Solarization and Chemical Alternatives to Methyl Bromide for Preplant Soil Treatment of Strawberries

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~~Summary~~. **Solarization and chemical alternatives to methyl bromide (MeBr) soil fumigation for strawberry (*Fragaria (XtimesX)ananassa*) were evaluated in a 3-year study in Savannah, Ga. Solarization using clear or black plastic, metam sodium (Sectagon), dazomet (Basamid), 1,3-dichloropropene and chloropicrin (Telone C-35), MeBr, and untreated control treatments were used. Solarization produced maximal soil temperatures of 55 to 60 °C (131 to 140 °F) at the 2.5 cm (1 inch) depth, and 42 to 48 °C (108 to 118 °F) at the 15 cm (6 inch) depth. Clear and black plastic were generally equally effective in heating the soil. A double layer of clear plastic raised soil temperatures 1 to 2 °C (2 to 4 °F) above those under a single layer of clear at the 2.5 cm depth, although this occurred less frequently at the 15 cm depth. MeBr treatment increased yield by 46% and 128% in the first and second years, respectively, compared to the untreated control, but all treatments were similar in yield in year three. Season average fruit size differed among treatments in only the first year, with MeBr resulting in fruit 13% to 25% larger than other treatments. Yield for the metam sodium treatment in the first year was 34% lower than for MeBr, but comparable to MeBr in the other 2 years. Solarization treatment yields were similar to those of MeBr in the first and third years, but could not be analyzed in the second year due to plot damage. Dazomet treatment yields were similar to those of MeBr, metam sodium, and the untreated control in its single year of testing, but logistics of application and high costs may disfavor this treatment. The 1,3-dichloropropene/chloropicrin treatment performed as well as MeBr in its single year of testing. Three treatments-metam sodium, 1,3-dichloropropene/chloropicrin, and solarization with black plastic-offer viable, lower cost alternatives to MeBr.**

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Preplant fumigation of soil with methyl bromide (MeBr) has been practiced for decades in strawberry production, since yield and quality are reduced by soil-borne diseases, nematodes, and weed competition (Ristaino and Thomas, 1997). MeBr has been implicated in ozone depletion, and therefore had been scheduled to be phased out of production by 2001 by the Clean Air Act of 1990 (U.S. EPA, 2001). In 1998, the US Congress voted to extend the phase out schedule until 2005, allowing more time for alternatives to be researched and developed.

Alternatives to MeBr for preplant soil treatment are many, and fall into chemical and nonchemical categories (Himelrick and Dozier, 1991; Noling and Becker, 1994). Of the nonchemical alternatives, solarization has been researched extensively. Solarization involves heating the soil to lethal or sublethal temperatures [37 to 60 °C (99 to 140 °F)] by covering with plastic to kill or reduce populations of pathogenic soil organisms (Katan et al., 1976; Katan and Devay, 1991). Plastic films allow short wave radiation to penetrate, but retard the escape of long wave radiation, resulting in temperature increase via the greenhouse effect. Solarization has been shown to work even in cloudy, humid climates that have less solar radiation than arid areas (Chase et al. 1999; Chellemi et al., 1994). Clear plastic is used most often since it allows maximum transmittance of short wave radiation into the soil, but must be removed or painted before applying black plastic mulch for strawberry production. Although the black plastic mulch itself may provide substantial soil heating (Ham et al., 1993), the majority of studies have reported better performance of clear than black plastics (Chase et al., 1999; Horowitz et al., 1983). Using the same black plastic for solarization and mulch in strawberry plasticulture would simplify the process, reduce costs, and minimize plastic disposal problems.

Chemical alternatives to MeBr have been evaluated, and although most alternatives do not control as broad a spectrum of organisms, specific pests have been adequately controlled (Himelrick and Dozier, 1991). Chemicals applied through the irrigation system are attractive since plasticulture strawberries are drip-irrigated, and the chemicals simply can be injected into irrigation lines after the beds are prepared. Metam sodium (MS) is one such chemical, which compared favorably to MeBr in one other study on strawberry (Albregts et al., 1996). Dazomet is a dry, granular compound which can be broadcast and tilled into the soil prior to bed preparation. Another chemical that shows promise is 1,3-dichloropropene (1,3-D), either alone or mixed with chloropicrin (Chellemi et al., 1997; Stapleton and DeVay, 1983). 1,3-D is applied with the same equipment used for MeBr, so adoption of this alternative would constitute a fairly seamless transition for growers.

The objective was to evaluate solarization and some chemical alternatives to MeBr for preplant soil treatment of plasticulture strawberries grown in the lower coastal plain of the southeastern United States.

Materials and methods

~~Site, experimental design.~~ Studies were conducted for 3 years at the University of Georgia Coastal Gardens research facility in southwest Savannah, Ga. (81°W, 32°N), beginning in July 1997 and ending in May 2000. The soil type is an Ocilla series loamy fine sand. 'Chandler' strawberries were cultivated using standard plasticulture practices. Beds were 20 cm (8 inches) high and 72 cm (28 inches) wide, containing 2 rows of (staggered) plants spaced 35 cm (14 inches) apart within and between rows, with beds spaced 1.4 m (4.5 ft) on center. In the first year (1997-98), a field was used which had a history of strawberry plasticulture and MeBr fumigation of several years. The experiment was moved to a nearby field for the second (1998-99) and third (1999-2000) years of the study which did not have a history of MeBr fumigation, and was previously used for vegetable production. This field was larger allowing additional treatments and larger replicates for years two and three.

In the first year (1997-98), a latin square design was employed using four replications of four treatments. Plots were 6 m (20 ft) long and contained about 40 plants. Since interspersing different soil treatments along a given bed (as in 1997-98) was logistically difficult for fumigant application, treatments were applied to an entire bed in the second and third years (1998-99 and 1999-00). In year two, two replications 20 m (65 ft) long were used per treatment, although in year three, four replicates of shorter length (10 m or 32 ft) were used since some variation along a given bed was noticed in year two. Treatments were arranged randomly across the field in year two, and this arrangement was maintained in year three so that treatments were applied to the same areas of the field in both years.

SOLARIZATION TREATMENTS. Solarization treatments were initiated in early July each year, and continued until site preparation and bedding in October. Solarization with a single layer of 4-mil clear (CLR) plastic [100 μm (0.004 inch) UV-stabilized polyethylene, Hummert International, Earth City, Mo.] was included in all 3 years of the study. In the first year, 2 {XtimesX} 8 m (6 {XtimesX} 26 ft) plastic sheets were spread on recently tilled and irrigated soil; the soil was smoothed and firmed by hand raking and foot traffic before covering with plastic to improve thermal conductivity. Each plastic sheet was centered on the area where the bed was subsequently made to ensure that all of the soil mounded in the bedding process had been solarized. In years two and three, solarization was performed after beds were formed with a commercial bedding implement since raised beds had been shown to increase soil temperatures versus flat ground solarization (Chellemi et al., 1997). Also in years two and three, solarization with 1.25-mil black plastic (BLK) [31 mm (0.00125 inch) conventional embossed black polyethylene] was added to the trial, which basically constituted preparing beds about 3 months earlier than normal, since the black plastic used for solarization was the same as that used for mulch. Clear plastic was replaced with black plastic mulch when the plots were bedded and planted in October each year.

To study temperature regimes under double- versus single-layer plastics, about 2.5 m (8 ft) at the ends of a bed for both clear and black plastics was covered with a single layer of clear plastic, yielding clear over clear (CLR/CLR) and clear over black (CLR/BLK) test areas. Soil temperature was the only data collected from these areas.

Soil temperatures were measured with 24-gauge, copper-constantan thermocouples and a Campbell Scientific CR-7 datalogger (Campbell Scientific, Logan, Utah). Thermocouples were placed at the 2.5 cm and 15 cm depths in the center of the beds or areas being solarized. The datalogger was programmed to average temperature readings made each second over a 2-h period, and store the results at 2-h increments. In the CLR and BLK treatments, there were four thermocouples at each depth, and in the CLR/CLR, CLR/BLK, and bare soil (control) treatments, there were two thermocouples at each depth. Soil temperatures were monitored for at least 30 d during July and early August in each year. Air temperature and rainfall were monitored at a weather station about 100 m (325 ft) from the plot.

CHEMICAL TREATMENTS. MeBr (bromomethane), MS (sodium N-methyldithiocarbamate, Sectagon, Oregon-California Chemicals, Junction City, Ore.), and an untreated control were used in all three years of the study. MeBr was applied at the standard rate of 483 kg·ha^{-1} (430 lb/acre), and was a mixture of 98% MeBr and 2% chloropicrin. MS was applied at a rate of 764 L·ha^{-1} (80 gal/acre) in accordance with the "high" rate recommendation by the manufacturer. In the second year, dazomet (tetrahydro-3,5-dimethyl-2H-1,3,5-thiadiazine-2-thione, Basamid, BASF, Research Park, N.C.) was added to the experiment. It was broadcast at a rate of 425 kg·ha^{-1} (375 lb/acre) as per manufacturer's recommendation and tilled to a depth of 15 to 20 cm (6 to 8 inches). The dazomet was tested in the second year only. In the third year (only), a mixture of 1,3-dichloropropene (65%), and chloropicrin (35%) (abbreviation 1,3-D, Telone C35, Dow Agrisciences, Sylvester, Ga.) was included, since it had shown efficacy in other regional trials but had not been tested in Georgia. It was placed over the former dazomet plots. The 1,3-D was applied with the same equipment as the MeBr, but injected 10 cm (4 inches) deeper in the soil as per manufacturer's recommendation, at the standard rate of 327 L·ha^{-1} (35 gal/acre).

DATA COLLECTED. Strawberries were harvested approximately twice per week beginning in March and continuing through late May in each year of the study. Total weight per replicate per harvest was recorded, and cumulative yields calculated at the end of the season. A 10-berry sample was removed from each replicate, and the fresh weight determined to estimate fruit size at each harvest date. In May or June of each year, soil samples were extracted from each replicate and plant parasitic nematode populations were determined by the University of Georgia Plant Disease Diagnosis Laboratory. Weed pressure was also estimated each year by counting the number of weeds per replicate. Weeding time per plot was measured in the first year of the study, which was the only year when hand weeding was required. Soil- and root-borne fungi were sampled in only the third year of the study by taking 10 plant samples per replicate in May and plating root cross sections on acidified potato dextrose agar media. Fungi were isolated and identified to genus based on colony characteristics, and hyphal, spore, and conidiophore morphology.

STATISTICAL ANALYSIS. Data collected in different years were analyzed separately since treatments, plot size, and replication varied among years. Yield and fruit size data were analyzed using a two-way analysis of variance, with treatment and harvest date as independent variables (SigmaStat 2.03 software, SPSS, Inc., Chicago). When the interaction between harvest date and treatment was significant, yield and/

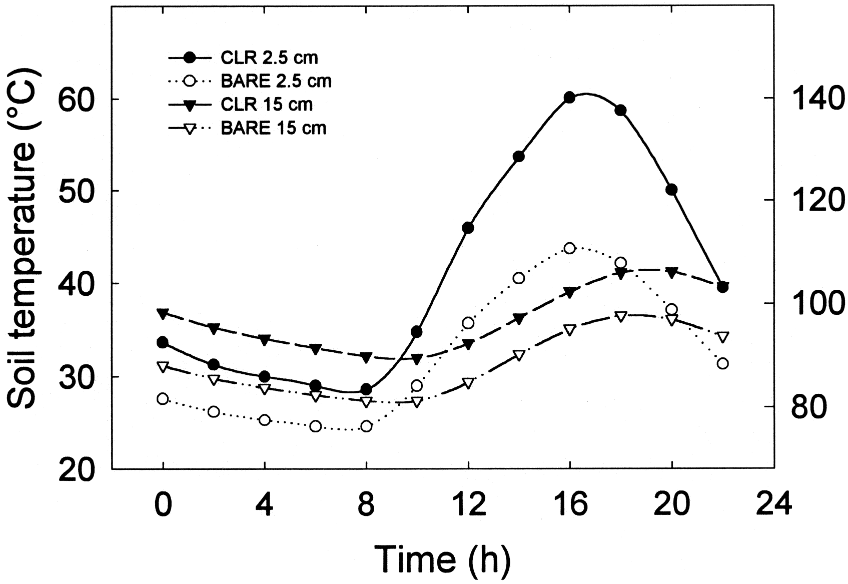

Fig. 1. Soil temperatures at the 2.5 cm (1 inch) and 15 cm (6 inch) depths in clear plastic solarization (CLR) and bare soil (BARE) treatments for 20 July 1997, representative of the 1997 results. Solarization was performed by covering flat ground with a sheet of 4-mil [100 µm (0.004 inch)] clear polyethylene; temperatures were recorded in the middle of the solarized or bare area. For all data points, n = 4.

or size were analyzed by harvest date for treatment effects. Weed, nematode, and fungi data were analyzed by one-way analysis of variance. Soil temperature data were analyzed by one-way analysis of variance among treatments at the time corresponding to the maximum daily soil temperature for either depth. Maximum daily soil temperatures generally occurred at 1600 HR for the 2.5 cm depth, and 1800 HR for the 15 cm depth. Only those days where soil temperature under clear plastic differed significantly from temperature of bare soil were considered in the analysis of solarization data.

Results

SOLARIZATION AND SOIL TEMPERATURE. In the first year (1997), there was only one solarization treatment - a single layer of clear plastic applied over a flat soil surface. Soil temperatures during a typical day are presented in Fig. 1. Solarization raised maximum daily soil temperature by about 15 °C (27 °F) at the 2.5 cm depth, and 5 °C (9 °F) at the 15 cm depth, on all days without rain or complete cloud cover. These results showed the potential for raising soil temperature into the sublethal and lethal range for weeds (Horowitz et al., 1983), nematodes (Stapleton and DeVay, 1983), and fungi (Pullman et al., 1981), despite the cloudy, hazy conditions that prevail at Savannah, Ga.

Although solarization was performed on raised beds in the second and third years, soil temperature regimes were generally similar to those of the first year. Data for a day typical of the 1998-99 results are shown in Fig. 2. Chellemi et al. (1997) also reported

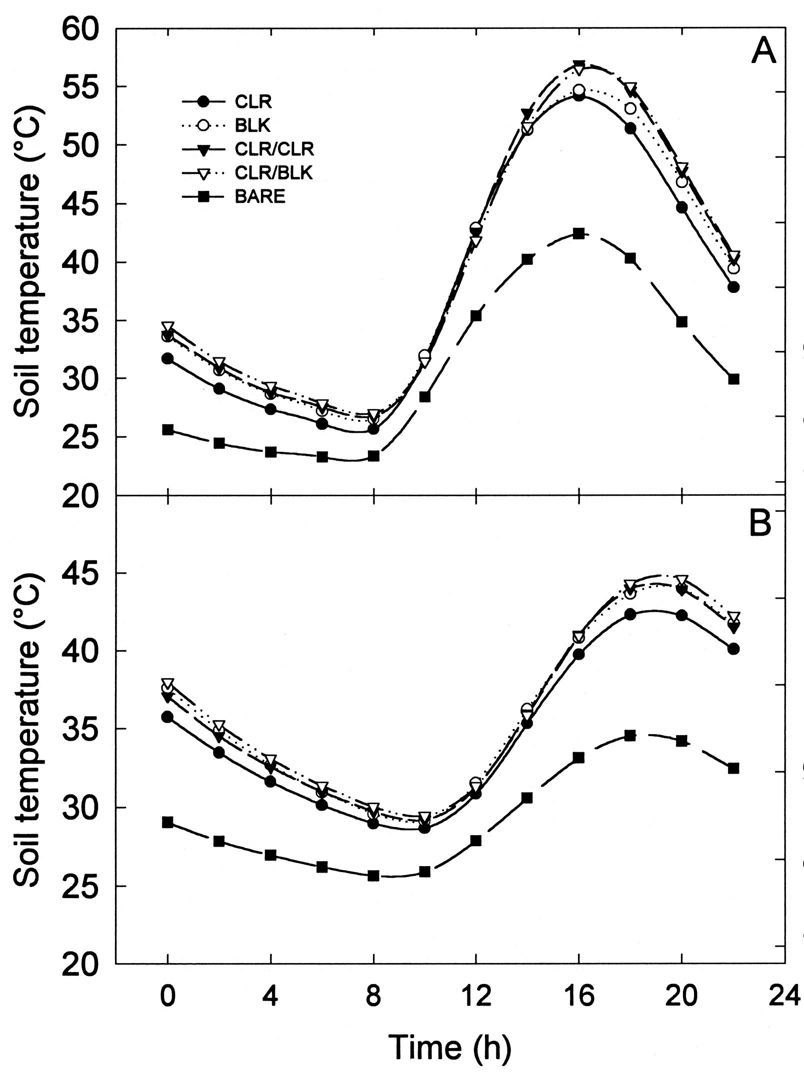

Fig. 2. Soil temperatures in various solarization treatments and bare soil (BARE) at the 2.5 cm (1 inch) depth (A) and 15 cm (6 inch) depth (B) for 8 July 1998, representative of the 1998 and 1999 results. Solarization was performed on raised beds covered with one layer of 4-mil [100 µm (0.004 inch)] clear polyethylene (CLR), one layer of 1.25-mil [31 µm (0.00125 inch)] black polyethylene mulch (BLK), two layers of clear (CLR/CLR), and a layer of clear over black (CLR/BLK). Temperatures were recorded in the middle of the bed. For CLR and BLK, n = 4 at each depth, for CLR/CLR, CLR/BLK, and BARE, n = 2 at each depth.

Table 1. Percentage of days monitored during July and August 1998 and 1999 when maximum daily soil temperatures were 1) equal beneath clear and black plastic (clear = black), 2) greater beneath two layers of clear than one layer of clear plastic (clear/clear > clear), and 3) greater beneath black plastic covered with clear than black plastic alone (clear/black > black) (P < 0.05). Maximum daily soil temperatures generally occurred at 1600 ~~HR~~ for the 2.5 cm (1 inch) depth, and 1800 ~~HR~~ at the 15 cm (6 inch) depth.

Year[z]	Clear = Black	Clear/Clear > Clear	Clear/Black > Black
		2.5 cm depth	
1998	100	82	18
1999	92	35	0
		15 cm depth	
1998	71[y]	47	12
1999	100	4	0

[z]In 1998, percentages are based on a total of 17 d, and in 1999, a total of 26 d. Maximum soil temperature data were analyzed for the above effects if temperatures beneath clear plastic differed significantly (P < 0.05) from those beneath bare soil.
[y]When temperatures differed in 1998, black plastic produced greater temperatures than clear at the 15 cm depth.

similar temperature regimes for flat ground versus bed solarization methods. Bedding raised soil temperatures 2 to 4 °C (4 to 7 °F) compared to flat ground in their study, but not in this study. Maximal soil temperatures for all solarization treatments were about 10 to 15 °C (18 to 27 °F) higher than temperatures beneath bare soil, with greater differences at the shallower depth (Fig. 2A). In contrast to other studies comparing black and clear plastics (e.g., Chase et al. 1999), soil temperatures generally were similar for the BLK and CLR treatments (Fig. 2A and B). At the 2.5 cm depth, temperatures of BLK and CLR plastics did not differ significantly on over 90% of the days monitored in 1998 and 1999 (Table 1). At the 15 cm depth, temperatures under BLK were significantly higher than those under CLR on 29% of the days monitored in 1998, but always similar in 1999. Temperatures for CLR and BLK diverged in the afternoon, and remained slightly higher through the night in the BLK treatment (e.g., Fig. 2B). A similar trend was seen at the 2.5 cm depth (e.g., Fig. 2A), but afternoon temperature differences were somewhat less. Reasons for the occasionally higher temperatures under BLK than CLR are unknown, but could be due to differences in thickness of the BLK and CLR plastics, or the greater absorptivity of shortwave radiation for BLK (Ham et al., 1993).

A double layer of clear plastic raised soil temperatures compared to a single layer of clear, although this effect was more pronounced at the 2.5 cm than the 15 cm depth, and occurred more frequently in 1998 than 1999 (Table 1). However, adding a layer of clear over black plastic resulted in higher soil temperatures in only one of two years, and then on only 12-18% of the days monitored. Temperature differences between single and double layer treatments were typically only 1 to 2 °C (2 to 4 °F) (e.g., Fig. 2).

Yield and fruit size

~~Year 1~~. In 1998, there was no harvest date (XtimesX) treatment interaction, so cumulative yield could be compared statistically. The MeBr treatment produced higher yield than the MS or untreated control (Fig. 3A). Solarization resulted in intermediate yields that did not differ from the other three treatments. Fruit were 13-25% larger in the MeBr than the other treatments (Fig. 3B), which partly explained the increased yield. Commercial yield of strawberries in Georgia generally ranges from 11,200 to 22,400 kg·ha^{-1} (10,000 to 20,000 lb/acre), in agreement with yields obtained in this study for 1998. Yield in the untreated control of over 14,000 kg·ha^{-1} (12,470 lb/acre) was higher than expected, and may have

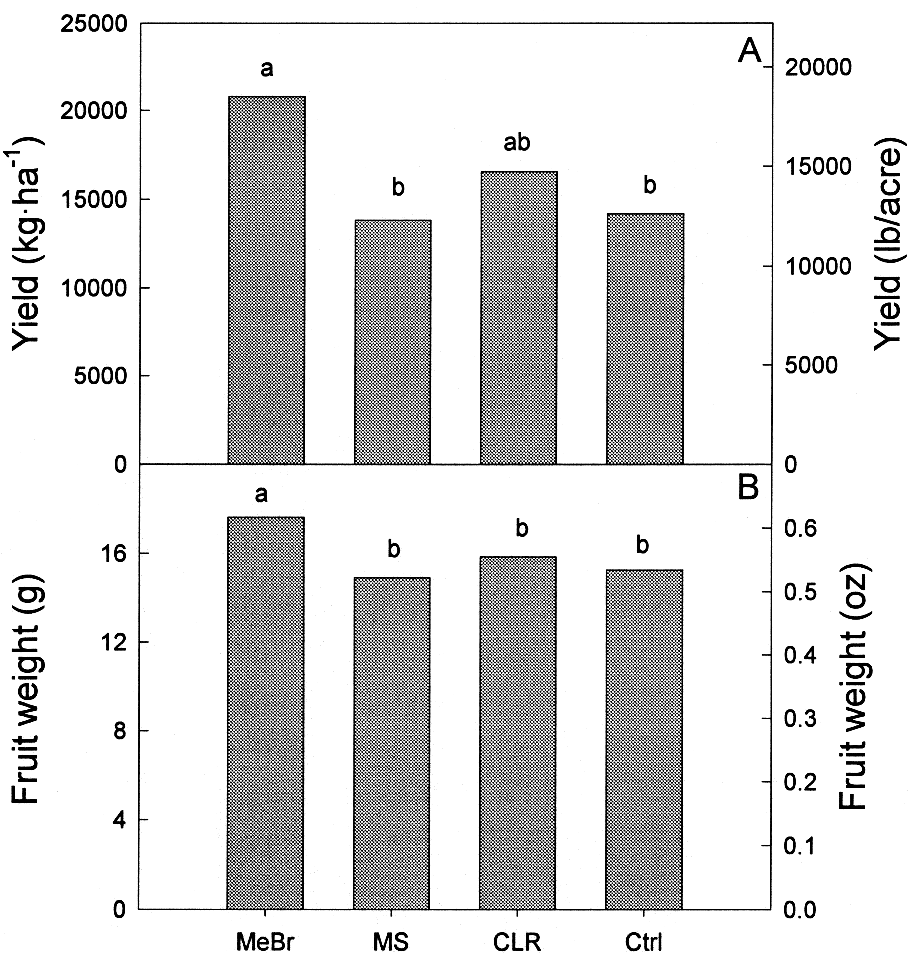

Fig. 3. Cumulative fruit yield (A) and average fruit weight of strawberries (B) for the 1998 season for the methyl bromide (MeBr), metam sodium (MS), solarization (CLR), and untreated control treatments (Ctrl). Different letters signify statistical differences at P = 0.05, Tukey's mean separation test.

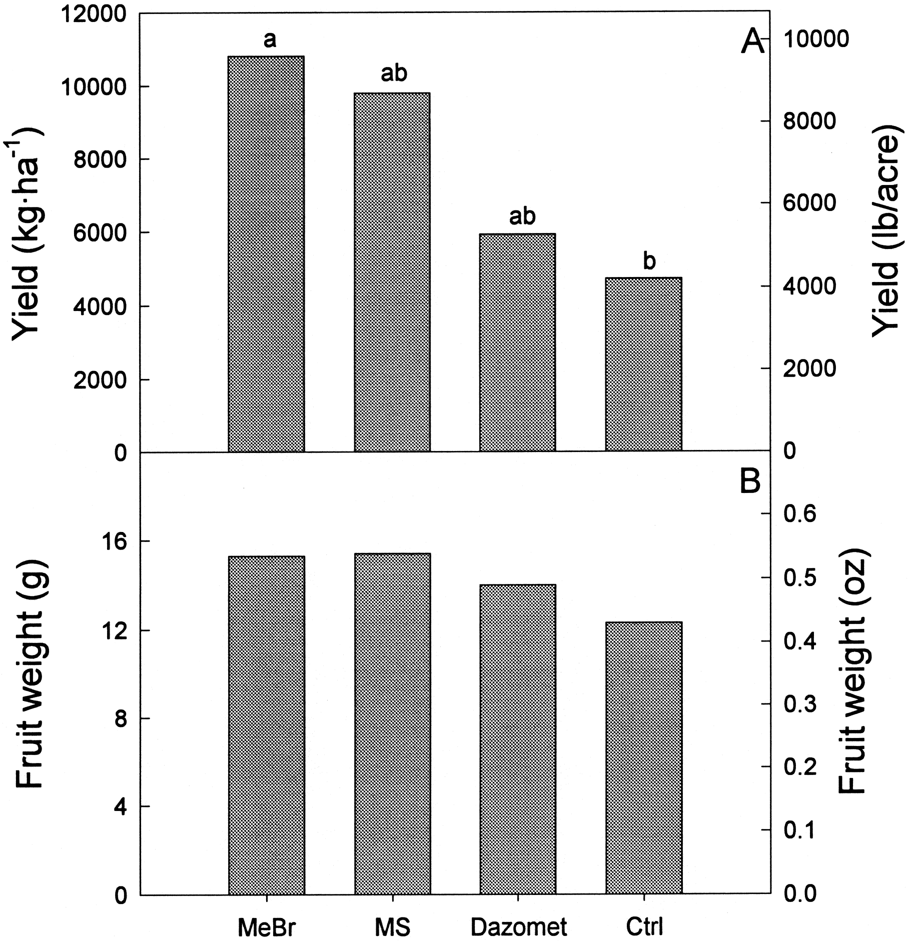

Fig. 4.Cumulative fruit yield (A) and average fruit weight of strawberries (B) for the 1999 season for the methyl bromide (MeBr), metam sodium (MS), dazomet, and untreated control treatments (Ctrl). White-tailed deer damage precluded comparison of yield and size from solarization treatments. Different letters signify statistical differences at *P* = 0.05, Tukey's mean separation test. Significant harvest date x treatment interactions for fruit weight precluded overall statistical comparisons.

been partly attributable to the MeBr fumigation history of the site; this carryover effect has been reported by others (Albregts et al., 1996). This was one reason for moving to another site which had not been fumigated with MeBr for years two and three of the study.

Year 2. The late planting date (1 Nov.) and frost injury reduced the yields in 1999 compared to years one and three. White tailed deer (*Odocoileus virginianus macrourus*) feeding on the strawberry plants was evident in the solarization treatments, which were at the far end of the field; therefore, data for these treatments were not included in the analysis. As in 1998, there was no harvest date {XtimesX} treatment interaction in 1999, so cumulative yield of the four remaining treatments could be compared statistically. MeBr produced more than double the yield of the untreated control, with dazomet and MS producing intermediate yields that did not differ from other treatments (Fig. 4A). Treatments affected fruit size in similar fashion, yet significant harvest date {XtimesX} treatment interactions precluded statistical comparison of season average fruit size (Fig. 4B). When analyzed by harvest date, MeBr and MS treatments produced fruit about 10 g (0.4 oz) larger than the untreated control on one harvest date in April (data not shown). Thus, fruit size was unaffected by treatment with the exception of one harvest date.

Year 3. Favorable fall weather, lack of frost or deer damage, and a warm, dry spring produced the highest yield and fruit size of the 3 years studied. There were significant harvest date {XtimesX} treatment interactions for both yield and fruit size, precluding statistical comparisons of cumulative yield and season average fruit size. Yields ranged from 25,000 to 30,000 kg·ha^{-1} (22,250 to 26,700 lb/acre), up to 50% higher than typical commercial yields in Georgia (Fig. 5A). However, several Georgia growers reported yields in this range for the 1999-2000 season (Krewer, personal communication), and yield was comparable to the 28,000 to 42,000 kg·ha^{-1} (24,940 to 37,400 lb/acre) range reported for commercial strawberries in the USA over the last 10 years (USDA, 1999).

Yield per harvest differed among treatments on only 5 of 16 harvest dates (data not shown). Differences among the three chemical treatments were found on only one of these five dates: 1,3-D had higher yield than MeBr and MS on the first harvest date. The CLR solarization treatment never differed from the untreated control, but the BLK solarization treatment out-yielded the control on two of the five dates when treatment differences occurred. The CLR and BLK treatments had similar yield on all except one date, and were not different from the MeBr treatment on any date.

Fruit size averaged 20 to 22 g (0.7 to 0.8 oz) per berry (Fig. 5B), and differed among treatments on only 3 of 16 harvest dates in 2000 (data not shown). No single treatment consistently had the greatest fruit size, but the control had smaller fruit than at least one other treatment on two of three dates when treatment differences occurred.

Weeds, nematodes, and fungi

Weed competition was a problem only in the first year. In the second and third years, there were 0.1 weeds or less per meter (0.03 weeds/ft) of row length in all treatments. In the first year, the MeBr treatment had about 0.5 weeds/m (0.15 weeds/ft) of row length, significantly less than the other treatments with 1.25 to 2.0 weeds/m (0.4 to 0.6 weeds/ft). Weeds were removed by hand in the middle of the harvest season as they became quite large, but weeding time was not affected by treatment, averaging 2 to 4 min per plot. The most common weeds were carolina geranium (*Geranium carolinianum*), dogfennel (*Eupatorium capillifolium*), wandering cudweed (*Gnaphalium pennsylvanicum*), and narrowleaf cudweed (*Gnaphalium falcatum*).

Nematode populations did not differ among treatments in any year (data

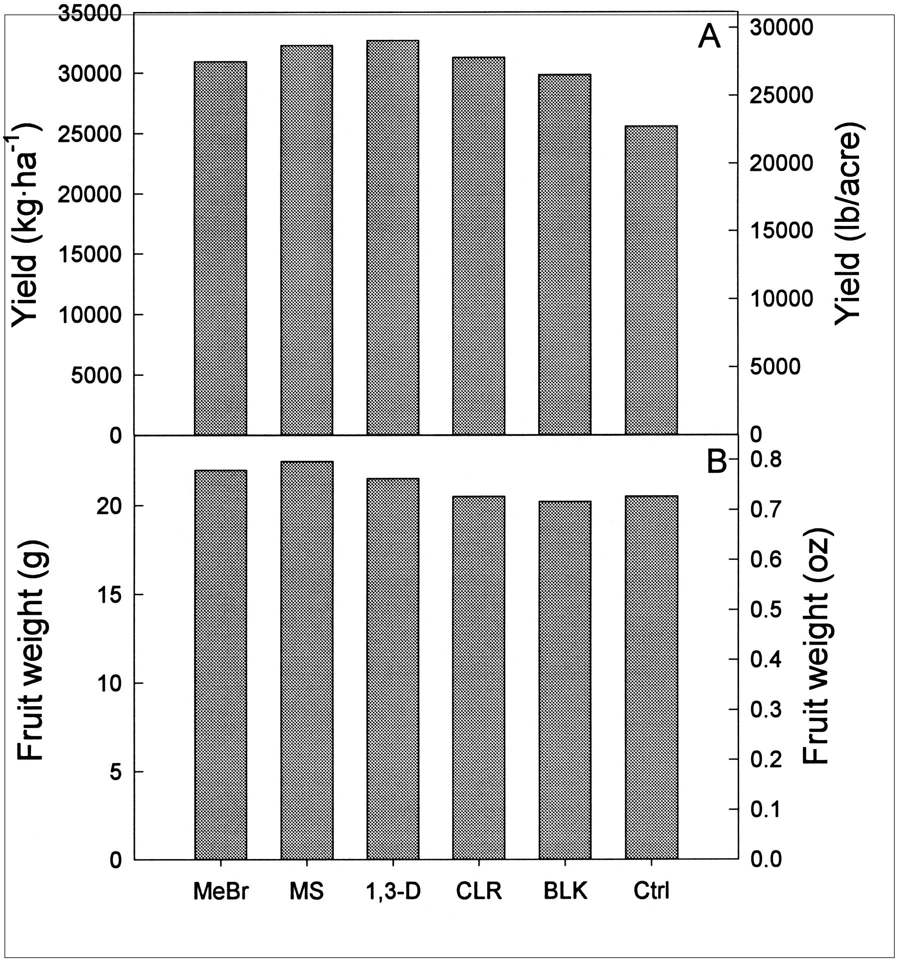

Fig. 5. Cumulative fruit yield (A) and average fruit weight of strawberries (B) for the 2000 season for the methyl bromide (MeBr), metam sodium (MS), 1,3-dichloropropene:chloropicrin (1,3-D), clear plastic solarization (CLR), black plastic solarization (BLK) and untreated control treatments (Ctrl). Significant harvest date x treatment interactions for yield and fruit weight precluded overall statistical comparisons.

not shown). When found, populations ranged from 1 to 12 nematodes per 100 cm^3 (6 $inch^3$) of soil. The most common types were stubby root (*Paratrichodorus* sp.) and ring nematode (*Criconemella* sp.). There were more nematodes in the second year of the study than either the first or third years. The second year of the study was the first year of using the field that had not been fumigated with MeBr in the past. A decline from 3 to 12 nematodes per 100 cm^3 of soil in 1999 to 0 to 1 per 100 cm^3 in 2000 across all treatments suggests a generalized decrease in nematodes following cultivation of the site.

Twenty-one genera of fungi were isolated from roots of plants sampled in May of the third year (data not shown). The most common isolate was *Rhizoctonia*, followed by *Phoma* and *Botrytis.* Less than 20% of the samples cultured contained fungi of any type regardless of treatment, and no treatment produced significantly different frequencies of fungal isolates.

Discussion

Solarization with clear plastic has been the norm since some studies have reported poorer results with black or other types of plastics than clear (Chase et al., 1999; Horowitz et al., 1983). However, clear plastic must be replaced with black or colored plastic, or painted to prevent light penetration during crop production. Otherwise, weeds will sprout beneath plastic as temperatures cool in autumn. In two separate years, we found that black plastic increased soil temperature to the same extent as clear during the hottest portion of the year. Yield and fruit size were largely unaffected by plastic type in year three of our study, and results for solarization were similar to chemical treatments in years one and three. Thus, solarization could be accomplished by merely preparing beds in early July instead of late September with the same plastic mulch and equipment normally used in strawberry plasticulture. It is not clear why our results differ from those of other studies performed in different locations, particularly northern Florida which has a soil type and climate similar to Savannah, Ga. However, our results agree with those reported by Ham et al. (1993) who showed that black plastics produced similar or slightly higher temperatures than clear plastic in Kansas. Our clear plastic was about 3-fold thicker than the black plastic, thus differences in thickness between the BLK and CLR treatments may explain why our results differ from those of other authors.

Cumulative yield in solarization treatments was similar to that of MeBr in both years when data could be analyzed (first and third), in agreement with results obtained in Florida for strawberry (Albregts et al. 1996; Overman et al., 1987). However, fruit in the solarization treatment were smaller than the MeBr treatment in year one. Therefore, growers should use caution when employing solarization. Solarization also eliminates the possibility of additional income from a summer crop when used in strawberry plasticulture. However, there are few summer crops lucrative enough to add significantly to the annual income from strawberry plasticulture, so this may not be a major disadvantage.

Solarization data also suggest that double layer plastics can increase soil temperatures compared to single layer by 1 to 2 °C, with the clear over clear combination working better than the clear over black. However, the biological significance of such a temperature increase is questionable, and might not warrant the extra expense and effort required to apply double layer plastics. All solarization treatments produced temperatures within the range that kills or severely reduces populations of many soil organisms in the upper 15 cm of soil (Horowitz et al., 1983; Pullman et al., 1981; Stapleton and DeVay, 1983).

With the exception of year two when frost, late planting, and deer feeding affected outcomes, yield and fruit size equaled or exceeded expectations for Georgia. The third year (1999-2000) had the most favorable weather, and also may have contained a carryover effect since treatments were applied in the same locations as the previous year. Thus, the 2000 season may have been the best indication of treatment performance of the three year trial. The relatively high yield and overall lack of treatment effects in 2000 (Fig. 5) suggest that growers may have several options to exercise once MeBr is phased out of production. Reasonably high yield for untreated controls in year one indicates that growers may experience a carry-over effect when growing strawberries on sites with a long history of fumigation. Since yields of untreated control plots were also high in year three, with no long history of MeBr use and 2 consecutive years of strawberries, it may be possible to crop well for at least 2 years on new sites before soilborne problems arise. This suggests that crop rotation may be a viable option for strawberry plasticulture when chemical soil treatments are not used, as was true before the advent of MeBr (Noling and Becker, 1994).

Differences in yield, when they occurred, could not be attributed to nematode populations, and were influenced by weed pressure in only 1 of 3 years. Unfortunately, fungal samples were made in only the third year, when no overall differences occurred among treatments in either yield or fruit size. The presence of genera of fungi known to contain strawberry pathogens in all treatments suggests that root diseases could have contributed to yield differences in years one and two. There was a notable absence of yellow nutsedge (*Cyperus esculentus*) at our site, which differs from observations in the southeast where MeBr alternatives lacking herbicidal activity have performed poorly due to high nutsedge competition (Himelrick et al., 1995b). Lack of weed pressure at our site may have been fortuitous, and the positive results obtained with MeBr alternatives lacking herbicidal activity may be valid only where weeds are not a problem.

MS performed as well as MeBr in 2 of 3 years tested, and the dazomet was comparable to MeBr in the year it was tested. However, dazomet requires an additional 2-week period between bed preparation and planting, and must be tilled into the soil before bedding. A 2-week delay in planting can reduce yield of plasticulture strawberries substantially (Himelrick et al., 1995a). Thus, MS may be a better alternative for growers than dazomet. Adoption of 1,3-D as a MeBr replacement would involve the least effort for growers of the chemicals tested, as it requires the same equipment and application methods used with MeBr (with minor adjustments in shank depth and calibration).

Costs of each treatment were estimated by contacting chemical manufacturers or custom applicators, and ranked as follows: dazomet $2875/ha ($1164/acre), MeBr $2178/ha ($882/acre), CLR solarization $1447/ha ($586/acre), 1,3-D $1297/ha ($525/acre), MS $1032/ha ($418/acre), and BLK solarization $0/ha. Solarization with black plastic adds no cost since the beds are simply made earlier than normal with the same materials and labor, and is the only "no-cost" alternative. Solarization with clear plastic does not seem feasible given equivalent performance but higher cost than solarization with black plastic. Dazomet provides the lowest returns per dollar spent on soil treatment, which disfavors this alternative, particularly when the drawbacks listed above are considered. MS is the most affordable of the chemical alternatives at about 47% the cost of MeBr, while 1,3-D is intermediate at 60% the cost of MeBr. Taking cost and effects on yield and fruit size into account, three treatments-metam sodium, 1,3-D, and solarization with black plastic-appear to offer the best alternatives to MeBr at present.

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