# Long Term Large Scale Soil Solarization as a Low-input Production System for Florida Vegetables

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**Keywords**: Compost, nematodes, organic amendments, soil nutrients, sustainable agriculture, and weeds

**Abstract**

**Profound changes will occur from the loss of methyl bromide by the vegetable industry, since it is a key component in production systems. Many growers have relied only on methyl bromide to manage soil pathogens, nematodes, and weeds. This system combined with raised beds, plastic mulch, and drip irrigation has been very effective to produce high vegetable yields. Non-chemical alternatives like solarization and organic amendments are as yet largely unproven but do offer promise of sustainable solutions free of government regulation. The objective of this research was to study the effects of long-term, large-scale use of sustainable methods utilizing soil solarization and organic amendments on weed populations, nematodes, yields and soil fertility on peppers (*Capsicum annuum* L.) and cucumbers (*Cucumis sativus* L.). The field experiment was conducted during 1998 and 1999 season in a commercial vegetable farm in Boynton Beach, FL. There were five large plots consisting of 10 beds, 610 m long (1.3 ha). Treatments consisted of: 3 years of soil solarization and organic amendment; 2 years of soil solarization and organic amendment; 2 years of soil solarization and non-organic amendment; and methyl bromide as a control. At the end of the second crop, solarized treatments had higher % weed cover and were populated primally by bermudagras (*Cynodon dactylon* L. Pers.) a warm weather spreading perennial weed as compared with the methyl bromide production system, dominated by redroot pigweed (*Amaranthus retroflexus* L.) an annual weed easier to control than bermudagrass illustrating, a weak point of a long term solarization system. Population levels of the root-knot nematode [*Meloidogyne incognita* (kofoid and white) chitwood] fluctuated throughout the experiment. During 1999 and 2000, the lowest numbers occurred in the conventional system with methyl bromide. However on each sampling date, numbers in at least one of the sustainable systems were statistically similar to those in the methyl bromide-treated plots. Marketable yields of peppers appeared to be similar within the production systems for the 1998-1999 season. On all testing dates, organic matter, pH, and Mehlich 1-extractable P, K, Ca, Mg, and Zn were higher in systems where compost was applied than in systems without compost. Manganese was not**

**affected, and Cu and Fe varied by year. The results suggest that large-scale soil solarization and organic amendment can be an attractive alternative to methyl bromide. However, methyl bromide produce the more consistent results.**

## INTRODUCTION

Profound changes will occur from the loss of methyl bromide by the vegetable industry, since it is a key component in U.S. production systems. In most cases, growers have relied only on methyl bromide to manage soil pathogens, nematodes, and weeds. This fumigation system combined with raised beds, plastic mulch and drip irrigation has been very effective to produce high vegetable yields. Chemical alternatives are the more desirable methyl bromide alternative by vegetable grower, but none of the products available now can completely replace methyl bromide as a soil fumigant, and these products are more expensive and may also be subject to future restrictions (Spreen et al., 1995). Non-chemical alternatives like solarization and organic amendments are as yet largely unproven but do offer promise of sustainable solutions free of government regulation.

Long-term, large-scale soil solarization can offer the opportunity to evaluate the effectiveness of systems in controlling the most difficult soil pest problems. Weed seed germination and seedling growth is suppressed by high soil temperature (Horowitz, 1980). Clear polyethylene plastic under solar radiation can raise soil temperature above the thermal death point for most weed seedlings and seeds. Soil moisture increases soil heat conductivity and sensitizes seeds to high temperatures. Depending on the type of plastic used, soil temperature can exceed 40°C (clear plastic and UV-absorbing clear plastic can raise temperature to 45 and 50°C, respectively). Clear plastic mulch decreased pigweed (*Amaranthus* spp.) populations within two weeks to less than 10% for one year (Horowitz et al., 1983), demonstrating the sensitivity of annual weeds to solarization. Yellow (*Cyperus esculenthus* L.) and purple (*Cyperus rotundus* L.) nutsedge, which are difficult to manage with conventional methods, have also been controlled (Chellemi et al., 1996).

Compost is not considered fertilizer; however, significant quantities of nutrients (particularly N, P, and micronutrients) become bio-available with time as the compost decomposes in the soil. Amending soil with compost provides a slow-release source of nutrients, whereas mineral fertilizer is usually water-soluble and is immediately available to plants (Ozores-Hampton et al., 1998). Compost usually contains large quantities of plant-available micronutrients

The objective of this research was to determine the effects of large-scale, long-term use of sustainable methods on weed populations, nematodes, yields, and soil fertility on peppers and cucumbers utilizing soil solarization and organic amendments.

## MATERIALS AND METHODS

A large-scale soil solarization field experiment was conducted during 1998 and 1999 season at Boynton Beach, FL (Table 1). The experiment used five large plots consisting of 10 beds, 610 m long (1.3 ha). All beds were 20 cm high, 92 cm wide, and spaced 1.7 m center to center. Bell pepper (*Capsicum annuum* L.) plants were spaced 25 cm apart and two offset rows per beds space 45 cm apart giving a plant population of 43,055 plants.ha-1. Clear solarization polyethylene used in both years in this experiment was low-density 1.2-mil containing UV light inhibitors (Sonoco Products Co., Orlando, FL). Subsurface irrigation was used throughout the growing season. The plants were monitored for insects and diseases and pesticide were applied as needed according to Univ. of Florida Extension guidelines (Maynard and Olson, 2000).

Compost made from a mixture of yard trimmings and biosolids in a 4:1 ratio and composted using an in-vessel composting method for 21 days (Palm Beach Solid Waste Authority, Palm Beach Co., FL) was utilized in this experiment. Chemical and physical properties were analyzed by the Soil and Water Science Department, Univ. of Florida, Gainesville (Table 2). Fertilizer was applied in all plots at 71N-39P-44K kg.ha-1 broadcast application and 283N-0P-279K kg.ha-1 was bedded in the bed centers.

**1998 -1999 Season**

Compost was applied prior to the bed formation at the rate of 78 Mg.ha-1. On 5 August 1998, raised beds were constructed and covered with clear polyethylene mulch. Beds were solarized until 19 October 1998, when the polyethylene was sprayed with white latex paint, for a total of 11 weeks of solarization.

The conventional treatment (treatment 4) was fumigated with a 98% methyl bromide: 2% chloropicrin mixture at 202 kg.ha-1 on 30 August 1999. Bell peppers >Boynton Bell= were transplanted into the beds on 24 September 1998, and cucumbers (*Cucumis sativus* L.) >Speeway= on date 30 January 1999.

**1999 -2000 Season**

Compost was applied prior to the bed formation at the rate of 78 Mg.ha-1. On 26 July 1999, raised beds were constructed and covered with polyethylene mulch. Beds were solarized until 6 September 1999, when the polyethylene was sprayed with white latex paint for a total of 6 weeks of solarization.

The conventional treatment (treatment 4) was fumigated with a 98% methyl bromide: 2% chloropicrin mixture at 202 kg.ha-1 19 August 2000. Bell peppers were transplanted into the beds on 13 September 1999, and >Speedway= cucumbers were planted 25 January 2000. Due to storm damage cucumber yields were low and yield data was not reported.

**Data Collection**

In both season, total marketable yield of the vegetable crops were collected and given as number of cartons of fruit per 1.3 ha. Soil samples were collected before planting and after harvesting the crops in both years. Samples were oven-dried, passed through a 1-mm screen, and extracted with Mehlich-1 solution (Hanlon and DeVore, 1989). The extract was analyzed for Ca, Mg, P, K, Cu, Mn, Fe, and Zn (Hanlon and DeVore, 1989). Soil pH was determined in a 1:2 dilution (v/v) with water, and organic matter (OM) was determined by ignition (Dellavalle, 1992). Soil samples for analysis of plant-parasitic nematodes were collected on seven sampling dates. In July and October 1998 and April 2000, three samples per plot were collected. In January, April, and September 1999, and January 2000, nine samples per plot were collected. Soil samples were shipped overnight to the University of Florida campus in Gainesville, where 100-cm3 sub-samples were removed for extraction using a sieving and centrifugation procedure (Jenkins, 1964). Weeds in the plots were visually evaluated on the bed as percent weed cover and dominate weed species. Percent weed cover was determined by randomly chosen an area 0.02 m2 area in each plot. Observations were made from 60 sub-samples in each plot at the end of the second crop in 1998 season only.

Data were subjected to analysis of variance (ANOVA) and mean separation according to Duncan's Multiple Range Test. Percent weed ground cover data (if >40% difference within experiment) were subjected to arcsin-square-root transformation prior to conducting an ANOVA.

## RESULTS AND DISCUSSION

**Weeds 1998-1999 Season**

At the end of the second crop solarized treatments 1, 2, and 3 had higher % weed cover and were populated primally by bermudagras (*Cynodon dactylon* L. Pers.) a rhizomatous and stoloniferous, warm weather spreading perennial weed as compared with the methyl bromide production system 4, dominated by redroot pigweed (*Amaranthus retroflexus* L.) an annual weed easier to control than bermudagrass, illustrating a weak point of a long term solarization system (Table 3). In general, soil solarization offered a level of weed suppression to the point of eliminating their effects on crop yield after an adequate solarization period of a 6-8 week, but complete elimination of weeds under the plastic mulch is often not obtained (Chellemi et al., 1997). Annual weeds such as pigweed can be control effectively with solarization, but perennial weeds were relatively resistant to control (Horowitz et al., 1983). Perennial weeds under a long term solarization can be a problem to eliminate, since an additional chemical treatment or expensive hand labor may be required to remove the weeds from the field.

**Soil Analysis**

At all testing dates, organic matter was higher in systems where compost was applied (treatments 1 and 2) than without compost (3 and 4) (Table 4). Except on the first date, pH was always higher in plots with compost. Potassium, Ca, Mg, and Zn were generally higher when compost was applied. Roe et al. (1997) reported similar increased concentrations of soil P, K, Mg, and Ca when 134 t.ha-1 of yard trimming/biosolids compost was added to a sandy soil. Considerable amounts of these nutrients are applied with most composts (Table 4). Manganese was not affected, and Cu and Fe varied by year. Most benefits of soil-applied compost have been attributed to improved physical properties due to increased organic matter concentration rather than nutrient value (Gallardo Lara and Nogales, 1987; Hernando et al., 1989; McConnell et al., 1993).

**Yields**

Since the main point of this investigation was to study the effects of the production systems as a whole on soil characteristics and biology, yield comparisons were not considered as critical. Marketable yields of peppers appeared to be similar within the production systems for the 1998-1999 season (Table 5). Cucumber yields for the second crop were higher in production systems 2 and 4 than systems 1 and 3. Pepper yields were recorded for the season 1999-2000, but were extremely low due to loss to *Phytophthora capsici* after a 400-mm rainfall event. Plants in systems 3 and 4 produced more because they survived for a longer period of time than those did in systems 1 and 2. It appeared that the compost retained water in those blocks longer than in the blocks without compost, enhancing the environment for the growth of the pathogen.

**Nematodes**

Population levels of the root-knot nematode [Meloidogyne incognita (kofoid and white) chitwood] fluctuated throughout the experiment (Table 6). This nematode was not detected in the fall sampling. During 1999 and 2000, the lowest numbers occurred in the conventional system with methyl bromide. However on each sampling date, numbers in at least one of the sustainable systems were statistically similar to those in the methyl bromide-treated plots (Table 6). Stubby-root (*Paratrichodorus minor*), spiral (*Helicotylenchus* spp.), and lesion (*Pratylenchus* spp.) nematodes occurred sporadically in the plots (Table 7). In several cases, numbers of these nematodes present in methyl bromide-treated plots had resurged to higher levels than those found in the sustainable systems (Table 7). Stubby-root nematodes are known to resurge to high levels following soil fumigation (Weingartner et al., 1983), and resurgence following solarization has been recently demonstrated as well (McSorley et al., 1999). Results from the current study suggest that the resurgence problem may be more severe following methyl bromide fumigation than following solarization.

Results of the current experiment are fairly consistent with those of other large-scale field tests (Chellemi et al., 1997), since in both cases, equivalent levels of nematode control were achieved by solarization and methyl bromide fumigation in several instances. However in both current and previous (Chellemi et al., 1997) studies, the suppression of root-knot nematodes was more consistent with methyl bromide than with solarization. In addition, methyl bromide is also useful for managing weeds and soilborne diseases. Therefore, effective alternatives to methyl bromide must include several factors. The systems based on solarization and compost amendment that were examined here are attractive alternatives that affected nematodes, weeds, nutrients, diseases, and crop yields, although not always consistently. Methyl bromide, on other hand, produced more consistent results.

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**Tables**

Table 1. Treatments description, 1998-99 and 1999-2000 seasons.

| Production system | Compost | Solarization | Polyethylene |
|---|---|---|---|
| 1. Solar 3 yr, compost | Yes[1] | Yes, 3 years[1] | Painted |
| 2. Solar 2 yr, compost | Yes[2] | Yes, 2 years[2] | Painted |
| 3. Solar 2 yr, inorg. | No | Yes | Painted |
| 4. Conventional (MB, inorg.) | No | No (methyl bromide)<br>(methyl bromide)<br>(bromide bromide) | White on black |

[1] This treatment was solarized and received compost at the beginning of the 1996-97 and 1997-98 seasons.

[2] This treatment was solarized and received compost at the beginning of the 1997-98 season.

Table 2. Elemental concentration, chemical and biological analysis of YT-BS composts.

| Characteristic | 1998/99[1] |
|---|---|
| | **(% dry weight)** |
| C | 24.7 |
| N | 1.68 |
| P | 0.89 |
| K | 0.51 |
| Ca | 5.01 |
| Mg | 0.29 |
| Fe | 0.85 |
| | **(mg $kg^{-1}$ dry weight)** |
| Cd | 1.0 |
| Cu | 131 |
| Mn | 75 |
| Pb | 28 |
| Ni | 9 |
| Zn | 232 |
| | **Additional Properties** |
| Moisture (%) | 51.3 |
| C:N ratio | 14.6 |
| pH | 7.0 |
| E.C. (DS $m^{-1}$) | 4.7 |

[1] Means of two samples taken before compost application and analyzed by the Soil and Water Science Department, Univ. of Florida, Gainesville.

Table 3. Influence of production systems on % weed cover and predominant weed species in 1998-99 season.

| **Production system** | **% weed cover** | **Dominant weed species** |
|---|---|---|
| 1. Solar 3 yr, compost | 54.2a[1] | Bermudagrass (*Cynodon dactylon*) |
| 2. Solar 2 yr, compost | 63.8a | Bermudagrass |
| 3. Solar 2 yr, inorg. | 60.5a | Bermudagrass) |
| 4. Conventional (MB, inorg.) | 14.8b | Pigweed (*Amaranthus retroflexus*) |

[1] Means in columns followed by the same letter do not differ ($P \leq 0.05$) according to Duncan=s multiple range test.

Table 4. Effects of production systems on soil chemical properties and nutrient content.

| Production system | OM | pH | P | K | Ca | Mg | Zn | Mn | Fe | Cu |
|---|---|---|---|---|---|---|---|---|---|---|
| | (%) | | ------------------------- (mg.kg) --------------------------------------- | | | | | | | |
| | ------------------------------------------------------------- **July, 1998** ------------------------------------------------ | | | | | | | | | |
| 1.Solar 3 yr, compost | 2.6a[1] | 6.9a | 369a | 38.0b | 3,817a | 70.7a | n/a[2] | n/a | n/a | n/a |
| 2.Solar 2 yr, compost | 2.2a | 6.9a | 319ab | 59.3a | 2,620b | 56.0b | n/a | n/a | n/a | n/a |
| 3.Solar 2 yr, inorg. | 1.6b | 6.0b | 288ab | 23.0c | 1,549c | 32.0c | n/a | n/a | n/a | n/a |
| 4.Conventional (MB, inorg.) | 1.6b | 6.6a | 244b | 43.4b | 2,605b | 69.8a | n/a | n/a | n/a | n/a |
| | ------------------------------------------------------------- **January, 1999** ------------------------------------------------ | | | | | | | | | |
| 1.Solar 3 yr, compost | 3.0a | 7.1a | 388a | 84.0ab | 4,245a | 128.0a | n/a | n/a | n/a | n/a |
| 2.Solar 2 yr, compost | 2.6b | 7.1a | 326b | 94.7a | 3,975a | 136.0a | n/a | n/a | n/a | n/a |
| 3.Solar 2 yr, inorg. | 1.6c | 6.0c | 353ab | 76.3b | 1,798c | 72.4b | n/a | n/a | n/a | n/a |
| 4.Conventional (MB, inorg.) | 1.6c | 6.6b | 320b | 43.4c | 2,605b | 69.8b | n/a | n/a | n/a | n/a |
| | ------------------------------------------------------------- **April, 1999** ------------------------------------------------ | | | | | | | | | |
| 1.Solar 3 yr, compost | 3.4a | 6.4a | 412a | 101.6b | 4,494a | 161.3a | 23.9a | 36.2a | 76.4a | 10.9c |
| 2.Solar 2 yr, compost | 2.9b | 6.4a | 389a | 63.8c | 2,585b | 85.3bc | 13.6b | 39.0a | 90.3a | 14.3c |
| 3.Solar 2 yr, inorg. | 1.5c | 5.6b | 283b | 161.1a | 1,020c | 89.0bc | 7.2c | 42.7a | 73.2a | 29.5b |
| 4.Conventional (MB, inorg.) | 1.7c | 5.7b | 323b | 59.5c | 1,227c | 74.7c | 7.9c | 29.7a | 71.0a | 39.2a |
| | ------------------------------------------------------------- **April, 2000** ------------------------------------------------ | | | | | | | | | |
| 1.Solar 3 yr, compost | 3.4a | 6.6a | 164.5a | 88.4a | 2,026a | 197.5a | 21.7a | 30.9a | 131.5b | 24.9a |
| 2.Solar 2 yr, compost | 2.7b | 6.6a | 163.1a | 63.7b | 1,495b | 149.3b | 13.6b | 39.6a | 151.7a | 127.9a |
| 3.Solar 2 yr, inorg. | 1.6c | 5.3b | 162.2a | 67.5b | 770.8c | 90.7c | 8.5c | 42.3a | 89.6c | 37.5a |
| 4.Conventional (MB, inorg.) | 1.6c | 5.3b | 160.5a | 48.7b | 797c | 61.5d | 5.7c | 36.8a | 101.3c | 40.0a |

[1] Within each sampling date, means in columns followed by the same letter do not differ (P≤ 0.05) according to Duncan=s multiple range test.
[2] n/a= nutrient not analyzed in 1998-1999.

Table 5. Effects of production systems on marketable crop yields.

| Production system | Peppers ($Mg^{.}ha^{-1}$) | |
|---|---|---|
| | **1998-99** | **1999-2000** |
| 1. Solar 3 yr, compost | 34.1 | 8.8 |
| 2. Solar 2 yr, compost | 38.5 | 1.8 |
| 3. Solar 2 yr, inorg. | 35.8 | 14.6 |
| 4. Conventional (MB, inorg.) | 36.3 | 15.6 |
| | **Cucumbers ($Mg^{.}ha^{-1}$)** | |
| | **1998-99** | **1999-2000** |
| 1. Solar 3 yr, compost | 16.2 | n/a[1] |
| 2. Solar 2 yr, compost | 35.6 | n/a |
| 3. Solar 2 yr, inorg. | 25.7 | n/a |
| 4. Conventional (MB, inorg.) | 32.9 | n/a |

[1] n/a= data not available

Table 6. Effect of production systems on root-knot nematode populations in soil, season 1998-2000.

| **Production system** | -------------------------------------- **Nematodes per 100 cm$^3$ soil** ------------------------------------ | | | | | | |
|---|---|---|---|---|---|---|---|
| | 17 July 98 | 8 Oct. 98 | 8 Jan. 99 | 30 Apr. 99 | 12 Sep. 99 | Jan. 00 | 17 Apr. 00 |
| 1. Solar 3 yr, compost | 17.7 a[1] | 0 | 18.6 a | 3.7 a | 0 | 193.3 ab | 19.7 b |
| 2. Solar 2 yr, compost | 1.0 b | 0 | 15.3 a | 0.2 b | 0 | 20.9 b | 5.7 b |
| 3. Solar 2 yr, inorg. | 8.0 ab | 0 | 0.1 b | 1.6 ab | 0 | 678.1 a | 97.0 a |
| 4. Conventional (MB, inorg.) | B | B | 0.3 b | 0 b | 0 | 0.4 b | 0 b |

[1] Means in columns followed by the same letter do not differ (P#0.05) according to Duncan=s multiple-range test.

Table 7. Effect of production systems on stubby-root, spiral, and lesion nematode populations, spring 2000.

| | Nematodes per 100 cm$^3$ soil | | | | | |
|---|---|---|---|---|---|---|
| | Stubby-root | | Spiral | | Lesion | |
| Production system | Jan. | Apr. | Jan. | Apr. | Jan. | Apr. |
| 1. Solar 3 yr, compost | 0 b[1] | 1.7 b | 0 b | 0 | 0 b | 0 |
| 2. Solar 2 yr, compost | 0.1 b | 3.0 b | 0 b | 0 | 0 b | 0 |
| 3. Solar 2 yr, inorg. | 0 b | 1.0 b | 0 b | 0 | 0 b | 0 |
| 4. Conventional (MB, inorg.) | 1.0 a | 23.7a | 5.8 a | 0 | 1.8 a | 0 |

[1] Means in columns followed by the same letter do not differ (at P#0.05) according to Duncan=s multiple-range test. These nematodes were not detected in samples collected before Jan. 2000.