GREEN MANURE CROPS AND SOIL SOLARIZATION EFFECTS ON APHANOMYCES ROOT ROT AND OOSPORE SURVIVAL

Carol E. Windels, Jason R. Brantner, and *Alan T. Dyer

Professor of Plant Pathology, Research Fellow, and *Graduate Assistant, respectively
University of Minnesota, Northwest Research and Outreach Center, Crookston and
*Department of Plant Pathology, St. Paul

Aphanomyces cochlioides (= A. cochlioides) is a soilborne pathogen that causes seedling stand loss and chronic root rot of older sugarbeet plants when soil is warm and wet. Unusually wet summers in the last 10 years have favored increases in the prevalence and severity of Aphanomyces diseases on sugarbeet. A survey conducted in 1999 concluded that 51% of acres planted to sugarbeet in Minnesota and North Dakota are infested with A. cochlioides. The 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 that affect viability of oospores, but a visual technique was recently described to distinguish viable (living) from dead oospores (1).

Control of A. cochlioides includes early planting (to avoid warm, wet soils favorable for infection), seed treatment with the fungicide Tachigaren (hymexazol), selection of partially resistant varieties, water management (installing tiles or ditches to improve 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 limited disease control options are available, novel strategies are being explored. Green manure crops are reported to suppress several soilborne pathogens and pests on many crops (5). 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. Soil solarization (attained by covering wet soil with transparent, polyethylene plastic to capture solar energy and increase soil temperatures, ideally to 97-122 (F in the upper 12 inches) sometimes is lethal to soilborne fungi, weed seeds, and other pests (2). Solarization has been successfully applied in tropical climates and also has been effective in temperate regions when combined with other methods of control, such as organic amendments, reduced dosages of chemicals, or biological control organisms. For instance, Fusarium wilt of cabbage was most effectively reduced when plots amended with cruciferous residues were covered with plastic tarp and solarized compared to either treatment alone (4).

OBJECTIVES

The purpose of this research was to determine the effect of several green manure crops and soil solarization in the field on 1) suppression of Aphanomyces root rot on sugarbeet and 2) viability of oospores of A. cochlioides. This report provides results for the first field season of a 2-year study at one site.

MATERIALS AND METHODS

On May 15, 2001 the trial was established in the Aphanomyces nursery at the University of Minnesota, Northwest Research and Outreach Center, Crookston. Treatments consisted of 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 seed/A, respectively. The control was fallow soil. Each plot measured 20 x 30 ft and they were arranged in a randomized block design with six replicates. At planting, soil cores (6, 2.5-inch diameter) were collected to a depth of 6 inches and combined per plot. Soil samples were assayed in the greenhouse with a sugarbeet seedling assay and Aphanomyces soil index values were determined 4 weeks after planting. Values ranged from 0 to100; 0 = healthy and 100 = all sugarbeet seedlings dead (6).

On July 11 (8 weeks after planting), all crops were mowed and the green residue was disked and rototilled into soil to a 3-4-inch depth (soil was too dry and compacted to incorporate residue deeper). Amounts of buckwheat, oilseed radish and sorghum sudan grass incorporated into plots averaged 8, 17 and 6 tons/A, respectively. Fallow control plots also were disked and rototilled. Each main plot (green manure crops and fallow) then was split into subplots for subsequent tarping and solarization or for no treatment. Soil samples were collected in each subplot and indexed for Aphanomyces root rot in the greenhouse, as previously described.

To directly observe the effect of green manure crops on oospore survival, with and without soil solarization, bags of sugarbeet hypocotyls (portion of the seedling between point of seed attachment and cotyledonary leaves) containing oospores of A. cochlioides were buried in subplots of four replicates. Oospores were produced in the laboratory by placing excised segments of 2-week-old sugarbeet hypocotyls in sterile water, adding zoospore inoculum of A. cochlioides, and then incubating them in water in the dark at 68 + 5 (F for 7 weeks. Each segment (~ 0.6-inch length) was microscopically examined and estimated as infested with at least 2,800 to over 10,000 viable oospores (average of 8,000 oospores). One hypocotyl segment was placed in the bottom of a nylon monofilament mesh fabric (less than 10 (pores) bag (1 x 1 inch), which was closed with string and placed in a pan of water to prevent drying until placed in soil. Bags of oospores were buried at depths of 3, 6 and 9 inches in the green manure crop and fallow subplots designated to be solarized or not solarized. Two bags were buried per depth, one for retrieval immediately after solarization and the other for removal 4 weeks later (effects of solarization on survival structures, such as oospores, can be delayed).

Thermocouples were buried at 3, 6 and 9 inches in subplots of one replicate and soil temperatures were continuously monitored and recorded on a Watchdog (Spectrum Technologies, Plainfield, IL) data logger every 15 minutes while subplots were solarized.

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 about 12 inches deep in furrows plowed along borders of solarized subplots.

Nine weeks later (September 13), tarps were removed from solarized subplots. One set of buried oospores was removed from the three depths of each subplot and nearly 4 weeks later (October 8), the second set of buried oospores was removed. Retrieved bags of oospores were placed in plastic bags, moistened with water, and stored in a refrigerator until examined. Each bag was carefully opened along the outside seams and hypocotyls were removed and inspected (directly and microscopically at 16 to 180 X magnification), to determine the amount of tissue and number of oospores present. Relative amounts of hypocotyl tissue remaining 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% tissue present, 3 = 41-60%, 4 = 61-80% and 5 = 81-100%. When microscopically scanning the hypocotyl tissue and interior of bags, 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 400X 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, which were removed with two-sided transparent cellophane and assessed for viability.

Data for relative amounts of sugarbeet hypocotyl tissue, relative numbers of oospores and percent viable oospores were subjected to appropriate transformations (if needed) and analyzed by Analysis of Variance. If significant ($P < 0.05$), means were separated by Least Significant Difference (LSD). Correlations were calculated for relative amounts of hypocotyl tissue and total numbers of oospores and for relative amounts of hypocotyl tissue and percent viable oospores.

RESULTS

Greenhouse assay for Aphanomyces soil index values. Before green cover crops were sown, the average Aphanomyces soil index value was 97 (Table 1). After incorporation of green manure crops (and before solarization), soil index values were reduced and averaged 63, 75 and 78 for buckwheat, oilseed radish and sorghum sudan grass, respectively (Table 1). The index value for fallow plots remained virtually the same before green cover crops were planted (98) and after they were incorporated (97).

Soil temperatures attained by solarization. Maximum soil temperatures recorded in green manure crop subplots (illustrated for oilseed radish) were similar to the fallow control whether solarized or not solarized (Table 2). At the 3-inch depth, solarization resulted in maximum soil temperatures between 106–109 (F, and were nearly 20 (F higher than temperatures recorded in nonsolarized soils. A less dramatic temperature differential between solarized and nonsolarized soils occurred with increasing soil depths. At 9 inches, maximum soil temperatures were about 10 (F higher in solarized (91-93 (F) than in nonsolarized (81 (F) soils. The highest ambient temperature recorded during the solarization process was 95 (F.

Table 1. Aphanomyces soil index values determined in the greenhouse for field soil collected when green cover crops were planted and 8 weeks later (after they were incorporated); the control consisted of fallow soil.

	Soil index valuez		
Soil Treatmenty	Before green crop sown	After green manure crop incorporated	Change
Buckwheat	96	63	-33
Oilseed radish	98	75	-22
Sorghum sudan grass	96	78	-18
Fallow control	98	97	-1
Mean	97	78	-19

Y Cover crops were sown on May 15 and green crop residue was mowed and incorporated into soil by disking and rototilling to a 3-4-inch depth on July 11, 2001.
Z Each value based on planting 25 sugarbeet seed/4 pots of soil per treatment (6 soil cores, 2.5-inch diameter collected to a 6-inch depth and combined). Four weeks after planting, index values were determined on a 0-100 scale; 0 = healthy plant, 100 = all

plants dead or severely rotted.

Table 2. Maximum soil temperatures recorded in fallow and green manure crop subplots (illustrated for oilseed radish) that were solarized (soil tarped with clear, polyethylene plastic) or not solarized. Data loggers were buried at 3, 6 and 9 inches and temperatures were continuously monitored and recorded every 15 minutes during soil solarization from July 13 to September 13.

	Maximum soil temperature ((F)/depth (inches)		
Soil treatment	3	6	9
Solarized			
Fallow	106	100	91
Oilseed radish	109	97	93
Nonsolarized			
Fallow	88	84	81
Oilseed radish	90	86	81

Fig. 1. Magnified view of a sugarbeet hypocotyl containing oospores of Aphanomyces cochlioides retrieved after burial in field plots for 9 weeks. A) intact cortex of hypocotyl with abundant oospores (bar scale = 150 µ) and B) decomposed hypocotyl with no cortex and some vascular tissue associated with a few oospores (bar scale = 20 µ).

Oospore survival and viability. Examination of sugarbeet hypocotyls removed from soil immediately after solarization and 4 weeks later revealed various stages of tissue decomposition. Some hypocotyls were fairly intact and the cortex surrounding vascular tissue contained abundant oospores (Fig. 1A). In other cases, the cortex was severely decomposed and only vascular tissue, which contained a few oospores, remained (Fig. 1B). Occasionally, no hypocotyl tissue remained and no oospores, or only a few, were attached to the interior of the mesh bag.

The relative amount of sugarbeet hypocotyl tissue in mesh bags averaged 2.1 (21-40% of original tissue buried in soil) for samples retrieved after solarization was completed, and this amount was the same for samples removed 4 weeks later (data not shown). Green manure crop, solarized and nonsolarized treatments, and depth of burial in soil did not have a significant effect on amount of hypocotyl tissue remaining at either sampling date (data not shown).

Immediately after solarization, the relative number of oospores remaining in buried sugarbeet hypocotyls averaged 2.2 (100-1,000 oospores) and when the second set was removed 4 weeks later, averaged 2.1 (data not shown). Green manure crop and fallow treatments, solarized and nonsolarized treatments, and depth of burial in soil did not significantly affect relative numbers of oospores in hypocotyls at either sampling date (data not shown).

There was a significant and positive correlation between the relative amount of hypocotyl tissue and relative number of oospores for samples removed after solarization and 4 weeks later. Since data were nearly identical on both dates for solarized and nonsolarized soils, results are illustrated for samples retrieved from solarized plots after polyethylene tarps were removed (Fig. 2). The number of oospores remaining increased with increasing amounts of recovered hypocotyl residue at the 3, 6 and 9 inch depths. Oospores were rare or absent in mesh bags containing severely decomposed sugarbeet hypocotyls, which suggests that the other oospores had already decomposed.
Fig. 2. Relationship between relative amount of sugarbeet hypocotyl tissue and number of oospores of Aphanomyces cochlioides after burial at 3, 6 and 9 inches in solarized soil for 9 weeks. Relative amount of hypocotyl tissue based on a 1-5 scale; 1 = 1-20% of original tissue present, 5 = 81-100% present. Relative number of oospores based on a 1-4 scale; 0 = none observed, 4 = more than 10,000 present.

Fig. 3. Magnified view of Aphanomyces cochlioides oospores. A) densely organized uniform granular (DOUG) appearance of a living oospore compared to B) loosely organized nonuniform granular (LONG) appearance of a dead oospore (1). Bar scale = 10 µ.

Examination of sugarbeet hypocotyl tissue, however, did not reveal whether oospores were viable (alive) or dead. At high magnification (400X), viable oospores are characterized by a densely organized uniform granular appearance (Fig. 3A) and dead oospores have a loosely organized nongranular appearance (Fig. 3B).

Table 3. Percent living oospores of Aphanomyces cochlioides in sugarbeet hypocotyls after burial at three depths in plots where 8-week-old green manure crops had been incorporated or left fallow. Half of each green manure crop plot was solarized by covering it with a clear polyethylene tarp for 9 weeks (July 13 to September 13) to increase soil temperatures and the other half was not solarized (not covered). Hypocotyls were retrieved and microscopically assessed for viable oospores immediately after solarization and also, 4 weeks later.

	% Viable (living) oospores after buried in soil	
Treatment	9 Weeks	13 Weeks
Precrop treatmentw		
Sorghum sudan grass	52	41
Oilseed radish	48	31
Buckwheat	32	36
Fallow soil	33	

35

Mean
41
36

LSD (P = 0.05)x
NS
NS

Soil Treatmenty

Solarized
35
43

Nonsolarized
47
28

Mean
41
36

LSD (P = 0.05)x
NS
13

Depth (inches)z

3
38
25

6
34
35

9
52
48

Mean
41
36

LSD (P = 0.05)x
NS
16

w Each value averaged across soil treatments and depths.

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

y Each value averaged across precrop treatment and depth.

z Each value averaged across precrop treatment and soil treatment.

Data on oospore viability are summarized in Table 3. There were no significant interactions between main treatments so data are presented only for main treatments. Oospores in sugarbeet hypocotyls retrieved from soil after solarization and also 4 weeks later, averaged 41% and 36% viability, respectively. For samples removed immediately after solarization, percentages of viable oospores observed were not significantly affected by green manure crop and fallow treatments, solarized and nonsolarized treatment or depth of burial. For hypocotyls removed 4 weeks later, oospore viability was not significantly affect by green manure crop or fallow treatment but was significantly higher in solarized (43%) than nonsolarized plots (28%). Oospore viability also was significantly higher with increasing depth of burial in soil.

After solarization, there was a significant and positive correlation between amounts of hypocotyl tissue and percent viable oospores for samples collected in solarized soils at all depths and in nonsolarized soils at 3 and 9 inches (data not shown). At the 6-inch depth in nonsolarized soils, viability of oospores was about 25%, regardless of amount of hypocotyl tissue present (data not shown). For samples collected 4 weeks later, correlations between percent living oospores and relative amounts of sugarbeet hypocotyl tissue are shown for solarized (Fig. 4A) and nonsolarized soils (Fig. 4B). Both soil treatments had significant and positive correlations between relative amounts of hypocotyl tissue and percent living oospores for samples buried at 6- and 9-inch depths. For samples buried at 3 inches, a low percentage of oospores (about 25%) were alive in solarized and nonsolarized soils, regardless of the amount of hypocotyl tissue present.
Fig. 4. Relationship between relative amount of sugarbeet hypocotyl tissue and percent living oospores of Aphanomyces cochlioides after burial in soil at three depths. Samples retrieved from soil on September 13 that had been A) solarized from July 13 –

September 13 and B) not solarized. Relative amount of hypocotyl tissue based on a 1-5 scale; 1 = 1-20% of original tissue present, 5 = 81-100% present. Relative number of oospores based on a 1-4 scale; 0 = none present, 4 = more than 10,000 observed.

DISCUSSION

Greenhouse Aphanomyces soil index values indicated that soil-incorporation of green residues of buckwheat, oilseed radish and sorghum sudan grass reduced Aphanomyces root rot compared to a fallow control. Whether the same response occurs in the field will be determined in 2002 when a sugarbeet crop is grown and evaluated for disease, yield and quality across all treatments established in 2001. When the trial is planted to sugarbeet, soil samples again will be collected in all treatments (green manure crops, solarized and not solarized in 2001) and assayed in the greenhouse to determine root rot index values. It will be important to determine the relative disease potential of Aphanomyces root rot early in the 2002 season because effects of solarization can be delayed (oospores dying after the polyethylene tarp is removed) and because overwintering may change pathogen populations.

It is unknown if A. cochlioides oospores in soil of the Aphanomyces nursery and those in mesh bags buried in nursery soil responded similarly to green manure crops, solarization and depth of burial. Green manure crops reduced Aphanomyces root rot index values compared to fallow soil, but they did not directly affect viability of buried oospores compared to fallow soil. If green manure crops reduce Aphanomyces root rot in the field, various mechanisms other than a direct effect on oospore viability may be involved. They may interfere with zoospore production or the infection process, enhance microbial degradation of oospores weakened by exposure to sublethal heat, increase populations of antagonistic microorganisms that inhibit germination of oospores, increase soil tilth by production of extensive root systems that deeply infiltrate soil, or produce toxic volatile compounds emanating from decomposing organic matter (2).

Considerable decomposition of sugarbeet hypocotyls buried in soil occurred from mid July through early September throughout the upper 9 inches of the soil profile in both solarized and nonsolarized soils. The top 12 inches of soil corresponds to the portion most highly populated by saprophytic microorganisms and soilborne fungal pathogens. Apparently, soil temperatures attained in these plots did not interfere with, nor did they have a significant differential effect on, microbial degradation of sugarbeet hypocotyls buried at different depths in soil. Lack of further degradation of sugarbeet hypocotyl tissues in the interval from September through October suggests that microbial activity and decomposition had stabilized.

A direct relationship between the amount of A. cochlioides-infested sugarbeet hypocotyl tissue persisting in soil and numbers of oospores in the hypocotyl illustrates the dependency of oospores on previously infected plant tissue for survival. As hypocotyl tissue decomposed, oospores also decomposed and died. Fresh organic matter introduced into soil is highly vulnerable to microbial decomposition, which accounts for rapid loss of tissue (and hence, loss of oospores embedded in hypocotyls) during the period of solarization. When hypocotyls were buried in soil, each contained from 2,800 to over 10,000 viable oospores. It is doubtful that viable oospores passed through the mesh fabric when buried in soil because A. cochlioides oospores average 21 + 5 (in diameter and would be too large to pass through the 10 (-sized pores of the mesh bags. Unfortunately, there is no way to monitor changes in actual oospore numbers in each hypocotyl before and after burial in soil because the tissue must be macerated for extraction of oospores.

A majority of oospores (about 60%) died within 9 weeks after A. cochlioides-infested sugarbeet hypocotyls were buried in soil, regardless of green manure crop, soil solarization, or depth of burial. Samples observed 4 weeks after tarps were removed from solarized soils revealed a small, additional loss in viable oospores. Although amounts of hypocotyl tissue retrieved at 3, 6 and 9 inch soil depths were not significantly different 4 weeks after solarization, only 25% of oospores buried at 3 inches were alive, which was significantly lower than the 48% alive at 9 inches. The green manure crops were incorporated only 3-4 inches into soil and thus, may have hastened oospore decomposition in this region. Fluctuations in soil temperatures and moisture also occur at shallow depths and may have weakened and hastened oospore decomposition, especially over an extended period of time. Pfender and Hagedorn (1983) 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.

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, or pathogen propagules are too resistant to heat, to have this effect. In our study, soil temperatures attained 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. Hot climates can attain temperatures of 120 (F at a 9-inch depth in tarped soils, but our study attained temperatures slightly over 105 (F at 3 inches. We found no differences in percent viable oospores retrieved from samples buried in solarized and nonsolarized soils after solarization had been completed, but survival was significantly higher in solarized (43%) than in nonsolarized (28%) soils 4 weeks later. Perhaps saprophytic microbial populations were reduced in the solarized soil and thus, parasitism of oospores was reduced. Another possibility is that certain environmental stresses, such as high temperatures, could precondition oospores so they are less vulnerable to dying. Dyer found that oospores of A. cochlioides exposed to low humidity (desiccation) were less likely to die when exposed to typically lethal temperatures (unpublished). Although solarization did not significantly decrease survival of A. cochlioides oospores in buried hypocotyls compared to nonsolarized soil, we will not know if solarization reduces Aphanomyces root rot in the nursery until sugarbeets are grown in these plots in 2002.

Overall, the first year of this trial has raised and reiterated several important questions. For instance, does oospore death (based on viability observed in buried, A. cochlioides-infested sugarbeet hypocotyls) correspond to disease reduction on sugarbeet in the field? How does A. cochlioides maintain adequate inoculum densities in soil for years if oospores die as plant tissue from previous infections decomposes in soil? Do weed species such as pigweed, lamb's-quarters, kochia, and other species play a significant role in maintaining inoculum densities of A. cochlioides? Does A. cochlioides infect crops rotated with sugarbeet without causing symptoms and increase inoculum? What is the minimum inoculum density of oospores that has an economic impact on sugarbeet production, assuming conditions are favorable for infection? Also, how important are numbers of surviving oospores of A. cochlioides when one germinating oospore can produce 100-200 infective zoospores as primary inoculum?

CONCLUSIONS

Soil incorporation of green manure residue of buckwheat, oilseed radish and sorghum sudan grass in the field significantly reduced Aphanomyces soil index values compared to fallow soil based on greenhouse assays.

2. A majority of oospore of A. cochlioides embedded in sugarbeet hypocotyls died as the plant tissue decomposed and disintegrated in soil.

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Oospores

B

A

Vascular
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Vascular tissue

Hypocotyl with oospores

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 = 0.75)
Relative amount hypocotyl tissue
 Arial
Relative # oospores
ObjInfo
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SummaryInformation
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Jason Brantner B
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_("$"* #,##0.00_);_("$"* \(#,##0.00\);_("$"* "-"??_);_(@_)
_(* #,##0.00_);_(* \(#,##0.00\);_(* "-"??_);_(@_)à
Chart1
Set 1 all reps…
Set 1 data…
Set 1 correlations…
Set 1a
Set 1b
Set 1c
Cover crop
Solarization
Relative hypocotyl
tissue present
Relative oospores

present
Number of oospores
Percent
fallow
radish
buckwheat

ssgrass:
2001 Cover crop/solarization effect on oospores, first set;
2001 Cover crop/solarization effect on oospores, second set
buckwt
oilrad
Relative oospores present
23 cm!
Relative hypocotyl tissue present
Adjusted
adjDOUG
MîĀHP DeskJet 710C
HP DeskJet 710C
HP DeskJet 710C
Œelative amount hypocotyl tissue'
Œelative # oospores'
œolarized Soil'
3" (R2 = 0.694)
" (R2 = 0.694)'
6" (R2 = 0.814)
" (R2 = 0.814)'
9" (R2 = 0.75)
" (R2 = 0.75)'
MîĀHP DeskJet 710C
HP DeskJet 710C
HP DeskJet 710C
Cover crop
×BÀ̊ XĘ~PhPPPhPPPhPPPhPPP^PPPhPPPhPP
(~PhPPPhPPPhPPPhPPP^PPPhPPPhPPÌ
×D, lɞPPPhPPPhPPPhPPPhPPP^PPPhPPPhPP
^PPPhPPPhPPPhPPPhPPP^PPPhPPPhPPÌ
hPPPhPPPhPPPRPPPhPPPRPPPhPPPhPPÌ
hPPPhPPPhPPPhPiP
MîĀHP DeskJet 710C
HP DeskJet 710C
HP DeskJet 710C
Cover crop
à瓙×B"̊ XĘ~PPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
(~PPPPPPPPPPPPPPPPPPPPPPPPPPPPÌ
PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPÌ
PPPPPPPPPPPPPPPPPPPiÈ
Œelative hypocotyl tissue'
Œelative oospores present'
KŒelative oospores vs. relative hypocotyl tissue present, non-solarized soil'
Œelative hypocotyl tissue'
Adjusted DOUG

djusted DOUG'
Adjusted DOUG vs. relative hypocotyl tissue present, non-solarized soil
GŁdjusted DOUG vs. relative hypocotyl tissue present, non-solarized soil'
MîĀHP DeskJet 710C
HP DeskJet 710C
HP DeskJet 710C
Œelative hypocotyl tissue'
Œelative # oospores'
œolarized soil'
3" R2 = 0.694
" R2 = 0.694'
6" R2 = 0.814
" R2 = 0.814'
9" R2 = 0.75
" R2 = 0.75'
MîĀHP DeskJet 710C
HP DeskJet 710C
HP DeskJet 710C
Œelative hypocotyl tissue'
Adjusted DOUG
djusted DOUG'
Adjusted DOUG vs. relative hypocotyl tissue present, solarized soil
CŁdjusted DOUG vs. relative hypocotyl tissue present, solarized soil'
MîĀHP DeskJet 710C
HP DeskJet 710C
HP DeskJet 710C
Cover crop
Solarization
`L```X```X```X```L```X```X``
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Œelative oospores presentQ
Œelative hypocotyl tissue'
Œelative oospores'
)Œelative oospores vs hypocotyl tissue, 3"'
Œelative oospores presentQ
Œelative hypocotyl tissue'
Œelative oospores'
)Œelative oospores vs hypocotyl tissue, 6"'
MîĀHP DeskJet 710C
HP DeskJet 710C
HP DeskJet 710C

Œelative oospores presentQ
Œelative hypocotyl tissue'
Œelative oospores'
)Œelative oospores vs hypocotyl tissue, 9'''
MîĀHP DeskJet 710C
HP DeskJet 710C
HP DeskJet 710C
Œelative oospores presentQ
Œelative hypocotyl tissue'
Œelative oospores'
1Œelative oospores vs hypocotyl tissue, all depths'
Percent DOUG
ercent DOUGQ
Œelative hypocotyl tissue'
Percent DOUG oospores
ercent DOUG oospores'
Percent DOUG oospores vs relative hypocotyl tissue, all depths
>Őercent DOUG oospores vs relative hypocotyl tissue, all depths'
MîĀHP DeskJet 710C
HP DeskJet 710C
HP DeskJet 710C
Cover crop
`L```X```L```X```X```X```X``
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L```X```X```L```X```X```X```X``Ì
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MîĀHP DeskJet 710C
HP DeskJet 710C
HP DeskJet 710C
n = 15<
Œelative oospores presentQ
Œelative oospores presentQ
Œelative hypocotyl tissue'
Œelative oospores'
8Œelative oospores vs hypocotyl tissue,
non-solarized 3'''
n = 12<
Œelative oospores presentQ
Œelative hypocotyl tissue'
Œelative oospores'
4Œelative oospores vs hypocotyl tissue,
solarized 3'''
n = 15<

Œelative oospores presentQ
Œelative hypocotyl tissue'
Œelative oospores'
8Œelative oospores vs hypocotyl tissue,
non-solarized 6"'
n = 12<
Œelative oospores presentQ
Œelative hypocotyl tissue'
Œelative oospores'
4Œelative oospores vs hypocotyl tissue,
solarized 6"'
n = 15<
Œelative oospores presentQ
Œelative hypocotyl tissue'
Œelative oospores'
8Œelative oospores vs hypocotyl tissue,
non-solarized 9"'
n = 12<
Œelative oospores presentQ
Œelative hypocotyl tissue'
Œelative oospores'
4Œelative oospores vs hypocotyl tissue,
solarized 9"'
MîĀHP DeskJet 710C
HP DeskJet 710C
HP DeskJet 710C
Cover crop
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MîĀHP DeskJet 710C
HP DeskJet 710C
HP DeskJet 710C
n = 45<
Œelative oospores presentQ
Œelative hypocotyl tissue'
Œelative oospores'
AŒelative oospores vs hypocotyl tissue,
non-solarized, all depths'
n = 36<
Œelative hypocotyl tissue'
Œelative oospores'

=Œelative oospores vs hypocotyl tissue,
solarized, all depths'
MîĀHP DeskJet 710C
HP DeskJet 710C
HP DeskJet 710C
Cover crop
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MîĀHP DeskJet 710C
HP DeskJet 710C
HP DeskJet 710C
n = 15<
Œelative oospores present 8 cmQ
Œelative oospores present 15 cmQ
Œelative oospores present 23 cmQ
Œelative hypocotyl tissue'
Œelative oospores'
8Œelative oospores vs hypocotyl tissue
non-solarized soil'
Œ2 = 0.6245'
Œ2 = 0.6876'
Œ2 = 0.2474'
Œelative hypocotyl tissue'
Œelative # oospores'
7Œelative # oospores vs hypocotyl tissue
solarized soil'
MîĀHP DeskJet 710C
HP DeskJet 710C
HP DeskJet 710C
Solarization
Cover crop
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!Œelative hypocotyl tissue present'
Œelative oospores present'
KŒelative oospores vs. relative hypocotyl tissue present, non-solarized soil'
!Œelative hypocotyl tissue present'
Adjusted DOUG
djusted DOUG'
Adjusted DOUG vs. relative hypocotyl tissue present, non-solarized soil
GŁdjusted DOUG vs. relative hypocotyl tissue present, non-solarized soil'

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!Œelative hypocotyl tissue present'
Œelative oospores present'
GŒelative oospores vs. relative hypocotyl tissue present, solarized soil'
MîĀHP DeskJet 710C
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HP DeskJet 710C
!Œelative hypocotyl tissue present'
Adjusted DOUG
djusted DOUG'
Adjusted DOUG vs. relative hypocotyl tissue present, solarized soil
CŁdjusted DOUG vs. relative hypocotyl tissue present, solarized soil'
University of Minnesota
Set 1 all reps
Set 1 data
Set 1 correlations
Set 1a
Set 1b
Set 1c
Chart1
Worksheets
Charts
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CompObj
CompObj
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"System
Non-solarized Soil$
 = 0.062)
 = 0.360)
 = 0.638)
Relative amount hypocotyl tissue
 Arial
% Living oospores
Microsoft Excel Chart
Excel.Chart.8
Jason Brantner
Jason Brantner
Microsoft Excel

ObjInfo
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Workbook
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SummaryInformation
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"$"#,##0.00_);[Red]\("$"#,##0.00\)
_("$"* #,##0_);_("$"* \(#,##0\);_("$"* "-"_);_(@_)
_(* #,##0_);_(* \(#,##0\);_(* "-"_);_(@_)
_("$"* #,##0.00_);_("$"* \(#,##0.00\);_("$"* "-"??_);_(@_)
_(* #,##0.00_);_(* \(#,##0.00\);_(* "-"??_);_(@_)à
Chart3
Set 1 all reps…
Set 1 data…
Set 1 correlations…
Set 1a
Set 1b
Set 1c
Cover crop
Solarization
Relative hypocotyl
tissue present
Relative oospores

present
Number of oospores
Percent
fallow
radish
buckwheat

ssgrass:
2001 Cover crop/solarization effect on oospores, first set;
2001 Cover crop/solarization effect on oospores, second set
buckwt
oilrad
Relative oospores present
23 cm!
Relative hypocotyl tissue present
Adjusted
adjDOUG
MîĀHP DeskJet 710C
HP DeskJet 710C
HP DeskJet 710C
Œelative amount hypocotyl tissue'
% Living oospores
Living oospores'
Non-solarized Soil
on-solarized Soil'
3" (R2 = 0.062)
" (R2 = 0.062)'
6" (R2 = 0.360)

" (R2 = 0.360)'
9" (R2 = 0.638)
" (R2 = 0.638)'
ffffff
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fffffæ0@
33333³8@
3333335@
fffff&C@
333333U@
ffffff
?
33333sP@
33333³E@
333333
333333
?
333333
33333³J@
fffffæ6@
333333
33333ÓW@
fffff¦@@
ffffff
fffffÆQ@
ffffff
333333H@
33333SS@
ffffffF@e
MîĀHP DeskJet 710C
HP DeskJet 710C
HP DeskJet 710C
Cover crop
×BÀ̆̈ XĘ~PhPPPhPPPhPPPhPPP^PPPhPPPhPP
(~PhPPPhPPPhPPPhPPP^PPPhPPPhPPÌ
×D,   lɘPPPhPPPhPPPhPPPhPPP^PPPhPPPhPP
^PPPhPPPhPPPhPPPhPPP^PPPhPPPhPPÌ
hPPPhPPPhPPPRPPPhPPPRPPPhPPPhPPÌ
hPPPhPPPhPPPhPìP
MîĀHP DeskJet 710C
HP DeskJet 710C
HP DeskJet 710C
Cover crop
à玀×B"̆̈ XĘ~PPPPPPPPPPPPPPPPPPPPPPPPPPPP
(~PPPPPPPPPPPPPPPPPPPPPPPPPPPÌ
PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPÌ

PPPPPPPPPPPPPPPPPPPiÈ
Œelative hypocotyl tissue'
Œelative oospores present'
KŒelative oospores vs. relative hypocotyl tissue present, non-solarized soil'
Œelative hypocotyl tissue'
Adjusted DOUG
djusted DOUG'
Adjusted DOUG vs. relative hypocotyl tissue present, non-solarized soil
GŁdjusted DOUG vs. relative hypocotyl tissue present, non-solarized soil'
MîĀHP DeskJet 710C
HP DeskJet 710C
HP DeskJet 710C
Œelative hypocotyl tissue'
Œelative # oospores'
œolarized soil'
3" R2 = 0.694
" R2 = 0.694'
6" R2 = 0.814
" R2 = 0.814'
9" R2 = 0.75
" R2 = 0.75'
MîĀHP DeskJet 710C
HP DeskJet 710C
HP DeskJet 710C
Œelative hypocotyl tissue'
Adjusted DOUG
djusted DOUG'
Adjusted DOUG vs. relative hypocotyl tissue present, solarized soil
CŁdjusted DOUG vs. relative hypocotyl tissue present, solarized soil'
MîĀHP DeskJet 710C
HP DeskJet 710C
HP DeskJet 710C
Cover crop
Solarization
`L```X```X```X```L```X```X``
`L```X```X```X```L```X```X``Ì
D(□lɘ```X```X```X```L```L```X```X``
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X```X```X```X`iÈ
Œelative oospores presentQ
Œelative hypocotyl tissue'
Œelative oospores'
)Œelative oospores vs hypocotyl tissue, 3"'
Œelative oospores presentQ

Œelative hypocotyl tissue'
Œelative oospores'
)Œelative oospores vs hypocotyl tissue, 6"'
MîĀHP DeskJet 710C
HP DeskJet 710C
HP DeskJet 710C
Œelative oospores presentQ
Œelative hypocotyl tissue'
Œelative oospores'
)Œelative oospores vs hypocotyl tissue, 9"'
MîĀHP DeskJet 710C
HP DeskJet 710C
HP DeskJet 710C
Œelative oospores presentQ
Œelative hypocotyl tissue'
Œelative oospores'
1Œelative oospores vs hypocotyl tissue, all depths'
Percent DOUG
ercent DOUGQ
Œelative hypocotyl tissue'
Percent DOUG oospores
ercent DOUG oospores'
Percent DOUG oospores vs relative hypocotyl tissue, all depths
>Őercent DOUG oospores vs relative hypocotyl tissue, all depths'
MîĀHP DeskJet 710C
HP DeskJet 710C
HP DeskJet 710C
Cover crop
`L```X```L```X```X```X```X``
`L```X```L```X```X```X```X``Ì
×D4□lɘ```X```X```L```X```X```X```X``
X```X```X```L```X```X```X```X``Ì
D(□lR```X```X```L```X```X```X```X``
L```X```X```L```X```X```X```X``Ì
X```X```X```X`iÈ
MîĀHP DeskJet 710C
HP DeskJet 710C
HP DeskJet 710C
n = 15<
Œelative oospores presentQ
Œelative oospores presentQ
Œelative hypocotyl tissue'
Œelative oospores'
8Œelative oospores vs hypocotyl tissue,
non-solarized 3"'
n = 12<

Œelative oospores presentQ
Œelative hypocotyl tissue'
Œelative oospores'
4Œelative oospores vs hypocotyl tissue,
solarized 3'''
n = 15<
Œelative oospores presentQ
Œelative hypocotyl tissue'
Œelative oospores'
8Œelative oospores vs hypocotyl tissue,
non-solarized 6'''
n = 12<
Œelative oospores presentQ
Œelative hypocotyl tissue'
Œelative oospores'
4Œelative oospores vs hypocotyl tissue,
solarized 6'''
n = 15<
Œelative oospores presentQ
Œelative hypocotyl tissue'
Œelative oospores'
8Œelative oospores vs hypocotyl tissue,
non-solarized 9'''
n = 12<
Œelative oospores presentQ
Œelative hypocotyl tissue'
Œelative oospores'
4Œelative oospores vs hypocotyl tissue,
solarized 9'''
MîĀHP DeskJet 710C
HP DeskJet 710C
HP DeskJet 710C
Cover crop
`L```X```L```X```X```X```L``
`L```X```L```X```X```X```L``Ì
X碌D4 lɘ```X```X```L```X```X```X```X``
X```X```X```L```X```X```X```X``Ì
D4□lɘ```X```X```X```X```L```X```X``
X```X```X```X```X```L```X```X``Ì
X```X```X```X`iÈ
MîĀHP DeskJet 710C
HP DeskJet 710C
HP DeskJet 710C
n = 45<
Œelative oospores presentQ
Œelative hypocotyl tissue'

Œelative oospores'
AŒelative oospores vs hypocotyl tissue,
non-solarized, all depths'
n = 36<
Œelative hypocotyl tissue'
Œelative oospores'
=Œelative oospores vs hypocotyl tissue,
solarized, all depths'
MîĀHP DeskJet 710C
HP DeskJet 710C
HP DeskJet 710C
Cover crop
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xN\\\N\iÈ
MîĀHP DeskJet 710C
HP DeskJet 710C
HP DeskJet 710C
n = 15<
Œelative oospores present 8 cmQ
Œelative oospores present 15 cmQ
Œelative oospores present 23 cmQ
Œelative hypocotyl tissue'
Œelative oospores'
8Œelative oospores vs hypocotyl tissue
non-solarized soil'
Œ2 = 0.6245'
Œ2 = 0.6876'
Œ2 = 0.2474'
Œelative hypocotyl tissue'
Œelative # oospores'
7Œelative # oospores vs hypocotyl tissue
solarized soil'
MîĀHP DeskJet 710C
HP DeskJet 710C
HP DeskJet 710C
Solarization
Cover crop
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!Œelative hypocotyl tissue present'
Œelative oospores present'

KŒelative oospores vs. relative hypocotyl tissue present, non-solarized soil'
 Œelative amount hypocotyl tissue'
% Living oospores
 Living oospores'
Non-solarized Soil
on-solarized Soil'
3" R2 = 0.062
" R2 = 0.062'
6" R2 = 0.360
" R2 = 0.360'
9" R2 = 0.638
" R2 = 0.638'
MîĀHP DeskJet 710C
HP DeskJet 710C
HP DeskJet 710C
!Œelative hypocotyl tissue present'
Œelative oospores present'
GŒelative oospores vs. relative hypocotyl tissue present, solarized soil'
MîĀHP DeskJet 710C
HP DeskJet 710C
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 Œelative amount hypocotyl tissue'
% Living oospores
 Living oospores'
œolarized Soil'
3" R2 = 0.001
" R2 = 0.001'
6" R2 = 0.386
" R2 = 0.386'
9" R2 = 0.783
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University of Minnesota
Set 1 all reps
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% Living oospores
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Jason Brantner
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Chart2
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Cover crop
Solarization
Relative hypocotyl
tissue present
Relative oospores

present
Number of oospores
Percent
fallow
radish
buckwheat

ssgrass:
2001 Cover crop/solarization effect on oospores, first set;

2001 Cover crop/solarization effect on oospores, second set
buckwt
oilrad
Relative oospores present
23 cm!
Relative hypocotyl tissue present
Adjusted
adjDOUG
MîĀHP DeskJet 710C
HP DeskJet 710C
HP DeskJet 710C
Œelative amount hypocotyl tissue'
% Living oospores
Living oospores'
œolarized Soil'
3" (R2 = 0.001)
" (R2 = 0.001)'
6" (R2 = 0.386)
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9" (R2 = 0.783)
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MîĀHP DeskJet 710C
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HP DeskJet 710C
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Cover crop
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Œelative hypocotyl tissue'
Œelative oospores present'
KŒelative oospores vs. relative hypocotyl tissue present, non-solarized soil'
Œelative hypocotyl tissue'
Adjusted DOUG
djusted DOUG'
Adjusted DOUG vs. relative hypocotyl tissue present, non-solarized soil
GŁdjusted DOUG vs. relative hypocotyl tissue present, non-solarized soil'
MîĀHP DeskJet 710C
HP DeskJet 710C
HP DeskJet 710C
Œelative hypocotyl tissue'
Œelative # oospores'
œolarized soil'
3" R2 = 0.694
" R2 = 0.694'
6" R2 = 0.814
" R2 = 0.814'
9" R2 = 0.75
" R2 = 0.75'
MîĀHP DeskJet 710C
HP DeskJet 710C
HP DeskJet 710C
Œelative hypocotyl tissue'
Adjusted DOUG
djusted DOUG'
Adjusted DOUG vs. relative hypocotyl tissue present, solarized soil
CŁdjusted DOUG vs. relative hypocotyl tissue present, solarized soil'
MîĀHP DeskJet 710C
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Cover crop
Solarization
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Œelative oospores presentQ
Œelative hypocotyl tissue'
Œelative oospores'
)Œelative oospores vs hypocotyl tissue, 3"'
Œelative oospores presentQ
Œelative hypocotyl tissue'
Œelative oospores'
)Œelative oospores vs hypocotyl tissue, 6"'
MîĀHP DeskJet 710C
HP DeskJet 710C
HP DeskJet 710C
Œelative oospores presentQ
Œelative hypocotyl tissue'
Œelative oospores'
)Œelative oospores vs hypocotyl tissue, 9"'
MîĀHP DeskJet 710C
HP DeskJet 710C
HP DeskJet 710C
Œelative oospores presentQ
Œelative hypocotyl tissue'
Œelative oospores'
1Œelative oospores vs hypocotyl tissue, all depths'
Percent DOUG
ercent DOUGQ
Œelative hypocotyl tissue'
Percent DOUG oospores
ercent DOUG oospores'
Percent DOUG oospores vs relative hypocotyl tissue, all depths
>Őercent DOUG oospores vs relative hypocotyl tissue, all depths'
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Cover crop
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MîĀHP DeskJet 710C
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n = 15<
Œelative oospores presentQ
Œelative oospores presentQ
Œelative hypocotyl tissue'
Œelative oospores'
8Œelative oospores vs hypocotyl tissue, non-solarized 3"'
n = 12<
Œelative oospores presentQ
Œelative hypocotyl tissue'
Œelative oospores'
4Œelative oospores vs hypocotyl tissue, solarized 3"'
n = 15<
Œelative oospores presentQ
Œelative hypocotyl tissue'
Œelative oospores'
8Œelative oospores vs hypocotyl tissue, non-solarized 6"'
n = 12<
Œelative oospores presentQ
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Œelative oospores'
4Œelative oospores vs hypocotyl tissue, solarized 6"'
n = 15<
Œelative oospores presentQ
Œelative hypocotyl tissue'
Œelative oospores'
8Œelative oospores vs hypocotyl tissue, non-solarized 9"'
n = 12<
Œelative oospores presentQ
Œelative hypocotyl tissue'
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4Œelative oospores vs hypocotyl tissue, solarized 9"'
MîĀHP DeskJet 710C
HP DeskJet 710C
HP DeskJet 710C
Cover crop
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HP DeskJet 710C
HP DeskJet 710C
n = 45<
Œelative oospores presentQ
Œelative hypocotyl tissue'
Œelative oospores'
AŒelative oospores vs hypocotyl tissue,
non-solarized, all depths'
n = 36<
Œelative hypocotyl tissue'
Œelative oospores'
=Œelative oospores vs hypocotyl tissue,
solarized, all depths'
MîĀHP DeskJet 710C
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Cover crop
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n = 15<
Œelative oospores present 8 cmQ
Œelative oospores present 15 cmQ
Œelative oospores present 23 cmQ
Œelative hypocotyl tissue'
Œelative oospores'
8Œelative oospores vs hypocotyl tissue
non-solarized soil'
Œ2 = 0.6245'
Œ2 = 0.6876'
Œ2 = 0.2474'
Œelative hypocotyl tissue'
Œelative # oospores'
7Œelative # oospores vs hypocotyl tissue
solarized soil'
MîĀHP DeskJet 710C
HP DeskJet 710C
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Solarization

Cover crop
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!Œelative hypocotyl tissue present'
Œelative oospores present'
KŒelative oospores vs. relative hypocotyl tissue present, non-solarized soil'
!Œelative hypocotyl tissue present'
Adjusted DOUG
djusted DOUG'
Adjusted DOUG vs. relative hypocotyl tissue present, non-solarized soil
GŁdjusted DOUG vs. relative hypocotyl tissue present, non-solarized soil'
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!Œelative hypocotyl tissue present'
Œelative oospores present'
GŒelative oospores vs. relative hypocotyl tissue present, solarized soil'
MîĀHP DeskJet 710C
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 Œelative amount hypocotyl tissue'
% Living oospores
 Living oospores'
œolarized Soil'
3" R2 = 0.001
" R2 = 0.001'
6" R2 = 0.386
" R2 = 0.386'
9" R2 = 0.783
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University of Minnesota
Set 1 all reps
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APHANOMYCES ROOT ROT AND OOSPORE VIABILITY
C. Windels
Normal
Jan Solheim
Microsoft Word 8.0
University of Minnesota
GREEN MANURE CROPS AND SOIL SOLARIZATION EFFECTS ON
APHANOMYCES ROOT ROT AND OOSPORE VIABILITY
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Long crop.jpg
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^GREEN MANURE CROPS AND SOIL SOLARIZATION EFFECTS ON APHANOMYCES ROOT ROT AND OOSPORE VIABILITY
C. Windels
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Jan Solheim
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