2003 Sugarbeet Research and Extension Reports. Volume 34, Page 256-263

STRATEGIES FOR REDUCTION OF APHANOMYCES ROOT ROT ON SUGARBEET BY GREEN MANURE CROPS AND SOIL SOLARIZATION

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Aphanomyces cochlioides (= *A. cochlioides*) is a soilborne "water mold" that causes seedling stand loss and chronic root rot of older sugarbeet plants when soil is warm and wet. Unusually wet summers since 1993 have resulted in an increase in prevalence and severity of Aphanomyces diseases on sugarbeet. This pathogen produces thick-walled oospores in infected roots which survive in soil for years, even when a sugarbeet crop is not grown. Little is known about factors affecting survival of oospores, but a visual technique was recently described to distinguish viable (living) from dead oospores (2).

Current control measures for Aphanomyces damping-off and root rot include early planting (to avoid warm, wet soils favorable for infection), seed treatment with the fungicide Tachigaren (hymexazol), planting partially resistant varieties, water management (installing tiles or ditches to improve soil drainage, cultivating to dry soil), and weed control (*A. cochlioides* infects several common weed species, e.g., pigweed, lamb's-quarters, kochia). When fields have high potential for disease, producers are advised to avoid planting sugarbeet because if the season is wet and warm, control options are inadequate and do not result in an economic return.

Since disease control options are limited in effectiveness, other novel strategies (green manure crops and soil solarization) are being explored. Green manure crops are reported to suppress several soilborne pathogens and pests on many crops. Examples of disease suppression by green manure crops include: sorghum sudan grass for Verticillium wilt on potato, buckwheat for scab on potato, oilseed radish for the sugarbeet cyst nematode, and oat for Aphanomyces root rot on pea and sugarbeet (7). Soil solarization also can reduce disease and is accomplished by covering wet soil with clear polyethylene plastic to capture solar energy and increase soil temperatures, ideally to 97-122 °F in the upper 12 inches. High soil temperatures "pasteurize" soil and rid it of certain soilborne fungi, weed seeds, and other pests (3). Equipment is available for large-scale solarization in fields and has been applied most effectively in geographic areas with intense solar radiation to control a wide range of soilborne plant pathogens on economic crops. Solarization also can be effective in temperate regions when combined with green manure crops, reduced dosages of chemicals, or biological control organisms (3). For instance, Fusarium wilt of cabbage was most effectively reduced when plots with cruciferous residues were covered with plastic tarp and solarized compared to either treatment alone (6).

OBJECTIVES

The purpose of this research was to determine the effect of several green manure crops and soil solarization on 1) survival of oospores of *A. cochlioides* and 2) suppression of Aphanomyces root rot on sugarbeet.

MATERIALS AND METHODS

Precrop and solarization treatments. Cover crops were sown in fields infested with *A. cochlioides* on May 15, 2001 in the Aphanomyces Nursery at the University of Minnesota, Northwest Research and Outreach Center (NWROC), Crookston; May 24, 2002 in a growers' field near Crookston; and May 8, 2003 in the Aphanomyces Nursery, NWROC. In 2001, seed of green manure crops were sown by hand and raked into soil. Crops included buckwheat var. Koto, oilseed radish var. Colonel and sorghum sudan grass var. Green Grace Supreme sown at the equivalent of 45, 18, and 13.5 lb/A, respectively. In 2002 and 2003, the same crops were drill-seeded (except for oilseed radish, which was sown by hand) and two were added: oat var. Dane and wheat var. 2375 (each sown at 2 bu/A). Oat has been shown to suppress Aphanomyces on sugarbeet and wheat commonly is grown the season before sugarbeet. The control was fallow soil. Each plot measured 20 x 30 ft in 2001; 40 x 30 ft in 2002; and 40 x 35 ft in 2003. Treatments were arranged in a randomized block design with six replicates in 2001 and four replicates in 2002 and 2003. At planting, soil cores (6, 2.5-inch diameter) were collected to a depth of 6 inches and combined per plot. Soil samples were evaluated by a sugarbeet seedling assay in the greenhouse and Aphanomyces soil index values (range from 0 to100; 0 = healthy and 100 = all sugarbeet seedlings dead) were determined.

On July 11, 2001 (8 weeks after planting), all green manure crops were mowed and the residue was disked and rototilled into soil to a 3- to 4-inch depth. Amounts of buckwheat, oilseed radish, and sorghum sudan grass incorporated into plots averaged 8, 17, and 6 tons fresh weight/A, respectively. In 2002, green manure crops were mowed and incorporated on July16 (7½ weeks after planting) and amounts of buckwheat, oilseed radish, sorghum sudan grass, oat, and wheat averaged 6, 17, 13.5, 12, and 10 tons fresh weight/A, respectively. In 2003, green manure crops were mowed and incorporated on July 17 (8 weeks after planting) and amounts of

buckwheat, oilseed radish, sorghum sudan grass, oat, and wheat averaged 8, 8, 11, 12, and 7 tons fresh weight/A, respectively. Fallow control plots also were disked and rototilled. Each main plot (green manure crops and fallow) then was split into two subplots (one for solarization and the other not solarized). Soil samples then were collected in each subplot and later indexed for Aphanomyces root rot in the greenhouse, as previously described.

Thermocouples were buried at 3, 6, and 9 inches in subplots of one replicate per trial and soil temperatures were monitored and recorded on a Watchdog data logger (Spectrum Technologies, Plainfield, IL) every 15 minutes during solarization. In 200l, the trial was irrigated (1.2 inches) and then plots designated for solarization were covered with a clear, horticultural grade polyethylene plastic (3 mil thick) on July 13. Edges of tarps were manually buried in furrows along borders of solarized subplots. Plots were similarly covered with plastic on July17, 2002 but were not irrigated due to lack of facilities (plots had received about 6.6 inches of rainfall in June and 0.2 inches in July before solarization). Plots were covered with plastic on July 18, 2003, but were not irrigated because of adequate rainfall (2.6 inches in July, including 0.9 inches 3 days before plastic was installed).

Oospore survival. Oospores of *A. cochlioides* also were buried in soil to observe the effect of green manure crops, with and without soil solarization, on oospore survival. To establish this experiment, oospores were produced in the laboratory by placing excised, 0.75-inch segments of 2-week-old sugarbeet hypocotyls (portion of the seedling between point of seed attachment and cotyledonary leaves) in sterile water. Zoospores of *A. cochlioides* then were added and tissues were incubated in the dark at 68 $\pm$ 5 °F for 7 weeks. Several hypocotyls then were macerated and the contents were microscopically examined to determine total number of oospores. In 2001, 2002, and 2003 there were an average of 8,000, 15,000, and 4,600 oospores/hypocotyl, respectively. One hypocotyl segment was placed in the bottom of a bag (1 x 1 inch) of a nylon monofilament mesh fabric (less than 10µ pores), which was closed with string and placed in a pan of water to prevent drying until buried in soil. All hypotocotyls had been microscopically examined to ensure they contained oospores. Bags were buried at 3-, 6-, and 9-inch depths in the green manure crop and fallow subplots designated to be solarized or not solarized (four replicates/treatment). Two bags were buried per depth, one for retrieval immediately after solarization and another for removal 4 weeks later (effects of solarization on survival structures, such as oospores, can be delayed), but the second set of oospores was examined only in 2001.

Tarps were removed from subplots after solarization for 9, 7, and 8 weeks in 2001, 2002, and 2003, respectively. Bags of oospores were retrieved from each subplot, placed in plastic bags, moistened with water, and stored in a refrigerator until examined. Each bag was carefully opened along the outside seams. Hypocotyls were removed and microscopically inspected to determine the amount of tissue and number of oospores present. Relative amounts of hypocotyl tissue were assessed on a 0-5 scale: 0 = no tissue present, 1 = 1-20% of original tissue present (or only vascular tissue remaining), 2 = 21-40%, 3 = 41-60%, 4 = 61-80%, and 5 = 81-100% of original tissue intact. In 2001, relative numbers of oospores also were assessed on a 0-4 scale: 0 = none observed; 1 = 100 or fewer; 2 = more than 100 to 1,000; 3 = more than 1,000 to 10,000; and 4 = more than 10,000. Hypocotyl tissue was transferred to a microscope slide and oospores were examined at 400 X magnification to assess if they were viable (alive) or dead. A minimum of 100 oospores were evaluated per sample, if available. When hypocotyls were severely deteriorated, interiors of mesh bags were microscopically scanned for oospores and if observed, they were removed with two-sided transparent cellophane tape and assessed for viability.

In 2002 and 2003, numbers of oospores were directly quantified after condition of each hypocotyl had been assessed, as described above. The hypocotyl was placed in a 2 ml Wheaton tissue grinder; 1 ml of distilled water was added; and the plunger was depressed 15 times. Contents were transferred to a 1.5 ml tube and centrifuged 10 minutes at 10,000 rpm. A 750 µl aliquot of supernatant (not containing oospores) was decanted and the remaining 250 µl (containing oospores and macerated hypocotyl tissue) was vortex-mixed for several seconds. Subsamples were placed in a Speirs-Levy eosinophil counting chamber and oospores were microscopically examined and counted.

Sugarbeet following precrops and soil solarization. On May 22, 2002 and May 8, 2003, non-solarized plots established the previous year were fertilized with nitrogen (100 lb/A) to equal nitrogen in solarized plots. Sugarbeet seed of variety Beta 2088 was sown at a 1.25-inch spacing in 30 ft rows, 22 inches apart. Counter was applied in a 7-inch band at 1.8 lb a.i./A at planting. In both years, microrates of herbicides were applied in late May and twice in June (0.5 pint Betamix, 1/8 oz Upbeet, 60 ml Select, 40 ml Stinger, 1½ pint Scoil [product/A] per application). In 2002, plots were cultivated on July 1; thinned on July 2; and irrigated on May 29, June 3 and 7, and July 3 at 253, 181, 181, and 217 gallons/two middle rows of each subplot, respectively. Rainfall was abundant after early July (3.7 inches), followed by 9.2 inches in August. In 2003, plots were not cultivated and were thinned on July 1 and 2. Plots were off-station and rainfall was adequate, with 9 inches in June through August. In both seasons, fungicides for controlling Cercospora leaf spot were applied twice in August and in early September with 5 oz Supertin, 13 oz Eminent, and 5 oz Supertin (product/A), respectively.

Data were collected on the two middle rows of each subplot at 2 and 4 weeks after planting for seedling stand. At 6 weeks after planting in 2002, 40 plants also were collected in rows adjacent to the two middle rows of each subplot in three replicates and assessed for root rot on a 0-4 scale (0 = root clean; 1 = less than 10% of the root surface scarred, root malformed; 2 = 10-25% of root surface scarred, root malformed; 3 = 26-75% root surface scarred, lower half of root rotted or malformed; and 4 = 76% or more of root surface scarred and/or no root tip). Harvest data were collected on the two middle rows of each subplot for number of marketable roots, Aphanomyces root rot, yield, and quality. Twenty roots were randomly selected from each subplot and rated for root rot (0-7 scale, 0 =

healthy, 7 = root completely rotted and foliage dead). Ten of these roots were analyzed for yield and sucrose quality by the American Crystal Sugar Company Quality Laboratory, East Grand Forks, MN.

Data analysis. Data for amounts of sugarbeet hypocotyl tissue, relative number of total oospores, percent living oospores, number of total oospores (living and dead), and number of living oospores were subjected to appropriate transformations (if needed) and analysis of variance. If significant ($P \leq 0.05$), means were separated by Least Significant Difference (LSD). Correlations were calculated for relative amounts of hypocotyl tissue and total oospores (living and dead) and for relative amounts of hypocotyl tissue and living oospores.

RESULTS

Greenhouse assay for Aphanomyces soil index values. Before green manure crops were sown in 2001, 2002, and 2003, Aphanomyces soil index values were 97, 99, and 84, respectively (Table 1). After incorporation of green manure crops (and before solarization), soil index values were reduced by all precrop treatments in each season (except for wheat in 2003) by varying amounts (Table 1). Buckwheat, oat, and sorghum sudan grass resulted in the greatest reduction of root rot by in 2001, 2001, and 2003, respectively. Soil index values for fallow plots remained virtually unchanged during this period in the three seasons.

Soil temperatures achieved by solarization. Maximum soil temperatures recorded in green manure crop subplots (illustrated for oilseed radish) were similar to the fallow control (solarized or not solarized) in all seasons (Table 2). At the 3-inch depth, solarization resulted in maximum soil temperatures between 102 to 112 °F, and were from 11 to 19 °F higher than temperatures recorded in non-solarized soils. A less dramatic temperature differential between solarized and non-solarized soils occurred with increasing soil depths. At 9 inches, maximum soil temperatures were at least 10 °F higher in solarized (90-101 °F) than in non-solarized (76 - 87 °F) plots. The highest ambient temperature recorded during the solarization periods in 2001, 2003, and 2003 were 96, 90, and 98 °F, respectively.

Oospore survival. Examination of sugarbeet hypocotyls and oospores removed from soil immediately after solarization in three seasons and a second sampling 4 weeks later in 2001 (samples from 2002 and 2003 were not completely assessed, so data are not presented) revealed various stages of tissue decomposition in both seasons. Some hypocotyls were fairly intact and the cortex surrounding vascular tissue contained abundant oospores (8). In other cases, the cortex was severely decomposed and only vascular tissue, which contained a few oospores, remained (8). Occasionally, no hypocotyl tissue or oospores (or only a few oospores) were attached to the interior of the mesh bag.

Table 1. Aphanomyces soil index values determined in the greenhouse for field soil collected when green manure crops were sown (May 15, 2001; May 24, 2002; May 8, 2003) and after they were incorporated (July 11, 2001; July 16, 2002; July 17, 2003) the day before solarization began; the control was fallow soil. In 2001 and 2003, plots were located in the Aphanomyces Nursery at the University of Minnesota, Northwest Research and Outreach Center, Crookston and in 2002, were in a growers' field near Crookston that was naturally infested with *Aphanomyces cochlioides.*

	Soil index value[z]								
	2001			2002			2003		
Soil Treatment	Before green crop sown	After green crop incorporated	Change	Before green crop sown	After green crop incorporated	Change	Before green crop sown	After green crop incorporated	Change
Buckwheat	96	63	-33	99	90	-9	86	48	-38
Oat	-	-	-	99	79	-20	69	27	-42
Oilseed radish	98	75	-22	100	86	-14	93	68	-25
Sorghum sudan grass	96	78	-18	99	90	-9	96	40	-56
Wheat	-	-	-	99	83	-16	67	71	+4
Fallow soil	98	97	-1	100	96	-4	91	97	+6
Average	97			99			84		

z Each value based on planting 25 sugarbeet seed of variety ACH 261/pot (four pots/soil treatment). Six soil cores had been collected to a 6-inch depth per treatment and combined. Four weeks after planting, index values were determined on a 0-100 scale where 0=plant healthy, 100=all plants dead or severely rotted; - = precrop not grown. Each value is based on six replicates in 2001 and four replicates in 2002 and 2003.

Table 2. Maximum soil temperatures recorded in fallow and green manure precrop plots (illustrated for oilseed radish) that were solarized (soil covered with clear, polyethylene plastic) or not solarized from July 13 to September 13, 2001 and from July 18 to September 11, 2003 in the Aphanomyces Nursery at the University of Minnesota, Northwest Research and Outreach Center, Crookston and from July 17 to September 4, 2002 in a growers' field near Crookston that was naturally infested with *Aphanomyces cochlioides.*

	Maximum soil temperature (°F)/depth (inches)[z]								
	2001			2002			2003		
Soil treatment	3	6	9	3	6	9	3	6	9

Solarized									
Oilseed radish	109	97	93	102	99	90	112	99	100
Fallow	106	100	91	110	96	90	107	102	101
Non-solarized									
Oilseed radish	90	86	81	91	83	76	94	85	87
Fallow	88	84	81	91	86	80	89	85	81

z Data loggers were buried at 3-, 6-, and 9-inch depths in one replicate each season and temperatures were monitored and recorded every 15 minutes during the term of soil solarization.

In 2001, the relative amount of sugarbeet hypocotyl tissue in mesh bags retrieved after solarization and 4 weeks later averaged 2.1 for both sampling times (data not shown). In 2002 and 2003, the relative amount of hypocotyl tissue after solarization averaged 2.6 and 1.7, respectively (data not shown). Green manure crops and the fallow control, solarized and non-solarized treatments, and depth of burial in soil did not have a significant effect on amount of hypocotyl tissue in the three years (data not shown).

Viability assessments of oospores for three years are summarized in Table 3. There were no significant interactions between main treatments, so data are presented only for main treatments. Of oospores present in sugarbeet hypocotyls retrieved from soil immediately after solarization and 4 weeks later in 2001, 41% and 36% were alive, respectively. Oospores were directly quantified for samples removed after solarization in 2002 and 2003. In 2002, an average of 1,675 out of 7,050 present (24%) were alive; an average of 15,000 oospores were in hypocotyls when they were buried, so overall oospore survival after burial in soil for 7 weeks was about 11%. In 2003, an average of 454 out of 1,682 present (27%) were alive; an average of 4,600 oospores were in hypocotyls when they were buried, so overall survival after burial for 8 weeks was 10%.

Table 3. Survival of oospores of *Aphanomyces cochlioides* within sugarbeet hypocotyls buried in field trials conducted in 2001, 2002, and 2003. Oospores were buried at three depths within 1 day after various green manure crops had been incorporated into soil and then plots were solarized (covered with a clear polyethylene tarp from July 13 - September 13, 2001 [9 weeks], July 17 - September 4, 2002 [7 weeks], and July 18 - September 11, 2003 [8 weeks]); controls included non-solarized plots of each green manure precrop and fallow plots (solarized and non-solarized). Hypocotyls were retrieved and oospores within this tissue were microscopically assessed for viability immediately after solarization and 4 weeks later in 2001 and immediately after solarization in 2002 and 2003. The 2001 and 2003 trials were established in the Aphanomyces Nursery at the University of Minnesota, Northwest Research and Outreach Center, Crookston and the 2002 trial was in a growers' field near Crookston that was naturally infested with *A. cochlioides*.

	2001 - % Living oospores[u]			2002 – Number of oospores at 7 weeks[u.v]			2003 – Number of oospores at 7 weeks[u.v]	
Treatment	9 weeks	13 weeks		Total (living and dead)	Living		Total (living and dead)	Living
Precrop[w]								
Sorghum sudan grass	52	41		7,430	1,770		1,648	395
Oilseed radish	48	31		5,950	1,790		1,782	524
Buckwheat	32	36		8,040	1,470		1,535	435
Oat	-	-		7,040	1,660		1,588	441
Wheat	-	-		7,580	1,900		1,977	620
Fallow	33	35		6,280	1,460		1,553	305
Mean	41	36		7,050	1,675		1,682	454
LSD ($P \leq 0.05$)[z]	NS	NS		NS	NS		NS	NS
Soil treatment[x]								
Solarized	35	43		7,180	2,230		2,054	527
Non-solarized	47	28		6,920	1,117		1,311	380
Mean	41	36		7,050	1,675		1,683	454
LSD ($P \leq 0.05$)[z]	NS	13		NS	809		505	NS
Depth (inches)[y]								
3	38	25		6,670	1,770		1,493	269
6	34	35		6,920	1,420		1,679	496
9	52	48		7,750	1,840		1,874	596
Mean	41	36		7,050	1,675		1,682	454

LSD ($P \leq 0.05$)[z]	NS	16		NS	NS		NS	234

u Each value for percent living oospores and number of total oospores (living and dead) is based on observing and counting at least 1,800 oospores per precrop in 2001, 2002 and 2003; 3,600 per soil treatment in 2001 and 5,400 in 2002 and 2003; and 2,400 per depth in 2001 and 3,600 in 2002 and 2003. These values reflect oospores that were observable after they were retrieved from soil; many oospores died as sugarbeet hypocotyls decomposed in soil and therefore, could not be counted. Number of living oospores per 0.75-inch hypocotyl before burial in soil in 2001, 2002, and 2003 averaged 8,000, 15,000, and 4,600, respectively.

v A method to quantify number of total (living and dead) and living oospores was used in 2002 and 2003.

w Each value averaged across soil treatment and depths; - = cover crop not sown. In 2001, precrops were sown on May 15 and incorporated on July 11; in 2002, they were sown on May 24 and incorporated on July 16; and in 2003, they were sown on May 23 and incorporated on July 17.

x Each value averaged across precrop treatment and depth.

y Each value averaged across precrop treatment and soil treatment.

z LSD = Least Significant Difference; if significant, LSD value provided for mean separations; NS = not significant.

For samples removed immediately after solarization, oospores (total of living + dead, or living oospores) were not significantly affected by green manure crop and fallow treatments in three seasons (Table 3). Solarization tended to have the highest recovery of oospores compared to non-solarized plots in the three seasons (Table 3). There were significantly more living oospores in solarized plots 4 weeks after solarization in 2001 and immediately after solarization in 2002 compared to nonsolarized plots. In 2003, there was a significantly higher total number of oospores (living + dead) in solarized than in non-solarized soil, but there were no significant differences for number of living oospores. Oospore survival tended to be higher with increasing soil depth in the three seasons (Table 3). There were significantly more oospores surviving 4 weeks after solarization at the 9-inch depth in 2001 and 2003 compared to the 3-inch depth; depth of burial had no significant affect on oospore survival in 2002.

Table 4. Sugarbeet seedling emergence, root rot ratings, and sugarbeet yield and quality of Beta 2088 grown in 2002 and 2003 in plots planted to several green manure precrops the previous field season. The precrops were incorporated into soil in mid-July and then plots were solarized (covered with a clear polyethylene tarp) for 9 weeks in 2001 and 7 weeks in 2002. Controls included non-solarized plots of each green precrop and fallow plots. The 2002 trial was in a grower's field near Crookston that was naturally infested with *A. cochlioides* and the 2003 trial was in the Aphanomyces Nursery at the University of Minnesota, Northwest Research and Outreach Center, Crookston.

	No. plants/60 ft row (WAP)[v]		Root rot rating	No. marketable	Root rot[x,y] rating	Yield	Sucrose[x]		
	2	4	(6 WAP)[w]	roots/60 ft row[x]		(T/A)[x]	%	lb/T	lb recoverable/A
2002									
Precrop									
Sorghum sudan grass	421	372	1.28	70	2.6	22.1	15.5	279	6,167
Buckwheat	415	370	1.25	70	2.5	22.5	15.8	286	6,421
Oilseed radish	424	375	1.23	67	2.5	21.6	15.8	288	6,202
Fallow	432	372	1.33	68	2.7	21.7	15.4	276	5,984
LSD (P=0.05)[z]	NS	NS	NS	NS	NS	NS	NS	NS	NS
Soil treatment									
Solarized	477	427	1.15	70	2.4	23.2	15.6	281	6,497
Non-solarized	369	318	1.40	68	2.7	20.8	15.7	284	5,890
LSD (P=0.05)[z]	14	16	0.23	NS	0.2	1.1	NS	NS	306
2003									
Precrop									
Fallow	317	365	-	63	4.2	19.4	14.8	255	4,933
Buckwheat	332	366	-	61	4.3	18.3	15.6	273	4,984
Oat	294	343	-	61	4.3	19.7	15.4	268	5,280
Oilseed radish	329	365	-	57	4.6	17.4	15.6	274	4,753
Sorghum sudan grass	330	368	-	59	4.3	17.9	15.2	266	4,719
Wheat	311	365	-	64	4.1	19.2	15.3	265	5,068
LSD (P=0.05)[z]	NS	NS		NS	NS	NS	NS	NS	NS
Soil treatment									
Solarized	320	370	-	61	4.4	18.5	15.4	269	4,941
Non-solarized	318	354	-	61	4.2	18.8	15.2	265	4,971

LSD (P=0.05)[z]	NS	NS		NS	0.2	NS	NS	NS	NS

v Seeds planted at a 1.25-inch spacing on May 24, 2003 and May 8, 2003. For each precrop, values are averaged across solarized and non-solarized plots and for each soil treatment, values are averaged across all precrops (six replicates in 2002 and four replicates in 2003).

w Root rot rating 6 weeks after planting (WAP) based on a 0-4 scale, 0 = root healthy, 4 = more than 75% of root surface scarred and/or no root tip. For each precrop (40 roots per replicate), values are averaged across solarized and non-solarized plots and for each soil treatment, values are averaged across all precrops (three replicates); - = ratings not made in 2003.

X For each precrop, values are averaged across solarized and non-solarized plots and for each soil treatment, values are averaged across precrops.

Y Root rot rating based on a 0 – 7 scale, 0 = root healthy; 7 = root completely rotted and foliage dead.

Z LSD = Least Significant Difference; if significant, LSD value provided for mean separations; NS = not significant.

In 2001, 2002, and 2003, there usually were significant and positive correlations between the relative amount of hypocotyl tissue remaining after solarization and the number of total oospores (living and dead) and living oospores in solarized plots at all depths of burial in soil (data not shown). That is, the number of total and living oospores increased as the amount of intact hypocotyl tissue increased. In non-solarized plots, this relationship was not as consistent as observed in solarized soils (data not shown).

Sugarbeet following precrops and soil solarization. There were no significant interactions between main treatments (precrop or soil solarization) for data collected on sugarbeet in 2002 and 2003, so data are presented only for main treatments (Table 4). Green manure crops grown the previous season and the fallow control had no significant effect on sugarbeet stands at 2 and 4 weeks after planting in both years. Stands at 2 and 4 weeks after planting were significantly higher in solarized than non-solarized plots in 2002 but not in 2003. Precrop also did not affect severity of Aphanomyces root rot on sugarbeet roots rated 6 weeks after planting in 2002, but disease ratings were significantly lower in plots that had been solarized compared to non-solarized plots (this data was not collected in 2003).

At harvest in both years, precrop treatments had no significant effect on number of marketable sugarbeet roots, Aphanomyces root rot ratings, yield, or quality. In 2002, solarization of plots the previous season resulted in a significant reduction in root rot and significant increases in tons of roots and recoverable sucrose/A, but had no effect on number of marketable roots, percent sucrose, or pounds of sucrose/ton when compared to non-solarized plots (Table 4). In 2003, root rot ratings were significantly higher in solarized than nonsolarized plots, although root rot was so severe, these difference were not biologically significant; solarized and nonsolarized plots were the same for number of marketable roots, yield, and quality (Table 4).

DISCUSSION

This research illustrates the rapid loss of oospore viability (90%) in infected plant tissues buried in soil for 7 to 8 weeks, regardless of previous green manure crops or soil solarization. We found a direct relationship between oospore survival and persistence of infected tissue in soil, which has not been reported previously. Boosalis and Scharen (1) found oospores of *A. euteiches* associated with diseased plant debris extracted from soil, but it has been assumed oospores remain free in the soil matrix as debris decomposes (4). *A. cochlioides* oospores average 21 $\pm$ 5 µ in diameter and would be too large to pass through 10 µ pores of the nylon mesh bags. Fresh organic matter introduced into soil is vulnerable to immediate microbial decomposition, which accounts for rapid loss of tissue (and hence, loss of oospores embedded in hypocotyls) after burial in soil. Hypocotyl tissue also is immature and delicate and decomposes readily. Oospores of *A. cochlioides* may survive longer in diseased, mature sugarbeet roots that have secondary thickenings and decompose slowly in soil.

Solarization tended to slightly enhance survival of *A. cochlioides* oospores compared to non-solarized soil (Table 3). Soil solarization typically hastens decline of survival propagules of some soilborne fungi and other pests by generating high temperatures that directly kill propagules or weaken them so they are vulnerable to parasitism by other soilborne organisms. Some climates do not result in sufficiently high temperatures during solarization to kill pathogens, or certain pathogen propagules may be resistant to heat. There are no reports in the literature documenting the effects of solarization on survival of *Aphanomyces* species (3). In our study, soil temperatures reached under polyethylene tarps may have been inadequate, or did not prevail for a sufficient length of time, to effectively reduce numbers of oospores. Dyer has shown that 90% of oospores of *A. cochlioides* die when exposed to 104 °F for 72 hours or to 122 °F for 4 hours (*unpublished)*. Tropical climates attain temperatures of 120 °F at a 9-inch depth in tarped soils, but our study reached temperatures slightly over 112 °F at 3 inches. Perhaps solarization preconditioned oospores so they were slightly less vulnerable to dying than in nonsolarized soils.

It is unknown if oospores of *A. cochlioides* in infested fields, and those buried in mesh bags in soil, respond similarly to green manure crops, solarization, and depth of burial. Green manure crops reduced Aphanomyces root rot index values immediately after soil-incorporation compared to fallow soil but they did not directly affect viability of buried oospores compared to fallow soil, nor did they benefit the subsequent sugarbeet crop in 2002 (in combination with solarization or alone). Perhaps disease suppression by green

manure crops is short-term and does not carry over the winter to benefit a subsequent sugarbeet crop. Previous greenhouse trials have shown a green oat precrop consistently reduces Aphanomyces damping-off on sugarbeet but in the field, may not perform consistently. Other reports indicate that growing a green oat precrop in producers' fields reduces Aphanomyces root rot of peas caused by *A. euteiches* (7).

To date, soil solarization and/or production of green manure crops are inadequate, inconsistent, and impractical for reducing Aphanomyces diseases (or increasing sugarbeet growth and yield) in fields in the Red River Valley. The most significant result of this study is the observation that oospore survival is dependent upon condition of host debris. Based on a most probable number assay, Pfender and Hagedorn (5) reported a substantial loss of inoculum of *A. euteiches* of nearly 50% within 1 year after growing peas. Their data suggested that taking a field out of pea production for several years would allow inoculum to decrease to negligible densities until fields were safe to plant, but this projection has not been substantiated by field experience or observations. Perhaps nonhost crops support populations of *Aphanomyces* species without causing symptoms. Also, survival of only a few oospores in a small volume of soil, is deceptive. A single oospore of *A. cochlioides* produces 100 to 300 zoospores of primary inoculum, so low inoculum densities can result in considerable disease under warm, wet conditions.

ACKNOWLEDEGMENTS

We thank the Sugarbeet Research and Education Board of Minnesota and North Dakota for partial funding of this research; Jeff Nielsen and Todd Cymbaluk, University of Minnesota, Northwest Research and Outreach Center, Crookston, for planting, maintaining and harvesting plots; Jeff Nielsen for statistical analyses; our 2002 grower cooperator for providing land; Dave Braaten for providing seed of oilseed radish and buckwheat; and American Crystal Sugar Co. Quality Laboratory, East Grand Forks, MN for sugarbeet yield and quality analyses.

LITERATURE CITED

1. Boosalis, M.G., and Scharen, A.L. 1959. Methods for microscopic detection of *Aphanomyces euteiches* and *Rhizoctonia solani* and for isolation of *Rhizoctonia solani* associated with plant debris. Phytopathology 49:192-198.

2. Dyer, A.T., and Windels, C.E. 2003. Viability and maturation of *Aphanomyces cochlioides* oospores. Mycologia 95:321-326.

3. Katan, J. 1987. Soil solarization. Pages 77-105 *in*: Innovative Approaches to Plant Disease Control. I. Chet, ed. John Wiley & Sons, New York. 372 pp.

4. Papavizas, G.C., and Ayers, W.A. 1974. Aphanomyces Species and Their Root Diseases in Pea and Sugarbeet. United States Dept. Agric., Agric. Res. Serv., Tech. Bull. No. 1485. Washington, D.C.

5. Pfender, W.F., and Hagedorn, D.J. 1983. Disease progress and yield loss in Aphanomyces root rot of peas. Phytopathology 73:1109-1113.

6. Ramirez-Villapudua, J., and Munnecke, D.E. 1988. Effect of solar heating and soil amendments of cruciferous residues on *Fusarium oxysporum* f. sp. *conglutinans* and other organisms. Phytopathology 78:289-295.

7. Windels, C.E. 1997. Altering community balance: Organic amendments, selection pressures, and biocontrol. Pages 282-300 *in:* Ecological Interactions and Biological Control. Andow, D.A., Ragsdale, R.W., and Nyvall, R.F., eds. Westview Press, Boulder, Colorado. 334 pp.

8. Windels, C.E., Brantner, J.R., and Dyer, A.T. 2002. Green manure crops and soil solarization effects on Aphanomyces root rot and oospore survival. 2001 Sugarbeet Res. Ext. Rept. 32:269-278.