LACK OF CONTROL 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. 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 current disease control options are limited in effectiveness, other strategies such as green manure crops and soil solarization (singly and in combination) are being explored. Green manure crops suppress several soilborne pathogens and pests on many crops including: 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 (5). Solarization also reduces disease by "pasteurizing" soil through a process where wet soil is covered with clear polyethylene plastic to capture solar energy and increase soil temperatures, ideally between 97 to 122 °F in the upper 12 inches (3). Equipment is available for large-scale solarization of fields and is applied most effectively in geographic areas with intense solar radiation. Solarization also can be effective in temperate regions when combined with green manure crops (4), reduced dosages of chemicals, or biological control organisms (3). Recent research in The Netherlands has shown that incorporation of fresh broccoli or grass into soil followed by tarping with plastic reduced several soilborne fungal pathogens and nematodes by rapidly depleting oxygen and not by thermal inactivation (1, 2).

OBJECTIVES

The purpose of this research was to determine the effect of several green manure crops and soil solarization on suppression of Aphanomyces root rot on sugarbeet. In 2001-2003, oospore survival of *A. cochlioides* also was included in these trials and has been reported (6).

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 buckwheat 'Koto' and oilseed radish 'Colonel' were sown by hand at 45 and 18 lb/A, respectively, and raked into soil; sorghum sudan grass 'Green Grace Supreme' was drill-seeded at 13.5 lb/A. In 2002 and 2003, the same crops were drill-seeded (except for oilseed radish, which was sown by hand in 2002) and two were added: oat 'Dane' and wheat '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 and 40 x 30 ft in 2002 and 2003. Treatments were arranged in a randomized block design with six replicates in 2001; four replicates in 2002; and three in 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 (0 to 100 scale; 0 = healthy and 100 = all sugarbeet seedlings dead) were determined (7).
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 soil) 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. Soil temperatures were 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 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). Tarps were removed from subplots after solarization for 9, 7, and 8 weeks in 2001, 2002, and 2003, respectively.

Sugarbeet following precrops and soil solarization. On May 22, 2002; May 8, 2003; and May 27, 2004, all plots were fertilized to reach a total of 150 lb nitrogen/A. Sugarbeet seed of '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 all 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, 2002. In 2003, plots were thinned on July 1 and 2; plots were off-station and rainfall was adequate, with 9 inches in June through August. In 2004, plots were cultivated on June 29, thinned on July 15, and not irrigated because of adequate rainfall. All trials were treated with fungicide (5 oz Supertin, 13 oz Eminent [product/A]) as needed to control Cercospora leaf spot.

Stand counts were made on the two middle rows of each subplot at 2 and 4 weeks after planting. At 6 and 7 ½ weeks after planting in 2002 and 2004, respectively (data were not collected in 2003), 40 plants were removed from rows adjacent to the two middle rows of each subplot in three replicates. Plants were 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 were subjected to analysis of variance and if statistically significant ($P \leq 0.05$), means were separated by Least Significant Difference (LSD).

RESULTS

Greenhouse assay for Aphanomyces soil index values. Before green manure crops were sown in 2001, 2002, and 2003, Aphanomyces soil index values averaged 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 soil index values in 2001, 2002, and 2003, respectively. Soil index values for fallow plots remained virtually unchanged during this period in the three years.

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 and 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 smaller temperature difference 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, 2002, and 2003 were 96, 90, and 98 °F, respectively.

Table 1. Aphanomyces soil index values determined in controlled environment chambers 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 Six soil cores were collected to a 6-inch depth per plot, combined, and sown with 25 sugarbeet seed of 'ACH 261' per pot (four pots/plot). 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 treatment value was based on six replicates in 2001, four replicates in 2002, and three in 2003.

Table 2. Maximum soil temperatures recorded in fallow and green manure precrop plots (illustrated by 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 all treatments of one replicate each season; temperatures were recorded every 15 minutes during the term of soil solarization.

Table 3. Sugarbeet seedling stand, root rot ratings, yield, and quality of 'Beta 2088' in 2002-2004 in plots planted to several green manure precrops the previous field season. Precrops were incorporated in mid-July and then plots were solarized (covered with a clear polyethylene tarp) for 9, 7, and 8 weeks in 2001, 2002, and 2003, respectively. Controls included non-solarized plots of each green manure precrop and fallow plots. The 2002 and 2004 trials were sown in the Aphanomyces Nursery at the University of Minnesota, Northwest Research and Outreach Center, Crookston; the 2003 sugarbeet trial was in a grower's field near Crookston naturally infested with *Aphanomyces cochlioides.*

Treatment	No. plants/60 ft row (WAP)[v]		Root rot rating (6 WAP)[w]	No. marketable roots/60 ft row[x]	Root rot[x,y] rating	Yield (T/A)[x]	Sucrose[x]		
	2	4					%	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 ($P \leq 0.05$)[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 ($P \leq 0.05$)[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 ($P \leq 0.05$)[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 ($P \leq 0.05$)[z]	NS	NS		NS	0.2	NS	NS	NS	NS
2004									
Precrop									
Fallow	289	266	1.0	65	1.4	19.6	16.5	305	5999
Buckwheat	240	225	0.9	67	1.3	21.1	16.6	309	6511
Oat	273	266	1.1	-	-	-	-	-	-
Oilseed radish	283	267	1.1	67	1.4	20.0	16.6	309	6175
Sorghum sudan grass	310	273	1.0	68	1.2	20.2	16.6	309	6246
Wheat	335	303	0.9	67	1.3	17.3	17.2	322	5522
LSD ($P \leq 0.05$)[z]	53	35	NS	NS	NS	NS	NS	NS	NS
Soil treatment									
Solarized	294	274	1.0	68	1.2	19.4	16.8	312	6029
Non-solarized	282	259	1.0	65	1.4	19.9	16.7	309	6152
LSD ($P \leq 0.05$)[z]	NS	NS	NS	NS	0.2	NS	NS	NS	NS

v Sugarbeet sown at a 1.25-inch spacing on May 24, 2002; May 8, 2003; and May 27, 2004. For each precrop, values are averaged across solarized and non-solarized plots and for each soil treatment, values are averaged across all precrops (6 replicates in 2002 and 4 replicates in 2003 and 2004).

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; - = sugarbeet crop following the oat precrop was not harvested in 2004 because of water damage. .

[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.

Sugarbeet following precrops and soil solarization. There were no significant interactions between main treatments (precrop or soil solarization) for data collected on sugarbeet in any year, so results are presented only for main treatments (Table 3). 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 2002 and 2003. In 2004, a precrop of wheat resulted in statistically ($P \leq 0.05$) higher stands of sugarbeet at 2 and 4 weeks after planting compared to the other precrops (except sorghum sudan grass, which had stands nearly as high as wheat) and previously fallow plots. Precrop did not affect severity of Aphanomyces root rot on sugarbeet roots rated 6 weeks after planting in 2002 and 2004 (Table 3); data was not collected in 2003.

In 2002, previously solarized plots had statistically ($P \leq 0.05$) higher stands at 2 and 4 weeks after planting compared to non-solarized plots but in 2003 and 2004, there were no statistical differences in stand between these treatments (Table 3). At 6 weeks after planting in 2002, disease ratings were significantly lower in plots solarized in 2001 compared to non-solarized plots but in 2004, there were no statistical differences in disease ratings between plots solarized or not solarized in 2003.

None of the precrop treatments had a statistical effect on number of marketable sugarbeet roots, Aphanomyces root rot ratings, yield, or quality in the three years (Table 3). Sugarbeet grown in 2004 after an oat precrop were not harvested because of water damage in one block.

In 2002, plots solarized the previous season resulted in a significant reduction in root rot and significant increases in tons of roots and recoverable sucrose per acre, but had no effect on number of marketable roots, percent sucrose, or pounds of sucrose per ton when compared to non-solarized plots (Table 3). In 2003, disease was severe and root rot ratings were significantly higher in previously solarized plots than non-solarized plots; number of marketable roots, yield, and quality were the same in solarized and non-solarized plots (Table 3). Aphanomyces root rot ratings were low at harvest in 2004, but plots pretreated with solarization had statistically lower disease ratings than non-solarized plots; there were no differences for any yield variables between solarized and non-solarized plots (Table 3).

DISCUSSION

Combining green manure crops and soil solarization did not consistently reduce Aphanomyces root rot of sugarbeet or improve yield or quality in three field trials. Immediately after soil-incorporation, however, green manure crops markedly reduced Aphanomyces root rot index values compared to fallow soil. Perhaps disease suppression by green manure crops is short-term and does not carry over the winter to benefit a subsequent sugarbeet crop. Other reports indicate a green oat precrop reduces Aphanomyces root rot of peas (caused by *A. euteiches*) in producers' fields (5) but peas are a short-season crop.

Solarization typically hastens decline of survival propagules of 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. Soil temperatures attained during solarization in our 2002 – 2004 field trials likely were inadequate, or did not prevail for a sufficient length of time, to effectively reduce numbers of oospores. It is unknown if *Aphanomyces* species are vulnerable to solarization (3), although Dyer found that 90% of oospores of *A. cochlioides* die when exposed to 104 °F for 72 hours or to 122 °F for 4 hours (*unpublished)*. Oospore survival studies in these field trials (6), however, suggest soil solarization may have preconditioned oospores so they were somewhat less vulnerable to dying than in non-solarized soils. Overall, soil solarization (with or without green manure crops) is inadequate for reducing Aphanomyces diseases or increasing sugarbeet growth and yield in fields in the Red River Valley.

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