8*	269.4*	149.3a
NF Mean		51.5e	68.2d	84.3c	120.3b	187.0a	

† Determined following main crop harvest and before establishing cover crops and applying NF rates. Other data are soil nitrates at end of CC growth (10 October). Means within columns and soil depths and means within rows followed by the same letter do not differ ($P > 0.05$). CC x NF interaction was not significant ($P>0.05$).Soil NO_3-N means followed by an asterisk differ ($P<0.05$) from initial soil NO_3-N.

20 November (Table 3). Air temperatures in 1996 and in August 1997 were near average; however, mean monthly temperatures in September and October 1997 were above average (data not shown). Accumulated GDDs (base 4.4°C) during CC growth in 1996 and 1997 were 1761 and 1937. The higher temperatures and more favorable growing conditions might explain the apparent greater mineralization in 1997.

Over all CC treatments and soil profile depths, residual nitrate-N increased ($P<0.05$) with increased NF rates, as expected (Tables 2 and 3). Over all NF rates, unseeded plots had greater ($P<0.05$) amounts of soil NO_3-N in the lower soil profile levels (30-60 and 60-90 cm depths) than the CCs.

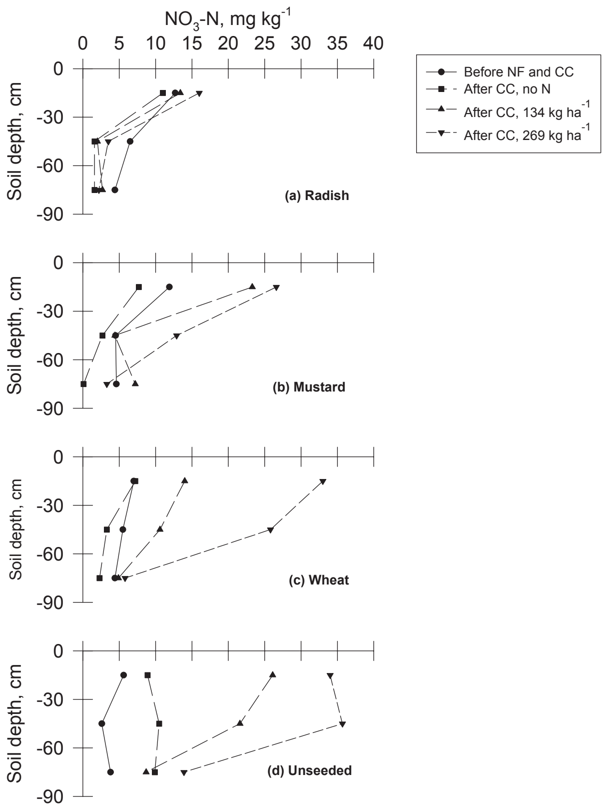

Fig. 2. Soil nitrogen profile before and after growing nitrogen fertilized (NF) cover crops (CC) in 1997.

Table 3. Soil nitrates initially† and following cover crops (CC) grown with five nitrogen fertilizer (NF) rates at three soil depths and total soil profile, Torrington, WY, 1997.

Cover crop	Initial soil NO_3-N†	Nitrogen fertilizer (NF) rate, kg ha^{-1}					CC mean
		0	67	134	202	269	
				kg ha^{-1}			
				0-30 cm			
Radish	56.9	49.3	41.7	60.0	139.3	71.7	72.6b
Mustard	53.3	34.5	81.5	104.4	106.2	119.2	89.2ab
Wheat	33.2	32.3	44.8	62.7	158.1	147.8	89.2ab
Unseeded	25.1	39.9	105.3	116.9	106.6	152.3	104.4a
NF Mean		39.0c	68.5bc	86.0ab	127.7a	122.8a	
				30-60 cm			
Radish	29.1	7.2	5.4	9.0	12.5	15.7	10.0c
Mustard	20.2	12.1	24.6	19.7	42.1	57.8	31.3bc
Wheat	24.6	10.3	31.7	47.5	80.6	115.6	57.1b
Unseeded	11.6	47.0	84.7	96.8	121.4	159.9	102.0a
NF Mean		19.3c	36.7c	43.3bc	64.1ab	87.3a	
				60-90 cm			
Radish	19.7	7.2	12.1	12.1	7.6	9.9	9.9c
Mustard	20.6	0.4	12.1	32.3	14.3	14.8	14.8c
Wheat	19.7	10.3	51.5	22.0	22.0	26.0	26.4b
Unseeded	18.4	44.4	47.9	39.0	85.1	62.3	55.6a
NF Mean		15.7b	30.9a	26.4ab	32.3ab	28.2a	
				Total soil profile (0-90 cm)			
Radish	105.7	63.7*	59.2*	81.1	159.4*	97.3	92.1d
Mustard	94.1	47.0*	118.2	156.4*	162.6*	191.8*	135.2c
Wheat	77.5	52.9*	128.0*	132.2*	260.7*	289.4*	172.6b
Unseeded	55.1	131.3*	237.9*	252.7*	313.1*	374.5*	261.9a
NF Mean		73.7c	135.8b	155.6b	224.0a	238.3a	

† Determined following main crop harvest and before establishing cover crops and applying NF rates. Other data are soil nitrates at end of CC growth (10 October). Means within columns and soil depths and means within rows followed by the same letter do not differ ($P > 0.05$). CC x NF interaction was not significant ($P>0.05$).Soil NO_3-N means followed by an asterisk differ ($P<0.05$) from initial soil NO_3-N.

Cover crops grown without NF reduced soil NO_3-N concentrations at all soil depths, compared with initial concentrations (before NF or CC treatments applied) (Figs. 1 and 2). In 1996, with no applied N, radish, mustard, and wheat reduced ($P<0.05$) total profile NO_3-N 46, 101, and 18 kg ha^{-1}, respectively (Table 2). In 1997, with no applied N, radish, mustard and wheat reduced ($P<0.05$) total profile NO_3-N 42, 47, and 24 kg ha^{-1}, respectively (Table 3).

With 134 kg ha^{-1} NF application, radish in 1996 and 1997 and mustard in 1996 reduced ($P<0.05$) total soil profile NO_3-N, compared to initial NO_3-N amounts (Tables 2 and 3). Mustard in 1997 and wheat in 1996 and 1997 increased ($P<0.05$) total profile NO_3-N. This indicates that radish (both years) and mustard (1996) took up in excess of the amount of NF applied (134 kg N ha^{-1}), while mustard (1997) and wheat (both years) took up less than the amount of NF applied. Weinhert et al. (2002) reported that over-wintering wheat and rye reduced soil mineral N 155 kg N ha^{-1} in a 180-cm profile, compared with bare fallow. Their soil profile initially contained a substantially greater amount of soil nitrates than the profile in our study.

Compared with the unseeded (fallow) treatment, at the end of the study radish had reduced ($P<0.05$) residual soil NO_3-N in the 0-90 cm profile 82 and 170 kg ha^{-1} in 1996 and 1997, respectively; mustard had reduced ($P<0.05$) NO_3-N 53 and 127 kg ha^{-1} in 1996 and 1997, respectively; and wheat had reduced NO_3-N 53 and 89 kg ha^{-1} in 1996 and 1997, respectively (Tables 2 and 3).

Over all NF rates and in both years, CCs were equally effective ($P>0.05$) in utilizing NO_3-N in the surface 30 cm of soil (Tables 2 and 3). In the 60 to 90 cm zone, CCs did not differ ($P>0.05$) in soil NO_3-N content in 1996; however, in 1997 NO_3-N content following radish and mustard was lower ($P<0.05$) than following wheat (Tables 2 and 3). At greater depths, radish and mustard tended to lower soil NO_3-N to a greater extent than wheat. Total profile NO_3-N in 1996 was lower ($P<0.05$) for radish than for mustard or wheat, which were similar ($P>0.05$). In 1997, total profile NO_3-N was lowest ($P<0.05$) with radish and highest ($P<0.05$) with wheat.

Root growth was not measured in this study; however, 60-to 90-cm soil cores of radish and mustard had noticeably more roots than soil cores of wheat. Thorup-Kristensen et al. (2003), noted that radish depleted lower soil profiles to a greater extent than Italian ryegrass (*Lolium multiflorum* Lam.). In their study, the crucifers radish and rape (*Brassica napus* L.) had a rooting depth of 1.5 m, while rye and oat (*Avena sativa* L.) roots were 0.9- to 1.0-m and ryegrass 0.6-m deep at 1000 degree days after planting. Deeper rooting would help reduce leaching of nitrate-N past the crop rooting zone and eventually into underground water. Soil NO_3-N leaching was not measured in our study. Irrigation was limited to 90% field capacity, unseeded plots were covered after initial irrigation, and the largest rainfall event was 1.0 cm; therefore, NO_3 leaching was likely minimal.

Mustard was more ($P<0.05$) productive than radish or wheat with no supplemental N, particularly in 1997 (Fig. 3 and 4). With NF increasing from 0 to 269 kg ha^{-1}, mustard dry matter increased from 2.4 to 8.4, radish increased from 1.1 to 6.1 and wheat increased from 1.1 to 5.5 Mg ha^{-1} in 1996. In 1997, mustard increased from 7.0 to 9.1, radish increased from 3.7 to 5.9 and wheat increased from 2.0 to 2.5 Mg ha^{-1}. Radish showed signs of severe N deficiency with no NF. Over all NF rates, mustard was most productive ($P<0.05$), accumulating 90 and 224% more dry matter in 1996 and 1997 than wheat, the least ($P<0.05$) productive CC.

There was no difference ($P>0.05$) in plant N concentration among CCs; however, N concentration in radish, mustard and wheat increased ($P<0.05$) from 18.0 to 40.0, 20.8 to 42.0, and 24.0 to 42.0 g kg^{-1}, respectively, with NF increase from 0 to 269 kg ha^{-1} (data not shown). Species differences in plant N accumulation were primarily related to differences in dry matter accumulation (Fig. 3 and 4). Over the two years, mustard accumulated the most ($P<0.05$) N in the above-ground biomass, 222-228 kg N ha^{-1}, while wheat accumulated the least ($P<0.05$), 46-130 kg

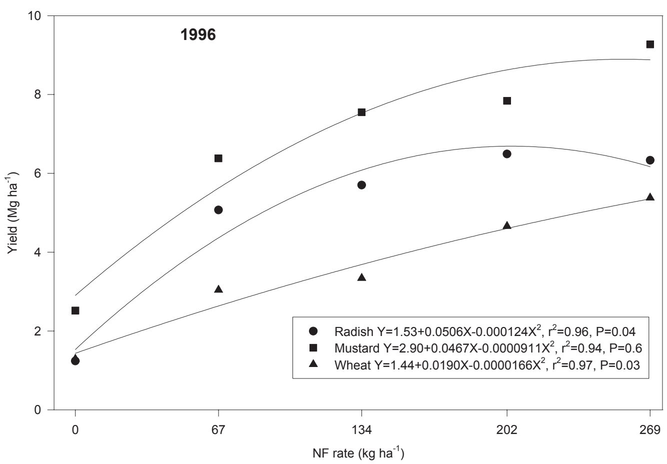

Fig. 3. Relationship between nitrogen fertilizer rates and dry matter yield of three cover crops in 1996, Torrington, WY.

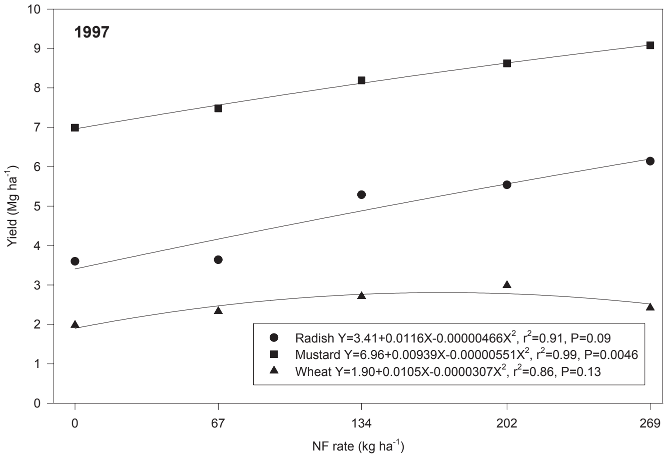

Fig. 4. Relationship between nitrogen fertilizer rates and dry matter yield of three cover crops in 1997, Torrington, WY.

N ha^{-1} (Tables 3 and 4). Radish N uptake was 133-157 kg ha^{-1} and was similar to that reported by Smukalski et al., 1991. They found 127 kg N ha^{-1} in the shoot and 23 kg N ha^{-1} in radish roots. Chapman et al., 1949, reported that mustard recovered 112 kg N ha^{-1} when fertilized with 112 kg N ha^{-1}, about half that recovered by mustard in our study.

Cover crop N uptake (Table 4) increased ($P<0.05$) with increasing NF rates to 134 kg applied N ha^{-1} in 1996 and in 1997, the result of an increase in dry matter production Fig. 3 and 4) and an increase in plant N concentration (data not shown). The unfertilized wheat in 1997 showed symptoms of nitrogen deficiency, in contrast to 1996. Radish and mustard accumulated more ($P<0.05$) N than wheat over all NF rates both years (Table 4). All CCs recovered greater ($P<0.05$) amounts of N at the 134 kg ha^{-1} rate of applied N than with no applied fertilizer. There was no significant difference ($P>0.05$) in N recovery with 134 to 269 kg applied N ha^{-1}. It would appear that SBN-resistant trap crop N uptake is limited more by N availability than by N uptake capacity.

The large amounts of accumulated plant N in our study were likely due to the late July/early August planting. Planting trap crops radish and mustard after a short-season crop, rather than a full-season crop, also was necessary for economical control of the sugarbeet nematode in Wyoming (Koch and Gray, 1997; Koch et al., 1998). Over 10 trials, shoot production of trap crop radish and mustard following spring barley

Table 4. Plant nitrogen uptake† of three cover crops (CCs) and five nitrogen fertilizer (NF) rates, Torrington, WY.

Treatment	1996	1997
	N uptake kg ha^{-1}	
CC		
Radish	157b	133b
Mustard	222a	228a
Wheat	130c	46c
NF rate		
0	35d	46b
67	125c	118b
134	172ab	184a
202	227ab	173a
269	289a	175a

Means within columns followed by the same letter do not differ ($P > 0.05$). CC x NF rate was not significant, $P > 0.05$.

† Plant nitrogen uptake = dry matter yield of top growth x N content of top growth.

(*Hordeum vulgare* L.) was more than three times greater than production following corn (*Zea mays* L.) or dry bean (*Phaseolus vulgaris* L.). This was attributed to a growth period of 1450 growing degree days (GDD) following barley, compared with 620 to 660 GDD following corn and dry bean (Krall et al., 2000).

High N accumulation by CCs reduces the potential for nitrate leaching below the crop root zone and helps recycle N to the following crop. Nitrogen fertilizer recovery commonly ranges from 50 to 80% in forages (Dougherty and Rhykerd, 1985). In our study, wheat both years and mustard and radish in 1997 were within this range. Follet et al., 1995, reported an average recovery of 49% in perennial grasses with N application of 0 to 224 kg N ha^{-1}, supplied by ammonium nitrate.

In our study, radish and mustard were winter-killed. Cover crops that winter-kill reduce the need for herbicide before planting the next main crop. Over-wintering CCs (e.g., winter wheat) are capable of continued scavenging in the spring, but may be more likely to negatively affect the succeeding crop through diminished soil moisture or temporary N immobilization from wide C/N ratios.

In addition to controlling the SBN, SBN-resistant cultivars of radish and mustard planted after a short-season crop, with adequate available

N, effectively scavenge soil nitrates and reduce the potential for over-winter leaching of nitrates. A soil sample should be taken following the short-season crop. If there is less than 150 kg NO_3-N in the 0-90 cm zone, fertilizer N may be needed to maximize radish and mustard above-ground and root growth and uptake of soil nitrates. In our study, a total of about 200 kg initial (0-90 cm) and applied NO_3-N ha^{-1} maximized nitrate uptake. Although our study showed that SBN-resistant radish and mustard produce high-quality biomass, long-term studies are needed to determine N cycling to succeeding crops. The multiple benefits of SBN-resistant radish and mustard merit their consideration for a place in sugarbeet rotations.

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