Effects of Soil Solarization with Different Plastic Films on Yield Performance of Strawberry Protected Plantations in Sicily

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Keywords: *Fragaria* × *ananassa*, mulching, soil fumigation, soil temperature, colored film

Abstract

Two main alternatives to replace methyl-bromide soil fumigation are soil solarization, which is feasible in geographical areas with high solar radiation, and the combination of the nematocide 1,3-dichloropropene (1,3-D) and the fungicide chloropicrin (Pic) applied through drip irrigation lines. The objective of this two-year study was to evaluate solarization and fumigation with 1,3-D + Pic as preplant soil treatments for plasticulture strawberry production in the northern coast of Sicily. Plots to be solarized were covered with transparent polyethylene (PE) or with green ethylene-vinylacetate (EVA) film mulches and left undisturbed for 69 and 77 days in 2009 and 2010, respectively. Freshly bare rooted plants and containerized plants were transplanted in the first and second year, respectively. Cultivars 'Candonga' and 'Nora' were tested using standard plasticulture practices. Soil temperatures recorded in PE solarized plots were higher than 37°C for 792 and 750 hours, in 2009 and 2010 respectively, whereas cumulative exposure above 37°C in green-EVA film solarized soil was 615 and 592 hours in the first and second year, respectively. These temperature are considered lethal for several soil pathogens. In both years, regardless of the cultivars tested, total marketable fruit yields in fumigated and solarised plots were significantly higher than in the untreated plots. Our results demonstrated the efficiency of solarization with either transparent-PE or green-EVA mulching films as alternative to 1,3-D + Pic soil preplant treatment. The green-EVA plastic mulch, was designed to be kept on soil after the end of soil solarization during the cropping season because it prevents infestation with weeds and therefore may need not to be replaced by traditional black plastic mulch. The green-EVA film induced both thermal regimes and fruit yields comparable to those obtained under conventional PE film. Therefore, it was concluded that its use would be a feasible option and a considerable reduction of plastic waste.

INTRODUCTION

The estimated world total area harvested for strawberry in 2010 was 243,907 ha with a total production of 4,366,662 tons (FAOSTAT). Italy ranks eleventh (153,875 tons) in strawberry fruit world production after USA, Turkey, Spain, Egypt, Korea, Mexico, Japan, Poland, Russia, and Germany. More than 60% (almost 3,300 ha) of the Italian strawberry production is currently located in the southern regions and in the island of Sicily. More than 300 hectares of strawberry plantations are concentrated on the northwestern coast of Sicily where mild winters and the use of plastic films have favored the rapid development of strawberry production under multi-span tunnels. Soil diseases are a main concern for Italian strawberry growers who frequently face yield decreases due to a complex of lethal and sub-lethal soilborne pathogens (Ciccarese and Cirulli, 1983; Tamietti and Valmaggia, 1994). The soil fumigant methyl bromide which has been used for many years by Italian strawberry growers for eliminating serious diseases, nematodes and weeds has been phased out in compliance with the Montreal Protocol. Solarization, achieved by covering moist, preirrigated soil with polyethylene film, is an effective method of soil disinfestations for high-value crops grown in areas with hot summers (Stapleton, 1996; Katan, 2000) and a viable alternative to methyl bromide fumigation

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(Hartz et al., 1993; Rieger et al., 2001). The Sicilian coastal areas, like other regions with Mediterranean climate, have appropriate environmental conditions to apply soil solarization in strawberry planting (Iapichino et al., 2008). Commercial strawberry fields in Sicily are annually established by various runner type plants. The use of both freshly bare root and containerized transplants is increasing in importance in the Sicilian strawberry industry. Compared to cold stored plants, fresh plants enhance earliness and fruit quality, maximize use of available water resources and extend the harvesting period. Furthermore, planting in the fall with fresh plants as opposed to summer planting with frigo-plant prolongs the time for soil solarization and therefore improves the efficiency of this pre-planting method for controlling soil-borne diseases and pests. This in turn has encouraged its adoption in commercial practice. Solarization is also known to enhance plant growth in the absence of major pathogens, by increasing the concentration of mineral nutrients, improving the soil structure, stimulating the growth of soil beneficial microorganisms and by inhibiting harmful but non pathogenic microorganisms (Katan, 1981). Currently another alternative to replace methyl-bromide soil fumigation is the combination of the nematocide 1,3-dichloropropene (1,3-D) and the fungicide chloropicrin (Pic) applied through drip irrigation lines. This disinfection treatment is currently preferred by Sicilian growers because has been proved to be effective against nematodes and fungal pathogens (Csimos et al., 2000; D'Anna et al., 2007). The objective of this two-year study was to compare solarization (with PE or green-EVA films) and fumigation with 1,3-D + Pic as preplant soil treatments for plasticulture strawberry production in the northern coast of Sicily.

MATERIALS AND METHODS

The research was conducted for two years in a commercial strawberry field at Marsala (long. 12°26'E, lat. 37°47'N) in the North-western coast of Sicily (Italy) between June 2009 and May 2011. The field trial was conducted in a sandy litosoil (80% sand, 8% silt and 12% clay). The soil had a two year history of 1,3-D + Pic fumigation and had been used during the last three years for strawberry production. At the end of May of each year of the study, the field was plowed and rototilled to incorporate 50N-150P-150K kg·ha^{-1}. The field was worked into raised beds, 20 cm high and 72 cm wide, in early June of each year. Preplant soil treatments, consisting of solarized, 1,3-D + Pic fumigated and untreated plots, were applied to the same areas of the field for the entire trial duration. In both years, solarization was conducted for 9-11 weeks during early July to late September. Plots to be solarized were covered with a 40-µm-thick linear low density (PE) transparent polyethylene (PE) film (SI.SAC. S.p.a., Italy) or with a 50-µm-thick photo-selective film (SI.SAC. S.p.a., Italy) produced by the coextrusion of a layer of 25-µm-thick uncolored ethylene-vinylacetate (EVA) film and a layer of 25-µm-thick green-colored EVA. The green color of the EVA film filters out over 90% of the photosynthetic active radiation (PAR) and transmits near infra-red radiation; it is designed to be maintained on soil after the end of soil solarization during the cropping season. All plots were irrigated to field capacity and left undisturbed for 69 and 77 days in 2009 and 2010, respectively. During the solarization period, soil temperature was measured using thermocouple probes positioned at 15 cm depth in the center of the bare and solarized beds and connected to a microprocessor logging thermometer (Hanna Instruments, R.I., USA). The data logger was programmed at a scan rate of 15 min and averaged hourly. Soil plots receiving 1,3-D + Pic were mulched with virtually impermeable black film (VIF) (30 µm thick) and the combination of 1,3-D + Pic was applied through drip irrigation lines at recommended dosage 16 and 18 g·m^{-2}, respectively. Untreated plots were neither solarized nor fumigated. After solarization and fumigant application, all plastic mulch films, except the green-EVA film designed to be kept on soil during the cropping season, were removed from the plots and soil beds, including those of the untreated plots, were covered with black polyethylene mulch. One drip irrigation line per bed was buried 5 cm deep. Two cultivars, 'Candonga' and 'Nora' were tested.

Planting occurred at a density of 7.7 plants·m^{-2}. In the first year of this study, freshly bare rooted plants were transplanted through the mulch in the first week of October, whereas in the second year containerized plants were transplanted in the first week of September. Each bed contained two rows of plants, spaced 40 cm apart between rows and 26 cm within rows with beds spaced 1.0 m on center. Each plot consisted of two beds, each 8 m in length. Plants were cultivated using standard plasticulture practices. The experiment was a split-plot design with preplant soil treatments as the main plots and the cultivars as the subplots. Each soil x cultivar treatment had three replicates. In all years multispan plastic (transparent PE) tunnels supported by wire hoops were placed over the soil beds in the first week of December. Data were collected on number of shoots per crown by the end of December, cumulative marketable yield by March 31 (early yield) and by May (total yield) and average fruit weight. Marketable productivity by March was included as it provides the highest return to Sicilian strawberry growers. Fruits were harvested in all the plants of each plot at the stage of full ripeness when complete fruit surface was red. Total soluble solids (TSS) were evaluated using a refractometer (Atago Co. Ltd., Tokio) on a random sample of 10 fruits taken from each replicate-treatment. Fruit firmness was measured on a random sample of 10 different fruits per replicate using a penetrometer (Chantillon model) with a 6-mm^2 surface needle. Data collected were analyzed separately for each year because of different planting time and type of plants used in the first year compared with the second. All data were subjected to analysis of variance (ANOVA) and mean separation was performed by Duncan's multiple range test.

RESULTS AND DISCUSSION

Preliminary researches (D'Anna and Iapichino, unpublished) have shown that along the Sicilian coastal areas a minimum of 60 days of soil solarization is required to maintain soil temperature above 37°C for 500 hours. Based on this assumption, we adopted a soil solarization exposure of 69 and 77 days in 2009 and 2010, respectively. In the present study, thermal accumulation in the bare-soil plots never exceeded 35°C; therefore only the number of hours during which the soil temperature exceeded threshold values from 37 to 45°C are shown (Table 1). Temperatures recorded in 2009 in PE solarized soil were higher than 37, 40, and 45°C for 792, 411, and 50 hours, respectively. Soil thermal accumulation under green-EVA film was slightly inferior to that recorded under transparent PE as 615, 320, and 42 hours were recorded above 37, 40, and 45°C, respectively. This difference can been attributed to the light transmission characteristics of the films tested. Vitale et al. (2011) found similar results in comparisons of PE transparent and green-EVA mulching films in solarization trials performed in southern Sicily. Temperatures developed in 2010 were lower than those observed in 2009 possibly due to a solarization period characterized by sunny conditions unusually interrupted by broken cloud cover cumulus. However, the trend of thermal accumulation observed under both mulching films was similar to that of the first year. Our observations indicated that solarization treatments with either PE transparent or green-EVA mulching films produced, for an extended period of time, soil temperatures between 37 and 50°C, which are considered lethal for several soil pathogens (Pullman et al., 1981).

The interaction between soil treatments and cultivars was not significant for either the 2009 or the 2010 season, therefore, for all the parameters tested, only main effects are presented. In both years, regardless of the cultivars tested, the number of shoots per crown in the fumigated and solarized plots was significantly higher than in the untreated plots. D'Anna et al. (2007) found similar results in strawberry solarization trials performed in Sicily testing cultivar 'Tudla'. In both years, no significant difference was found in terms of number of shoots per crown between the cultivar 'Candonga' and 'Nora' (Tables 2 and 3). Fruit yield data are presented as cumulative yield per strawberry plant for each year. In both years, early marketable yield was not affected by soil treatments. In the first year trial, regardless of the cultivar tested, the combination of 1,3-D + Pic gave the highest total marketable yields, followed by solarization with PE film, which in turn gave higher yields than solarization with green-EVA film. However, there was no significant difference in fruit production between transparent PE plots and green-EVA plots. Untreated plots gave the lowest total marketable fruit yield. Based on visual observation, soil-borne pathogens affecting strawberries were not monitored in untreated plots. However, many factors, including reduced plant vigor, decreased concentration of mineral nutrients, increasing weeds and generally less favorable environmental growing conditions might have negatively affected transplant growth in untreated plots and consequently exerted a significant influence on strawberry performance and yield. In the successive season, total marketable yields produced in 1,3-D + Pic fumigated plots, PE and green-EVA solarized plots averaged over the cultivars were 505, 524, and 520 $g \cdot plant^{-1}$, respectively. These yields, again were significantly higher than those on untreated plots. Solarization in the absence of major pathogens, is known to enhance plant growth by increasing the concentration of mineral nutrients, improving the soil structure, stimulating the growth of soil beneficial microorganisms and by inhibiting harmful but non pathogenic microorganisms (Katan, 1981). In both years, regardless of the soil treatment, 'Nora' gave significantly higher early and total yields than 'Candonga'. Average fruit weight and number of fruits per plant averaged over the cultivars generally paralleled total marketable yields. In 2009, regardless the soil treatments, 'Nora' produced a significantly higher number of fruits per plant than 'Candonga'. However, no difference in terms of number of fruits per plant were detected in 2010. This response might be attributed to the different type of runner plants (freshly bare rooted plants in the first year and containerized plants in the second year) used during the two-year trial. In both years, fruit firmness and TSS detected in untreated plots were significantly lower than in fumigated and solarized plots. No significant difference in fruit firmness and TSS were found among 1,3-D + Pic fumigated plots, transparent PE plots and green-EVA plots. Regardless of the soil treatments, in both years 'Candonga' and 'Nora' showed almost equivalent TSS, whereas fruit firmness was always significantly higher in 'Candonga'.

Our results demonstrated the efficiency of solarization with either PE transparent or green-EVA mulching films as alternative to 1,3-D + Pic soil preplant treatment for plasticulture strawberry production in the northern coast of Sicily. The green-EVA plastic mulch, was designed to remain in place for the entire duration of the crop because it prevents infestation with weeds and therefore may need not to be replaced after solarization by traditional black plastic mulch. In the present, study the green-EVA film induced both thermal regimes and fruit yields comparable to those obtained under conventional PE film, as a consequence its use would be a feasible option and a considerable reduction of plastic waste. This knowledge represents a further step toward the adoption of soil solarization in commercial practice.

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Tables

Table 1. Thermal accumulation in the soil solarization treatments in 2009 and 2010.

Mulch	Cumulative hours above 37°C		Cumulative hours above 40°C		Cumulative hours above 45°C	
	2009	2010	2009	2010	2009	2010
Transparent PE	792	750	411	390	54	50
Green-EVA	615	592	320	307	42	40

Table 2. Strawberry vegetative and productive characteristics in 2009.

	Shoots/crown (n.)	Early mark. yield (g/plant)	Total mark. yield (g/plant)	Early fruit weight (g/fruit)	Total fruit weight (g/fruit)	Fruits/plant (n.)	TSS (Brix°)	Fruit firmness (g)
Soil treatments								
1,3-D + Pic	3.6a[z]	200.0a	709.5a	22.2a	19.5a	36.7a	7.8a	660a
Transp. PE	3.6a	213.5a	678.0 ab	21.0b	19.1a	35.6a	7.8a	675a
Green-EVA	3.8a	213.4a	658.2b	21.2b	19.1a	34.8a	7.9a	671a
Bare soil	2.4b	193.5a	465.0c	20.0c	14.9b	31.2b	6.5b	525b
Cultivar								
Candonga	3.4a	181.5b	602.0b	21.3a	20.6a	29.9b	7.3a	661a
Nora	3.5a	228.5a	665.7a	18.1b	18.0b	36.6a	7.7a	604b

[z]Values within columns that are followed by the same letter are not significantly different at P=0.05 using Duncan multiple range test.

Table 3. Strawberry vegetative and productive characteristics in 2010.

	Shoots/crown (n.)	Early mark. yield (g/plant)	Total mark. yield (g /plant)	Early fruit weight (g/fruit)	Total fruit weight (g/fruit)	Fruits/plant (n.)	TSS (Brix°)	Fruit firmness (g)
Soil treatments								
1,3-D + Pic	2.8a[z]	140.1a	505.0a	21.1a	18.1a	28.0a	8.4a	648a
Transp. PE	2.7a	135.2a	524.0a	22.2a	18.3a	28.7a	8.2a	639a
Green-EVA	2.7a	135.0a	520.5a	21.0a	18.4a	28.4a	8.3a	644a
Bare soil	1.4b	135.3a	373.3b	20.7a	15.3b	24.6b	6.7b	557b
Cultivar								
Candonga	2.3a	113.5b	457.7b	21.2a	17.7a	25.9a	7.7a	674.5a
Nora	2.7a	159.2a	503.0a	20.8a	17.4a	29.0a	8.1a	569.5b

[z]Values within columns that are followed by the same letter are not significantly different at P=0.05 using Duncan multiple range test.