Eco-Compatible Plastic Films for Crop Mulching and Soil Solarization in Greenhouse

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Abstract

The study was conducted in 2002-2004 close to Experimental Farm "Pantanello" (Lat. 40°20' N; Long. 16°48' E) located in Southern Italy (Basilicata Region). Tomato mulching was studied by using several innovative films (three co-extruded and three biodegradable ones), compared with a traditional film (LDPE), and on soil solarization conducted from July to September 2002 and 2003 by using two different innovatory plastic films (a co-extruded and a biodegradable one) compared to LDPE and EVA. Moreover, in order to evaluate the efficiency of soil solarization, two vegetable crops were grown: melon after the first soil solarization and lettuce after the second one. For each vegetable crop, yield, quality traits, root-knot nematodes and weeds, were analysed. For mulching trials, co-extruded films, in the first trial, and the lactescent biodegradable one, in the second trial, increased soil temperatures and had better agronomic results, in terms of yield traits, respect to the other mulching films, both traditional (LDPE) and innovative ones. Weed control was performed by all the tested films except for the lactescent biodegradable one in the second trial. In soil solarization experiments, the two innovatory films had the same agronomic and nematological results (in melon crop) respect to LDPE and EVA. All the solarizing films controlled weeds reducing their number by 72% and 97% in melon and lettuce crop, respectively.

INTRODUCTION

Among different agronomic techniques, mulching by using plastic films represents for vegetable crops, even in greenhouse cultivation, one useful practice to improve soil temperature and, simultaneously, a better alternative to the use of chemicals compounds for weed control programs. Soil solarization is widely applied as an effective alternative to the use of fumigants (i.e., methyl bromide) for the control of root-knot nematodes and weeds (Katan, 1981). However, it must be noted that these techniques need large amounts of plastic materials, causing the production of enormous quantities of waste, whose inappropriate management may have negative effects on the whole agro-ecosystem. In fact, it is estimated that the annually use of plastics in agriculture is about 2.9 million tons around the world (Jouët, 2001, 2004). This constitutes a problem more and more evident in terms of environment and economy as far as management and disposal of plastics.

The problem can be partly solved by using both co-extruded ultrathin films, which are able to reduce the plastic quantity to be managed per unit area, and biodegradable films, that spontaneously start up a degradation process after their application (Castronuovo, 2003). This study conducted in Southern Italy (Basilicata Region) evaluated co-extruded multilayered ultrathin films and biodegradable ones for tomato mulching and for melon and lettuce soil solarization.

MATERIALS AND METHODS

Trials were conducted at "Pantanello" experimental farm (40°20'N; 16°48'E) in Metaponto area (Southern Italy), using an unheated plastic-greenhouse having a metallic structure, covered by a LDPE film, 200 µm thick, and with a volume/surface index of 3.0 m^3 m^{-2}. The greenhouse soil was sandy type (82.7% sand, 8.9% limestone and 8.4% clay), with a pH of 8.4, poor in total nitrogen (0.5 g kg^{-1}), very poor in organic matter content (3.3 g kg^{-1}) and well-supplied with phosphorus (28.4 mg kg^{-1}) and with exchangeable potassium (307.0 mg kg^{-1}).

For tomato mulching, three co-extruded (LDPE-EVA-LDPE) ultra thin mulching films, 20, 25 and 30 µm thick, brown (used in the 2nd trial only), silver and yellow in color respectively, two black biodegradable films 12 and 15 µm thick plus a lactescent biodegradable one 40 µm thick (used in the 2nd trial only) and a black LDPE film 50 µm thick, functioning as a control, were studied.

Placement of the film was performed by hand on soil strips (0.8 m wide) after correctly ploughing it down to a depth of 0.3 m and successively milled. The mulching treatments were arranged in a randomized block design with 3 replications, considering also an un-mulched soil as control. During mulching trials soil temperatures were monitored at 20 cm depth every 30 minutes by precision probes (PT 100) and recorded by a CR10x data-logger.

The transplanting occurred on March 28, 2002 and on March 12, 2003 by using seedlings of tomato (*Lycopersicon esculentum* Mill. cv. Tomito F_1) at the stage of 3rd - 4th true leaf; the row distance was 1.80 m, while the distance between plants on the rows was 0.30 m, in order to obtain a density of 1.85 plants per m^2. A drip irrigation system was applied by means of drippers of 2.5 L h^{-1} placed under the mulching films at 0.20 m on the rows. The harvesting, performed in the first trial on June 17 and on June 27, 2002, and in the second trial on June 13, 20 and 27, 2003, was conducted by picking all the tomato clusters which had at least 80% of their berries red in color.

At every harvest, number and weight of the picked clusters, both marketable and waste, were determined in each plot. Successively, on significant berry samples same qualitative traits were analyzed: mean weight, diameter, firmness (kg cm^{-2}), soluble solid (°Brix) and dry matter content. Furthermore, at the end of both crop cycle, all the weeds of each plot, emerging on the soil mulched samples (2 m^2), were botanically classified and counted. Crop earliness was evaluated by the Harvest Mean Time (HMT), that analytically is equal to the following formula $HMT\ (d) = \sum(p_1 \cdot d_1)\ldots\ldots(p_n \cdot d_n) / P$; where d is expressed in days and indicates the days from the first harvest; p indicates the yield for each harvest, and P indicates the cumulative yield at the last harvest.

Soil solarization treatments were applied from July 13 to September 13 during 2002 and 2003, on 30 m^2 plots, after rotavation and irrigation of the soil, by using two plastic films: a co-extruded one 25 µm thick and a biodegradable lactescent one 40 µm thick, compared to traditional plastic films: EVA 35 µm thick and LDPE 50 µm thick used as control. Plots were arranged in a randomized block design with three replications of each treatment. An un-solarized soil was considered the control. During solarization, soil temperatures were monitored at 10 and 30 cm depth. For each film, the number of hours above 40°C, assumed as the minimum effective temperature on soil pathogens (Katan, c.w.), was calculated.

To evaluate the efficiency of the soil solarization, two vegetable crops were grown: a melon crop (*Cucumis melo* L. var. *reticulatus* Naud. cv. Drake F_1), after the first soil solarization, in spring 2003 (from March 21 to July 6) and lettuce (*Lactuca sativa* L. var. *crispa* L. cv. Moringa F_1), after the second heated soil treatment, in spring 2004 (from March 19 to May 20). Melon plants were arranged at 2 m between rows and at 1 m within rows, and lettuce seedlings were placed at 0.5 m between rows and at 0.3 m within rows resulting in 0.5 and 6.7 plants m^{-2}, respectively.

In each melon plot, number and weight of marketable fruits were recorded on a 16 m^2 area (eight plants) and soluble solids (°Brix) and pulp dry matter content (%) were determined on ten fruits. Root-knot nematode gall index was measured on eight plants of each plot, according to a 0-5 scale (Di Vito et al., 1979) and weeds from a 2 m^2 sample area were counted and classified. In each lettuce plot, number and weight of marketable heads were determined on a 3 m^2 area. Head size (mean weight, diameter and length) was measured. Dry matter of leaves were also determined. Weeds from a 1 m^2 sample area were counted and classified.

In mulching and soil solarization trials, agronomic data were subjected to analysis of variance (ANOVA) and means were separated by Duncan's Multiple Range test. Samples of mulching and solarizing films, both new and conventional ones were periodically taken from each experimental plot and were mechanically characterized by using a computerized press Galdabini PMA 10. Mechanical measurements were conducted to determine the percentage stretch at break, according to the Italian Norm UNI 8422. For each film, as the rules required, ten samples were stretched to their breakage point, so that bilateral intervals with 95% probability could be calculated.

RESULTS

Tomato Mulching

In the first trial, both co-extruded films yielded more respect to the others and to the un-mulched soil; biodegradable ones had a similar behavior of traditional film (LDPE) (Table 1). In the second trial, the latescent biodegradable film had higher yield, reaching 58.5 t ha^{-1}, as compared with the other mulching films, except for the co-extruded brown that was statistically similar to the above biodegradable film, reaching 55 t ha^{-1}. However, every mulching film yielded more than the un-mulched soil except for the co-extruded silver. In both years, qualitative traits of berries were low and affected by mulching materials (not reported data). Crop earliness was statistically influenced by mulch technique in the second trial only, when the lactescent biodegradable film had the lowest value of HMT (7.8 days), due to the higher soil mean temperatures that it has been recorded (24.2°C) with respect to the other mulching films. In fact, the above film exceeded the un-mulching soil mean temperature of 2.9°C, while all the others averaged 1.6°C. In 2002, thermal behaviors of different mulching films were somewhat similar with each other with 0.5°C, differences from the control.

In 2002, mulching reduced on average 71% the number of weeds respect to the non-mulched control, with no differences among films. In 2003, the biodegradable lactescent film had the same statistically number of weeds as the control. All the other films slightly reduced weed number.

In 2002 and 2003, the new biodegradable films had the lowest percentage stretch at break that constantly decreased to very low values after about 70 days. All the new co-extruded ultrathin mulching films had values of percentage stretch at break similar to the LDPE, that lightly decreased in the first 40 days, to increase later and to decrease again near the end of the trial (Fig. 1).

Melon and Lettuce Yield as Affected by Soil Solarization

Solarization positively influenced some productive aspects of the melon cultivation (Table 3). In fact, the marketable yield of 17.8 t ha^{-1} for the control was surpassed to over 39 t ha^{-1}, on average, with all solarization films. The fruit number per plant increased from 2.5 (control) to about 5 (solarized plots). Among the qualitative traits, dry matter and soluble solid content (°Brix) of the fruit were higher with solarization than plastic films. The root gall-index of melon plants was higher in the un-treated plots than solarized plots. The floristic measurements conducted at the end of the melon cycle resulted in solarization practice with 72% reduction in the number of total weeds.

Lettuce yield was positively affected by soil solarization; in fact, the marketable yield was equal to 31.9 t ha^{-1} in the untreated soil and to 45.7 t ha^{-1}, on average, in the solarized soil without any differences among the 4 plastic laminates. The same trends were observed for head mean weight and their length. Finally, at the end of the lettuce cycle solarization technique, the number of total weeds per m^2 decreased up to 97% without difference among solarizing films.

The mechanical measurements on new solarizing biodegradable film at the start of trials were similar in values of percentage stretch at break compared to the other films (Fig. 2), nonetheless it rapidly decreased with time, until reaching 25%. The new co-extruded ultra-thin film registered the most elevated value of percentage stretch at break, equal to about 481%. The traditional films: EVA and LDPE had the same values of percentage stretch at break, as were found in previous tests (Fig. 2).

The duration as number of hours for each film at 10 and 30 cm depth, during which, the 40°C thermal limit was surpassed, was calculated for the entire period of solarization both in 2002 and in 2003. At 10 cm there are no differences among the tested films, even if the biodegradable film registered the highest number of hours during the temperature interval of 40-45°C; the co-extruded ultra-thin demonstrated the best thermal level in the interval 46-50°C, especially in 2003, followed by EVA, LDPE and biodegradable. In 2002, at 30 cm of depth, in the temperature range 40-45°C, the biodegradable resulted the most solarizing film, followed by the EVA, the LDPE, and by the co-extruded ultra-thin. In 2003, the best film was the EVA followed by the biodegradable, the LDPE and the co-extruded one (Table 2).

DISCUSSION AND CONCLUSIONS

In mulching trials, co-extruded films, in the first trial, and the lactescent biodegradable one, in the second trial, had increased soil temperatures and resulted in improved yield traits, as compared with the other mulching films (both traditional (LDPE) and innovative ones). Weed control was effective by all the tested films except for the lactescent biodegradable one.

The agronomic results confirmed the validity of solarization as a good physical mean of improving the productive levels of melon and lettuce yield in protected cultivation, both by quantitative and qualitative considered aspects. Solarization has more than doubled the marketable yield of the melon that was attributed to the control of the root-knot nematodes. The absence of galls on the roots in the solarized soil increased the number of fruits per plant, resulting in higher quality due to a higher content of dry matter and of soluble solids. Solarization increased lettuce yield, over 43%. In both crops, solarization reduced the emergency and the development of weeds in the solarized area, as was stated in previous works by Candido et al. (2002).

The new films, used for mulching and soil solarization, have demonstrated values of percentage stretch at break superior to the minimum required by the European norm prEN 13655. Specifically, it has been shown that only the biodegradable film was characterized by a rapid decline in mechanical characteristics. However, such a rapid decline was not accompanied by a reduction in thermal performance that was always similar to the other laminated plastics. Furthermore, a decline in mechanical properties of the biodegradable film is an expected behavior which is due mostly to the processes of degradation that the film undergoes during its use, in order to avoid its removal and disposal after its use.

In conclusion, this study supplied positive indications about the practices of mulching and soil solarization, confirming the efficiency of the use of eco-compatible plastic films, which guarantee, therefore, compatible agricultural practices and safeguard the environment through the reduction of plastic refuse and of the substitution of the methyl bromide use.

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Tables

Table 1. Yield, harvest mean time, dry weight of weeds and soil temperatures as affected by mulching in tomato (cv. Tomito F_1) vegetable crop.

MULCHING FILMS	TRAITS[1]						Soil temperatures (°C) at 20 cm depth	
	Yield (t ha^{-1})		Harvest mean time (days)		Total weeds[2] (n. m^{-2})			
	2002	2003	2002	2003	2002[2]	2003[3]	2002	2003
No film	23.5 B	44.4 D	12.5 A	12.0 A	19.3 A	15.3 A	21.9	21.3
LDPE	22.8 B	49.7 C	12.6 A	10.7 C	5.0 B	0.0 B	22.7	23.1
Biodegradable black 12 µm	24.2 B	48.4 C	12.4 A	11.2 AC	6.3 B	1.3 B	22.4	22.5
Biodegradable black 15 µm	22.3 B	51.4 BC	12.3 A	11.8 AB	9.7 B	1.0 B	22.3	22.6
Biodegradable lactescent	-	58.5 A	12.6 A	7.8 D	-	16.6 A	-	24.2
Co-extruded silver	29.5 A	46.5 CD	12.3 A	11.6 AC	3.7 B	0.9 B	22.3	22.7
Co-extruded yellow	28.1 A	54.7 B	12.2 A	10.6 C	3.3 B	0.0 B	22.5	22.9
Co-extruded brown	-	55.2 AB	12.4 A	10.9 BC	-	0.0 B	-	23.3

[1]Values within each trait are statistically different at the 0.05 P level (small letters) and at 0.01 P (capital letters).
[2]The following weed species are included in 2002: *Cyperus rotundus* L., *Portulaca oleracea* L., *Digitaria sanguinalis* (L.) Scop., *Setaria viridis* (L.) Beauv., *Melilotus sulcatus* Desf.
[3]The following weed species are included in 2003: *Cyperus rotundus* L., *Portulaca oleracea* L., *Digitaria sanguinalis* (L.) Scop., *Setaria viridis* (L.) Beauv.

Table 2. Duration of soil temperatures above 40°C at different depth during solarization treatments (hours).

SOLARIZING FILMS	Soil depth (cm)	Hours temperature interval (n.) 40-45°C Years 2002	2003	46-50°C Years 2002	2003	51-60°C Years 2002	2003
Biodegradable	10	563	374	232	266	5	103
	30	669	817	0	0	0	0
Co-extruded ultrathin	10	425	418	242	457	25	307
	30	612	567	0	216	0	76
EVA	10	543	416	242	418	5	302
	30	620	857	0	163	0	0
LDPE	10	410	410	261	379	65	232
	30	683	698	0	157	0	0
No film	10	74	289	0	166	0	0
	30	0	5	0	0	0	0

Table 3. Solarization effects on yield, root-knot nematodes and weed control of melon and lettuce vegetable crops.

TRAITS	SOLARIZING FILMS[1] Biodegra-dable	Co-extrused ultrathin	EVA	LDPE	No film
	Melon				
Marketable yield (t ha^{-1})	37.8 A	41.4 A	37.9 A	40.8 A	17.8 B
Marketable fruits per plant (n.)	4.9 A	4.9 A	4.7 A	5.5 A	2.5 B
Fruit soluble solids (°Brix)	11.4 a	10.9 a	11.5 a	10.9 a	9.7 b
Fruit dry matter (%)	8.6 a	8.9 a	8.5 a	8.4 a	7.4 b
Root-knot nematodes gall index (0-5)	0.3 B	0.4 B	0.1 B	0.3 B	3.6 A
Total weeds (n. m^{-2})[2]	9.3 B	6.3 B	7.0 B	6.0 B	25.7 A
	Lettuce				
Marketable yield (t ha^{-1})	45.1 A	46.6 A	44.2 A	47.0 A	31.9 B
Head size: mean weight (g)	695 A	739 A	693 A	747 A	576 B
Head size: length (cm)	15.6 a	15.8 a	15.4 a	15.7 a	14.7 b
Total weeds (n. m^{-2})[3]	3.3 B	0.3 B	2.7 B	2.7 B	82.0 A

[1]Values within each trait followed by different letters are statistically different at the 0.05 P level (small letters) and at 0.01 P (capital letters).

[2]The following weed species are included: *Cyperus rotundus* L., *Portulaca oleracea* L., *Setaria viridis* (L.) Beauv., *Digitaria sanguinalis* (L.) Scop.

[3]The following weed species are included: *Portulaca oleracea* L., *Setaria viridis* (L.) Beauv., *Solanum nigrum* L., *Amarantus retroflexus* L., *Cyperus rotundus* L., *Sonchus oleraceus* L.

Figures

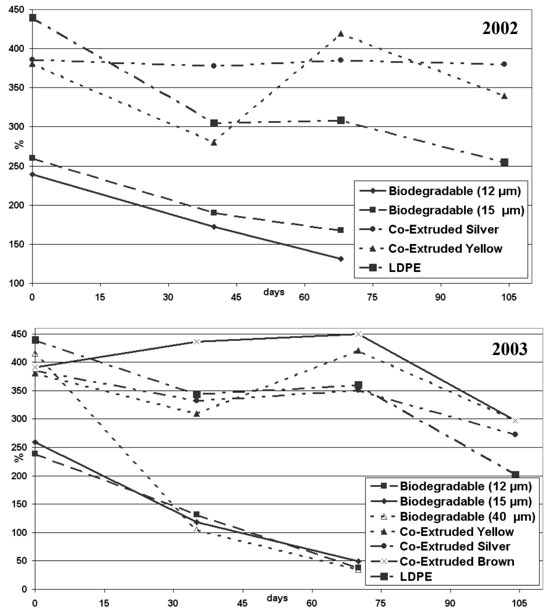

Fig. 1. Percentage stretch at break of mulching films in 2002 and in 2003.

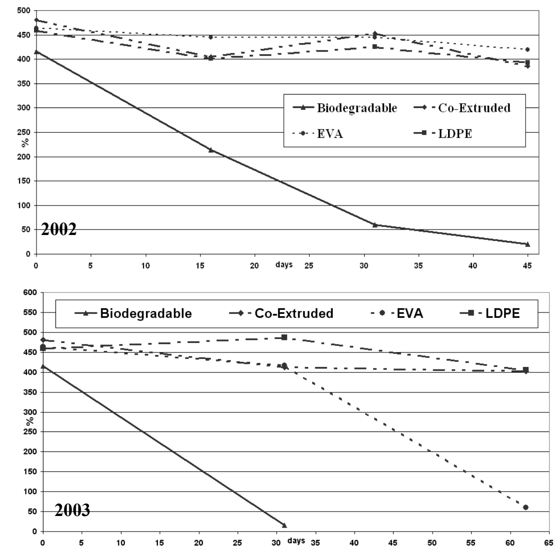

Fig. 2. Percentage stretch at break of solarizing films in 2002 and in 2003.