Tree Planter's Notes, Vol. 36, No. 1 (1985)

Soil Solar Heating for Control of Damping-Off Fungi and Weeds at the Colorado State Forest Service Nursery

Diane M. Hildebrand

Biological technician, USDA Forest Service, Rocky Mountain Region, Timber, Forest Pest, and Cooperative Forestry Management, Lakewood, CO.

*Solar heating with a 2-mil clear polyethylene covering for 55 days beginning in early July resulted in significant (P < 0.05) reductions in damping-off fungi-*Pythium *spp. (reduced 60 percent) and* Fusarium *spp. (reduced 74 percent) and in weed cover (reduced 97 percent).*

Soil-borne pests such as weeds and damping-off fungi often cause significant seedling losses in forest tree nurseries. Chemical fumigation of the soil is the best control method at present because fungal pathogens and weeds are eradicated in a single application (5). Although soil fumigation in forest nurseries is cost effective (14), many kinds of desirable organisms such as mycorrhizal fungi are also destroyed (18). In addition, fumigation chemicals are hazardous, requiring special handling and disposal procedures. A less expensive and less hazardous method for soil-borne pest control is solar heating. Solar heating of soil (also referred to as solarization or solar pasteurization) is a recently developed technique in which moist soil is covered with a clear polyethylene tarp for several weeks during the hottest part of the growing season (13).

In some locations, application of polyethylene film allows solar radiation to increase soil temperatures to over 40 °C at a 30-centimeter depth (20), chiefly by eliminating evaporation and partly by the greenhouse effect (15). Continuous or repeated sub-lethal temperatures under moist conditions over long periods either kill pathogenic fungi directly or weaken them so they cannot compete effectively with soil saprophytes. Plant pathogenic fungi are apparently more sensitive to elevated temperatures than are saprophytes. Mycorrhizal fungi can survive solar heating and colonize crop roots (20). Solar heating of soil alters the balance of microorganisms to the detriment of plant pathogens, and thus solar heating can be considered an integrated pest management technique (11).

Solar heating has been effective against a variety of pathogens. The fungi *Verticillium dahliae* Kleb., *Fusarium oxysporum* Schlecht., *Rhizoctonia solani* Kuehn, and *Pythium* spp., and the nematodes *Pratylenchus thornei* Sher & Allen and *Ditylenchus* sp. have been controlled on a variety of agricultural crops through solar heating (1, 6, 13, 20, 22). Disease reduction was still evident the second growing season after solar heating. Annual weeds, the parasitic herb broomrape (*Orobanche* spp.), and many perennial weeds have also been greatly reduced (9, 10).

In addition to pest control, solar heating has other beneficial effects. It affects the soil chemistry; increased levels of nitrate and ammonium nitrogen, potassium, calcium, magnesium, chloride, and phosphate in the soil solution have been reported (2, 23). The disease reduction and the increase in soluble minerals both contribute to the increased growth response observed in crops grown in solar heated soil.

Soil solar heating in conifer nurseries has been evaluated recently in a few areas of the United States. Preliminary results at the Iowa State Nursery indicated some reduction in populations of *Fusarium* sp. and soil nematodes from solar heating (4). In trials at the Bend Forest Nursery in eastern Oregon, *Fusarium* sp. population levels were reduced an average of 32 percent due to solar heating, but tree seedling survival after 10 weeks was similar in control and solar heated plots (3). In Wisconsin, no significant reductions in populations of *F. oxysporum, R. solani*, or *Cylindrocladium floridanum* Sobers & Seymour were achieved through solar heating (24). In a northern California nursery near Placerville, *F. oxysporum* was eliminated in soil at and above 10 centimeters depth, and reduced in soil between 10 and 20 centimeters, while *Macrophomina phaseolina* (Tassi) Goid. survived at all depths after solar heating (16).

Solar heating trials were undertaken to assess the effectiveness of the technique in controlling damping-off fungi and weeds at a conifer nursery in the Rocky Mountain Region, the Colorado State Forest Service (CSFS) Nursery, located on the western edge of Fort Collins, Larimer County, CO, at 1561 meters (5120 feet) elevation. The study area soil was sandy clay loam (52 percent sand, 25 percent silt, and 23 percent clay) mapped as Altvan sandy loam in the Kim loam series by the Larimer County Soil Survey (17). Tree seedling production began at the nursery in the middle 1960's.

Study plots were set up in a nursery block in which an entire spruce planting had been recent plowed under because of excessive losses to damping off. The nursery block is 91 by 61 meters (300 by 200 feet), slopes gently (1 to 3 percent) to the southeast, and has never been fumigated.

Figure 1—*Polyethylene tarp in place on a solar heating plot in early July 1982 at the Colorado State Forest Service Nursery.*

Materials and Methods

Six plots, 3.7 by 61 meters (12 by 200 feet), were arranged in a randomized block design parallel with nursery beds. Three plots were covered with 2-mil polyethylene film for solar heating (fig. 1), and three plots were left untreated as controls. Buffer strips were left between treatment plots and between the edge of the block and the plots. The block was disked and harrowed in June 1982, and all plots were established June 30. After irrigation to field capacity, tarps were placed on solar plots on July 2, anchored at the edges with soil, and removed after 55 days.

Six Peabody Ryan model J thermographs were buried before the plots were covered with polyethylene. One thermo graph was buried at 8 centimeters and one at 15 centimeters along the center of each of two solar and one control plot at a random distance from the ends. The thermograph for the 8 centimeter depth in the control plot was not buried until July 12 because of equipment malfunction.

Soil samples for laboratory assay of populations of damping-off fungi and viable weeds were taken in late June before solar heating, in late August after the tarps were removed, and the following April. Four soil samples (composites of six 15-centimeter soil-probe cores taken in a 30-centimeter radius) were collected at 12-meter intervals along the center of each of the six plots, the first sample spot being chosen at random. Soil samples were assayed as previously described for *Pythium* spp. (7) and *Fusarium* spp. (19).

Analyses of covariance were performed and minimum significant ranges for the means were computed by Tukey's honestly significant difference method (21) for population levels of *Pythium* spp. and *Fusarium* spp. For comparison purposes, population levels of *Pythium* spp. of less than 10 propagules per gram of soil were considered low, 10 to 40 moderate, and over 40 propagules per gram high. Population levels of *Fusarium* spp. of less than 1000 were considered low, 1000 to 4000 moderate, and over 4000 propagules per gram high.

Soil for weed tests was collected from the top 2.5 centimeters of soil from within a 929-square-centimeter frame placed at 12-meter intervals (four per plot) for each of the six plots. Soil was poured in aluminum foil pans, watered, and kept in a Scherer Environmental Chamber at 12 hours of light at 25 °C and 12 hours of dark at 18 °C. After 2 weeks, weed seedings were counted. Minimum significant ranges for the means of weed seed germination counts were computed by Tukey's method. For each weed soil sample taken in August (after solar heating), the percent of the area within the frame shaded by the weed canopy was visually estimated and recorded as percent weed cover. Significant differences in percent weed cover were determined by analysis of variance.

Results

Solar heating resulted in a significant ($P < 0.05$) decrease in population levels of *Pythium* spp. and *Fusarium* spp., and in numbers of germinated weed seedlings. Although fungal population levels were quite variable within plots, the effect of solar heating was still significant.

Analysis of covariance between values for control and for solar heated plots in August adjusted by the June (before solar heating) values as covariates showed a significant ($P < 0.01$) difference in population levels of *Pythium* spp. (table 1). Population levels of *Pythium* spp. dropped significantly ($P < 0.01$), an average of 60 percent, due to solar heating from June to August, whereas control plot levels remained high (fig. 2A). In samples from the following spring (April 1983), *Pythium* spp. levels had decreased over the winter in all plots-levels in check plots fell from high to moderate, while levels in solar plots fell from moderate to low.

Minimum significant ranges computed for the means of population levels of *Fusarium* spp. showed a significant ($P < 0.05$) reduction due to solar heating from June to August (fig. 2B), whereas control plot levels did not. Population levels of *Fusarium* spp. dropped an average of 74 percent, from moderate to low, due to solar heating. Between August and the following April, *Fusarium* spp. population levels increased in all plots, but although levels in control plots increased from moderate to high, levels in solar plots remained low. The major pathogenic species encountered were *F. oxysporum* and *F. solani* (Mart.) Sacc.

By August most of the weed seeds in the control plots had germinated and matured, and a new crop of weed seeds was accumulating on the ground. The major weed species growing in the control plots and adjacent areas were purslane (*Portulaca oleracea* L.), clammy groundcherry (*Physalis heterophylla* Nees), and redroot pigweed (*Amaranthus retroflexus* L.). Few weeds grew under the solar tarps,

Table 1—*Analysis of covariance table for propagules per gram of soil of* Pythium *spp. in control and solar-heated plots (August values) adjusted by pretreatment (June) values as covariates*

Source of variation	Sum of squares	df	Mean square	F
Covariates	1423.4	1	1423.4	2.20
Solar heating effect	7360.3	1	7360.3	11.35**
Within group error	13617.0	21	648.4	
Total	22400.7	23		

**Significant at $P < 0.01$.

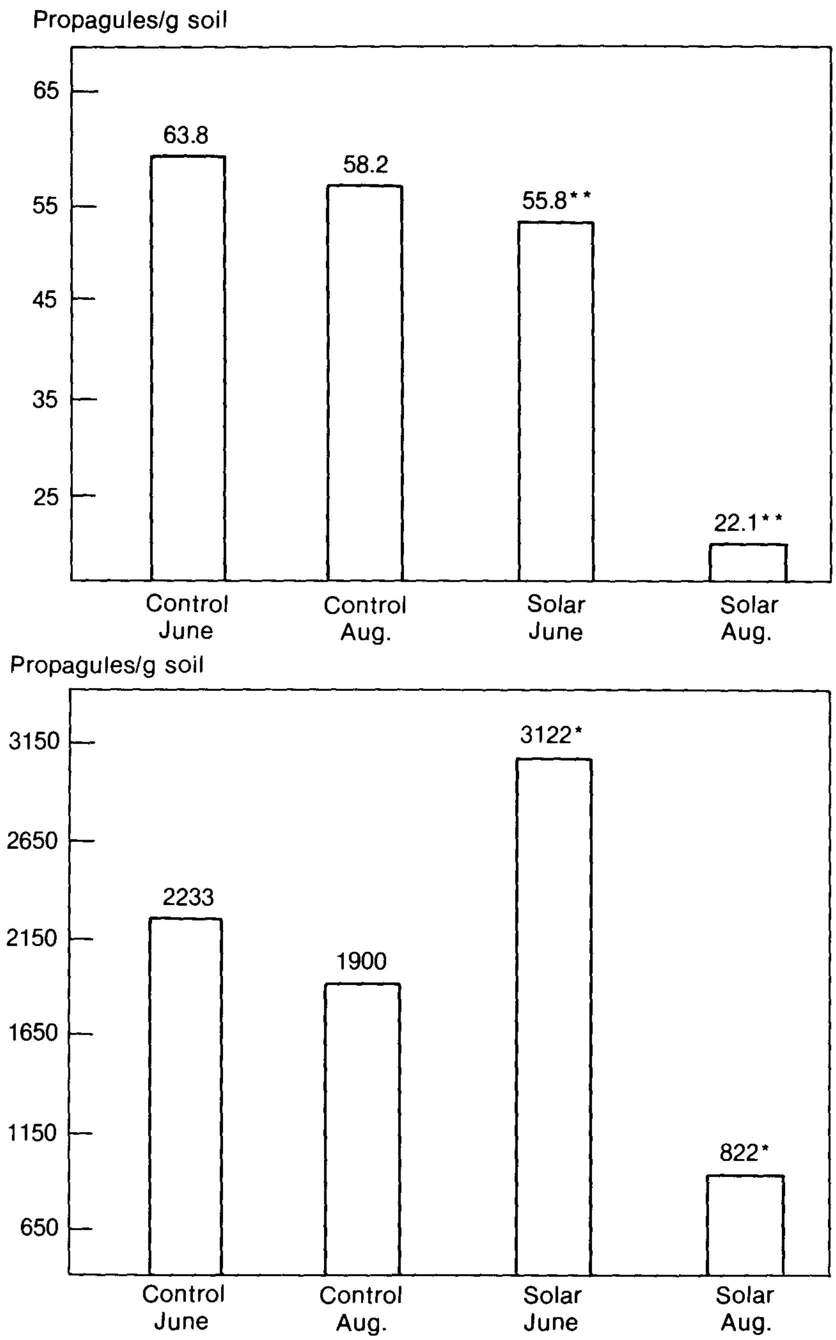

Figure 2—*Effect of solar heating on fungi (average propagules per gram of soil) at the Colorado State Forest Service Nursery.* **A (top)**—*Significant ($P<0.01$) effect on* Pythium *spp.* **B (bottom)**—*Significant ($P<0.05$) effect on* Fusarium *spp.*

although some purslane was growing slowly in spots (fig. 3). Some dead weed seedlings were noticed when tarps were removed. Weed cover in solar plots averaged 97 percent less than in control plots. Minimum significant ranges computed for the means of weed germination counts showed significant ($P < 0.05$) reductions due to solar heating when comparing the June and August solar plot values (fig. 4).

Occasionally, holes in the polyethylene tarps, caused mostly by deer stepping on them to drink from puddles on the surface, required mending. Thick clear-plastic tape was effective. The tarps remained essentially intact until August 23 (after 54 days) when high winds shredded the by-then-brittle plastic.

Surface temperatures of soil averaged 9 °C higher under the tarps than in control plots; at 15 centimeters, temperatures exceeded 41 °C under the tarps. The average high temperature under the tarps at 8 centimeters was 39.6 °C and at 15 centimeters, 34.7 °C. The values are actually higher for solar heated plots, because temperatures exceeding the recording range of the thermograph (10 to 40 °C) were calculated as 41 °C. In control plots, the highest temperature recorded by the 15-centimeter-deep thermograph was 34.2 °C, and by the 8-centimeter-deep thermograph, 38.5 °C. The average high temperature in control plots at 8 centimeters was 28.2 °C and at 15 centimeters, 27.1 °C.

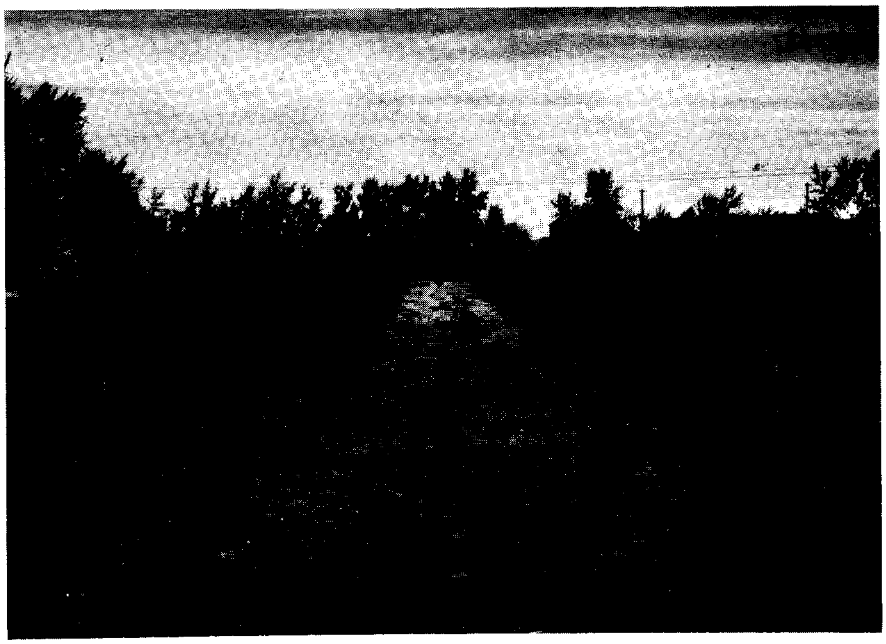

Figure 3—*Solar heated plot in late August 1982 after polyethylene tarp was removed at the Colorado State Forest Service Nursery.*

Temperatures were highly variable from day to day between thermographs at the same depth under solar tarps. Under the solar tarps the 15-centimeter-deep thermographs did not register temperatures greater than 41 °C until late in the third week, whereas readings on the 8-centimeter-deep thermographs exceeded 41 °C on the first day. July temperatures did not differ appreciably from those achieved in August in solar plots. However, for control plots, the August highs averaged several degrees lower than those in July, probably due to shading by weeds.

Discussion

Results in the solar plots show that solar heating of the soil can be effective in reducing populations of damping-off fungi and weeds at a high-elevation Colorado nursery. Weed populations would not become reestablished by the following spring if the entire block were covered with tarp for solar heating and adjacent areas were periodically mown or disked. Population levels of fungal pathogens were significantly reduced, on the average, by solar heating, although the extent of control and the temperatures achieved were quite variable within the plots. The fungal assay as used in this evaluation might give inflated counts because weakened propagules, which may give rise to a colony in the assay but might not survive under field conditions (12), are counted.

In the present evaluation, the soil gradually became drier as weeks passed and was fairly dry by late August, but it probably was sufficiently moist for effective solar heating under the tarps for the first 5 or 6 weeks (6). In addition, the soil was not in the best of tilth. The surface was cloddy and irregular, which increased the size and frequency of air pockets and shadows and may have contributed to the variation in temperatures achieved. Better soil preparation might afford less variation in fungal pathogen control.

Both solar heating and chemical fumigation require favorable weather and the same use of tractor, personnel, tarps, and rollers. With solar heating the safety hazards and cost of handling the toxic fumigant are eliminated. The cost-savings on the price of the fumigant is conservatively estimated at $350 per acre (8). A disadvantage of solar heating is the attention required from nursery personnel to prevent and repair any damage to the tarps during the treatment period. In addition, solar heating requires that the land being treated is taken out of production for the summer before planting.

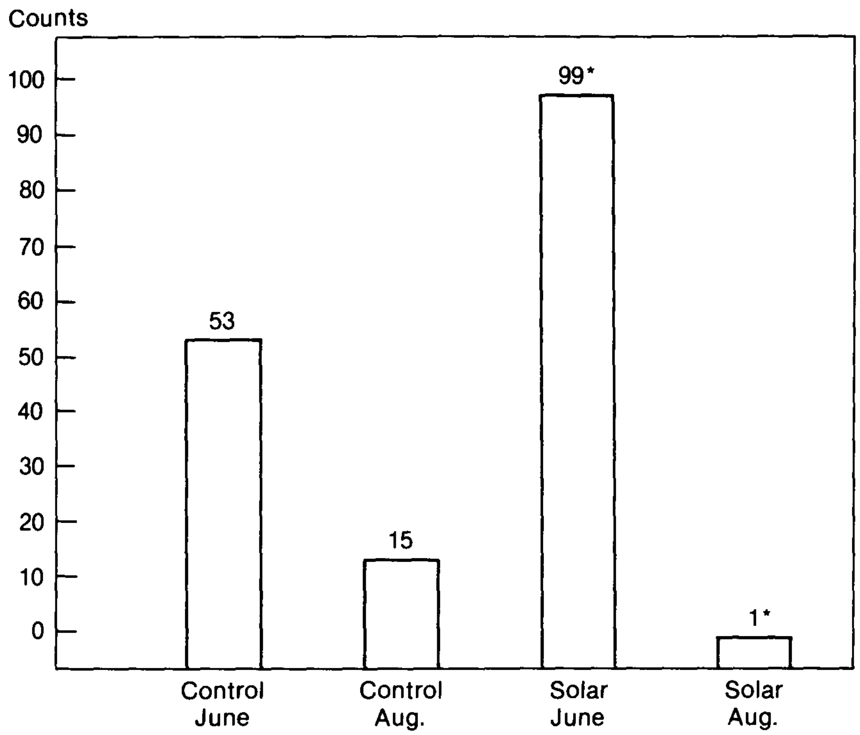

Figure 4—*Average counts of germinated weeds at the Colorado State Forest Service Nursery (1982).*

The ultimate test of the effectiveness of soil solar heating is, of course, survival of planted trees. A spring planting of ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) was planned for this evaluation to reveal the effect of residual fungal populations, but weather and nursery problems delayed planting in the study area until too late in the season for any meaningful seedling mortality information. Based on laboratory tests, the good control of weeds and the degree of control of soilborne fungal pathogens afforded by soil solar heating makes the technique a useful alternative, especially where fumigation is not accepted or cannot be used.

Literature Cited

1. Ashworth, L.J., Jr.; Gaona, S.A. Evaluation of clear polyethylene mulch for controlling Verticillium wilt in established pistachio nut groves. Phytopathology 72: 243-246; 1982.
2. Chen, Y.; Katan, J. Effect of solar heating of soils by transparent polyethylene mulching on their chemical properties, Soil Science 130: 271-277;1980.
3. Cooley, S. Soil solarization in a forest nursery for the control of nursery pests. Forest Pest Management Report. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 1983. 15 p.

4. Croghan, C.F. Personnel communication. U.S. Department of Agriculture, Forest Service, St. Paul, MN. 1983.
5. Gillman, L.S. Soil fumigation with methyl bromide-chloropicrin; Mt. Sopris Tree Nursery, Carbondale, Colorado. Biol. Eval. R2-77-18. Lakewood, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Region; 1977. 4 pp.
6. Grinstein, A.; Orion, D.; Greenberger, A.; Katan, J. Solar heating of the soil for the control of *Verticillium dahliae* and *Pratylenchus thornei* in potatoes. In: Proceedings, International symposium on soil-borne plant pathogens, 1978; Munich.
7. Hendrix, F.F.; Jr.; Kuhlman, E.G. Factors affecting the direct recovery of *Phytophthora cinnamomi* from soil. Phytopathology 55: 1183-1187, 1965.
8. Hinz, J. Personal communication; U.S. Department of Agriculture, Forest Service, Halsey, NE. 1984
9. Horowitz, M.; Regev, Y.; Herzlinger, G. Solarization for weed control. Weed Science 31: 170-179; 1983.
10. Jacobsohn, R.; Greenberger, A.; Katan, J.; Levi, M.; Alon, H. Control of Egyptian broomrape (*Orobanche aegyptica*) and other weeds by means of solar heating of the soil by polyethylene mulching. Weed Science 28: 312-316; 1980.
11. Katan, J. Solar pasteurization of soils for disease control: status and prospects. Plant Disease 64: 450-454; 1980.
12. Katan, J. Solar heating (solarization) of soil for control of soil-borne pests. Annual Review of Phytopathology. 19: 211-236; 1981.
13. Katan, J.; Greenberger, A.; Alon, H.; Grinstein, A. Solar heating by polyethylene mulching for the control of diseases caused by soil-borne pathogens. Phytopathology 66: 683688; 1976.
14. Landis, T.D.; Gillman, L.S.; Hildebrand, D.M. Effectiveness of soil fumigation with methyl bromide-chloropicrin at Mt. Sopris Tree Nursery, White River National Forest, September 1976. Biol. Eval. R2-76-15. Lakewood, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Region; 1976. 6 pp.
15. Mahrer, Y. Prediction of soil temperatures of a soil mulched with transparent polyethylene. Journal of Applied Meteorology. 18: 1263-1267; 1979
16. McCain, A.H.; Bega, R.V.; Jenkinson, J. L. Solar heating fails to control *Macrophomina phaseolina*. Abstr. 442 Phytopathology 72: 985; 1982.
17. Moreland, D.C. Soil survey of Larimer County area, Colorado. U.S. Department of Agriculture, Soil Conservation Service and Forest Service, in cooperation with the Colorado Agricultural Experiment Station; Map Sheet No. 24.
18. Munnecke, D.E.; Van Gundy, S.D. Movements of fumigants in soil, dosage responses, and differential effects. Annual Review of Phytopathology 17: 405-429; 1979.
19. Nash, S.M.; Snyder, W.C. Quantitative estimations by plate counts of propagules of the bean root rot, *Fusarium* spp., in field soils. Phytopathology 52: 567-572; 1962.
20. Pullman, G.S.; DeVay, J.E.; Garber, R.H.; Weinhold, A.R. Soil solarization: effects on Verticillium wilt of cotton and soil borne populations of *Verticillium dahliae*, *Pythium* spp., *Rhizoctonia solani*, and *Thielaviopsis basicola*. Phytopathology 71: 954-959; 1981.
21. Sokal, R.R.; Rohlf, F.J. Biometry: the principles and practice of statistics in biological research, 2d ed. San Francisco: W. H. Freeman and Co.; 1981. 859 p.
22. Solarization Research Team. Solar heating of the soil for the control of soilborne pathogens, nematodes, and weeds in vegetable crops. Phytoparasitica 9: 237; 1981.
23. Stapleton, J.I.; Devay, J.E.; Quick, J.; Van Rijckevorsel, H.; BeBoer, C.J.. Increased solvable mineral nutrients in soils as related to increased plant growth response following soil solarization. Abstr. 380 Phytopathology 73: 814; 1983.
24. Zarnstorff, J.C. Effects of soil solarization and of amending soil with soybean meal on populations of *Cylindrocladium floridanum*, *Fusarium oxysporum*, and *Rizoctonia solani*. Master of Science Thesis, University of Wisconsin, Madison; 1983. 70 p.