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Efficacy of Mulches and Methyl Bromide Alternatives on Soilborne Pests and Weeds in Spring Tomato

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Abstract: Tomato (*Lycopersicon esculentum* Mill.) field studies were conducted to determine the impact of mulch types combined with soil fumigants on spring tomato yields and on soilborne pests and weeds. Fumigants were: a) untreated control, b) methyl bromide + chloropicrin (67/33%, respectively) at a rate of 400 kg ha^{-1}, c) chloropicrin at 400 kg ha^{-1} plus the herbicide pebulate at 4.5 kg ha^{-1}, d) 1,3-dichlopropene at 325 kg ha^{-1} + chloropicrin at 67 kg ha^{-1} (83/17%, respectively) plus pebulate at 4.5 kg ha^{-1} and e) metam sodium at 485 kg ha^{-1} plus pebulate at 4.5 kg ha^{-1}. Mulch types were either black low-density polyethylene film (0.038 mm thick) or black paper mulch. Results indicated that all fumigants with either mulch type had higher tomato yield and more effective soilborne disease and purple nutsedge (*Cyperus rotundus* L.) control than the non-fumigated control. Paper mulch appeared to be a valuable alternative to control purple nutsedge with no fumigants and with low-volatility fumigants, such as metam sodium, whereas plastic mulch might retain high-volatility fumigants, such as methyl bromide, longer, thus increasing efficacy.

Key words: Methyl bromide, 1,3-dichloropropene, chloropicrin, metam sodium, pebulate

INTRODUCTION

Tomato is one of the main vegetable crops throughout the world. During the 2002 season, almost 4 million ha were planted of this vegetable worldwide[1]. In the United States, tomato represented more than US$1170 million in 2002[2]. In many countries of Central America, the Caribbean and North America, the majority of fresh tomato is produced during spring (February to May) and winter (September to December) seasons. Particularly during spring, high disease and weed pressures are observed mainly due to increasing temperatures and sunlight hours, which normally leads to massive weed germination and sprouting, as well as soil pathogen growth and reproduction. For many years, methyl bromide has been successfully utilized as a soil fumigant to ameliorate the incidence of soilborne fungi, bacteria and nematodes and to reduce weed populations. Unfortunately, this fumigant will be totally removed from the market by the year 2005, because it is considered as an ozone-depleting agent[3]. This ban has propelled a great deal of research to identify alternative practices to replace methyl bromide in tomato.

Some of the most frequent soilborne pathogens in tomato fields are Fusarium wilt (*Fusarium oxysporium* Schlecht. f.sp. *lycopersici* (Sacc.) Snyder and Hansen), Fusarium crown rot (*Fusarium oxysporium* Schlecht. f.sp. *radicis-lycopersici* Jarvis and Shoemaker) and rootknot nematode (*Meloidogyne incognita* (Kafoid and White) Chitwood. On the other hand, purple nutsedge (*Cyperus rotundus* L.) is the most troublesome weed in polyethylene-mulched tomato, because its leaf tips can easily penetrate the polyethylene mulch, lateral sprouts multiply rapidly from tubers and there are few herbicides to control it. When allowed to grow, purple nutsedge can reduce tomato yields up to 40%[4]. There are few selective herbicides labeled for weed control in tomato[5]. Of these only one is labeled for purple nutsedge management. The most common purple nutsedge management strategy has been based in between-row applications of non-selective herbicides, such as paraquat, along with bed fumigation with methyl bromide. Previous reports have indicated promising results for soil pathogens with several materials, such as 1,3-dichloropropene combined with chloropicrin in 83 and 17% (v/v) proportions and metam sodium[6]. However, these products have been

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inconsistent in controlling purple nutsedge[7,8]. Moreover, these studies have indicated the necessity of adding a supplementary herbicide, such as pebulate, to reduce purple nutsedge populations in polyethylene-mulched tomatoes.

In those tomato-planting systems, the effect of the mulch utilized could have a profound effect on disease, nematode and weed management. Traditionally in spring tomato, black low-density plastic films are laid on planting beds three to four weeks before transplanting, immediately after soil fumigation. This type of mulch increases soil temperatures during the first 30 days after transplanting, which is beneficial for actively growing plants during this part of the year. Unfortunately, this temperature increase allows pathogens and weeds to multiply their reproductive and sprouting structures. From the fumigant standpoint, the effect of other mulch types on tomato growth and yield has not been deeply studied. Therefore, the objective of this study was to determine the impact of mulch types used with soil fumigation on spring tomato yield.

MATERIALS AND METHODS

Field trials were conducted during spring 1998 at the University of Florida Gulf Coast Research and Education Center, in Bradenton. The soil was classified as EauGallie fine sand (Alfic Haplaquods, sandy, siliceous, hyperthermic) with 1.0% organic matter and pH 7.3. Tomato 'Sunbeam' transplants were established in two trials started on February 15 (early spring) and March 15 (late spring), 1998, respectively. Fields have a history of heavily rootknot nematode, purple nutsedge and soilborne disease infestations. Treatments within each experiment were distributed in a split-plot design with six replications. Combinations of soil fumigants with the herbicide pebulate comprised the main plots, while mulch types were the subplots. Fumigants levels in main plots were: a) untreated control, b) methyl bromide + chloropicrin (67/33%, respectively) at a rate of 400 kg ha^{-1}, c) chloropicrin at 400 kg ha^{-1} plus pebulate at 4.5 kg ha^{-1}, d) 1,3-dichloropropene at 325 kg ha^{-1} + chloropicrin at 67 kg ha^{-1} (83/17%, respectively) plus pebulate at 4.5 kg ha^{-1} and e) metam sodium at 485 kg ha^{-1} plus pebulate at 4.5 kg ha^{-1}. Subplots were either black low-density polyethylene film (0.038 mm thick) or black paper mulch (Appleton Paper Rolls, Appleton, Wisconsin, USA). These factors and levels combinations resulted in ten possible treatments.

Pebulate was applied directly to the soil by using a tractor mounted three-nozzle boom with 8004 flat fan nozzles, calibrated to 275 L ha^{-1} and pressurized to 240 kPa. Immediately after pebulate spraying, all plots, including those not receiving the herbicide, were rototilled within 15 to 20 cm of the soil. Afterwards, beds were formed and pressed (0.15 m tall by 0.75 m wide) and all soil fumigants, except MNa, were injected with a standard pressurized fumigation rig on tractor-mounted bedder equipment. Three chisels per bed spaced 30 cm apart were used. Fumigant flow was controlled by a flowmeter, which was calibrated to deliver the specified quantity of fumigant about 5 cm below the bottom of each finished bed. The fumigant metam sodium was sprayed on the surface of finished bed during the same day as the other fumigants. Immediately after fumigant applications, beds were covered with their respective mulch. All treatments received 15-0-25 (N-P-K) as a started fertilizer at a rate of 285 kg ha^{-1}.

Single tomato rows were planted on top of the beds. Raised beds were 0.75 m apart and tomato plants were transplanted at 0.45 m apart. Experimental units were a single bed of 10.67 m long (approximately 8 m^2). Drip irrigation was provided according to the water requirements of the crops. Subsurface irrigation was continuous to maintain a water table at 45 cm from the bed surface. Insecticides and fungicides were applied weekly beginning 3 weeks after transplanting following current recommended practices[9].

Tomato plant vigor was estimated as an indicator for plant growth and toxicity caused by fumigants or the herbicide. This variable was determined at 4 and 8 weeks after transplanting, using a scale from 0 to 100%, where 0% equals total plant death and 100% indicates no visible damage. Purple nutsedge density was determined by counting emerged plants within the whole area of each treatment at 10 weeks after transplanting for both early and late spring trials. Plants with symptoms of Fusarium wilt, Fusarium crown rot and rootknot nematode were counted within each experimental unit every week beginning at 4 weeks after transplanting and final counts were made the day of final fruit harvest. There were two tomato harvests during each trial (12 and 14 weeks after transplanting). Tomato fruits were counted and graded following current market standards. Those grades are a) cull (non-marketable fruits), b) medium, c) large and d) extra large.

Data collected for tomato plant vigor was normalized with arc sin transformation, while purple nutsedge densities were transformed with a log+1 function. Resulting values were submitted to analysis of variance and significant differences ($p \leq 0.05$) among treatment means were separated by Waller-Duncan K-ratio test. With respect to soilborne disease and nematode data, incidence or number of infected plants were analyzed with analysis of variance, whereas disease severity was assessed by calculating Fusarium crown rot (CRI) and rootknot nematode indexes (RNI) as follows:

CRI = [(vsl x 1) + (sl x 2) + (m x 3) + (sv x 4) + (vsv x 5)]/(vsl + sl + m + sv + vsv);

RNI = (sl x 1) + (m x 3) + (sv x 5)]/(ni + sl + m + sv);

where vsl, sl, m, sv, vsv and ni represent the number of plants with very slight, slight, moderate, severe, very severe and no infected. The resulting values were examined with the Friedman's nonparametric test (p=0.05) and ranked means were separated with a Waller-Duncan K-ratio test.

RESULTS AND DISCUSSION

There were no significant trial by treatments interactions for all the variables. Therefore, only the data from one of the trials will be discussed. In the early spring trial, there were significant fumigant and mulch type effects for plant vigor, but not for the interaction between the main effects. The lowest vigor values at 4 and 8 weeks after transplanting were obtained when no fumigant was applied (82 and 80%, respectively) and with paper mulch (90 and 82%, respectively) (Table 1). No significant differences were found among all fumigants applied, with averaged plant vigor of 90 and 88% at 4 and 8 weeks after transplanting, respectively. Plastic mulch treatments resulted in highest overall tomato vigor than plots with paper mulch.

At 10 weeks after transplanting, purple nutsedge density was significantly affected by fumigants applied, but not by mulch types or the interaction between both factors. The non-fumigated controls averaged 29.3 plants m^{-2}, which was higher than the fumigated treatments (Table 1). These fumigated plots did not differ among themselves and none exceeded 2 purple nutsedge plants m^{-2}. With regard to Fusarium wilt, Fusarium crown rot and rootknot nematode damages, there were significant fumigant effects beginning at 4 weeks after transplanting on disease and nematode incidence, based on the number of infected plants. However, mulch types and fumigant by mulch type interaction were not significant. At 14 weeks after transplanting, the non-fumigated control had the highest number of wilted plants by Fusarium (12400 plants ha^{-1}), while no differences among treatments that received fumigants (Table 2). At the same time, Fusarium crown rot followed the same trend observed with Fusarium wilt. With respect to rootknot nematode, at 14 weeks after transplanting there were no significant differences among chloropicrin, metam sodium and the non-fumigated check, which resulted in an average of 9,000 galled plants ha^{-1} (Table 2). Methyl bromide and the combination of 1,3-dichloropropene + chloropicrin showed the lowest root galling incidence. Crown rot index (CRI) revealed severe Fusarium crown rot damage in the non-fumigated control (CRI≈4). All remaining treatments showed from very slight (CRI≈1) to slight (CRI≈2) crown rot damage. Root galling severity (RNI) was almost not present (RNI<1) in methyl bromide and 1,3-dichloropropene + chloropicrin treatments, while slight to moderate galling was observed with the remaining fumigants (Table 2).

Tomato fruit number and weight were significantly influenced by both fumigant and mulch types, but not by the interaction between both factors. Within fumigants, lowest total fruit number and weight were observed with non-fumigated control, while no differences were found among other treatments (Table 3). This yield reduction represented losses of 23 and 22% in fruit number and weight with respect to the average means of other treatments. In all cases, the non-fumigated check had the lowest fruit number and weight for each tomato grade. For mulch types, low-density polyethylene mulch had the highest yield, increasing approximately 10 and 12% for fruit number and weight, respectively (Table 3).

Based on the data collected in these studies, it appeared seasonal changes during the planting dates for both trials did not cause different responses to mulch types. In the early spring trial, average air and soil temperatures during the first 30 days were 23.2 and 20.3°C, respectively. In contrast, average air and soil temperatures were 25.2 and 23.1°C, respectively, for the same period in the late spring trial. At the same time, changes in daylight duration from February to March 1998 did not have an impact in the crop responses. Although previous reports have showed that temperature and day length variations have an impact on purple nutsedge emergence and interference with crops[10-13] the extent of these variations in these trials did not cause major changes in crop responses, which indicated that the tested fumigants and mulch types cause significant impact on soilborne pest and weed populations in tomato under a broad range of environmental conditions.

During both trials, purple nutsedge showed to be a strong limiting factor for tomato growth and development. An example of this occurrence is the non-fumigated control during the early spring trial, which had the highest purple nutsedge population and lowest plant vigor. Rootknot nematode, Fusarium crown rot and Fusarium wilt appeared to play an important role in reducing tomato yield in the non-fumigated control. Similar results have been previously reported[14-16].

Table 1: Effect of fumigants and pebulate combinations and mulch types on tomato plant vigor

				Plant vigor (%)[z]		Purple nutsedge density[y]
Fumigants	Rate (kg ha^{-1})	Pebulate	Rate (kg ha^{-1})	4 WAT	8 WAT	Plants m^{-2}
None	----	None	----	82.3b	80.1b	29.3a
MBr	400	None	----	95.3a	89.0a	0.1b
Pic	400	PPI	4.5	92.8a	88.6a	0.3b
MNa	485	PPI	4.5	96.8a	85.8a	0.9b
1,3-D + Pic	325 + 67	PPI	4.5	94.9a	87.3a	1.7b
Mulch						
Plastic				95.0a	91.5a	---
Paper				89.8b	81.8b	---

[z]Data transformed through arc sin and means separated within columns by Waller-Duncan K-ratio (p=0.05)

[y]Data for 11 weeks after transplanting (WAT) transformed through (log + 1) and means separated within columns by Waller-Duncan K-ratio (p=0.05)

Table 2: Effect of soil fumigants and pebulate on Fusarium wilt (FW), Fusarium crown rot (CR) and rootknot nematodes (RN)

				Infected plants x 1000/ha[z]			Indexes[y]	
Fumigants	Rate	Pebulate	Rate (kg ha^{-1})	FW	CR	RN	CRI	RNI
None	----	None	----	12.4a	11.3a	11.6a	3.87a	1.73a
MBr	400	None	----	0.2b	0.4c	0.1b	0.75c	0.01b
Pic	400	PPI	4.5	0.2b	1.6bc	9.5a	2.00bc	1.58a
MNa	485	PPI	4.5	0.3b	3.2b	12.1a	1.70bc	1.63a
1,3-D + Pic	325 + 67	PPI	4.5	1.2b	1.9bc	0.1b	2.49b	0.01b

[z]Data means separated within columns for each factor by Waller-Duncan K-ratio (p=0.05)

[y]Crown rot (CRI) and rootknot nematode indexes (RNI) analyzed with Friedman's non-parametric test (p=0.05) and mean ranks separated with Waller-Duncan K-ratio (P=0.05)

Table 3: Effect of fumigants and pebulate combinations and mulch types on marketable-graded tomato fruit number and weight

				Number (x 1000)/ha[z]				Weight (t ha^{-1})			
Fumigants	Rate (kg ha^{-1})	Pebulate	Rate (kg ha^{-1})	Extra large[y]	Large	Medium	Total	Extra large	Large	Medium	Total
None	----	None	----	154.5b	95.6c	86.4c	336.5b	36.3c	17.1c	11.6c	65.0b
MBr	400	None	----	180.1a	141.9a	145.3a	467.3a	40.6bc	25.2a	19.8a	85.6a
Pic	400	PPI	4.5	184.2a	127.6ab	126.0ab	437.8a	43.1ab	21.6b	17.2ab	81.9a
MNa	485	PPI	4.5	194.1a	117.4bc	104.2bc	415.7a	47.3a	22.0ab	15.3b	84.6a
1,3-D + Pic	325 + 67	PPI	4.5	170.3ab	136.8ab	131.4a	438.5a	38.5bc	23.5ab	17.9ab	79.9a
Mulch											
Plastic				187.4a	129.0a	122.8a	439.2a	43.9a	22.8a	17.2a	83.9a
Paper				165.8b	118.7a	114.5a	399.0b	38.4b	20.9a	15.5a	74.8b

[z]Data means separated within columns by Waller-Duncan K-ratio (p=0.05). [y]5 x 6, 6 x 6 and 7 x 6 are medium, large and extra large fruits, respectively

As indicated earlier, purple nutsedge leaf tips can easily penetrate through stretched surfaces of low-density polyethylene films, thus growing mostly above the mulch surface. In contrast, because paper mulch is loosely placed on beds surfaces, the weed growing tips tend to bend inwards and grown below the mulch surface. As showed by the present results, this change in growth habit might account for the tomato yield and vigor and purple nutsedge growth differences in treatments where the same fumigants were applied, but different mulch types were present.

From the tomato yield standpoint, low-density polyethylene mulch was a better alternative than paper mulch. However, paper mulch should be further studied as a tool within an integrated management program for purple nutsedge because it could reduce its interference with the crop. Also, knowing that there were differences in the performance of some fumigants where they were applied under plastic film as compared with paper mulch, it gives an indication that those fumigants could volatilize faster under paper mulch than under polyethylene film. Previous reports have addressed fumigant volatilization, indicating that nutsedge control sharply decreases as fumigant losses increase[17]. However, fumigants, such as metam sodium, appeared not being affected by either mulch type. This fumigant, chloropicrin alone and 1,3-dichloropropene + chloropicrin seemed to be viable alternatives to replace methyl bromide. The efficacy of the 1,3-dichloropropene + chloropicrin combination on soilborne diseases and nutsedge in tomato fields has been previously emphasized[18]. Further studies should consider the role of fumigant volatilization on soilborne disease, nematode and weed control in tomato.

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