Soil Amendment with Cabbage Residue and Crop Rotation to Reduce Gummy Stem Blight and Increase Growth and Yield of Watermelon

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ABSTRACT

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Three cropping sequences, watermelon-cabbage-soil solarization-watermelon, watermelon-wheat-soybean-watermelon, and 3 years watermelon, were evaluated for the effect on gummy stem blight and watermelon fruit yield. The 3-year experiment was conducted three times, first in the fall of 1991 through the summer of 1993, then twice in the fall of 1993 through the summer of 1995, with one of these being a second cycle in the same plots as the first test. Cabbage-solarization ($P \leq 0.07$) and the wheat-soybean double crop ($P < 0.04$) reduced area under the disease progress curve for gummy stem blight in two experiments when compared with yearly cropping of watermelon. Plant stand, vine length, and fruit set were increased by 31, 26, and 64%, respectively, in cabbage-amended, solarized plots compared with the other two cropping sequences. Averaged across first-cycle experiments in 1993 and 1995, cabbage followed by soil solarization significantly ($P \leq 0.01$) increased the weight and number of marketable-sized (>6.35 kg) and total healthy fruit compared with the nonsolarized treatments. Marketable yields of cv. Charleston Gray were 59.4, 35.4, and 39.4 kg of watermelon per 15 m of row in plots cropped to cabbage-solarization, watermelon, and wheat-soybean, respectively, the preceding year. Yield of watermelons weighing <6.35 kg was greater ($P \leq 0.04$) after cabbage amendment and solarization than after the other two cropping sequences for both experiments in 1995. In 1994, thermotolerant fungi increased in solarized plots amended with cabbage residue and remained significantly ($P < 0.01$) higher in these plots than in nonsolarized plots the following year. Growth promotion and fruit yields in amended, solarized plots were not associated with changes in soil mineral nutrients, plant parasitic nematodes, or soil temperatures. Incorporating cabbage residue into mulched soil can increase growth and yield of watermelon.

Additional keywords: *Citrullus lanatus, Didymella bryoniae*

Gummy stem blight, caused by *Didymella bryoniae* (Auersw.) Rehm (=*Mycosphaerella citrullina* (C.O. Sm.) Gross.) anamorph *Phoma cucurbitacearum* (Fr.:Fr.) Sacc. (=*Ascochyta cucumis* Fautr. & Roum.), is the most destructive foliar disease of watermelon (*Citrullus lanatus* (Thunb.) Matsum. & Nakai) and other cucurbits in the southeastern United States (12,23). No cultivars of cantaloupe, watermelon, or cucumber have useful levels of resistance to this pathogen (18,27,28). Gummy stem blight often is not controlled adequately by currently registered fungicides (14). A minimum 2-year rotation away from all cucurbits is recommended to reduce soilborne inoculum of the pathogen (25), as *D. bryoniae* infects only members of the *Cucurbitaceae* (2).

Most growers are unable or unwilling to employ rotations longer than 1 year for several reasons. Because cucurbits can be profitable crops, cucurbit growers in the southeastern United States devote some portion of their acreage to these crops each year. Many of these growers have invested capital in drip or center-pivot irrigation systems and grow watermelon and cantaloupe each year to ensure a return on this investment. Other growers have a limited amount of land available for rotation away from watermelon and other cucurbits, and follow one cucurbit crop with a different cucurbit crop. Additional management techniques suited to commercial use are needed for gummy stem blight control.

Soil solarization in combination with organic amendments is more effective than solarization alone for reducing survival of some soilborne pathogens (5,10,19,20). Cabbage residue in heated soil produced volatile compounds, such as isothiocyanates and aldehydes, which contributed to the mortality of *Pythium ultimum* Trow (5), *Sclerotium rolfsii* Sacc. (5), and *Fusarium oxysporum* Schlechtend.:Fr f. sp. *conglutinans* (Wollenweb.) W.C. Snyder & H.N. Hans. (20). The benefit of combining organic amendments with solarization is that pathogen populations can be reduced at soil temperatures lower than those required without organic matter additions. For example, viable propagules of *P. ultimum* and *S. rolfsii* were eliminated from soil amended with 2% dried cabbage residue and heated to 38°C and from nonamended soil heated to 45°C, but were only reduced $\leq 36\%$ in nonamended soil at 38°C (5). To reduce *F. o.* f. sp. *conglutinans* and Fusarium yellows of cabbage, amending soil with 1% dried cabbage residue and covering it with polyethylene mulch was more effective than nonmulched amended soil (19,20). Combining solarization with organic amendments, such as cruciferous residues, may make solarization more effective in areas where frequent cloud cover limits the increase in soil temperatures, such as the humid southeastern United States (1).

The objectives of this study were to determine the effectiveness of cabbage (*Brassica oleracea* L. var. *capitata* L.) residue amendments plus soil solarization and an agronomic rotation, double-cropped wheat (*Triticum aestivum* L.) and soybean (*Glycine max* (L.) Merr.), for reducing gummy stem blight and improving plant growth and yield of watermelon. Yearly spring cropping of watermelon was included as a negative control. The effect of two cropping cycles (1991 to 1993 and 1993 to 1995) was compared to that of one cycle (1993 to 1995). A preliminary report has been published (11).

MATERIALS AND METHODS

Cropping sequences. Plots were established in the fall of 1991 at the Coastal Research and Education Center, Charleston, South Carolina, in Yonges loamy fine sand (Typic Albaquult). Watermelon grown in the field in late summer 1991 had an average of 76.5% leaf surface area affected with gummy stem blight due to natural infection by *D. bryoniae* (14). The experiment was designed as a randomized complete block with three treatments and four replications. Each plot measured 7.3 m wide × 69.8 m long. The three treatments during 1991 to 1992 were double-cropped wheat and soybean, cabbage followed by soil solarization, and watermelon.

On 14 November 1991 in the wheat-soybean plots, hard red winter wheat cv.

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Florida 301 was seeded at 101 kg/ha and fertilized with 329 kg/ha 10-10-10 N-P-K on 13 January 1992. Wheat was mowed without harvesting the grain, and straw was incorporated into the soil on 7 July. Soybean cv. Ransom was seeded in these plots at 123 kg/ha on 29 July. Sethoxydim (Poast 1.5EC, 0.34 kg/ha) was sprayed postemergence on soybeans on 5 August to control weeds. Soybean pods did not fill, and plants were mowed on 12 October.

In the cabbage-solarization plots, rye was seeded at 67 kg/ha on 29 October 1991 as a winter cover crop. Rye was mowed on 2 February 1992 and disked twice before 1,345 kg/ha 10-10-10 N-P-K fertilizer and the herbicide trifluralin (Treflan 4EC, 0.84 kg/ha) were incorporated to a depth of 20 cm. On 10 February, cabbage cv. Gourmet was direct-seeded, one seed per 15 cm, in single rows on eight beds per plot spaced 0.9 m apart. Cabbage was side-dressed with calcium nitrate at 134 kg/ha on 9 March and thinned to one plant per 30 cm on 16 to 17 March. On 8 June, cabbage heads ≥15 cm diameter were removed from the field. Residue (outer leaves and small heads) was rotary chopped, dried for 2 weeks, then incorporated into the soil by disking to a depth of 20 cm. On 30 June, 0.9-m-wide beds spaced 0.9 m apart were shaped and covered with 0.03-mm-thick, clear, low-density polyethylene mulch with UV-stabilizer (Edison Plastic Co., Lee Hall, VA). Soil temperatures were measured with a mercury thermometer at 10 and 20 cm depth on Fridays at 1300 h. Mulch was removed on 9 October.

In the watermelon plots, rye was seeded and mowed as described for the cabbage-solarization treatment. On 8 and 9 April 1992, plots were fertilized with 1,345 kg/ha 10-10-10 N-P-K fertilizer, and watermelon cv. Jubilee was direct-seeded, three seeds per hill, with 1.2 m between hills in four rows per plot spaced 1.8 m apart. Cucumber beetles were controlled with esfenvalerate (Asana-XL, 0.03 kg/ha) and carbaryl (Sevin 50WP, 4.5 kg/ha) applied on 4 and 12 May, respectively. Watermelons were side-dressed with 224 kg/ha 5-10-10 N-P-K fertilizer on 28 May. No fungicides were applied. Gummy stem blight development was assessed visually with the Horsfall-Barratt scale (8) on each row approximately every 10 days (four times). Watermelon fruit were removed from the field on 13 July, and vines were mowed on 15 July. Plots were disked on 27 July and seeded to sorghum at 5.6 kg/ha as a summer cover crop to reduce soil erosion.

Plots in all treatments were disked on 13 October 1992 and planted to rye. On 9 March 1993, rye was mowed and the field was disked. On 9 April, 560 kg/ha 15-0-15 N-P-K fertilizer was incorporated, and all plots were planted to watermelon cv. Charleston Gray, three seeds per hill with 1.2 m between hills, in three rows spaced 1.8 m apart. Plots were separated by a 0.9-m-wide strip of rye located on the western edge of each plot, the direction of the prevailing winds, to reduce dispersal of *D. bryoniae* inoculum among plots. Weeds were controlled with bensulide (Prefar 4E, 6.7 kg/ha) and naptalam (Alanap 2EC, 4.5 kg/ha) applied on 15 April. Watermelon seedlings were transplanted into plots with missing hills on 30 April. Watermelons were side-dressed with ammonium nitrate at 168 kg/ha on 18 May. Esfenvalerate (Asana-XL, 0.03 kg/ha) was applied on 19 May to control cucumber beetles. Because May and June were unusually dry, the field was irrigated with 0.6 cm of water 3 days per week to promote gummy stem blight development. No fungicides were applied.

Within each plot, two subplots 15.3 m long were marked for data collection. Visual disease ratings with the Horsfall-Barratt scale were made weekly from 12 May to 6 July on each of the three rows within each subplot. On 8 July, all melons were harvested from the center row of each subplot. Melons were graded no. 1 or 2 according to U.S. Department of Agriculture standards (16), weighed, and counted. Melons were separated into four size classes based on fruit weight: extra small (≤6.35 kg), small (>6.35 but <8.2 kg), medium (≥8.2 but ≤10 kg), and large (>10 kg).

Beginning in the fall of 1993, the cropping sequences described above were repeated in the same plots in the same field (designated D2) and in a second field (B10) at the Coastal Research and Education Center. The fields were separated by 0.25 km, including a 150-m-wide grove of pines and mixed hardwoods. Field B10, a Charleston loamy fine sand (Aquultic Hapludalf), had been cropped to watermelon in the spring of 1993 (3). When watermelon vines were incorporated into the soil on 23 July 1993, 63% of the leaf surface area was affected with gummy stem blight. The experimental design and treatments were the same as described above. Plots were 7.3 × 61 m. Crops were managed at the same time in both fields. Rye was planted as a winter cover crop in plots to be planted to watermelon or cabbage on 22 October 1993. Wheat was planted in wheat-soybean plots on 15 November 1993. Wheat was disked on 25 May 1994, and soybean was seeded on 12 July. Cabbage was seeded on 9 February 1994 and harvested on 26 May. Clear polyethylene mulch was laid for solarization on 14 July 1994 and removed on 5 October. Watermelon was seeded on 6 April 1994 and harvested in July. All plots were planted to rye as a winter cover crop on 4 November 1994.

Fields D2 and B10 were fertilized with 1,345 and 1,121 kg/ha 15-0-15 N-P-K, respectively, prior to planting. On 10 April 1995, watermelon cvs. Crimson Sweet and Charleston Gray were seeded in all plots in fields D2 and B10, respectively, as described above. Esfenvalerate (Asana-XL, 0.03 kg/ha) was applied three times to control cucumber beetles. Two 15.3-m-long subplots were marked within each plot in each field. Plant stand (number of plants) in all three rows of each subplot was counted on 19 and 22 May in fields D2 and B10, respectively. The longest runner on five plants chosen randomly per subplot was measured on 23 May. Gummy stem blight development was assessed weekly between 17 May and 5 July as described above. Fruit ≥10 cm in length were counted in all three rows of each subplot on 14 and 21 June in fields D2 and B10, respectively. Ripe fruit were harvested from all three rows of each subplot three times at weekly intervals between 3 and 20 July. Fruit were graded as described above.

Soil assays. Population densities of selected soil microorganisms were estimated by dilution plating to monitor the effects of soil solarization with cabbage residue. Soil samples were collected in fields D2 and B10 from the nonsolarized watermelon and cabbage-solarization treatments prior to and after the solarization period, 24 June and 6 October 1994, respectively, and on 30 to 31 May 1995. Twenty 2.5-cm-diameter cores collected from 0- to 15-cm depth from the center row of each subplot were composited and thoroughly mixed. A suspension of 10.0 g of soil in 90 ml of sterile deionized water was serially diluted, and 0.1 ml of two 10-fold dilutions was pipetted onto two plates of each medium. *Fusarium* spp., thermotolerant fungi, fluorescent *Pseudomonas* spp., *Bacillus* spp., and actinomycetes were cultured on Komada's agar (15), yeast-glucose agar (26), S1 medium (6), one-tenth-strength tryptic-soy agar, and M3 medium (22), respectively. To enrich for *Bacillus* spp., the 10^{-3} and 10^{-4} dilutions were heated in a water bath at 80°C for 10 min before plating. All plates were incubated at ambient temperature (22 to 26°C) except yeast-glucose agar, which was placed at 46°C (26). All plates were incubated in the dark except Komada's agar, which was held under fluorescent lights with a 12-h photoperiod. Colonies of fluorescent *Pseudomonas* were counted 2 days after plating; *Fusarium,* thermotolerant fungi, and *Bacillus* were counted after 4 to 5 days; and actinomycetes were counted after 7 days.

Soils from fields D2 and B10 were collected as described above on 5 October and 15 November 1994 for nematode and soil nutrient assays, respectively. Numbers of plant parasitic nematodes and soil nutrient concentrations were determined by the Agricultural Services Laboratory, Clemson University.

Because watermelon was repeatedly cropped in certain plots, occurrence of

Fusarium wilt of watermelon was monitored with a seedling bioassay (7). Twenty 2.5-cm-diameter soil cores were collected from 0- to 15-cm depth in each subplot of the watermelon and cabbage-solarization treatments in field D2 in 1994 and 1995. The soil from each subplot was thoroughly mixed, passed through a sieve with 2-cm openings, mixed with quartz sand (3:1 vol/vol, soil:sand), and placed in two 10-cm-diameter pots. Watermelon cv. Black Diamond (also known as Florida Giant) was seeded, 10 seeds per pot. Pots were placed in a screenhouse where the temperature ranged from 22 to 30°C. Emerged seedlings were counted after 10 days. Seedlings were checked twice per week for symptoms of Fusarium wilt starting 2 weeks after planting. Wilted seedlings were removed and surface disinfested in 0.5% sodium hypochlorite, and two pieces cut from the hypocotyl were placed on Komada's agar. Plates were incubated at ambient temperature (22 to 26°C) and a 12-h photoperiod.

Statistical analysis. All data were averaged across the two subplots per plot before analysis. Horsfall-Barratt ratings of disease severity were transformed to percent leaf surface area diseased with the midpoints of the percentage ranges represented by each Horsfall-Barratt value. Area under the disease progress curve (AUDPC) was calculated from percent leaf area diseased with standard iterative techniques (24). AUDPC values, plant growth measurements, yield data, population densities of soil microbes and nematodes, and concentrations of soil nutrients were subjected to analysis of variance with PROC GLM of SAS (version 6.10, SAS Institute, Cary, NC). Preplanned, single-degree-of-freedom contrasts were calculated to compare treatments and microbial sampling dates. Pearson correlation coefficients were calculated for 1995 microbial population densities with watermelon growth and yield parameters.

RESULTS

Cropping sequences. Gummy stem blight was present in watermelon plots each year. In field D2 in 1992, gummy stem blight affected 23.8 ± 10.6% (standard error) of the foliage. Gummy stem blight was first detected on 2 June 1993 in a plot that had been cropped to wheat and soybeans during 1992. In 1994, gummy stem blight severity in the watermelon plots remained <6% for most of the season until vines collapsed rapidly after 29.8 cm of rain fell in June. May 1995 was dry, with only 38% (3.8 cm) of the 120-year average precipitation for the month. Even with supplemental irrigation, gummy stem blight developed slowly and did not affect more than 18.5% of the leaf surface area in any plot before the first harvest. In field D2, wilted plants with cankers on the stem at the soil surface were observed on 23 May 1995. Isolations from 12 plants yielded one isolate of *Rhizoctonia solani* from the wheat-soybean treatment and five and two isolates of *D. bryoniae* from the watermelon and cabbage-solarization treatments, respectively. In 1993 and in both fields in 1995, gummy stem blight began to develop 9 weeks after planting. At harvest, average disease severity did not differ among the three treatments in any experiment.

In 1993, mean AUDPC of the rotated treatments (cabbage-solarization and wheat-soybean) was significantly less than that of nonrotated watermelon (Table 1). When compared with 2 years of watermelon, the wheat-soybean rotation reduced gummy stem blight development more than the cabbage-solarization treatment, although the two rotated treatments did not differ when compared with each other. Total weight of watermelons harvested from solarized plots was greater than from nonsolarized plots (mean of watermelon and wheat-soybean). Yield of marketable fruit (those weighing >6.35 kg apiece) was significantly greater in the cabbage-solarization plots than in the wheat-soybean and the 2-year watermelon plots. For example, weight (kg per 15-m row) of no. 1 marketable watermelons was 70.7, 39.6, and 39.1 in the cabbage-solarization, watermelon, and wheat-soybean plots, respectively. Weight and number of all marketable melons were 78 and 82% greater in the cabbage-solarization treatment than in the nonsolarized treatments. These differences were due to an increase in the number and weight of small marketable melons (>6.35 but <8.2 kg) in the cabbage-solarization plots compared with the other two treatments (F significant at $P \leq 0.01$), whereas number and weight of medium and large melons did not differ among the three treatments (Fig. 1). Average weight of individual small melons, 7.1 ± 0.03 kg, was similar in all three treatments.

In the two experiments conducted in 1995, there was no treatment × cycle interaction ($P < 0.10$) for any of the three plant growth measurements. Averaged across the first and second rotation cycles, the number of direct-seeded watermelon plants that survived 6 weeks after planting was 36 and 26% greater in solarized plots than in watermelon and wheat-soybean plots, respectively (Table 2). Watermelon vines were an average of 19 and 33% longer in solarized plots than in wheat-soybean and watermelon plots 6 weeks after planting (increases of 19.6 and 31.1 cm, respectively). By 10 weeks after planting, significantly more fruit were set on vines in solarized plots than in plots cropped to watermelon during the preceding 2 and 4 years. Average fruit number from both experiments was 64% greater (an increase of 17 melons per 45 m) in solarized plots than in nonsolarized plots. Averaged across rotated plots in both experiments, plant stand, vine length, and fruit number were 22, 23, and 68% greater, respectively, than in nonrotated watermelon plots.

As in 1993, AUDPC in 1995 was significantly lower in the wheat-soybean

Table 1. Area under the disease progress curve (AUDPC) and yield of watermelon grown in 1993 in plots previously cropped in 1992 to wheat followed by soybean, cabbage followed by soil solarization, or watermelon

Treatment in 1992	AUDPC	Total wt (kg/15 m)	Marketable wt (kg/15 m)[a]	Marketable no. per 15 m[a]
Wheat-soybean	32.2	68.6	45.6	5.5
Watermelon	43.8	88.5	47.6	6.0
Cabbage-solarization	36.7	120.6	83.1	10.4
Mean nonsolarized[b]	38.0	78.6	46.6	5.7
Mean rotated[c]	34.4	94.6	64.3	7.9
Contrast				
Wheat-soybean vs. watermelon	0.012[d]	0.29	0.85	0.68
Cabbage-solariz. vs. watermelon	0.072	0.11	0.011	0.0097
Wheat-soybean vs. cabbage-solariz.	0.21	0.024	0.0090	0.0059
Nonsolarized vs. cabbage-solariz.	0.67	0.031	0.0053	0.0039
Rotated vs. watermelon	0.016	0.70	0.097	0.10

[a] Fruit weighing >6.35 kg apiece in USDA grades no. 1 and no. 2.

[b] Average of wheat-soybean and watermelon treatments of 1992.

[c] Average of wheat-soybean and cabbage-solarization treatments of 1992.

[d] Probability of a greater F value for the contrast between paired treatments.

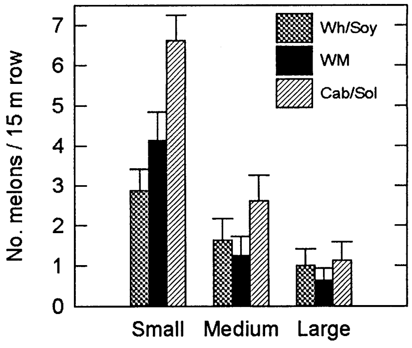

Fig. 1. Size distribution of marketable watermelons harvested in 1993: small, >6.35 kg but <8.2 kg; medium, ≥8.2 but ≤10 kg; and large, >10 kg. Plots were cropped in 1992 to wheat followed by soybean (Wh/Soy), watermelon (WM), or cabbage followed by solarization (Cab/Sol). Vertical bars give one standard error of the mean.

double-crop plots than in the continuous watermelon plots in the second-cycle experiment, although not in the first-cycle experiment (Table 3). AUDPC for nonrotated watermelon plots was 60% greater than the mean AUDPC for the rotated plots. In both experiments conducted in 1995, the total yield and the yield of fruit that reached marketable size (>6.35 kg) was less than that produced in 1993. Weight and number (data not shown) of marketable melons did not differ significantly among treatments. In the second-cycle experiment, total weight of ripe, healthy melons (all sizes harvested) was significantly greater in solarized plots (an increase of 80.5 kg) than in continuous watermelon plots. The weight of extra small melons (<6.35 kg) harvested from solarized plots was 75 and 50% greater than from the nonsolarized treatments in the first and second-cycle experiments, respectively. There were no differences among treatments in number or weight of small, medium, or large fruit sizes.

There was no interaction between year and treatment for yields of cv. Charleston Gray grown in field D2 in 1993 and field B10 in 1995, although yields were greater in 1993 than in 1995 (*F* significant at $P \leq 0.05$). For the two experiments, mean weights of total healthy, marketable, and marketable no. 1 fruit were significantly greater in the cabbage-solarization treatment than in the wheat-soybean (*F* significant at $P \leq 0.01$, 0.02, and 0.05, respectively) and the nonrotated watermelon treatments ($P \leq 0.025$, 0.01, and 0.02, respectively) (Fig. 2). Mean numbers of total, marketable, and marketable no. 1 fruit also were greater (*F* significant at $P \leq 0.04$, 0.01, and 0.02, respectively) in the solarized plots than in both nonsolarized treatments. Mean numbers of no. 1 marketable watermelons were 6.0, 3.5, and 3.7 melons per 15 m in the cabbage-solarization, watermelon, and wheat-soybean plots, respectively.

Soil assays. Soil temperatures measured weekly fluctuated greatly during the solarization period in 1992 and 1994. In 1992, mean weekly soil temperatures in solarized and nonsolarized plots were 36.8 and 36.4°C at 10 cm, respectively (*F* significant at $P = 0.09$), while temperatures at 20 cm averaged 31.9°C in both mulched and nonmulched plots. In 1994, mean weekly temperatures differed between fields, treatments, and depths (*F* values significant at $P \leq 0.01$), but no interactions were significant. Averaged across both fields, temperatures in solarized and nonsolarized plots were 37.1 and 36.4°C, respectively, at 10 cm, and 33.9 and 33.5°C, respectively, at 20 cm.

Population densities of selected soil microorganisms changed during solarization of soil amended with cabbage residue (Fig. 3). Thermotolerant fungi able to grow at

Table 2. Growth of watermelon planted in 1995 in plots previously cropped to wheat followed by soybean, cabbage followed by soil solarization, or watermelon in 1994 (first cycle) or 1992 and 1994 (second cycle)

	Plant stand (no./15 m)[a]			Vine length (cm)[a]			Fruit (no./45 m)[b]		
Treatment in 1994	First cycle	Second cycle	Mean[c]	First cycle	Second cycle	Mean[c]	First cycle	Second cycle	Mean[c]
Wheat-soybean	32.0	22.0	27.0	85.7	124.3	105.0	50.3	11.9	31.1
Watermelon	34.2	15.7	25.0	85.5	101.4	93.5	34.0	10.4	22.2
Cabbage-solarization	39.9	28.1	34.0	101.5	147.6	124.6	53.5	33.7	43.6
Mean nonsolarized[d]	33.1	18.9	26.0	85.6	112.9	99.3	24.1	11.1	26.6
Mean rotated[e]	35.9	25.1	30.5	93.6	136.0	114.8	51.9	22.8	37.3
Contrast									
Wheat-soybean vs. watermelon	0.65[f]	0.097	0.47	0.98	0.10	0.13	0.081	0.81	0.11
Cabbage-solarization vs. watermelon	0.27	0.0085	0.0052	0.11	0.0081	0.0007	0.045	0.0084	0.0011
Wheat-soybean vs. cabbage-solariz.	0.14	0.11	0.024	0.12	0.098	0.017	0.69	0.011	0.032
Nonsolarized vs. cabbage-solariz.	0.14	0.016	0.0045	0.077	0.015	0.0011	0.14	0.0055	0.0022
Rotated vs. watermelon	0.68	0.015	0.035	0.32	0.015	0.0042	0.037	0.056	0.0049

[a] Determined 6 weeks after planting.
[b] Counted 9 and 10 weeks after planting for the first-cycle and second-cycle experiments, respectively.
[c] Treatment by cycle interaction was not significant ($P < 0.10$).
[d] Average of wheat-soybean and watermelon treatments of 1994.
[e] Average of wheat-soybean and cabbage-solarization treatments of 1994.
[f] Probability of a greater *F* value for the contrast between paired treatments.

Table 3. Area under the disease progress curve (AUDPC) and yield of healthy watermelon fruit in 1995 in plots previously cropped to wheat followed by soybean, cabbage followed by soil solarization, or watermelon in 1994 (first cycle) or 1992 and 1994 (second cycle)

	AUDPC		Total wt (kg/45 m)		Marketable wt (kg/45 m)[a]		Extra small wt (kg/45 m)[b]	
Treatment in 1994	First cycle	Second cycle	First cycle	Second cycle	First cycle	Second cycle	First cycle	Second cycle
Wheat-soybean	62.7	20.4	161.8	145.7	99.7	50.1	62.1	95.7
Watermelon	39.8	33.7	126.4	107.3	69.8	21.8	56.6	85.5
Cabbage-solarization	49.2	21.8	211.0	187.8	107.1	52.2	104.0	135.6
Mean nonsolarized[c]	51.3	27.1	144.1	126.5	84.7	35.9	59.3	90.6
Mean rotated[d]	55.9	21.1	186.4	166.7	103.4	51.1	83.0	115.7
Contrast								
Wheat-soybean vs. watermelon	0.53[e]	0.040	0.50	0.17	0.44	0.21	0.74	0.51
Cabbage-solarization vs. watermelon	0.36	0.058	0.13	0.017	0.34	0.18	0.024	0.013
Wheat-soybean vs. cabbage-solarization	0.21	0.80	0.35	0.14	0.84	0.92	0.038	0.033
Nonsolarized vs. cabbage-solarization	0.81	0.28	0.16	0.028	0.50	0.38	0.017	0.011
Rotated vs. watermelon	0.098	0.029	0.20	0.032	0.32	0.14	0.10	0.053

[a] Fruit weighing >6.35 kg apiece in USDA grades no. 1 and no. 2.
[b] Fruit weighing <6.35 kg apiece.
[c] Average of wheat-soybean and watermelon treatments of 1994.
[d] Average of wheat-soybean and cabbage-solarization treatments of 1994.
[e] Probability of a greater *F* value for the contrast between paired treatments.

46°C, a majority of which were *Penicillium* spp., were more numerous at the end of the solarization period (October 1994) than before solarization (June 1994) (*F* significant at $P \leq 0.002$), but declined in these plots between October 1994 and May 1995 (Fig. 3A and B). Population densities were higher in solarized soil than in nonsolarized watermelon plots both immediately after solarization in October 1994 and again in May 1995 ($P \leq 0.01$). Thermotolerant fungi were more abundant at all three sampling times in the second-cycle field (Fig. 3B) than in the first-cycle field (Fig. 3A) ($P \leq 0.0001$). Fluorescent *Pseudomonas* spp. were not detected in solarized soil, although they were present in the plots before solarization and in nonsolarized watermelon plots sampled at the end of the solarization period (Fig. 3C). Numbers of actinomycetes, primarily *Streptomyces* spp., were not affected by solarization or by crop (Fig. 3D). Although population density of *Bacillus* spp. increased in solarized soil, it did not differ from that in nonsolarized soil in watermelon plots sampled at the same time (Fig. 3E). The population density of *Fusarium* spp. was lower after solarization than before solarization ($P \leq 0.0001$) and lower in solarized plots than in nonsolarized watermelon plots in October 1994 ($P \leq 0.01$) (Fig. 3F). In 1995, *Fusarium* spp. were more abundant in plots cropped to wheat and soybean than in plots cropped to watermelon or cabbage followed by solarization in 1994 ($P \leq 0.01$). Counts of thermotolerant fungi recovered in May 1995 were correlated positively with runner length ($r = 0.70$, $P = 0.0025$), whereas counts of actinomycetes were correlated negatively with the total number of fruit harvested ($r = -0.61$, $P = 0.012$). No other correlations between microbial counts and watermelon growth and yield were significant ($P \leq 0.01$).

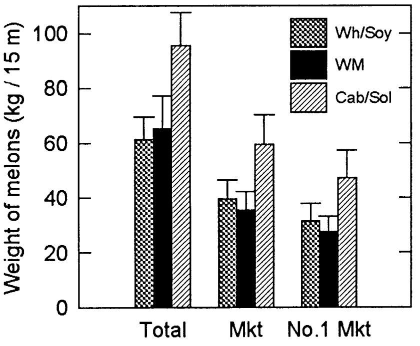

Fig. 2. Mean weight (kg/15 m row) of total, marketable, and marketable no. 1 healthy watermelon fruit harvested in 1993 and 1995 in plots previously cropped to wheat followed by soybean (Wh/Soy), watermelon (WM), or cabbage followed by solarization (Cab/Sol). Marketable melons weighed >6.35 kg apiece; total melons were all ripe, healthy watermelons harvested, regardless of size. Vertical bars give one standard error of the mean.

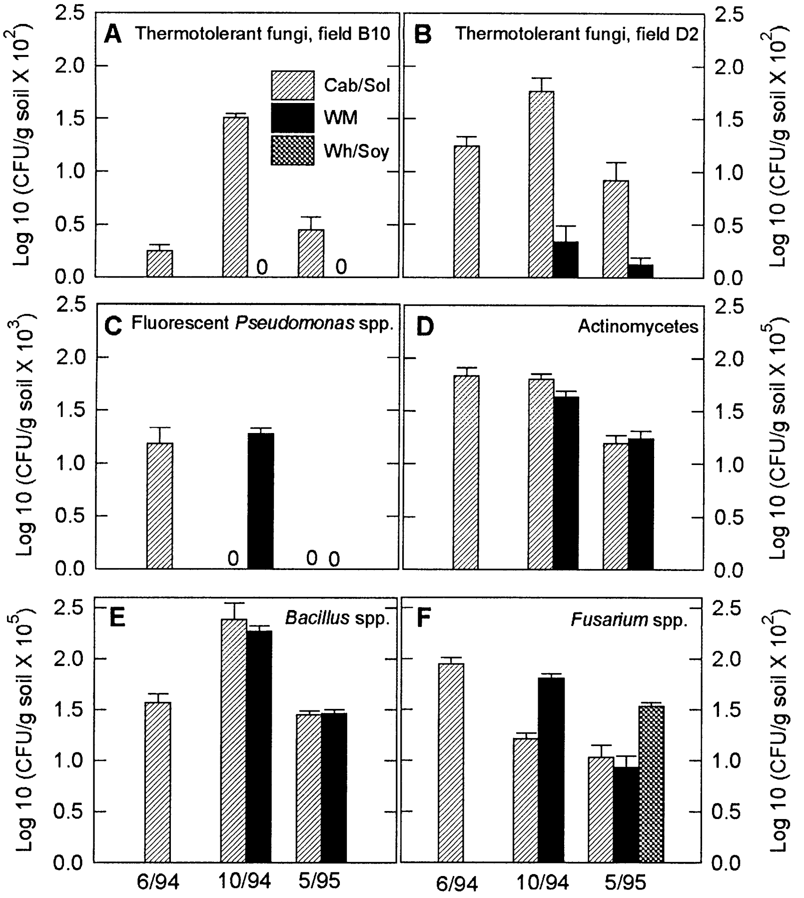

Fig. 3. Population densities of microorganisms recovered from soil cropped in 1994 to cabbage followed by solarization (Cab/Sol), watermelon (WM), or wheat followed by soybean (Wh/Soy) (*Fusarium* spp. only). **(A)** Thermotolerant fungi from field B10 (first cycle), **(B)** thermotolerant fungi from field D2 (second cycle), and **(C)** fluorescent *Pseudomonas* spp., **(D)** actinomycetes, **(E)** *Bacillus* spp., and **(F)** *Fusarium* spp. averaged over both fields. Soil was sampled after cabbage residue was incorporated into the soil but before solarization began (6/94), after solarization (10/94), and 7 weeks after all plots had been planted to watermelon the following year (5/95). Vertical bars give one standard error of the mean.

Populations of plant parasitic nematodes (sum of root-knot [*Meloidogyne* spp.], sting [*Belonolaimus* spp.], and stubby root [*Paratrichodorus* spp.] nematodes) did not differ among treatments. Mean population density in October 1994 was 11.7 ± 1.5 per 100 cm^3 of soil. Soil pH and the concentration of NO_3, P, K, Ca, and Mg in soil samples collected in the fall of 1994 did not differ among the treatments in either field. Concentrations of Zn were significantly higher in the cabbage-solarization plots (6.9 μ/g) than in the other two treatments in field D2, but not field B10. The concentration of Mn was highest in the wheat-soybean plots in both D2 (20.75 μg/g) and B10 (11.75 μg/g). Emergence of Black Diamond watermelon seedlings was slightly greater ($P < 0.10$) in soil samples collected from cabbage-solarization plots (75%) than from plots cropped yearly to watermelon (61%). There was no difference between treatments in the number of seedlings that wilted due to infection by *F. oxysporum*.

DISCUSSION

Although previous research has shown that 2 years without cucurbits is necessary to reduce gummy stem blight appreciably (25), small but significant reductions were observed in this study after 1 year without watermelon. Both rotated treatments reduced gummy stem blight development over the entire season, but the wheat-soybean double-crop was more effective than the cabbage-solarization treatment. Since many watermelon growers in the southeastern United States also produce agronomic crops, this rotation sequence may be useful as part of an integrated gummy stem blight management program. It is not clear why the wheat-soybean rotation did not reduce gummy stem blight development in the first-cycle experiment conducted in 1995. The wheat-soybean treatment did not appear to delay disease onset or the rate of disease increase. The epidemiological effect of this treatment may have been more apparent with higher levels of disease, as gummy stem blight was not severe enough in these experiments to reduce yields significantly (12).

Solarization combined with cabbage residue had a greater stimulatory effect on watermelon growth and yield than did rotation with double-cropped wheat and soybean. Plant survival, vine length, fruit set, and weight and number of harvested melons did not differ in plots cropped to wheat and soybean the previous year from that in plots cropped each year to watermelon, but were increased substantially by the cabbage-solarization treatment. Vines in the cabbage-solarization plots remained productive longer than in the other two treatments, based on the increase in the number of small or extra small melons. Growth stimulation of cabbage after cruciferous amendments plus solarization has been documented previously (20), but the current study is the first report of growth and yield stimulation in watermelon after solarization combined with cabbage residue. In Spain, solarization without organic amendments in greenhouses increased plant dry weight and yield of watermelon fruit compared with nonsolarized soil infested with *Fusarium oxysporum* f. sp. *niveum* (9). The slight differences in Mn and Zn concentrations detected in the rotated treatments in the current study were within the sufficiency ranges for watermelon. Since cabbage residue and solarization did not affect soil nutrient levels, the increased yield response is more likely explained by biological changes in the soil, such as increases in microbes beneficial to plant growth (10). In a previous study, fluorescent *Pseudomonas* spp. isolated from rhizospheres or roots of plants grown in solarized soils stimulated shoot growth when inoculated onto tomato seedlings (4). It is also possible that the plant stand and yield increases in the cabbage-solarization plots were partially due to control of *Pythium* (5) or unidentified minor root pathogens (4).

Although soil temperatures differed only slightly between mulched and nonmulched plots, populations of soil microorganisms in the mulched plots generally responded as previously reported for solarized soils (1,13,21,26). Diurnal temperature differences between mulched and nonmulched plots likely were greater than those recorded with weekly measurements. The heat-sensitive organisms monitored, *Fusarium* and fluorescent *Pseudomonas*, decreased in solarized soil, whereas heat-tolerant prokaryotes, such as *Bacillus* and actinomycetes, did not change. However, population densities of thermotolerant fungi not only increased significantly in solarized soil, but 8.5 months after solarization was ended, were still more numerous in solarized soil than in soil that had never been solarized. In a previous study, *Penicillium* and *Aspergillus* spp. increased in nonheated soil amended with cabbage residue, recovery of *F. o.* f. sp. *conglutinans* decreased, and actinomycetes were not affected (20). It is probable that changes in *Fusarium* spp. and thermotolerant fungi in the current study resulted from the combined effects of volatiles from the decomposing cabbage residue and soil heating. Whether *Penicillium* spp. and other thermotolerant fungi have a direct beneficial effect on watermelon yield has not been determined, although they were associated with increased vine growth in 1995.

Increases in number and weight of harvested watermelons occurred primarily with small melons or melons sometimes considered too small (<6.35 kg) to market. The beneficial effect of solarization with cabbage residue would have been greater if these additional melons had reached a larger size before ripening (29). Although polyethylene mulch is being used more extensively by watermelon growers in the southeastern United States to increase yields, mulch was not used in these studies in order to increase exposure of watermelon plants to soilborne inoculum of *D. bryoniae*. Additional research is needed to determine how solarization with cruciferous residues can be combined with polyethylene mulch to optimize yield of watermelon in a sustainable system.

Polyethylene mulch was left on the beds until early October to maximize the heating period, based on previous knowledge of typical soil temperatures in the southeastern United States (1,13,21). However, it may be possible to reduce the length of time the mulch remains in place and not affect the growth and yield stimulation. Reducing the mulching period would allow growers to crop the land during the fall planting season. In another study, *F. o.* f. sp. *conglutinans* was essentially eliminated from soil amended with cabbage residue and heated for 15 days; lengthening the heating period to 30 and 45 days had no effect (20). Because temperatures increased only slightly under clear polyethylene, it may be possible to use black polyethylene mulch to trap volatiles from decomposing cruciferous residue. Black polyethylene is less expensive than clear and could be used to mulch a subsequent fall crop. Another approach would be to use a *Brassica* species, such as *B. nigra* or *B. juncea,* that produces allyl-isothiocyanate without heating in concentrations that are fungicidal to fungal plant pathogens (17).

In 1995, there was no treatment by cycle interaction for any plant growth or yield data. Differences among treatments were more pronounced in the second-cycle experiment than in the first-cycle experiment, which indicates that changes in the soil due to the previous crop may not have been completely negated in the subsequent year or years. However, beneficial effects on yield were consistently apparent after only 1 year of cabbage followed by solarization with the cabbage residue. Growers may benefit economically from this cropping sequence, particularly if the spring cabbage crop can be marketed profitably to help offset the cost of the polyethylene mulch for solarization (29). The wheat-soybean double-crop and cabbage followed by solarization could be used in sequence during a 2-year rotation away from watermelon to optimize both the gummy stem blight reduction and the yield increase observed when these two treatments were applied separately.

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