Improvement of Growth and Yield of *Gypsophila paniculata* by Solarization or Fumigation of Soil or Container Medium in Continuous Cropping Systems

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ABSTRACT

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Disinfestation by solarization, fumigation with methyl bromide, and treatment with metam-sodium were studied in commercial greenhouses growing *Gypsophila paniculata* and experiencing yield decline under continuous cropping. Disinfestation of soil or tuff container medium (volcanic ash), each at two sites, resulted in improved growth and increased flower yield. Flower weight was increased 17–65% by solarization, 26–97% by methyl bromide, and 51% by metam-sodium. Solarization combined with a half-dose of methyl bromide increased yield to the same level as a full dose of methyl bromide. A long-term effect on yield increase over two to five successive crop cycles was apparent with solarization and methyl bromide fumigation, but not with metam-sodium. The quality of flowers also was improved by solarization of a tuff container medium. Disinfestation increased the percentage of early yield. Solarization or sterilization nullified growth reduction or mortality of gypsophila seedlings grown in pots containing soil or tuff container medium with a history of continuous gypsophila cropping or in noninfested soil in which roots of gypsophila plants had been incorporated. Pathogenic isolates of *Pythium* spp. and *Rhizoctonia solani* were isolated from plants from the commercial greenhouses and from roots of diseased plants from controlled studies. Microscopic observation of roots of gypsophila grown in monoculture systems revealed infection by *Olpidium brassicae* and *Polymyxa betae*.

Additional keywords: minor pathogens

Intensive farming of high-value crops often involves continuous planting of the same crop (monoculture). One consequence of monoculture is depressed plant growth and yield decline resulting from the accumulation of harmful biotic and abiotic agents (1,6,11,12,20,21,23). Soil disinfestation is an effective tool for improving plant growth and yield in such systems. In Israel, gypsophila (*Gypsophila paniculata* L.) is an ornamental plant used for cut-flower production. Rooted cuttings are planted in the fall in commercial greenhouses, and the crop is usually grown for several crop cycles, either in soil or in a container medium such as tuff (volcanic ash) (18). Suppressed growth and yield decline in gypsophila plants grown in monoculture systems have been observed in Israel (6). Plant growth is retarded, flowering is not uniform and therefore delayed, and yield is decreased significantly. Disinfestation of the soil used for gypsophila monoculture, by solarization or fumigation with methyl bromide, has been shown to improve plant growth and yield (6). Although many studies have dealt with the effectiveness of soil disinfestation, less is known about its effectiveness in container media (artificial growth substrates). The purpose of this study was to examine the short- and long-term effects of various disinfestation methods on the growth and yield of gypsophila in monoculture systems, in soil or in container medium, and to study the possible involvement of biotic agents in plant growth retardation and yield decline.

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MATERIALS AND METHODS

Plant material. Rooted cuttings of gypsophila (*G. paniculata* cv. Perfecta) were supplied by commercial nurseries and used for both commercial greenhouse and pot experiments. Seedlings, 3-wk-old, of cv. Single Alba grown from seeds sown in an autoclaved mixture of peat–vermiculite (1:1, w/w) were used for pot experiments.

Experimental design and disinfestation treatments. Four experiments were conducted in commercial greenhouses in the central region of Israel between 1987 and 1990. At two sites (Qidron and Kefar Pines), gypsophila was grown in brown-red sandy soils (sand texture); at the other two sites (Shekef and Ge'a), plants were grown in tuff container medium. All of these sites had a history of gypsophila cropping. The plots at Qidron and Kefar Pines had been cropped with gypsophila for 5 and 12 yr, respectively; and the soil had not been disinfested for 3 and 2 yr prior to the experiments. The plots at Shekef and Ge'a had been cropped with gypsophila for 8 and 10 yr, respectively. The tuff medium in Shekef and Ge'a had been disinfested with metam-sodium 1 and 2 yr, respectively, before the experiments. Yield decline was observed or suspected during the season immediately prior to the experiment.

The following disinfestation methods were tested: solarization, methyl bromide fumigation, and metam-sodium treatment. At Kefar Pines, a combination of solarization and fumigation with a half dosage of methyl bromide was also tested. Solarization was carried out manually by mulching preirrigated soil with transparent polyethylene sheets (40–50 μm thick) in July and August for a total of 40–55 days (7). Typical maximal temperatures of the solarized soils in Qidron, Shekef, and Ge'a at a depth of 10 cm were 45–48 C. The maximal temperatures of the corresponding nonsolarized soils were 7–12 C lower. The maximal temperatures at Kefar Pines during solarization were 3–5 C lower than at their counterparts at the other locations. Fumigation with methyl bromide was carried out by the hot gas technique (6) with commercial equipment at a rate of 25 or 50 g/m^2. The combined solarization–fumigation treatment was carried out by applying methyl bromide under the polyethylene sheets, after which the soil was left covered for the entire solarization period. Metam-sodium was applied at Ge'a at a rate of 120 ml/m^2 via sprinkler irrigation, according to the standard procedure (5). The growth medium at the Shekef and Ge'a sites was held in polyurethane containers 60 × 90 × 20 cm, and each plot was 9 m long and 90 cm wide. During metam-sodium application, nontreated plots at that site were covered with polyethylene (to prevent drift contamination), which was removed afterwards. Plots at Qidron and Kefar Pines were 8 × 6 m, with plants in double rows and four beds per replication. In Shekef and Ge'a, double rows were planted in each container row. All experiments were designed as randomized blocks. The experiments at Kefar Pines, Ge'a, and Shekef were conducted with four replications, and the experiment at Qidron with three replications. Additional plants were planted in each plot. They were used for fresh- and dry-weight determinations during the first 10 wk of growth. Flowers were harvested, counted, and weighed, usually twice a week. Flower yield (number and weight of flowers) was assessed from the middle 6 m of each plot. In one experiment (at Ge'a), the flowers were evaluated according to

standard commercial quality grading to assess the effect of solarization on flower quality. In some experiments, the percentage of early yield was calculated.

Simulation of the monoculture phenomenon under controlled conditions. The effect of continuous cropping on gypsophila plants was studied in pots. Samples of soil or tuff container medium taken from commercial greenhouses with a history of continuous cropping were used in these experiments. The samples were either nontreated, autoclaved for 1 hr (121 C), artificially heated in the solarization simulation system, or solarized in the field. Soil solarization was simulated by heating soil in modified Wisconsin soil temperature tanks as described previously (7). The heating system in the simulation tank resulted in a gradual warming of the soil to a maximum temperature of 45 C for approximately 4 hr every day, after which the temperature dropped gradually to 30–34 C. The daily heating course of the soil was similar to that occurring in the upper 10-cm layer of soil during natural solarization in Israel. Two-liter cylindrical glass jars (25 cm high, 12 cm diameter) were filled with soil moistened to field capacity. Jars were sealed with polyethylene sheets to prevent evaporation and maintained for 42 days in the tanks. Nontreated soil was prepared similarly and kept in a shaded part of the greenhouse at temperatures of 22–28 C. Field solarization was accomplished by placing moistened soil samples in perforated buckets (26 cm diameter × 26 cm deep). The buckets were placed under plastic mulch at the experimental farm of the Hebrew University in Rehovot and subjected to solarization as described above. Subsequently, soil samples from all treatments were placed in pots (12 cm diameter), and gypsophila seedlings (three per pot) or rooted cuttings (one per pot) were planted. The plants were maintained in the greenhouse at 22–28 C for 30 days, after which the dry weight of roots and shoots was determined. The number of dead seedlings in each pot also was recorded.

The role of root residues of gypsophila in monoculture systems as potential pathogen carriers and as an incitant of poor growth of gypsophila plants was examined. Roots of gypsophila were taken from the nontreated plots at Kefar Pines and Ge'a as well as from a commercial greenhouse at Orot that had been cropped with gypsophila for 6 yr in tuff medium. Root segments were placed in nylon nets filled with moistened sandy soil. These bags were either nontreated or buried in soil at a depth of 10–15 cm and solarized for 6 wk as described above. Afterwards, roots were separated from the soil, cut into 2–4 mm segments, and mixed with noninfested Rehovot sandy soil with no history of gypsophila cropping at a rate of 1 g of roots per kilogram of soil. Gypsophila seedlings or rooted cuttings were planted in pots filled with these soil mixtures and grown for 30 days in the greenhouse, as described above.

Pathogen isolation and plant inoculation. Segments of the roots from field- or pot-grown cuttings or seedlings were surface disinfested for 1 min in 1% sodium hypochlorite and plated on potato-dextrose agar (PDA) or on *Pythium* selective medium (PSM) (22). *Pythium* isolates from gypsophila were grown on a sterile mixture of peat and vermiculite (1:1, v/v), mixed with sterile carrot pieces (40 g/kg), and incubated at 30 C for 30 days. The inoculum was then mixed with noninfested Rehovot soil at a rate of 0.1%. *Rhizoctonia* isolates were grown on liquid glucose–yeast extract medium (10). Washed, macerated mycelia were used to infest the soil at rates of 40 and 200 mg/kg.

Microscopic studies. Roots and rootlets of plants from the experimental plots and from the pot experiments were examined microscopically for the presence of biotrophic fungi, as described previously (17). The roots were thoroughly washed with running tap water. They were cleared with 10% KOH, acidified with 1% HCl, stained with 0.05% tripan blue, and examined with a light microscope. A 6-grade infection index was established in which 0 indicated no infection and 5 indicated 80% or more of observed roots infected with the biotrophic fungi.

Statistical analyses. Data were analyzed with analysis of variance, *t* test, and nonparametric analysis of variance with randomized blocks. The Friedman test (2) was performed by ranking the index data and proceeding with a standard analysis of variance. Mean separations were carried out by Duncan's multiple range test, $P \leq 0.05$.

RESULTS

Effect of disinfestation on plant growth and yield in soil and container medium. Solarization or methyl bromide fumigation of soil with a history of monoculture at Kefar Pines increased shoot dry weight by 26–34% after 4 wk of growth and by 44–94% after 8 wk (Table 1). The comparable figure for the Qidron experiment after 4 wk was 23–58% (Table 2). Increases in total yield of flowers by disinfestation during the first crop cycle were observed in all four experiments carried out in either soil or tuff container medium (Tables 1–3, Fig. 1). Flower weight increases ranged from 17 to 65% following solarization, from 26 to 97% following methyl bromide fumigation, and 51% following treatment with metam-sodium. The corresponding increases in the number of flowers were 1–65%, 14–94%, and 41% for solarization, methyl bromide, and metam sodium, respectively. The combined treatment of solarization with a half dosage of methyl bromide increased yield to a level similar to that obtained with methyl bromide alone at full dosage at Kefar Pines (Table 1). Disinfestation also resulted in earlier yields at Kefar Pines. Thus, after eight harvests (out of 14 total), the increases in the number of flowers (over the nontreated control) following methyl bromide, methyl bromide + solarization, and solarization were 178, 165, and 100%, respectively. The corresponding numbers for weight were 177, 174, and 100%. These figures are higher than those obtained for all 14 harvests (63–97%) (Table 1). Solarization of tuff medium at Ge'a (Table 3) improved flower quality as expressed by flower weight (an important criterion for quality) as well as by the number and weight of the higher quality flowers, which were increased by 37 and 58%, respectively (Table 3). Solarization also increased the percentage of early yield (Table 3). After three harvests (out of eight), solarization had increased yield by 99–121%, as compared to a 26–31% increase for all eight pickings.

The long-term effect of disinfestation was tested in soil (at Qidron) and in container medium (at Shekef) for five and two crop cycles, respectively (Table 2, Fig. 1). In the Qidron experiment, a significant increase in flower weight in

Table 1. Effect of soil disinfestation by solarization (S), methyl bromide (MB) fumigation, or a combination of solarization with a reduced dose of methyl bromide, on growth and flower yield of *Gypsophila paniculata* in a commercial greenhouse at Kefar Pines, Israel

Soil treatment	Dry weight of shoots (g/plant)		Yield of flowers[x]		Infection index[y]	
	4 wk	8 wk	Number	Weight (kg)	*Olpidium*	*Polymyxa*
Nontreated	1.94 b[z]	11.70 c	35 c	0.73 c	1.8 a	1.84 a
Solarized	2.44 a	16.85 b	58 b	1.19 b	0.6 a	0.02 b
MB (50 g/m^2)	2.60 a	22.70 a	68 a	1.44 a	0.8 a	0.12 b
MB (25 g/m^2)+ S	2.44 a	19.33 ab	67 a	1.42 a	1.1 a	0.05 b

[x]Number and weight of flowers per meter of flower bed.

[y]A 6-grade index in which 0 = no infection and 5 = more than 80% of observed roots infected with the indicated fungus.

[z]Means in each column of dry weight or yield followed by the same letter are not significantly different according to Duncan's multiple range test ($P \leq 0.05$). Means in each column of infection index followed by the same letter are not significantly different according to Friedman's test ($P \leq 0.05$).

solarized and methyl bromide–treated plots was evident throughout the five crop cycles (Table 2). The increase in flower weight following methyl bromide fumigation and solarization ranged from 15 to 34% and from 12 to 22%, respectively. Flower number was significantly increased in four of five cycles by fumigation and two of five cycles by solarization. In the Shekef experiment, flower number (Fig. 1) and weight (*data not shown*) in the solarized plots during the second crop cycle were increased by 22 and 25%, respectively. Metam-sodium treatment had no significant effect on the second crop. Symptoms typical of major pathogens, such as collapse or rot, were not observed in any of the experiments, although growth retardation was frequently visible in the nontreated plots compared with the disinfested plots.

Simulating the monoculture phenomenon under controlled conditions. The effect of monocultured soil or tuff medium on seedlings or rooted cuttings of gypsophila was simulated under controlled conditions. Plant collapse and mortality in the nontreated soil and tuff samples ranged from 13 to 86% with seedlings but was not observed with rooted cuttings (Table 4). Autoclaving the soil, heating it in a solarization simulation system, or solarizing it in the field significantly reduced seedling mortality in five of nine tests. The variability in plant mortality among replications in the nontreated soil was high. The three treatments also significantly increased the dry weight of shoots and roots in the surviving seedlings by 24–241% and 186–317%, respectively; and of shoots from rooted cuttings by 49–72%. Growth of seedlings in a mixture of autoclaved soil and 10% nontreated soil from the Qidron experiment resulted in a pronounced growth retardation.

In an additional experiment, samples of a monocultured soil were brought from a commercial greenhouse at Olesh, along with samples of the same soil which had been fumigated in the field with methyl bromide at 50 g/m^2. Rooted cuttings of gypsophila were planted in pots filled with these soil samples. A soil from Rehovot which had no history of gypsophila culture served as a noninfested and nonfumigated reference soil for comparison. The dry weights of shoots of rooted cuttings grown for 30 days in the nonfumigated Olesh soil,

Table 2. Long-term effect of soil solarization or methyl bromide (MB) fumigation on flower yield (number and weight) of *Gypsophila paniculata* in a monoculture system over five crop cycles at Qidron, Israel[x]

		Month and year of harvest									
	Dry weight[y]	Jan. 1988		June 1988		Jan. 1989		June 1989		Jan. 1990	
Soil treatment	(g/plant)	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.
Nontreated	2.6 b[z]	127 b	2.3 c	75 b	1.5 c	116 c	2.3 c	175 a	5.6 b	96 b	2.0 b
Solarized	4.1 a	129 b	2.7 b	81 b	1.7 b	137 b	2.8 b	181 a	6.0 a	108 a	2.3 a
MB (50 g/m^2)	3.2 ab	145 a	2.9 a	89 a	1.9 a	147 a	3.1 a	176 a	6.5 a	107 a	2.3 a

[x]Figures represent number (No.) or weight (Wt.) in kilograms of flowers per meter of flower bed. The figures for the first two crop cycles were taken from reference 5 for comparison.
[y]Plants in the first crop cycle, 28 days after planting.
[z]Means in each column followed by the same letter are not significantly different according to Duncan's multiple range test ($P \leq 0.05$).

Table 3. Effect of solarization of tuff container medium on dry weight of plants after 30 days and on flower yield (number and weight) of *Gypsophila paniculata* in a commercial greenhouse at Ge'a, Israel

	Dry weight	Flowers[x] (no.)			Flowers[x] (wt.)			Early yield[y] (no.)			Early yield[y] (wt.)		
Treatment	(mg/plant)	Total	Super	I	Total	Super	I	Total	Super	I	Total	Super	I
Nontreated	304	115	19	96	1.79	0.65	1.14	20.0	9.9	10.1	0.6	0.43	0.17
Solarized	325	145*	26*	119	2.35*	1.03*	1.32	44.3*	18.1*	26.2*	1.2	0.83*	0.37*

[x]Yield (number or kg of flowers per meter of row) was separated into two quality categories: high (super) is more than 60 cm long, and low (I) is 40–50 cm long.
[y]Cumulative yield for the first three harvests (out of eight).
[z]Within each column, an asterisk denotes significant differences ($P \leq 0.05$) from the nontreated control, according to Student's t test.

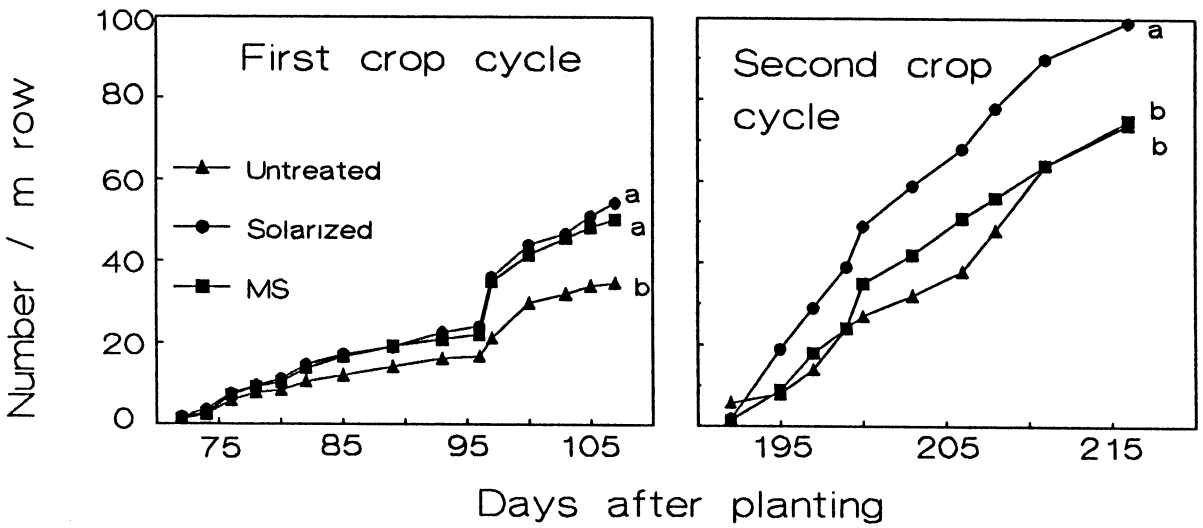

Fig. 1. Effect of soil solarization or treatment with metam-sodium (MS) on yield (number of flowers) of *Gypsophila paniculata* in monoculture tuff container medium over two crop cycles. The experiment was carried out in a commercial greenhouse at Shekef, Israel. In each crop cycle, different letters indicate significant differences among treatments according to Duncan's multiple range test ($P \leq 0.05$).

fumigated Olesh soil, and Rehovot soil were 850, 1,720, and 1,870 mg, respectively. Growth in the nonfumigated Olesh soil differed significantly ($P = 0.05$) from growth in the other two soils.

Roots of gypsophila plants were collected from plots with a history of monoculture and incorporated into noninfested sandy Rehovot soil with no history of gypsophila cropping. Seedlings or rooted cuttings of gypsophila were grown in pots containing this mixture to examine the potential of root residues as an inoculum source. Incorporation of roots from Kefar Pines resulted in a high level of seedling mortality (Table 5). Solarization of the infected roots reduced disease incidence by 90% and nullified the adverse effect of the roots on plant growth. Solarization also nullified the adverse effect of roots from Orot. Growth retardation also was evident in rooted cuttings grown in pots infested with roots from Kefar Pines.

Roots of plants from commercial greenhouses which had shown growth retardation, or seedlings which had shown collapse or growth retardation when grown in monocultured soils in the controlled-conditions experiments, were plated on PDA and PSM media. *Pythium aphanidermatum* (Edson) Fitzp., *P. paroecandrum* Drechs., *P. irregulare* Buisman, *P. sylvaticum* W.A. Campbell & J.W. Hendrix, and *Rhizoctonia solani* Kühn were recovered from these roots. Eight isolates of *Pythium,* representing the four species, and two isolates of *R. solani* were examined for pathogenicity. All were found to be pathogenic to gypsophila seedlings in inoculation experiments as expressed in seedling mortality, lesion formation, and growth retardation.

Five months after planting, at the end of the first crop-cycle season, roots and rootlets were collected from the Kefar Pines experiment. Both *Olpidium brassicae* (Woronin) P.A. Dang. and *Polymyxa betae* Keskin were detected (Table 1). The three disinfestation treatments significantly reduced infection by *P. betae* but not by *O. brassicae.* Roots and rootlets of gypsophila also were collected from additional sites in which monoculture had been practiced and were examined microscopically. *O. brassicae* was detected in three out of four sites, and *P. betae* was detected in three out of five sites. No viral symptoms were observed in any of the examined plants.

Table 4. Effect of disinfestation of soil or tuff container medium, previously cropped with *Gypsophila paniculata*, on dry weight of roots and shoots and seedling mortality in pot experiments[x]

Site	Growth medium	Treatment	Plant type	Dry weight (mg/plant)		Dead plants (%)
				Shoots	Roots	
Kefar Pines	Soil	Nontreated	Seedling	84 b[y]	...	30 a
		Simulation		146 a	...	3 a
		Autoclaved		164 a	...	13 a
Kefar Pines	Soil	Nontreated	Seedling	75 a	...	86 a
		Solarized		117 a	...	33 b
Kefar Pines	Soil	Nontreated	RC[z]	750 b	...	0
		Autoclaved		1,290 a	...	0
Qidron	Soil	Nontreated	Seedling	40 b	...	72 a
		Simulation		64 a	...	0 b
Qidron	Soil	Nontreated	Seedling	231 a	...	20 a
		Autoclaved		241 a	...	13 a
		Autoclaved +10% nontreated		106 b	...	40 a
Qidron	Soil	Nontreated	RC	1,000 b	...	0
		Autoclaved		1,490 a	...	0
Ge'a	Tuff	Nontreated	Seedling	127 b	48 b	53 a
		Solarized		158 a	200 a	0 b
Ge'a	Tuff	Nontreated	Seedling	169 b	...	33 a
		Autoclaved		328 a	...	0 b
Orot	Tuff	Nontreated	Seedling	46 b	21 b	86 a
		Solarized		157 a	60 a	7 b
Shekef	Tuff	Nontreated	Seedling	230 a	...	13 a
		Autoclaved		344 a	...	0 a
Geva Carmel	Tuff	Nontreated	Seedling	325 a	...	40 a
		Autoclaved		410 a	...	0 a

[x] Samples of soils or tuff container medium were collected from commercial greenhouses growing gypsophila in monoculture systems at the indicated locations. The samples were nontreated, autoclaved for 1 hr, or solarized, either in the field during June–August 1990 or in a simulation system, and then used for the pot experiment.

[y] Within each column, each site, and plant type, different letters denote significant differences among treatments according to Duncan's multiple range test ($P \leq 0.05$).

[z] Rooted cuttings.

Table 5. Effect of incorporating roots of gypsophila from monocultured soils or tuff container medium on growth of *Gypsophila paniculata* and on seedling mortality in pot experiments

Plant type	Site	Growth medium	Treatment	Dry weight (mg/plant)		Dead plants (%)
				Shoots	Roots	
Seedlings	Kefar Pines	Soil	Nontreated[w]	50	16.0	95
			Solarization[w]	163*[x]	31.6*	10*
	Ge'a	Tuff	Nontreated[w]	157	39.8	0
			Solarization[w]	171	30.2	0
	Orot	Tuff	Nontreated[w]	113	20.8	0
			Solarization[w]	170*	42.2*	0
Rooted cuttings	Rehovot	Soil	Nontreated[y]	1,534 a[z]	NT	0
	Kefar Pines	Soil	Nontreated[w]	931 b	NT	0
	Ge'a	Tuff	Nontreated[w]	1,490 a	NT	0
	Orot	Tuff	Nontreated[w]	1,340 a	NT	0

[w] Plants at the indicated sites were uprooted, and their roots were incorporated into noninfested Rehovot sandy soil. The soil with roots was either nontreated or solarized and replanted with seedlings or rooted cuttings.

[x] Asterisk denotes a significant difference from the respective nontreated control according to Student's t test ($P \leq 0.05$). NT = not tested.

[y] Noninfested control Rehovot soil without a history of gypsophila cropping which was not supplemented with roots.

[z] Different letters denote significant differences according to Duncan's multiple range test ($P \leq 0.05$).

DISCUSSION

Poor growth and yield decline of gypsophila plants were documented in soils and tuff container media with various histories of monoculture cropping. The resulting damage was shown through solarization and fumigation studies to be as severe as that caused by major pathogens in other crops. Our results confirmed those of Sewell (23) for apple replant disease. Hoestra (11) defined the harmful effect of monoculture on plant growth as self-induced disease, as seen also in our pot experiments in which the growth of gypsophila plants was suppressed in a soil mixed with gypsophila roots. Soil disinfestation by the three methods tested here was effective in reversing the negative effects of monoculture. The effectiveness of fumigants such as methyl bromide in controlling replant disease in apple, which is analogous to monoculture systems of annual crops, was demonstrated (3,4,6,9,21,23) and is regarded as an additional indication of the involvement of biotic factors. The extent of the yield increase resulting from the application of a certain disinfestant

depends on the composition of harmful agents present and on the effectiveness of the disinfestant in eliminating them. For example, metam-sodium was effective in controlling inocula of *Fusarium oxysporum* f. sp. *lycopersici, R. solani,* and *Pythium myriotylum* in tuff (25). Solarization was effective in controlling root rots of gerberas in a potting medium (13). The positive and negative side effects of disinfestation on soil microorganisms and soil properties also influence reinfestation rate and plant growth (1,14).

In Kefar Pines, methyl bromide was more effective than solarization. At this site, temperatures of the solarized soil were lower than usual for Israel, for unknown reasons, which may have reduced the effectiveness of solarization. However, combining solarization with methyl bromide at half dosage was sufficient to obtain results comparable to those obtained with methyl bromide at full dosage. Combining solarization with other methods of control for the reduction in pesticide dosage, for an improved or broader spectrum, or for a longer lasting control was demonstrated or suggested. For example, combining solarization with a reduced dosage of metam-sodium resulted in a synergistic effect in controlling delimited shell spots of peanuts (5). Such an approach should be further explored with other combinations of control methods.

Solarization of tuff container medium increased total yield in two experiments and also improved flower quality. This is in accordance with a study on tomatoes in a monoculture system, with composted separated manure as a container medium, in which solarization significantly increased the total yield and the percentage of high-quality fruit by up to 300% (8). It also indicates that, like soil, a container medium may lose potential productivity upon repeated cropping even before a buildup of major pathogen populations is apparent. Solarization is especially useful in container media which contain high levels of organic matter (40% or more) and are therefore more difficult to fumigate. Solarization and fumigation also increased the percentage of early yield in soil (Kefar Pines experiment) and in tuff medium (Ge'a). A long-term effect, over five crop cycles, was observed following the treatment of soil with either methyl bromide or solarization, and over two cycles following treatment of tuff container medium with solarization. No long-term effect was observed with metam-sodium. A long-term effect by solarization has been reported with a variety of pathogens, such as *Fusarium oxysporum* f. sp. *vasinfectum* (15,16).

The poor-growth phenomenon observed in monoculture systems was reproduced in tests with seedlings or rooted cuttings in pots of either the tested soils or tuff, as well as in noninfested soil amended with roots. Significant reduction in the dry weight of seedlings and seedling mortality were observed in most cases. The development of rapid, reliable, and inexpensive bioassays to predict yield decline would be of great value. The validity of the results from such pot tests for predicting the severity of replant disease has been discussed (12,24). Tests with young plants are the most convenient but do not necessarily represent mature plants under field conditions. In our pot tests, plant mortality was evident with seedlings but not with well-developed rooted cuttings, nor was mortality evident in the mature plants in commercial greenhouses. Thus, rooted cuttings provided the more realistic test results, whereas seedlings can be regarded as bait for the pathogens, reflecting the level of inoculum potential of the pathogens involved. In the above pot tests, plant growth was compared with plants grown in sterilized or disinfested soils. However, these soil treatments may themselves improve plant growth independent of pathogen control (1). Sewell (23) noted that biocidal soil treatment is the best, albeit problematical, method for the accurate assessment of replant disease severity. Thus, the improved growth and yield of plants following disinfestation may be related to the elimination of detrimental factors, including minor pathogens (7,19), and to other side effects not related to the control of harmful microorganisms.

Yield decline in gypsophila does not seem to be associated with mineral deficiencies. Pot experiments showed that the causal agents are controlled by sterilization or disinfestation, and that they are soilborne and associated with roots. Mixing nontreated, monocultured soil with a sterilized soil caused growth retardation, providing further evidence for the involvement of biotic agents. Several fungi, such as the pathogens *Pythium* and *Rhizoctonia* and the biotrophic fungi *O. brassicae* and *P. betae* were associated with the diseased seedlings and with plants from commercial greenhouses. The involvement of abiotic agents such as phytotoxic decomposition products (1,15,21) cannot be excluded.

Soil disinfestation is an effective method for improving plant health in monoculture systems, but it is expensive, complicated, and even hazardous when fumigants are used. Alternative methods, such as specific fungicides or beneficial microorganisms (20), need to be further explored.

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