Nematode-Resistant Oil Radish for *Heterodera schachtii* Control II. Sugarbeet-Dry Bean-Corn Rotations†

David W. Koch, Fred A. Gray and James M. Krall

Department of Plant Sciences. P.O. Box 3354, University of Wyoming. Laramie, WY 82071-3354

ABSTRACT

The sugarbeet cyst nematode (SBCN) is a serious pest of sugarbeet. Use of a nematode-resistant, trap-crop oil radish as a second crop following harvest of dry bean and corn was studied for its potential to reduce soil populations of SBCN and, therefore, reduce nematicide use. Radish (*Raphanus sativus* L.) was grown on four SBCN-infested fields, two following corn harvested as silage and two following dry bean harvest, in comparison to an unseeded control treatment (main plots). Subplots consisting of aldicarb at three rates were randomized within main plots at sugarbeet planting the following year. The design was a randomized complete block with six replicates. Moisture was not adequate for radish growth at one site. At the other sites, radish growth varied from 416 to 1453 kg ha^{-1}. Soil population of SBCN declined 57% ($P<0.05$) at one site, but was not reduced ($P>0.05$) at three other sites. Including SBCN-resistant radish in the dry bean-sugarbeet and corn-sugarbeet rotations increased ($P<0.05$) subsequent sugarbeet yield at only one of the four test sites (following silage corn). Aldicarb did not affect yield at this site ($P>0.05$). At the other site where silage corn was grown, aldicarb but not radish, increased sugarbeet yield ($P<0.05$). At the remaining two sites (following dry bean), neither radish nor aldicarb affected sugarbeet yield ($P>0.05$). No disease or insect pest was detected on radish, nor was any disease or insect pest of sugarbeet increased by growing SBCN-resistant radish as a second crop. This study showed that the potential of substituting SBCN-resistant oil radish for nematicide following dry bean and corn in southeast Wyoming is limited. Substituting a small grain for corn or dry bean would allow more growing degree days (GDDs) for radish growth and SBCN activity.

Additional Key Words: Biological control, trap crop, nematicide, aldicarb, sugarbeet cyst nematode, *Beta vulgaris*, sugarbeet

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The sugarbeet cyst nematode (SBCN) (*Heterodera schachtii* Schmidt) is one of the most destructive pests of sugarbeet (*Beta vulgaris* L.) worldwide (Griffin, 1981). In a recent survey of northwestern Wyoming, 57% of sugarbeet fields were infested with *H. schachtii* (Gray, 1995).

Crop rotation is important for controlling the SBCN; however, rotations of more than 2 to 3 years usually are not practical due to limited land in proximity to sugar refineries and the lack of adapted and profitable alternative crops. In Wyoming and other areas, sugarbeet is grown in 2- to 3-year rotations with the aid of nematicides (Griffin, 1987). An alternative SBCN control method that would reduce the rate or need for nematicides, would reduce environmental and worker risk and help sustain sugarbeet production.

Development of nematode-resistant cultivars has improved the prospects of using trap crops as a biological alternative to nematicides in controlling the SBCN (Müller and Steudel, 1983; Steudel and Müller, 1983). Unlike non-resistant cultivars and species that have been used as trap crops (Jenkins and Taylor, 1967), these SBCN-resistant cultivars of radish (*Raphanus sativus* var. *oleiformis* Pers.) and mustard (*Sinapis alba* L.) do not require timely destruction to be effective. These cultivars have been used increasingly in sugarbeet rotations in Europe (Cooke, 1991). Effective control of SBCN with European-bred trap crops has been reported in the U.S. (Gardner and Caswell-Chen, 1993; Hafez and Hara, 1989). Resistant cultivars of radish and mustard act as trap crops in that they stimulate hatch of SBCN eggs and allow juvenile invasion of radish and mustard roots, but do not allow development of reproductive adults (Gardner and Caswell-Chen, 1993). At least two cultivars (one radish and one mustard) are commercially available in the U.S.

In Wyoming, nematode-resistant trap-crop radish, planted in late July and early August after malting barley (*Hordeum vulgare* L.) harvest, reduced soil populations of SBCN eggs 50 to 75% and increased subsequent sugarbeet yield 8.7 to 11.0 Mg ha^{-1}. The sugarbeet yield response to radish was greater than the response to the nematicide aldicarb (Koch et al., 1997).

Reduction in sugarbeet root yield from parasitism by *H. schachtii* is primarily related to high initial nematode population density in the soil (Cooke and Thomason, 1979; Griffin, 1980; and Griffin, 1981) and soil temperature at planting (optimum is 24C) (Griffin, 1981). Other factors related to increased parasitism include plant age (very young seedlings are most susceptible (Griffin, 1981), soil type (clay-loam soil is most favorable) (Caveness, 1958) and low to moderate soil moisture (Wallace, 1959).

In some sugarbeet growing areas, malt barley or other small grains are not grown. In southeast Wyoming, dry bean (*Phaseolus vulgaris* L.) and corn (*Zea mays* L.) are the primary crops in rotation with sugarbeet. Both are harvested later than small grains, affording less time and fewer growing degree days (GDDs) for a second crop. Nematode-resistant radish is cold-tolerant and continues to grow until the soil temperature reaches 4.4C (Roberts and Thomason, 1981; Curi and Zmoray, 1966). However, optimum temperatures for SBCN egg hatching and juvenile activity are 25C and 15C, respectively; activity ceases when soil temperature reaches 10C (Cooke and Thomason, 1979; Wallace, 1963). Therefore, early planting is essential to obtain optimum SBCN control.

Planting a trap crop following the main crop, a common practice in Germany, is more likely to be cost-effective than growing a trap crop for the full season. However, trap crops need enough time with adequate temperature and soil moisture to produce an extensive root system in order to effectively reduce SBCN population density (Thomason and Fife, 1962; Caubel et al., 1985; Wilson et al., 1993). This study was conducted to determine efficacy of nematode-resistant radish cultivars, planted as a second crop after dry bean and corn harvest in southeastern Wyoming, for reducing SBCN populations in soil.

MATERIALS AND METHODS

Nematode-resistant radish was planted on four SBCN-infested fields with two cooperating sugarbeet growers in Goshen County (southeastern Wyoming) during 1992 through 1995. Radish was grown after silage corn harvest on two sites, Faegler Farm, Field 1 (FGL-1) and Faegler Farm, Field 2 (FGL-2). Radish was planted following dry bean on two different sites, Schick Farm, Field 3 (SCH-3) and Faegler Farm, Field 4 (FGL-4). Soil descriptions of each site are shown in Table 1.

The average frost-free (0C) growing season in the Torrington area is 18 May to 20 September (124 days). About half the annual precipitation of 30 cm occurs during this period. The elevation is 1249 m and the average variation in daily high and low temperatures is 19C. Mean monthly soil temperature at 10-cm depth (1971-80) in September is 20.4C and in October, 12.9C (Becker and Alyea, 1964; Becker et al., 1977; Martner, 1986). Weather and soil temperature data are from the University of Wyoming Research and Extension Center (Torrington), located within 4 km of the study sites. Other site information is shown in Table 1.

Corn was harvested as silage, leaving 20 to 23 cm of stubble. Dry bean residue was not removed; however, windrows were scattered at bean harvest. In 1992 and 1993, corn and dry bean harvests were delayed an estimated 10 to 14 days due to cooler than normal growing seasons. Growing degree days (GDDs), base 10C, between 1 May and 31 August in 1992 and 1993 were 8 and 12% lower, respectively, compared to the long-term average. In 1994, 15% more GDDs' than normal were received over the growing season; however, radish was planted only one day earlier than in 1992 because a late-maturing corn hybrid was grown.

Radish was drilled into the stubble within one day after harvest of corn silage (two fields) and dry bean (two fields). A double-disk drill

Table 1. Site information on four fields on which nematode-resistant trap-crop radish experiments were conducted in 1992-95.

Site/field†	FGL-1	FGL-2	SCH-3	FGL-4
Study period	1992-93	1994-95	1992-93	1993-94
Field rotation‡	S-B-C-S	S-C-S	S-B-S	S-B-S
Years	1992-93	1994-95	1992-93	1993-94
Soil	Haverson§	Haverson§	Mitchell¶	Heldt#
Texture	loam	loam	silt loam	clay
pH	7.9	7.9	7.9	7.5
Organic matter, %	1.5	1.6	1.3	1.5
Nitrate N, mg kg^{-1}	42	11	62	6
Phosphate P, mg kg^{-1}	10	8	29	12

†Sites were cooperator fields 1 through 4. FGL = Faegler; SCH = Schick.
‡ S = sugarbeet, B = dry bean, and C = corn harvested as silage.
§fine-loamy, mixed, calcareous, mesic.
¶coarse-silty, mixed, calcareous, mesic.
#fine, montmorillonitic Ustertic Haplocambid.

with 20-cm row spacing was used. 'Pegletta' radish was seeded in 1992 and 1993 and 'Adagio' radish was seeded in 1994 at 25 kg ha^{-1}. Because Pegletta was commercially replaced by Adagio, starting in 1994, the two cultivars were compared in a separate study in 1993. No significant differences (P>0.05) were measured between cultivars in stand density, reduction in SBCN population, or sugarbeet yield the following year (data not shown). Radish planting varied from 8 to 15 September (Table 2). Ammonium nitrate at 56 to 67 kg N ha^{-1} was broadcast at radish planting at all four sites. Soil analysis showed adequate phosphorus at all sites.

Except at the SCH-3 site, surface soil moisture at planting was adequate for germination and radish was drilled 1-cm deep. At the SCH-3 site, radish was drilled 2 cm deep, as soil moisture near the surface was inadequate for germination. All sites were furrow irrigated within two days following radish planting, except at the SCH-3 site, where irrigation water was not available. Soil temperature at radish planting varied from 12.5 to 20.6C (10-cm depth) (Table 2). No herbicide was used as few weeds were present.

Plots were sampled before and after growing radish and soil populations of *H. schachtii* were determined as described previously (Koch et al., 1997). Radish stands and growth and presence of disease and insect pests were evaluated in late October when soil temperature at the 10-cm depth was < 5C. Radish dry matter production and plant density were determined by clipping two 0.5 m^2 quadrats per plot. Plant ground cover was determined by the line transect method (Laflen et al., 1981) in late October.

Radish was plowed down in early spring. Equipment from cooperators was used to prepare the seedbed and plant sugarbeet over the experimental area. Sugarbeet was space-planted at 10 to 13 cm within rows spaced 76 cm apart, except at SCH-3, where rows were spaced 56 cm apart. Nematicide was applied to sub-plots in paired rows (4- to 6-row plots) through Gandy® boxes mounted on the sugarbeet planter units. Nematicide was banded within 5 cm on the irrigated side of the sugarbeet row (alternate row irrigation), according to labeled instructions.

A split-plot arrangement with a randomized complete block design and six replicates was used at all sites. Main plots were either radish-seeded or fallow (unseeded control) after silage corn and dry bean harvest. Sub-plots were applied the following spring when sugar-

Table 2. Nematode-resistant radish establishment and performance following corn silage and dry bean harvest on four fields.

Site	FGL-1	FGL-2	SCH-3	FGL-4
Previous crop	silage corn	silage corn	dry beans	dry beans
Main crop harvest date	8 Sept. 92	8 Sept. 94	15 Sept. 92	9 Sept. 93
Radish planting	9 Sept. 92	8 Sept. 94	15 Sept. 92	10 Sept. 93
Radish cultivar	Pegletta	Adagio	Pegletta	Pegletta
Soil temp., $^0C^{\dagger}$	12.6	20.6	12.6	12.5
GDDs, base $4.4^0C^{\ddagger}$	622 (+107)	749 (+159)	496 (+94)	551 (-16)
GDDs, base $10^0C^{\ddagger}$	296 (+51)	348 (+77)	231 (+41)	177 (-9)
Evaluation date	17 Oct. 92	25 Oct. 94	17 Oct. 92	29 Oct. 93
Stand density, no. m^{-2}	166	157	145	115
Top growth, kg ha^{-1}	416	1453	101	1346
Plant ground cover, %	45	52	15	47

†Soil temperature at 10-cm depth at radish planting.
‡Growing degree days for the period from radish planting until evaluation in October and deviation from 30-year average.

beet was planted and consisted of: (1) untreated check, (2) half-label rate (2.4 kg ai ha^{-1}), and (3) full-label rate (4.8 kg ai ha^{-1}) of aldicarb [2-methyl-2-(methylthio)propionaldehyde O-(methylcarbamoyl)-oxime]. The 15% granular formulation of aldicarb was used. Main plots were 12 by 12 m and subplots were 3 by 12 m (4 rows of sugarbeet, except at SCH-3, which was 6 rows).

Sugarbeet stand, clean root yield, and quality factors (sucrose and nitrate content) were determined on 3.1 m of row per plot at all sites. Sugarbeet was observed for incidence of diseases and insect pests during the growing season and at harvest.

Analysis of variance was performed using the Statistical Analysis System (SAS, 1988). Treatment means were separated on the basis of least significant difference (LSD) at P =0.05. Initial nematode populations were used as a covariant in subsequent population analyses to reduce experimental error.

RESULTS AND DISCUSSION

Radish establishment and growth. At least 115 radish plants m^{-2} were present in late October at all sites (Table 2). Even at the SCH-3 site, where radish was planted deeper, stand density (145 plants m^{-2}) was relatively high. Radish development prior to killing frost varied from the first true leaf at the SCH-3 site with 15 September planting and limited soil moisture to five fully-expanded leaves at the FGL-2 site with 8 September planting and sufficient soil moisture. Plant ground cover in late October varied from 15 to 52% for the same sites and was directly related to amount of radish growth. In the Goshen County Soil Conservation District (includes all study sites), winter cover crops are recommended, particularly on coarse-textured soils. At least 18 to 25% winter cover is recommended for conservation compliance (R. Baumgardtner, NRCS, pers. comm.). Early September trap-crop seedings likely would provide adequate winter soil protection.

In 1992, growth of radish tops on the SCH-3 site was poor (101 kg ha^{-1} of top growth) due to the late planting date and lack of irrigation water after seeding (Table 2). Growth was better on the FGL-1 site (416 kg ha^{-1}), where radish was planted one week earlier and irrigated. Radish growth was limited even though growing conditions in the fall of 1992, measured by growing degree days (GDDs), were better than the long-term average. Greatest radish growth (1453 kg ha^{-1}) was in 1994 when soil temperature at planting (20.6C) was higher than in 1992 and 1993 and the number of GDDs was greater than in the previous two years.

Radish effect on SBCN population. The initial SBCN population (Pi) varied from 1.5 at FGL-1 to 24.1 eggs and juveniles cm-3 of soil at FGL-4 (Table 3). Radish planting reduced the soil population of SBCN 57% ($P<0.05$) at the FGL-2 site. No significant reduction was observed ($P>0.05$) at the other three sites. Even though a 46% nematode reduction was measured at the FGL-2 site, soil population of *H. schachtii* was highly variable. The significant reduction in SBCN population at the FGL-2 site was associated with the greatest radish growth, 1453 kg ha^{-1}, and the greatest number of GDDs (Table 2). Across all sites and years, there were only 44% as many GDDs were related to nematode activity (base 10C) as there were GDDs that were related to radish growth (base 4.4C).

The initial soil population (Pi) of SBCN at the FGL-4 site was extremely high (24.1 eggs cm-3 soil) when radish was planted. Even though nematode population was reduced by 46% by late October (Pf = 13.0 eggs cm-3 soil), it still was relatively high.

Table 3. Effect of SBCN-resistant oil radish planted on four fields during 1992-94 on soil population of sugarbeet cyst nematode (SBCN). Means are averages of six replicates.

			Heterodera schachtii†				
Site/Field	Previous crop	GDDs (base 10C)‡	Pi	Pi sampling date	Pf	Pf sampling date	Reduction§
			———	———	no. cm^{-3}	———	%
FGL-1	Silage corn	296	1.5	9 Sep 92	1.3	17 Oct 92	17 n.s.
FGL-2	Silage corn	348	3.6	8 Sep 94	0.9	25 Oct 94	57 *
SCH-3	Dry bean	231	15.6	15 Sep 92	13.6	17 Oct 92	13 n.s.
FGL-4	Dry bean	177	24.1	10 sep 93	13.0	29 Oct 93	46 n.s

†Initial SBN population, Pi, determined at radish planting and final popu lation, Pf, determined at termination of radish growth.
‡Growing degree days during period of radish growth.
§*H. schachtii* population reduced ($P<0.05$) at FGL-2, but not at other sites.

Diseases and insect pests of trap-crop radish. The only insect pest detected at any of the four sites was the sugarbeet root aphid, *Pemphigus populivenae* Fitch (SBRA), which occurred at low levels at the FGL-1 site in 1992 (data not collected). No diseases were detected on either trap crop radish cultivar.

Radish effect on sugarbeet yield. The only radish planting that increased ($P<0.05$) sugarbeet yield the following year was on the FGL-1 field (Table 4). Sugarbeet yield was improved, even though the SBCN population was reduced only 17% (Table 3). Aldicarb had no effect at this site.

Sugarbeet yield in 1993 at the SCH-3 site was very low, evidently due to the very high SBCN population. On the FGL-4 field in 1994, sugarbeet was replanted due to a late frost. The late establishment, along with a resultant poor stand of sugarbeet, was likely the reason for the poor yields at this site. Previous work shows that parasitism by

Table 4. Effect of trap-crop radish (grown as second crop following silage corn and dry bean) or aldicarb on sugarbeet yield. Means are averages of six replicates.

	Sugarbeet yield			
Site/Field:	FGL-1	FGL-2	SCH-3	FGL-4
Year:	1993	1995	1993	1994
Previous crop:	corn	corn	bean	bean
		Mg ha^{-1}		
Rotation effect:				
Unseeded (fallow)	40.2	33.9	18.9	29.6
Radish seeded	46.0	34.1	17.7	25.1
Rotation LSD (0.05)	3.8	n.s	n.s.	n.s.
Aldicarb effect:				
Untreated	41.5	29.9	16.4	24.9
Half rate†	44.5	37.7	18.6	25.4
Full rate†	43.8	34.6	19.8	31.7
Aldicarb LSD (0.05)	n.s.	3.4	n.s.	n.s.
Interaction LSD (0.05)	n.s.	n.s.	n.s.	n.s.

† Half- and full-label rate, 2.4 and 4.8 kg ha^{-1}, of 15G formulation.

H. schachtii is greater with delayed sugarbeet planting (Griffin, 1981).
Nematicide effect on sugarbeet yield. Aldicarb applied at half-label rate at sugarbeet planting increased sugarbeet yield ($P<0.05$) at the FGL-2 site in 1995 (Table 4). Aldicarb had no effect ($P>0.05$) on sugarbeet yield at the other sites. The SBCN population density at the SCH-3 and FGL-4 sites may have been too high for effective control with aldicarb.

Radish effect on sugarbeet diseases and insect pests. Rhizoctonia root and crown rot (*Rhizoctonia solani* Kühn) (RRCR) and Cercospora leaf spot (*Cercospora beticola* Sacc.) (CLS) were identified on sugarbeet. RRCR was identified at the FGL-1 and SCH-3 sites. Less than 5% of plants were diseased at both sites, with no difference due to main or subplot treatments ($P>0.05$). CLS was identified at the FGL-2 and FGL-4 sites; however, the disease was minor (no disease rating made), with no apparent treatment effect.

The only insect pest found on sugarbeet was SBRA, which was found at the FGL-1 site only. At harvest, 18.0 and 29.3% of sugarbeet roots were infested following radish and fallow treatment, respectively. Although the SBRA was present the previous fall on roots of trap-crop radish, infestation level on sugarbeet roots the following year was not increased.

Cyst nematode effect on sugarbeet yield. Soil population densities of *H. schachtii* prior to sugarbeet planting at our test sites ranged from 1.3 eggs cm^{-3} at the FGL-2 site to 19.7 eggs cm^{-3} at the FGL-4 site (data not shown). The lowest soil population density (damage threshold) at which we measured a significant decrease in sugarbeet yield in the untreated control was 1.3 eggs cm^{-3} at the FGL-2 site, where soil temperature at 4 cm at planting was 12C. The full rate of aldicarb resulted in a 4.7 Mg ha^{-1} increase in yield over the untreated control. These results are in agreement with a previous study (Griffin, 1981) in which an initial population density of 1.6 eggs g^{-1} of soil and 12C soil temperature resulted in reduced sugarbeet yield at Rupert, Idaho.

Although economic thresholds for *H. schachtii* on sugarbeet were not determined in our study, previous researchers have reported economic thresholds of 2.0 eggs g^{-1} soil at 12C soil temperature at sugarbeet planting near Rupert, Idaho (Griffin, 1981) and 2.4 eggs cm^{-3} soil near Scottsbluff, Nebraska (Robb et al., 1992) at a similarly cold soil temperature.

The potential of using SBCN-resistant radish after dry bean and corn harvest in southeastern Wyoming, as an alternative to nematicide for SBCN control, appears to be limited. In this sugarbeet-growing region, due to the limited growth of second crop radish, aldicarb provided more consistent sugarbeet yield increase than the trap crop.

Substituting a small grain for corn or dry bean, which would allow a longer time for radish growth, might be an option. Also, irrigation water likely would be more available for a trap crop planted after small grains than with later plantings. In southeastern Wyoming, winter wheat (*Triticum aestivum* L.) is commonly planted as a winter cover crop after dry bean and corn harvest, particularly on light-textured soils for prevention of wind erosion. However, wheat is generally plowed down and corn or dry bean planted in the spring. A demonstrated effectiveness of trap crops following small grain to control SBCN would be an additional incentive to include winter wheat as a crop in sugarbeet rotations.

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