EFFECTS OF PLASTIC MULCHES ON GROWTH AND YIELD OF CUCUMBER (*CUCUMIS SATIVUS* L.) AND ON NEMATODE AND MICROBIAL POPULATION DENSITIES IN THE SOIL

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ABSTRACT

Coates-Beckford, P. L., J. E. Cohen, L. R. Ogle, C. H. Prendergast, and D. M. Riley. 1997. Effect of plastic mulches on growth and yield of cucumber (*Cucumis sativus* L.) and on nematode and microbial population densities in the soil. Nematropica 27:191-207.

The growth and yield of three crops of cucumber and rhizosphere populations of soil nematodes were monitored in an experiment conducted on sandy loam soil which was (a) mulched with 0.4-mm-thick, clear or black plastic for five or nine weeks, (b) mulched then fertilized with 1 kg N:P:K (4:16:4)/plot, (c) not mulched and treated with 45 g Banrot 40WP/plot or 10 or 20 g Furadan 10G/plot at planting, (d) not mulched, but fertilized, (e) not mulched and not fertilized. In a second experiment, plots were mulched for four, six and eight weeks with clear or black plastic or not mulched. Ambient and soil temperatures were monitored during the mulching periods. Cucumber seedlings in the fertilized or nonfertilized plots which were mulched with either color of plastic often grew faster than those in the nonmulched plots. Plants from plots treated with fungicide or nematicide either had shoots which were shorter or of the same lengths as those from the nontreated plots. Plants from nonfertilized plots mulched for four or more weeks with clear plastic yielded more than the controls in Experiment 2; whereas, with black plastic, only plots mulched for six or eight weeks yielded more than the controls. Population densities of fungi in soil mulched with clear plastic were lower than those in nontreated soil, but those of bacteria were similar. Phytoparasitic and nonparasitic nematode population densities were reduced by the nematicide and by mulching with either color of plastic, but sometimes rose to the initial levels by the time of harvest. Plastic mulching significantly controlled weed growth but many of the monocotyledonous plants in the field grew in soil under the clear plastic.

Key words: cucumber, fertilizer, fungicide, *Helicotylenchus erythrinae*, microbial population densities, nematicide, nonparasitic nematodes, plastic mulch, *Rotylenchulus reniformis*, soil solarization, temperature, weeds.

RESUMEN

Coates-Beckford, P. L., J. E. Cohen, L. R. Ogle, C. H. Prendergast y D. M. Riley. 1997. Efecto de cobertoras plásticas en el crecimiento y rendimiento del pepino (*Cucumis sativus* L.) y en las densidades de los nematodos y de las poblaciones microbianas de suelo. Nematropica 27:191-207.

El crecimiento y rendimiento de tres cultivos de pepino y de las poblaciones de nematodos en la rizofera, fueron monitoreados en un experimento conducido en suelo arena - limo, el que fue; (a) acolchado con plástico claro o negro de 0.4 mm de espesor durante cinco o nueve semanas, (b) cubierto y luego fertilizado con 1kg N:P:K (4:16:4)/parcela, o (c) sin acolchar y tratado con 45g de Banrot 40WP/parcela o 10 ó 20g de Furadan 10g/parcela al momento del plantío, (d) sin acolchar y fertilizado, o (e) sin acolchar y no fertilizado. En un segundo experimento, las parcelas fueron acolchadas por cuatro, seis, y ocho semanas con plástico claro o negro o no se acolcharon. Las temperaturas del ambiente y del suelo también fueron monitoreadas durante los periodos del recubrimiento. Las plantulas de pepino en las parcelas fertilizadas o no, que fueron cubiertas con plástico de cualquier color, con frecuencia crecieron más rápido que aquellas en las parcelas no cubiertas. Las plantas de las parcelas tratadas con fungicida o nematicida mostraron ramas más pequeñas o del mismo largo que aquellas en las parcelas no tratadas. Las plantas de las parcelas no fertilizadas, pero acolchadas durante cuatro o más semanas con plástico claro, rindieron más que los controles en el experimento 2, mientras que solamente las parcelas tratadas con plástico negro por seis u ocho semanas rindieron más que los controles. Las poblaciones de hongos en el suelo cubierto con plástico claro, fueron menores que aquellas en suelo no tratado, pero las poblaciones de bacterias fueron similares para ambos casos. Las densidades de las poblaciones de nematodos no parasíticos y fitoparasíticos fueron reducidas por el nematicida y por los acolchados con plástico de cualquier color, pero a veces subieron a los niveles iniciales en el tiempo de cosecha. Los acolchados, controlaron significativamente el crecimiento de las malezas, pero muchas de las plantas monocotiledóneas presentes en el campo, crecieron debajo del plástico claro.

Palabras claves: cubierta plástica, densidad de poblaciones microbianas, fertilizante, fungicida, *Helicotylenchus erythrinae*, malezas, nematicida, nematodos no-parásitos, pepino, *Rotylenchulus reniformis*, solarización del suelo, temperatura.

INTRODUCTION

Soil solarization, a process in which there is solar heating of soil wetted to field capacity and covered with clear plastic, has resulted in improved crop growth and control of soil-borne pests and pathogens under various conditions (Katan, 1981). The decade following the first description of this hydrothermal process (Katan *et al.*, 1976), which not only disinfests soil but also increases soil fertility, has seen several reports of its effectiveness, which are documented in a bibliography by Katan *et al.* (1987). In the subsequent decade, trials have continued to test the efficacy both on annual crops (Abdel-Rahim *et al.*, 1988; Keinath, 1995; Martyn and Hartz, 1986; Ristaino *et al.*, 1991; Sharma and Nene, 1990) and on perennial plants (Coates-Beckford and Pereira, 1994; Duncan *et al.*, 1992; Sztejnberg *et al.*, 1987; Tjamos *et al.*, 1991). There are also reports of the control of pathogenic bacteria (Chellemi *et al.*, 1994), fungi (Barbercheck and Broembsen, 1986; Chellemi *et al.*, 1994; Juarez-Palacios *et al.*, 1991; Keinath, 1995; Lopez-Herrera and Verdu-Valiente, 1994; Martyn and Hartz, 1986; Morgan *et al.*, 1991; Ramirez-Villapudua and Munnecke, 1987; Ristaino *et al.*, 1991; Sztejnberg *et al.*, 1987), and nematodes (Abdel-Rahim *et al.*, 1988; Barbercheck and Von Broembsen, 1986; Chellemi *et al.*, 1993; Coates-Beckford and Pereira, 1994; Duncan *et al.*, 1992; Heald and Robinson, 1987; Sharma and Nene, 1990), sometimes with subsequent yield increases.

In Jamaica, Coates-Beckford and Pereira (1994) successfully utilized solar heating of soil to halt a slow decline and increase the vigor of breadfruit trees (*Artocarpus altilis* [Parkinson] Fosberg) and to reduce the root and rhizosphere soil population densities of *Pratylenchus* spp. and soil population densities of *Helicotylenchus* spp.

The objectives of this study were to evaluate the effects of solarization and black plastic mulch on the growth of cucumber (*Cucumis sativus* L.) and the population densities of nematodes, fungi and bacteria in soil fertilized as recommended, or not fertilized, as practiced by many subsistence farmers in Jamaica.

MATERIALS AND METHODS

Experiment 1: An experiment was conducted in which three consecutive crops of cucumbers were grown to compare the effects of plastic mulches with other soil treatments on plant growth and yield, and on population densities in soil of nematodes and other microorganisms. The trial was conducted on Maverly sandy loam in the research field adjacent to the plant pathology laboratory of the University of the West Indies, Mona Campus, a location known to contain nematodes pathogenic to cucumbers, and where poor growth of young cucumber plants had been observed.

The land was plowed and rotovated, and then ten rows, each with four, 4 m × 4.5 m plots, were measured to leave 1 m between each row and 0.75 m between each plot. Five sets of two adjacent rows constituted five blocks, each with eight plots. The plots were tilled immediately before growing the second and third crops.

The soil treatments were: (a) mulching with clear or black plastic sheeting; (b) mulching with each color of plastic followed by fertilization with 1 kg N:P:K (4:16:4)/plot; (c) application of 45 g Banrot 40WP (terrazole + thiophanate-methyl) per plot for controlling any root-pathogenic fungi present; (d) application of 20 g Furadan 10G (carbofuran) per plot to control the root-pathogenic nematodes; (e) neither mulching nor fertilizing, or not mulching but fertilizing at the above-mentioned rate to provide controls for the nonfertilized and fertilized treatments, respectively. For Crop 3, the nematicide application rate was reduced to 10 g/plot.

Mulching of soil commenced on July 31, 1995, December 4, 1995 and August 8, 1996 and proceeded for five, five and nine weeks for the first, second and third crops, respectively. Plots selected for mulching were watered thoroughly. Then 0.4-mm-thick plastic sheeting was laid on the surface of the tilled soil and kept in position by covering the edges with soil until the time of planting, at which time the sheeting was removed.

The soil chemicals were applied over the entire area of the plot immediately after the mulching period, to coincide with the time of planting. The nematicide and fertilizer were incorporated into the top 2-cm layer of soil by tilling and the fungicide was applied by spraying the required amount on the soil surface in 10 L of water.

For Crop 1, the eight treatments were assigned randomly for each block. For Crops 2 and 3, the treatments were assigned randomly to the plots in one block and, for the remaining four blocks, assigned so that the history of the plots was the same in all five blocks.

Three cucumber cv. Poinsett seeds were sown approximately 30 cm apart in each of five furrows made 1 m apart in each plot and parallel to the short axis of the plot. When the seedlings were three weeks old, each furrow was thinned to leave 13, evenly-spaced seedlings.

Records were made of cucumber shoot lengths at various intervals during growth, shoot fresh weights at harvest, which was seven to eight weeks after planting, and fruit yield. Records also were made of the weeds occurring up to one month after mulching, and of the nematode, fungal, and bacterial soil population densities. Soil temperatures were monitored at depths of 5, 15 and 20 cm with the aid of soil cells connected to a SOILTEST MC-300 Series soil moisture-temperature meter (SOILTEST Inc., Illinois). The temperature was recorded each day at 3:30 p.m. during the mulching period, a time previously determined as having the maximum daily soil temperature. Rainfall, sunshine and ambient temperature data were obtained for the Mona area, where the University is located, from the Jamaican National Meteorological Service and the Physics Department of the University.

The experimental site was used to grow cucumber prior to trial initiation, left in weed fallow for five weeks between Crops 1 and 2, and grown to cowpeas (*Vigna unguiculata* L. cv. African Red) for 12 weeks between Crops 2 and 3.

In order to control weed growth, 1% Roundup (glyphosate) was sprayed on the entire field prior to mulching for Crop 1, and on the nonmulched plots on the same day that the plastic was laid for Crops 2 and 3. Subsequently, the plots were weeded manually. For controlling insects, 1% malathion was sprayed on all plants of Crops 2 and 3 at 10 and 14 days before harvesting, respectively, and 1% chlorpyrifos 2E was sprayed on all plants of Crop 3 at 10 days before harvesting.

Estimation of nematode soil population densities: Within each plot, approximately 200 cm^3 of soil was taken with a trowel from a depth of 2-20 cm from each of six, randomly-chosen spots before and after treating the soil and at harvest. For Crop 3, samples were taken after mulching, but before the application of fertilizer, fungicide and nematicide. At harvest, soil samples were taken randomly from the cucumber rhizosphere within the three central rows of plants, but excluding the plants at the ends of each row. On each occasion, the soil for each plot was combined and stored at 19°C in a plastic bag.

Within three to seven days of each sampling date, the composite sample for each plot was mixed gently and passed through a 4-mm-aperture sieve. The nematodes were extracted from duplicate 200-cm^3 subsamples of the sieved soil for 48 hr by the Baermann tray technique (Barker and Niblack, 1990). Each resulting nematode suspension was allowed to stand in a plastic tall-form container for 2 hr, the supernatant decanted, the remainder poured into a smaller tall-form glass, and the process repeated until the suspension was concentrated to less than 100 ml. The numbers of nematodes present in duplicate 1-ml aliquots of 100 ml of the concentrated suspension were recorded with the aid of the compound microscope and Peter's 1-ml counting slides.

Estimation of fungal and bacterial soil population densities: Fungal and bacterial soil population densities were estimated for Crop 1. Soil samples were taken immediately after the mulching period but before the addition of soil chemicals. Approximately 200 cm^3 of soil was collected from each plot in four, randomly-chosen blocks from a depth of 2-20 cm at three randomly-selected spots within each plot. The soil for each plot was combined and stored at 19°C in a plastic bag.

For each composite soil sample, a 10-g aliquot was placed in each of three Petri dishes and also in a sterile 50-ml beaker. The soil subsamples in the Petri dishes were dried to constant weight at 58°C for determination of the mean dry weight.

Working under aseptic conditions, 95 ml of sterile distilled water was added to the soil in the beaker and serial dilutions made of the resulting soil suspension to obtain dilutions of 10^{-5} and 10^{-6}. Then 1 ml of the 10^{-5} dilution was pipetted into 14 ml of acidified, molten 3.9% potato dextrose agar (PDA) contained in a Petri dish for each of three dishes. A 1-ml aliquot of the 10^{-6} dilution was transferred, similarly, to each of three 2.3% molten nutrient agar (NA) plates. Controls were set up by adding 1 ml of sterile distilled water to each of three PDA and NA plates. All mixtures were homogenized by gently swirling the plates clockwise and counterclockwise thrice on the laboratory bench immediately after addition of the soil suspension. The plates, which solidified within minutes, were incubated at 30°C. After three days, the numbers of fungal and bacterial colony-forming units (CFU) on each plate were counted. For each sample, estimates were made of the numbers of CFU in 10 g dry soil.

Experiment 2: A second experiment was set up adjacent to Experiment 1, in an area which was in weed fallow for more than six months, to evaluate the effects of the duration of plastic mulching of soil on cucumber yield. The seven treatments were replicated five times and were: (a) mulching of soil with clear or black plastic for four, six and eight weeks, commencing August 9, July 31, and July 17, 1996, respectively, and (b) no treatment, and were arranged in a randomized complete block design.

The land was prepared, the plots mulched, and the cucumber seeds sown as described for Experiment 1. Weeds were controlled by spraying 1% Roundup on the nonmulched plots on July 31 and August 9, 1996. All plots were weeded manually thereafter. Neither fertilizer nor insecticide was used in Experiment 2. Plant growth and temperature measurements were conducted as described for Experiment 1.

Data analysis: Analyses of variance were performed on all data and the Student's *t*, LSD, or Duncan's multiple range test used to compare the means (Steele and Torrie, 1960).

RESULTS

Climatic conditions: The amount of rainfall during the mulching periods was higher in August than in September and December (Table 1). There was a daily average of at least 7 hr of sunshine and the ambient temperature was high, even in the coolest month, December, 1995, which had a daily mean of 27.6°C (Table 1). The highest soil temperatures occurred under the clear plastic with mean maximum temperatures reaching 43.3°C and 41.7°C at depths of 5 cm and 15 cm, respectively, in August 1995, and 37.8°C at 20 cm in August, 1996 (Table 1). At each depth, the temperature in the soil under the black plastic was also higher than in the nonmulched plots.

Plant growth and yield - Experiment 1: In Crop 1, at three weeks after planting, plants from plots which were mulched with either color of plastic and fertilized or not fertilized had significantly longer vines than plants from their control plots, whereas plants from the fungicide- and nematicide-treated plots had significantly shorter shoots (Table 2). There was no difference between treated and control plots in yield. In Crop 2, no differences occurred between treated and control plots in shoot lengths, fresh shoot weights at harvest and fruit weights.

In Crop 3, plants from plots which were mulched with clear plastic and either fertilized or not fertilized had significantly longer vines than plants from the control plots after three weeks of growth and at harvest (Table 2). Shoots from plots mulched with black plastic and fertilized were significantly longer than their controls after three weeks of growth. At harvest, shoots from the fungicide-treated plots were significantly shorter than their controls. The fresh weights of shoots from plots mulched with either color of plastic and fertilized were greater than those from nonmulched, fertilized plots. Unusually heavy rainfall and cold weather for three days at the time of flowering resulted in the loss of flowers and the rotting of young fruit and leaves by bacteria. Therefore, yield data for Crop 3 were not available.

Plant growth and yield - Experiment 2: Plants from all the plastic-mulched plots had shoots significantly longer than those from the control plots at three and four weeks after planting (Table 3). The only plots in which fruit numbers and weights were not significantly greater than the control values were those mulched for four weeks with black plastic. There was a

Table 1. Total monthly rainfall, mean daily number of sunshine hours, mean daily, maximum and minimum ambient temperatures, and mean temperatures at 3:30 p.m. at three depths in soil mulched with clear or black plastic or not mulched, during the mulching periods in 1995 and 1996.

					Temperature (°C)									
						Soil								
						No mulch			Clear mulch			Black mulch		
Year	Month	Rainfall (mm)	Sunshine (hr)		Ambient	5 (cm)	15 (cm)	20 (cm)	5 (cm)	15 (cm)	20 (cm)	5 (cm)	15 (cm)	20 (cm)
1995	August	101	7.1	Daily	28.2	30.0	29.2	28.3	36.8	37.1	33.9	36.1	32.1	32.2
				Maximum	31.3	34.4	32.7	30.0	43.3	41.7	35.0	39.4	35.6	34.4
				Minimum	25.1	27.8	26.7	26.1	28.9	28.3	30.0	31.1	28.9	30.0
1995	December	35	8.4	Daily	27.6	—	—	—	—	—	—	—	—	—
				Maximum	32.0	—	—	—	—	—	—	—	—	—
				Minimum	23.1	—	—	—	—	—	—	—	—	—
1996	August	130	7.9	Daily	28.6	30.0	29.4	27.5	36.8	36.4	34.4	35.9	35.0	34.4
				Maximum	32.3	34.4	31.7	30.0	41.1	40.0	37.8	40.0	38.9	37.2
				Minimum	24.9	27.2	27.2	25.6	28.9	31.1	30.0	27.8	30.6	30.6
1996	September	39	7.1	Daily	29.6	25.2	24.8	23.1	26.6	24.9	24.9	27.3	25.9	30.1
				Maximum	33.4	28.9	26.7	24.4	28.9	27.8	27.8	30.0	28.9	28.9
				Minimum	25.8	21.1	21.1	21.1	24.4	23.3	23.3	23.3	22.8	21.7

Table 2. Mean shoot lengths at various intervals after planting, fresh weights of shoots at harvest, and yield from plots mulched with clear or black plastic or not mulched, treated with fertilizer, fungicide, or nematicide, or not treated, for three crops of cucumbers in Experiment 1.

Treatment[w]	Shoot length (cm)[x]		Shoot fresh weight (g)[x]	Fruit yield (kg/plot)[x]
	3 weeks	7-8 weeks		
	CROP 1[y]			
No mulch, - fertilizer	2.6[z]	—	—	0.24
No mulch, + fertilizer	3.1	—	—	0.53
Clear mulch, - fertilizer	6.5**	—	—	0.40
Clear mulch, +fertilizer	7.4**	—	—	0.67
Black mulch, - fertilizer	3.9**	—	—	0.28
Black mulch, + fertilizer	4.5**	—	—	0.78
Fungicide, - fertilizer	0.8**	—	—	0.39
Nematicide, - fertilizer	0.9**	—	—	0.14
	CROP 2[y]			
No mulch, - fertilizer	—	82	401	0.33
No mulch, + fertilizer	—	101	552	0.47
Clear mulch, - fertilizer	—	77	362	0.35
Clear mulch, +fertilizer	—	117	586	1.37
Black mulch, - fertilizer	—	98	435	0.72
Black mulch, + fertilizer	—	109	629	1.75
Fungicide, - fertilizer	—	81	431	0.40
Nematicide, - fertilizer	—	76	290	0.23
	CROP 3[y]			
No mulch, - fertilizer	17.5	72	540	—
No mulch, + fertilizer	35.5	82	723	—
Clear mulch, - fertilizer	27.1**	91*	731	—
Clear mulch, +fertilizer	44.3**	101**	1096**	—

[w]Fertilizer rate = 1 kg N:P:K (4:16:4)/plot; Fungicide rate = 45 g Banrot 40WP/plot; Nematicide rate = 20 g Furadan 10G/plot for Crops 1 and 2, and 10g/plot for Crop 3. Soil chemicals were applied throughout the plots (4 m × 4.5 m) at planting.

[x]For each plot, mean shoot lengths and weights were estimated from 10 of the central 33 plants and yield from all 33 plants.

[y]Mulching commenced July 31 and December 4, 1995 and August 8, 1996 and continued for five, five and nine weeks for Crops 1, 2, and 3, respectively.

[z]Each figure is the mean of five observations.

*,** = Significantly different from either the nonmulched and nonfertilized or the nonmulched and fertilized control at $P = 0.05$ and $P = 0.01$, respectively, by Student's t test.

Table 2. (Continued) Mean shoot lengths at various intervals after planting, fresh weights of shoots at harvest, and yield from plots mulched with clear or black plastic or not mulched, treated with fertilizer, fungicide, or nematicide, or not treated, for three crops of cucumbers in Experiment 1.

Treatment[w]	Shoot length (cm)[x]		Shoot fresh weight (g)[x]	Fruit yield (kg/plot)[x]
	3 weeks	7-8 weeks		
Black mulch, - fertilizer	22.8[y]	77	660	—
Black mulch, + fertilizer	49.0**	105	1208**	—
Fungicide, - fertilizer	15.7	55**	309	—
Nematicide, - fertilizer	17.3	68	377	—

[w]Fertilizer rate = 1 kg N:P:K (4:16:4)/plot; Fungicide rate = 45 g Banrot 40WP/plot; Nematicide rate = 20 g Furadan 10G/plot for Crops 1 and 2, and 10g/plot for Crop 3. Soil chemicals were applied throughout the plots (4 m × 4.5 m) at planting.

[x]For each plot, mean shoot lengths and weights were estimated from 10 of the central 33 plants and yield from all 33 plants.

[y]Mulching commenced July 31 and December 4, 1995 and August 8, 1996 and continued for five, five and nine weeks for Crops 1, 2, and 3, respectively.

[z]Each figure is the mean of five observations.

*,** = Significantly different from either the nonmulched and nonfertilized or the nonmulched and fertilized control at $P = 0.05$ and $P = 0.01$, respectively, by Student's t test.

higher percentage of well-shaped fruits harvested from all the mulched plots than from the control plots.

Nematode population densities: The most frequently-occurring phytopathogenic nematode species were *Helicotylenchus erythrinae* (Zimmermann) Golden and *Rotylenchulus reniformis* Linford and Oliveira. Also recovered in lower numbers were *Macroposthonia* sp., *Pratylenchus coffeae* (Zimmermann) Filipjev & Schuurmans Stekhoven, and *Tylenchorhynchus* sp.

In Crop 1, population densities of *H. erythrinae*, *R. reniformis*, and total parasites were lower than those of the control plots after treatment of plots with clear and black plastic mulches, clear plastic mulch and fertilizer, and nematicide (Table 4). Plots treated with other treatments had population densities similar to those of the controls after treatment of soil. Nonparasitic population densities decreased significantly in plots treated with clear plastic mulch and fertilizer, black plastic mulch, and nematicide (Table 4). At harvest, the population densities of the phytoparasitic nematodes in several of the treated plots remained significantly lower than those in the control plots, but those of the nonparasites did not differ among treatments (Table 4).

In Crop 2, the population densities of *H. erythrinae* were lower than those of the control plots after treatment with either clear or black plastic mulch and fertilizer, and with nematicide. Those of total parasites were less than control densities only in plots mulched with clear plastic and fertilized. Population densities of *R. reniformis* and nonparasites were similar in treated and control plots. At harvest, the only differences in population densities between treatments was exhibited by total parasites, and they were higher in plots mulched with clear plastic and fertilized than in control plots.

Table 3. Mean shoot lengths at various intervals after planting, number of fruit, percentage of well-shaped fruit, and yield for plants from nonfertilized plots mulched for various periods with clear or black plastic sheeting, or not mulched in Experiment 2.

Treatment[z]	Duration of mulching (weeks)[x]	Shoot length (cm)[y]		No. of fruit/ plot[y]	Well-shaped fruit/plot (%)[y]	Fruit yield (kg/plot)[y]
		3 weeks	4 weeks			
No mulch	—	13.1 a[z]	57.5 a	41 a	72 a	7.95 a
Clear mulch	4	16.6 cd	75.1 b	69 c	90 b	13.30 bc
Clear mulch	6	16.3 cd	86.8 b	58 bc	81 b	12.59 bc
Clear mulch	8	16.8 d	84.8 b	71 c	83 b	14.43 c
Black mulch	4	15.2 bc	76.8 b	48 ab	90 b	9.88 ab
Black mulch	6	15.9 bcd	83.0 b	69 c	92 b	14.68 c
Black mulch	8	16.0 b	86.1 b	63 bc	91 b	13.50 bc

[x]Mulching commenced August 9, July 31, and July 17, 1996 for the four-, six- and eight-week mulching periods, respectively.
[y]For each plot (4 m × 4.5 m), mean shoot lengths were obtained from 10 of the central 33 plants and yield from all 33 plants.
[z]Each figure is the mean of five observations. Figures in each column followed by the same letter are not significantly different, according to Duncan's Multiple Range Test.

In Crop 3, the population densities of *H. erythrinae*, total parasites, and nonparasites, but not of *R. reniformis*, were less in the mulched plots than in the controls after mulching of soil (Table 4). Population densities of *H. erythrinae* in plots to be treated with fungicide and nematicide also were less than control densities. At harvest, the population densities of nonparasites in plots mulched with clear or black plastic and those mulched with clear plastic and fertilized were less than those of the controls.

Fungal and bacterial populations: The number of fungal CFU/10 g dry soil was significantly lower in soil mulched with clear plastic than in nonmulched soil (Table 5). There were no differences in fungal population densities between the control plots and those mulched with black plastic, nor in the number of bacterial CFU amongst the three treatments.

Weeds: At the end of the mulching period, no weeds were present in plots mulched with black plastic and the plots remained free of weeds for at least one month subsequently. One dicotyledonous and seven monocotyledonous plants grew in plots mulched with clear plastic. Nine monocotyledonous species as well as 23 dicotyledonous species occurred in control plots (Table 6).

DISCUSSION

Plastic mulching of soil promoted early growth of cucumber plants, as noted also for nursery trees by Stapleton and De Vay (1985), perhaps due to nematode control, increased water conservation in soil, and increased soil fertility (Katan *et al.*, 1987). In contrast, rates of the fungicide and nematicide tested appeared to be phytotoxic in the hotter months, because there was retardation of the growth of plants in plots treated with these chemicals in Crop 1 and in the fungicide-treated plots in Crop 3

Table 4. Mean number of nematodes in 100 cm^3 rhizosphere soil before and after mulching plots with clear or black plastic and treating with fertilizer, fungicide, or nematicide, or not treating, and at harvest for three crops of cucumbers in Experiment 1.

Nematode	Time of Sampling	Number of nematodes: No mulch - Fert	No mulch + Fert[x]	Clear mulch - Fert[y]	Clear mulch + Fert[x,y]	Black mulch - Fert[y]	Black mulch + Fert[x,y]	Fungicide - Fert[x]	Nematicide - Fert[x]
CROP 1									
Helicotylenchus erythrinae	Before	16[z]	10	14	14	48*	22*	48*	18
	After	52	20	13*	6*	20*	16	62	12**
	At harvest	97	52	70	36	57**	62	122	38**
Rotylenchulus reniformis	Before	14	36	44*	32	60**	126*	138**	43
	After	58	48	8**	11**	15**	84	74	18**
	At harvest	81	46	36*	51	29*	90	127	32*
Total parasites	Before	36	54	64	56	108**	148*	189**	62*
	After	116	68	25*	17**	35*	100	136	30*
	At harvest	185	98	105*	87	86*	152	249	70**
Nonparasites	Before	92	118	104	153	105	179	102	126
	After	147	148	220	60*	49*	117	106	80*
	At harvest	71	145	261	170	171	145	237	107
CROP 2									
Helicotylenchus erythrinae	Before	36	97	57**	62*	70	38**	52	122*

[x]Fertilizer rate = 1 kg N:P:K (4:16:4)/plot; Fungicide rate = 45 g Banrot 40WP/plot; Nematicide rate = 20 g Furadan 10G/plot for Crops 1 and 2, and 10 g/plot for Crop 3. Soil chemicals were applied throughout the plots (4 m × 4.5 m) at planting.

[y]Mulching commenced July 31 and December 4, 1995 and August 8, 1996 and continued for five, five, and nine weeks for Crops 1, 2, and 3, respectively.

[z]Each figure is the mean of five observations.

*,** = Significantly different from either the nonmulched and fertilized or the nonmulched and nonfertilized control at $P = 0.05$ and $P = 0.01$, respectively, by Student's *t* test.

Table 4. (Continued) Mean number of nematodes in 100 cm^3 rhizosphere soil before and after mulching plots with clear or black plastic and treating with fertilizer, fungicide, or nematicide, or not treating, and at harvest for three crops of cucumbers in Experiment 1.

		Number of nematodes							
Nematode	Time of Sampling	No mulch - Fert	No mulch + Fert[x]	Clear mulch - Fert[y]	Clear mulch + Fert[xy]	Black mulch - Fert[y]	Black mulch + Fert[xy]	Fungicide - Fert[x]	Nematicide - Fert[x]
	After	56	50	26	32*	39	24*	32	19*
	At harvest	145	38	46	81	74	62	46	127
Rotylenchulus reniformis	Before	51	81	29	90	36	32*	46	127*
	After	77	28	24	42	32	55	24	62
	At harvest	81	46	36	51	29	90	127	32
Total parasites	Before	87	185	86	52	105	70	98	249
	After	107	98	41	60*	59	45	62	74
	At harvest	222	66	70	122*	106	117	70	189
Nonparasites	Before	170	171	171	145	261	107	145	237
	After	186	147	153	128	119	98	133	158
	At harvest	259	217	282	212	234	221	1058	273
				CROP 3					
Helicotylenchus erythrinae	Before	133	95	50	53	65	90	26	30
	After	131	91	31*	6**	26*	1**	43*	81*
	At harvest	16	16	1	1	6	11	6	16

[x]Fertilizer rate = 1 kg N:P:K (4:16:4)/plot; Fungicide rate = 45 g Banrot 40WP/plot; Nematicide rate = 20 g Furadan 10G/plot for Crops 1 and 2, and 10 g/plot for Crop 3. Soil chemicals were applied throughout the plots (4 m × 4.5 m) at planting.

[y]Mulching commenced July 31 and December 4, 1995 and August 8, 1996 and continued for five, five, and nine weeks for Crops 1, 2, and 3, respectively.

[z]Each figure is the mean of five observations.

*,** = Significantly different from either the nonmulched and fertilized or the nonmulched and nonfertilized control at $P = 0.05$ and $P = 0.01$, respectively, by Student's *t* test.

Table 4. (Continued) Mean number of nematodes in 100 cm^3 rhizosphere soil before and after mulching plots with clear or black plastic and treating with fertilizer, fungicide, or nematicide, or not treating, and at harvest for three crops of cucumbers in Experiment 1.

		Number of nematodes							
Nematode	Time of Sampling	No mulch - Fert	No mulch + Fert[x]	Clear mulch - Fert[y]	Clear mulch + Fert[xy]	Black mulch - Fert[y]	Black mulch + Fert[xy]	Fungicide - Fert[x]	Nematicide - Fert[x]
Rotylenchulus reniformis	Before	36	113	70	43	70	58	31	85
	After	96	31	11	1	36	1	21	21
	At harvest	96	61	36	11	91	41	91	96
Total parasites	Before	195	255	165	203	273	175	138	218
	After	271	196	71**	6**	106**	1**	151	226
	At harvest	141	101	46	26	106	61	131	116
Nonparasites	Before	1360	1030	855*	1058	1400	1115	978	1468
	After	926	756	476*	207**	481**	241**	711	716
	At harvest	1036	701	541**	628*	516*	631	851	826

[x]Fertilizer rate = 1 kg N:P:K (4:16:4)/plot; Fungicide rate = 45 g Banrot 40WP/plot; Nematicide rate = 20 g Furadan 10G/plot for Crops 1 and 2, and 10 g/plot for Crop 3. Soil chemicals were applied throughout the plots (4 m × 4.5 m) at planting.

[y]Mulching commenced July 31 and December 4, 1995 and August 8, 1996 and continued for five, five, and nine weeks for Crops 1, 2, and 3, respectively.

[z]Each figure is the mean of five observations.

*,** = Significantly different from either the nonmulched and fertilized or the nonmulched and nonfertilized control at $P = 0.05$ and $P = 0.01$, respectively, by Student's t test.

Table 5. Mean numbers of colony-forming units (CFU) of fungi and bacteria in 10 g dry soil after mulching with clear or black plastic for five weeks, or not mulching in Experiment 1.

	CFU (Log_{10} x + 1)			
	No mulch[y]	Clear mulch[z]	Black mulch[z]	LSD ($P = 0.05$)
Fungi	5.73	2.88*	3.79	2.23
Bacteria	8.04	8.08	8.01	—

[y]Figures are means of 16 observations.
[z]Figures are means of eight observations.
* = Significantly different from the values for nonmulched soil at $P = 0.05$ by the LSD test.

(when nematicide rates were reduced by half). Stapleton and de Vay (1986) and Stapleton *et al.* (1987) found that solarizing soil was equal or superior to treatment with nematicides or solarization-nematicide combinations for improving plant growth, since the high soil temperature and moisture levels associated with soil solarization may have affected pesticidal activity and pesticide dissipation in the soil.

Mulching soil with clear or black plastic for four, six, or eight weeks without subsequent fertilization led to similar increases in yield amongst treatments in Experiment 2 except when there was mulching with black plastic for four weeks, which did not result in any yield increase. Yields were small and similar amongst treatments for Crops 1 and 2 of Experiment 1 and yield data were not available for Crop 3. However, when plots in Crop 3 were mulched with clear or black plastic for nine weeks and fertilized, shoot fresh weights at harvest were greater than those of the nonmulched fertilized controls indicating that mulching had stimulated plant growth up to the time of harvest.

Soil temperatures in plots mulched with black plastic were lower than those treated with clear plastic, since black plastic is less effective in transmitting solar radiation (Katan, 1981). These lower temperatures may not have favored the microbial activities in the soil which promote plant growth as does the reduction in parasitic nematode population densities. However, the fertilization of plots mulched with black plastic sometimes significantly increased plant growth, perhaps due in part to the stimulation of certain microbial activities (Brady, 1974). Other workers have shown that the addition of fertilizers to soil mulched with black plastic reduces disease incidence and increases yields (Brown *et al.*, 1989; Elmer and Farrandino, 1991), and also that addition of organic amendments to solarized soil has increased yields above that obtained by either treatment separately (Ramirez-Villapudua and Munnecke, 1987).

Plastic mulching of soil significantly reduced the population densities of phytopathogenic nematodes in the cucumber plots. Possibly, resultant nematode-fungus interactions harmful to plants (Powell, 1963) also were reduced. Both factors could have contributed to the increased plant growth noted in the mulched plots. The nematicide also reduced nematode population densities, but the plant-growth-promoting qualities of plastic mulching made the latter the superior treatment.

Nematode population densities were never reduced by the fungicide, but were

Table 6. Weed species detected in plots one month after mulching with clear or black plastic for five or nine weeks, or not mulching, for three crops of cucumbers in Experiment 1.

	Mulch		
Species	None	Clear	Black
DICOTYLEDONS			
Amaranthus dubius Mart. ex Thell.	+[z]	—	—
Amaranthus viridis L.	+	—	—
Bidens pilosa L.	+	—	—
Boerhavia erecta L.	+	—	—
Cleome rutidosperma DC.	+	—	—
Cleome viscosa L.	+	—	—
Emilia javanica (Burm.F.) Robins.	+	—	—
Euphorbia glomerifera (Millsp.) L. C.Wheeler	+	—	—
Euphorbia heterophylla L.	+	—	—
Euphorbia hirta L.	+	—	—
Euphorbia hyssopifolia L.	+	—	—
Euphorbia prostrata Ait.	+	—	—
Kallstroemia maxima (L.) Torr. & A. Gray	+	—	—
Malvastrum americanum (L.) Torr.	+	—	—
Mimosa pudica L.	+	—	—
Parthenium hysterophorus L.	+	—	—
Phyllanthus amarus Schumach.	+	—	—
Portulaca oleracea L.	+	+	—
Priva lappulacea (L.) Pers.	+	—	—
Sida acuta Burm. F.	+	—	—
Spermacoce confusa Rendle	+	—	—
Spigelia anthelmia L.	+	—	—
Tribulus cistoides L.	+	—	—
MONOCOTYLEDONS			
Cenchrus echinatus L.	+	+	—
Commelina diffusa Burm.	+	—	—
Commelina elegans Kunth	+	—	—
Cyperus rotundus L.	+	+	—
Digitaria sp.	+	+	—
Echinochloa colonum (L.) Link.	+	+	—
Eleusine indica (L.) Gaertn.	+	+	—

[z]+,- = Species present, absent, respectively.

Table 6. (Continued) Weed species detected in plots one month after mulching with clear or black plastic for five or nine weeks, or not mulching, for three crops of cucumbers in Experiment 1.

	Mulch		
Species	None	Clear	Black
Panicum maximum Jacq.	+′	+	—
Panicum sp.	+	+	—

′+,- = Species present, absent, respectively.

reduced by all other treatments. For Crop 3 of Experiment 1, the initial parasitic population densities appeared to be high enough to affect cucumber growth adversely since, in other studies (Coates-Beckford, unpublished data), minimum initial densities of 95, 80 and 100/100 cm^3 soil of *H. erythrinae, R. reniformis,* and total parasites, respectively, were associated with lowered yields of cucumbers. The effects of plastic mulching on nematode populations were temporary as the population densities of both phytonematodes and nonparasites sometimes increased to reach initial levels or surpass them by the time of harvest. Other workers noted that the suppressive effects of solarized soil on a fungal pathogen of apple roots lasted at least 25 months (Sztejnberg *et al.*, 1987), and on disease control and yield increase for up to three seasons (Abdel-Rahim *et al.*, 1988).

As observed in these experiments, other workers have noted the suppressing effects of plastic mulching on *R. reniformis* (Abdel-Rahim *et al.*, 1988; Chellemi *et al.*, 1993; Heald and Robinson, 1987; Sharma and Nene, 1990) and species of *Pratylenchus* (Barbercheck and Von Broembsen, 1986; Duncan *et al.*, 1992; Sharma and Nene, 1990), *Helicotylenchus* (Sharma and Nene, 1990) and *Tylenchorhynchus* (Sharma and Nene, 1990). Other nematodes controlled by plastic mulching include species of *Criconemella,* and *Paratrichodorus* (Barbercheck and Von Broembsen, 1986; Chellemi *et al.*, 1993), but not always of *Meloidogyne* (Barbercheck and Von Broembsen, 1986; Duncan *et al.*, 1992). In Jamaica, solarization of breadfruit rhizosphere soil reduced population densities of *Helicotylenchus* spp. within six months, and *P. coffeae* and *R. reniformis* within three months, but not species of *Paratylenchus* nor *Tylenchorhynchus* (Coates-Beckford and Pereira, 1994).

The use of black rather than clear plastic for soil mulching was more effective in controlling weed growth, probably due to the exclusion of light which would otherwise facilitate growth of thermotolerant weeds. The ready growth of weeds in non-mulched plots appeared to contribute to the retardation of cucumber seedling growth, probably by competing for nutrients. Long-term weed control has been obtained in soil mulched with clear polyethylene (Abdel-Rahim *et al.*, 1988).

Although clear plastic generally is recommended for solarizing soil (Katan *et al.*, 1987), other workers have controlled diseases and hence increased yields by using black plastic mulches (Duncan *et al.*, 1992). In these studies, the use of a sheeting more than ten times thicker than recommended (Katan *et al.*, 1987) and than those used in other trials (Keinath, 1995) was effective, and plastic did not disintegrate within four weeks in the summer months, as occurred with thinner plastic sheeting in other trials (Coates-Beckford, unpublished data).

The soil temperatures noted in these trials during the summer months were similar to those noted at the same depths by Keinath (1995), who also worked with cucumbers, and were effective in promoting plant growth and disease control. Plastic mulching during the cooler period in Jamaica also was effective in reducing nematode populations in these trials and others (Coates-Beckford, unpublished data), because ambient temperature and number of sunshine hours were still relatively high. One factor possibly reducing the effectiveness of solarization was the absence of irrigation once the plastic was laid, especially with the low rainfall in December, 1995 and September, 1996, since solarization is a hydrothermal process.

These studies have shown that mulching of fertilized and nonfertilized soil with either clear or black plastic results in increased cucumber growth and yield. Soil nematode populations are suppressed by this process in both the hot and cool seasons in Jamaica. Although the economic cost of plastic mulching has not been calculated, it is estimated that savings from the purchasing and application of nematicide and herbicide, the reduced frequency of manual weeding, and, in some instances, the purchasing and application of fertilizer, would cover the cost of purchasing and laying the polyethylene sheeting in cucumber fields. The resultant increase in yield should then make plastic mulching profitable.

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