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Comparison of different mulch materials in a tomato (*Solanum lycopersicum* L.) crop

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Abstract

Black polyethylene as mulch is the most extended material among vegetable growers; however, photodegradable and biodegradable films have appeared as an alternative to conventional mulches due to the risk of the progressive contamination of soils. Reflective materials reflect back most of the incoming solar radiation, being recommended in areas characterized by high soil temperatures. We compared the effect of three mulches, black polyethylene, black biodegradable corn starch plastic and aluminized photodegradable plastic on a tomato crop in an open field. We measured mulch deterioration, soil temperature under mulches, tomato yield and fruit quality attributes (total soluble solids, firmness, dry weight, juice content and shape). Biodegradable mulch performed its function successfully and disappeared visually from the soil about three months after the crop was finished. Photodegradable mulch deteriorated prematurely and polyethylene film was practically intact at the end of season. Significant differences in mean soil temperature under mulches were observed (27.8ºC in biodegradable, 28.7ºC in aluminized and 31.8ºC in polyethylene), although they did not have a marked effect on the crop yield. Marketable yields were similar in both biodegradable and polyethylene mulches (9.82 and 8.66 kg m^{-2}, respectively), and higher than those recorded in aluminized photodegradable mulch (6.85 kg m^{-2}), which resulted in the highest sunscald in fruits. No effect on the fruit quality attributes was observed. Biodegradable plastic mulches could be a good alternative to the traditional plastic films, and aluminized photodegradable mulches seem not very advisable because they reduce marketable yield and could increase the incidence of sunscald.

Additional keywords: biodegradable mulch, fruit quality attributes, photodegradable mulch, polyethylene mulch, reflective mulch, soil temperature, yield.

Resumen

Comparación de diferentes materiales de acolchado en un cultivo de tomate (*Solanum lycopersicum* L.)

El polietileno negro es el acolchado más utilizado por los horticultores; sin embargo, debido al riesgo de progresiva contaminación de los suelos, han aparecido materiales fotodegradables y biodegradables como alternativa a los convencionales. Los materiales reflectivos reflejan la mayor parte de la radiación solar incidente, siendo recomendados en zonas con altas temperaturas de suelo. Se ha comparado el efecto de tres acolchados, polietileno negro, plástico negro biodegradable de almidón de maíz y plástico aluminizado fotodegradable, en un cultivo de tomate al aire libre. Se ha controlado su deterioro visual, la temperatura del suelo, la cosecha y parámetros de calidad de los frutos (sólidos solubles, firmeza, peso seco, jugosidad y forma). El material biodegradable cumplió con éxito su función y desapareció visualmente unos tres meses después de finalizar el cultivo. El fotodegradable se deterioró rápidamente y el polietileno negro permaneció prácticamente intacto al final del ciclo. Se observaron diferencias significativa en las temperaturas medias del suelo bajo los acolchados (27,8ºC en biodegradable, 28,7ºC en aluminizado y 31,8ºC en polietileno), aunque sin marcado efecto sobre la cosecha. Las producciones comerciales fueron similares en biodegradable y polietileno (9,82 y 8,66 kg m^{-2}, respectivamente), superiores a las del aluminizado fotodegradable (6,85 kg m^{-2}), tratamiento con mayor incidencia de frutos asolanados. No se han observado diferencias en los parámetros de calidad del fruto. Los acolchados con plásticos biodegradables constituyen una buena alternativa a los tradicionales, mientras que los aluminizados fotodegradables no parecen aconsejables porque reducen la producción comercial y pueden incrementar el asolanado en frutos.

Palabras clave adicionales: acolchado biodegradable, acolchado fotodegradable, acolchado reflectante, parámetros de calidad, polietileno, producción, temperatura del suelo.

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Abbreviations used: BER (blossom-end-rot), CE (European Community), DAT (days after transplanting), LLDPE (linear low density polyethylene), LSD (least significant difference), sh (solar hour), SIA (Servicio de Investigación Agraria), TmoV (*Tomato mottle virus*).

Introduction

For decades, a common practice among the vegetable growers in Central Spain has been the use of non-degradable plastic mulches in open fields, mainly for spring-summer season vegetable crops such as tomato, pepper, melon, watermelon, etc., for a variety of reasons (Green *et al.*, 2003), summarized in an improvement in earliness, yield and fruit quality. Plastic mulches directly affect the microclimate around the plant by modifying the radiation budget of the surface and decreasing the soil water loss (Liakatas *et al.*, 1986), resulting in more uniform soil moisture and a reduction in the amount of irrigation water, which is very important for summer crops in this area. The soil temperature in the planting bed is raised, promoting faster crop development and earlier harvest (Lamont, 1993). Mulching decreases the fluctuations in temperature in the first 20-30 cm depth in soils and promotes root development, reduces vegetative competition in the rooting zone, reduces fertilizer leaching and soil compaction, and the vegetable productions are cleaner since no soil is splashed onto the plants or fruits (Ham *et al.*, 1993).

Polyethylene is one of the most commonly used plastic materials for mulching, due to the fact that it is easy to process, has excellent chemical resistance, high durability, flexibility and is odourless as compared to other polymers. It forms a relatively impermeable vapour barrier on the soil surface, changing the pattern of heat flow and evaporation (Tripathi and Katiyar, 1984).

The colour of the mulch largely determines its energy-radiation behaviour and its influence on the microenvironment surrounding the plants. The soil temperature under a plastic mulch depends on the thermal properties (reflectivity, absorptivity, or transmittancy) of a particular material in relation to the incoming solar radiation (Schales and Sheldrake, 1963; Tripathi and Katiyar, 1984), so colour affects the surface temperature of the mulch and the underlying soil temperature (Lamont, 1993). The degree of contact between the mulch and the soil also affects soil warming. The better contact the mulch has with the soil, the more effective the warming properties of the mulch (Lamont, 1996).

There are three primary non-degradable mulch types used commercially in the production of vegetable crops (Lamont, 1993): black, clear and the group of white, white-on-black and silver/aluminium reflective mulches. Black polyethylene is the most popular because it prevents weed growth and warms the soil in the spring, in addition to its low cost. Clear mulch provides an even warmer soil environment than black plastic mulch, but requires the use of another technique to control weeds (herbicide, soil fumigant or solarization). White, white-on-black and silver/aluminium reflective mulches can result in a slight increase or even a slight decrease in soil temperature compared to bare soil, tending to minimize changes in soil temperature, because they reflect back into the plant canopy most of the incoming solar radiation (Ham *et al.*, 1993; Csizinszky *et al.*, 1997). Therefore, these mulches are recommended when soil temperatures are high and any reduction in this parameter is beneficial for the crops (Lamont, 1993; Díaz *et al.*, 2001). Previous reports (Mahmoudpour and Stapleton, 1997) show that the increase of light reflectivity from the reflective mulch surface allows greater photosynthetic activity of the plants, and this effect is limited by crop development. Thus, when plant canopies develop to the point of completely covering the mulched beds, effective reflectivity of the mulches is reduced to near zero. Additionally, silver/aluminium reflective mulches are effective at repelling insect pests, especially aphids and thrips from vegetable crops (Riley and Pappu, 2000; Stapleton and Summers, 2002), which can serve as a vector for various viral deseases.

An important problem associated with the use of these non-degradable materials is the removal from the field at the end of the crop cycle. Plastic mulches do not break down and should never be disked or incorporated into the soil (Lamont, 1993), which implies a serious risk for the environment. However, the process of recovering and recycling them later is difficult as approximately 80% of the weight are non-plastic materials (González *et al.*, 2003). A large proportion of plastic films is left on the field or burnt by the farmers without legal control, emitting harmful substances with the associated negative consequences to the environment (Briassoulis, 2006; Scarascia-Mugnozza *et al.*, 2006).

In the early 1960's, photo- or biodegradable materials were recognized as one solution to the disposal problem associated with plastic mulches (Lamont, 1993). Photodegradable plastic breaks down under ultraviolet sunlight. The rate of breakdown depends on several factors such as temperature, the type of crops and the amount of sunlight received during the growing season. Thus, when photodegradable mulches are used under crops that cover less of the mulch (e.g., pepper) or in regions and seasons that receive high solar radiation, the mulch can be disintegrated prematurely and results useless. When using these materials it is necessary to lift the buried edges out of the soil and expose them to sunlight at the end of the season to favour their decomposition, and its effect on soil composition is not clear (Lamont, 1996; Greer and Dole, 2003).

For this reason, the use as mulch of biodegradable polymers formed from renewable resources is increasing in the last few years. These materials are basically composed of biopolymers, mainly polysaccharides such as cellulose and starch. Starch films, mostly from corn, potato and rice crops, are impermeable to water but permeable to water vapour and degrade into harmless products (CO_2 and water) when placed in contact with the soil humidity and microorganisms (fungi and especially bacteria) (Chandra and Rustgi, 1998). Therefore, these materials do not contaminate the environment and do not have to be removed from the land.

The aim of this study was to analyze the behaviour and deterioration of black polyethylene, aluminized photodegradable and black biodegradable mulches and to evaluate the effects on soil temperatures, yield and fruit quality of an open-field tomato crop.

Material and methods

Field site

The trial was conducted in 2003 at the experimental farm "Dehesa Galiana", belonging to the University of Castilla-La Mancha, in Ciudad Real (Central Spain) (4º2' W, 38º59' N, altitude 640 m). This area is characterized by a mediterranean continental climate. The total rainfall and mean temperature during the cropping seasons (June to October) were 167 mm (126 mm of which corresponding to October), and 22.5ºC, respectively, and the accumulated solar global radiation during the crop months was 3455.4 MJ m^{-2} (Table 1). The soil was loamy-clay (24.5% sand, 41.7% lime, 33.8% clay), with a normal level of organic matter (2.4%, Walkley-Black) and total nitrogen (0.133%, Kjeldahl), and very high contents of phosphorus (40.13 ppm, Olsen), assimilable potassium, calcium and magnesium (1.30, 36.0 and 4.0 meq 100 g^{-1}, respectively, ammonium acetate). The soil pH (1:2.5 water ratio) was 8.0 and the electrical conductivity (1:5 soil extract) 1.91 dS m^{-1}.

Experimental design and mulches

A randomised complete block design was adopted with three mulch treatments and three replications. The following mulch treatments were tested: black biodegradable film (Mater-Bi U-4, Novamont) 55 gauges (13.75 microns) thick, composed of a corn starch base, aluminized photodegradable (Deltalene) and black linear low density polyethylene (LLDPE) film (Siberline), both 60 gauges (15 microns) thick. Each basic plot consisted in one row 4 m length and 1.5 m apart, with plants separated by 0.5 m. The crop was daily irrigated by a trickle irrigation system, consisting in one low density polyethylene trickle line for each crop row (12 mm diameter) and emitters of 4 L h^{-1} separated by 0.50 m. After transplanting, about 30 mm of water were provided to favour crop establishment. Throughout the crop cycle, irrigation water amounts were applied following the methodology proposed by Allen *et al.* (1998), with a total of 520 mm.

Plant material and establishment

The study was performed using determinate fresh market tomato (*Solanum lycopersicum* L.) cv. Mina. Planting took place in the open field on 4 June, after placing by hand the mulches, using nursery seedlings with 3-4 mature leaves. The fragile consistency of the biodegradable film forced to prepare soil carefully. The crop cycle lasted 143 days after transplanting (4 June to 25 October).

Evaluation of mulch deterioration and soil temperature

The deterioration of the exposed mulching films was evaluated twice a month throughout the crop cycle by means of a visual rating scale, ranging from 1 to 9, where "1" indicated complete deterioration and "9" indicated no deterioration (film practically intact). At the end of the crop season, the biodegradable film was buried to favour its biodegradation by soil microorganisms.

From 25 June to 8 October, the soil temperature at a depth of 10 cm was determined in the middle of the beds under the different mulches and bare soil (no mulch) in each plot. Air temperature was measured at a height of 1.5 m above the soil. The measurements were realized at 6:30 solar hour (sh) in 16 dates with a needle soil digital thermometer (ThermoProbe). A further two sets of determinations were made on clear days during the vegetative growth and fruit set period (4 and 24 July), from 6:30 sh to 20:00 sh, at intervals of one and half hour. These soil values were compared to the air temperature at 1.50 m above the ground level.

Harvesting and yield component determinations

Red fruits were hand-harvested from 23 August (80 days after transplanting, DAT) to 25 October (143 DAT) in a total of ten harvests, controlling marketable, non-marketable and total yield, number of fruits and mean fruit weight.

At each harvest, marketable fruits (according to european commercial specifications, Regulation EC 790/2000) were size-graded into the standard sizes, considering the equatorial diameter of the fruit and assigning the following letters: MM (47-57 mm), M (57-67 mm), G (67-82 mm), GG (82-102 mm), GGG (>102 mm). Fruits in each size category were then counted and weighed.

Four marketable fruits were selected at random from each plot harvest to analyse different fruit quality parameters such as total soluble solids (ºBrix), firmness, dry weight, juice content and shape, defined as the ratio between the equatorial and the longitudinal diameter. The measurements of total soluble solids and fruit firmness were realized by a digital refractometer PR-32, Atago Co. LTD and a penetrometer Bertuzzi FT-327, Facchini, Italia, with a 8 mm plunger, respectively. Dry weight determinations were made in a forced air oven at 70ºC until constant weight.

In non-marketable yield, sunscalded and other non-marketable fruits (blossom-end rot, damaged, deformed and little fruits) were controlled. The incidence of sunscald in fruits was analysed separately due to the fact that this injury is caused by a combination of heat and light, being prevalent in high light environments (Wien, 1997), and probably the differences in reflecting the incident sunlight by the mulches employed could have any effect on it.

Statistical analysis

Statistical analysis (ANOVA, least significant difference, LSD test) was performed at a probability level $P<0.05$. Percentage data were arcsin transformed before analysis (Little and Hills, 1991).

Results

Behaviour of mulches

The first signs of mulch deterioration appeared on 10 June 2003 in the biodegradable film, only seven days after transplanting, when the global radiation accumulated by the mulch materials was of 236 MJ m^{-2}. However, in spite of these early cracks, this film behaved successfully, covering the soil until the crop shaded the mulch.

On 1 July (20 DAT) the aluminized photodegradable film presented important cross-sectional cracks, specially in the areas exposed to the solar radiation, while the deterioration was less in the areas of the mulch shaded by the crop. During these days, the average air temperature amplitude was of 18.0ºC, with maximum values of 21.0ºC. The solar radiation accumulated until this date was of 799 MJ m^{-2}.

Since then, the photo- and biodegradable mulches were gradually degrading, much more quickly the first one than the second. These cracks were used for weeds to grow, which were very numerous at the end of the crop cycle, especially in the aluminized photodegradable film, which presented the biggest cracks. During the harvest period, this material appeared divided in fragments, reaching an estimated soil cover of about 50%.

At the end of the season, the aluminized photodegradable mulch was highly deteriorated (deterioration in the visual rating scale of 1.0) and was not necessary to remove it from soil. In relation to the biodegradable film, despite the thickness and its peculiar consistency, it presented a positive behaviour and performed its function successfully (deterioration of 2.0). This material disappeared visually from the soil about three months after the crop finished, which could be favoured by the copious rainfall occurring during October (Table 1). Black polyethylene, however, remained practically intact (deterioration of 8.0). The solar global radiation accumulated throughout the crop cycle (4 June to 25 October) was 3363.6 MJ m^{-2}.

Soil temperature

The temperature of the air, bare soil and soil at a depth of 10 cm under each mulch during the crop cycle at 6:30 sh properly fits to a polynomial function of third degree (Fig. 1). The temperatures registered in bare soil

Table 1. Average air temperatures (mean, maximum, minimum), rainfall and global radiation during the growth cycle of the experiment

	Average air temperature (ºC)			Rainfall (mm)	Global radiation (MJ m^{-2})
	Mean	Maximum	Minimum		
June	25.5	34.3	16.8	0.6	852.1
July	25.6	35.5	15.7	0.0	897.8
August	25.9	35.0	16.7	14.7	751.3
September	21.2	29.4	13.1	26.0	605.9
October	14.1	18.9	9.3	126.0	348.3

were always lower than under mulch treatments, and the soil temperature under the different mulches was affected by the type of material employed. In the selected measuring dates during the crop cycle, soil temperatures were significantly higher ($P<0.05$) in black polyethylene at 35, 43, 50, 71, 83 and 119 DAT. The lowest values were obtained under the black biodegradable film, although without significant differences with respect to the aluminized photodegradable mulch.

Soil temperatures decreased sharply until 43 DAT in all of the treatments (Fig. 1). Since then, the values remained practically unchanged until 105 DAT, suffering a marked drop at the end of the crop season, in concordance with the air temperature.

The maximum values were obtained in the black polyethylene mulch up to 71 DAT. Since this date, the air temperature was higher than the soil temperature under mulches. The differences among treatments were smaller as the cycle went on, being practically inappreciable at the end of the experiment. The average soil temperatures reached at 6:30 sh throughout the crop cycle were 20.7ºC, 21.2ºC, 22.7ºC and 19.3ºC under black biodegradable, aluminized photodegradable, black polyethylene and bare soil, respectively.

In relation to the air and soil temperatures behaviour averaged across two daily periods (4 and 24 July), bare soil temperatures were always lower than under mulches, corresponding the highest values to black polyethylene ($P<0.05$) at all measurements times (Fig. 2). In relation to mulches, the lowest temperatures were always reached under the black biodegradable film, but no statistical differences with respect to the aluminized photodegradable mulch were noted in any case.

Maximum soil temperatures occurred near 15:30 sh in all the treatments (Fig. 2), ranging from 36.9ºC in black polyethylene to 31.0ºC in bare soil. Intermediate values were reached in black biodegradable (32.1ºC) and aluminized photodegradable films (33.7ºC). The lowest soil temperatures were registered at 6:30 sh.

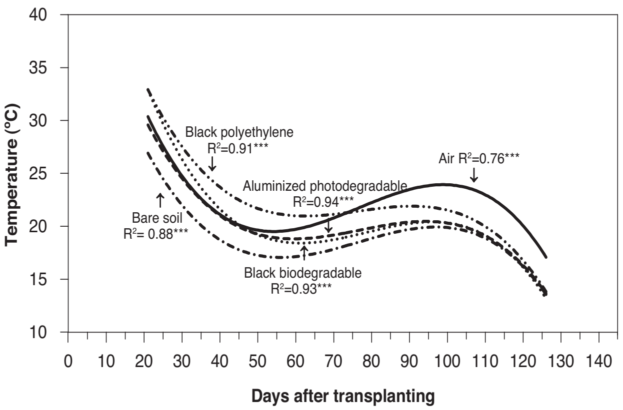

Figure 1. Evolution of temperature throughout the growth cycle in a tomato crop grown under different plastic films. Data measured at 6.30 solar hour. Soil temperature at a depth of 10 cm (temperatures averaged over three replications), air temperature at 1.50 m above ground.

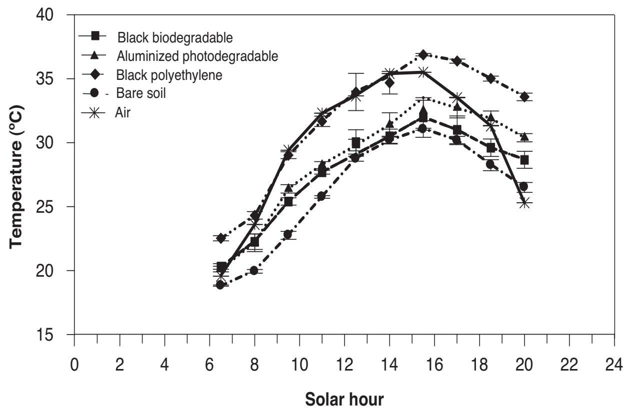

Figure 2. Diurnal patterns of air and soil temperatures averaged across two daily periods (4 and 24 July 2003). Soil temperature at a depth of 10 cm (temperatures averaged over three replications), air temperature at 1.50 m above ground. Vertical bars represent the standard error of the means.

Table 2. Average soil temperatures (mean, maximum and minimum), soil temperature amplitudes and excess mean soil temperature under mulches relative to bare soil (ΔT) averaged in two daily periods (4 and 24 July 2003) (ºC). Soil temperature at a depth of 10 cm (temperatures averaged over three replications)

	Average air temperature (ºC)			T amplitudes	ΔT
	Mean	Maximum	Minimum		
Black biodegradable	27.8 c	32.1	20.3	11.8 a	1.5 b
Aluminized photodegradable	28.7 b	33.7	20.1	13.6 a	2.5 b
Black polyethylene	31.8 a	36.9	22.5	14.4 a	5.6 a
Bare soil	26.2 d	31.0	18.8	12.2 a	-

Means followed by different letters in the same column are statistically different at $P<0.05$ (LSD test)

In all cases, the lowest values were obtained in black biodegradable and the highest ones in black polyethylene film (Table 2).

No statistical differences were found among the amplitudes (maximum less minimum data) of the diurnal soil temperatures measured (Table 2), being around 12.0ºC under black biodegradable and bare soil, but 13.6ºC and 14.4ºC under the aluminized photodegradable and black polyethylene films, respectively.

The daily mean soil temperatures registered under the biodegradable and the photodegradable films were only 1.5ºC and 2.5ºC higher than in bare soil, respectively, being up to 5.6ºC under the polyethylene mulch.

Yield and fruit quality

Marketable and total yields showed a similar behaviour related to the type of mulch employed, ranging from 6.85 to 9.82 kg m^{-2} and 7.43 to 10.33 kg m^{-2}, respectively (Table 2). Black biodegradable and polyethylene films were the most productive, without significant differences between them. Aluminized photodegradable film resulted in the lowest yields in both cases, with differences ($P<0.05$) with respect to the biodegradable mulch, being about 20% lower than that. The same trend was apparent in the number of fruits (Table 3), although no statistical differences were noted. In the same way, the type of mulch employed had no significant effect on marketable and total mean fruit weight (Table 3), although fruits of plants grown on the biodegradable film were slightly heavier than those of the other treatments, corresponding to the aluminized photodegradable film the lowest values in both cases. For this reason, the differences in yield among mulches were more marked than in number of fruits.

In relation to the non-marketable production (Tables 2, 3), the highest incidence of sunscald corresponded to the aluminized photodegradable film, with differences ($P<0.05$) with respect to the biodegradable mulch. In this last treatment, the injury was almost negligible. Aluminized photodegradable film multiplied by five the number of sunscalded in relation to the biodegradable mulch (Table 3), which represented an increase of the percentage of non-marketable fruits affected by this injury of 8.5 times. Intermediate values were attained in black polyethylene. Counts of blossom-end-rot (BER) fruits were practically inappreciable in all the treatments. For this reason, the BER fruits were added to the rest of the non-marketable fruit counts. The latter were

Table 3. Influence of mulch type on yield distribution according to the mulch treatments for a tomato crop grown in Central Spain

Mulch treatment	Marketable		Non-marketable						Total
			Sunscalded		Others		Total		
	kg m^{-2}	%	kg m^{-2}	%	kg m^{-2}	%	kg m^{-2}	%	kg m^{-2}
Black biodegradable	9.82 a	95.1 a	0.04 b	0.4 b	0.47 a	4.5 a	0.51 b	4.9 a	10.33 a
Aluminized photodegradable	6.85 b	92.2 a	0.25 a	3.4 a	0.33 a	4.4 a	0.58 b	7.8 a	7.43 b
Black polyethylene	8.66 ab	92.5 a	0.16 a	1.7 ab	0.54 a	5.8 a	0.70 a	7.5 a	9.36 ab
Mean	8.44	93.3	0.15	1.8	0.45	4.9	0.60	6.7	9.04

Means followed by different letters in the same column are statistically different at $P< 0.05$ (LSD test).

slightly higher in black polyethylene, although no significant differences were found with respect to the other treatments.

The evolution of the cumulative marketable fruit number and yield over the harvest period (Fig. 3) shows that the highest data were attained in black biodegradable and the lowest ones in aluminized photodegradable in both cases, being the differences more marked as the season advanced. Both biodegradable and polyethylene mulches presented similar values of the cumulative fruit number until 119 days after transplanting (Fig. 3a). Since this date, this parameter increased in a higher ratio in the biodegradable film. In relation to the cumulative marketable yield (Fig. 3b), the differences reached among mulches were bigger than in fruit number, showing the biodegradable film a more pronounced increase than the other treatments since 101 days after transplanting mainly as result of the increase in the mean fruit weight.

In relation to the partitioning of marketable yield into the different standard sizes (Table 4), in all the treatments the highest rate of fruits corresponded to the G size. The size distribution percentage was statistically similar in all the treatments except for GG, which was significantly higher ($P<0.05$) in the biodegradable mulch. Aluminized photodegradable and polyethylene films showed a certain trend to the smallest sizes (MM and M).

No significant differences among treatments were found in the quality attributes of marketable tomato fruits analyzed throughout the crop cycle (Table 5), resulting in similar values in shape, solid soluble solids, firmness, dry weight and juice content.

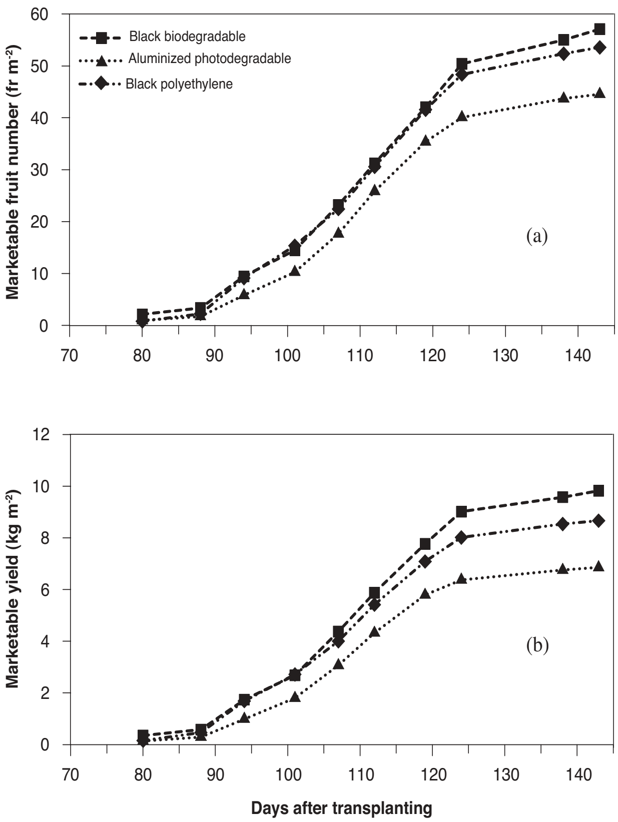

Figure 3. Evolution of the cumulative marketable fruit number (a) and yield (b) according to the mulch treatments for a tomato crop. Each point represents the average of three replications.

Discussion

Air temperature decreased more sharply at mid-afternoon compared to soil temperature due to the large heat capacity of the soil. The fluctuations of the air temperature throughout the day could cause a continuous dilatation/contraction process in the mulch materials. Consequently, the photodegradable mulch suffered important cross-sectional cracks early in the growing season and degraded prematurely; for this reason it was not necessary to remove it from soil at the end of crop cycle. Despite the thickness and the peculiar consistency of the biodegradable film, it performed its function successfully, disappearing visually from the soil a few months after the crop finished.

The effect of plastic coloured mulches on soil temperature has been widely studied (Streck *et al.*, 1995; Locher *et al.*, 2005; Lorenzo *et al.*, 2005; Moreno and Moreno, 2008). In general, plastic mulches increase soil temperature in relation to bare soil, these increases resulting higher in clear and dark materials than in the reflective colours such as white or silver/aluminium (Csizinszky *et al.*, 1997; Rangarajan and Ingall, 2001). In the latter, the temperatures can even be lower than in bare soil (Liakatas *et al.*, 1986; Lamont, 1996). The results obtained in this experiment support the previous studies; thus, the soil temperature in bare soil was always lower than under mulches, and the maximum soil temperatures were always reached under the black polyethylene film, followed by the aluminized mulch, because these last materials reflect back most of the incoming solar radiation (Ham *et al.*, 1993). For this reason, the reflective mulches are recommended to establish a crop when soil temperatures are high and any reduction in soil temperatures is beneficial (Lamont, 1996). The lowest soil temperatures were registered

Table 4. Influence of mulch type on fruit number distribution and mean fruit weight according to the mulch treatments for a tomato crop grown in Central Spain

Mulch treatment	Fruit number									Mean fruit weight (g)	
	Marketable		Non-marketable						Total		
			Sunscalded		Others		Total				
	Fr.m $^{-2}$	%	Fr.m $^{-2}$	%	Fr.m $^{-2}$	%	Fr.m $^{-2}$	%	Fr.m $^{-2}$	Market.	Total
Black biodegradable	57.07 a	88.9 a	0.36 b	0.6 b	6.76 a	10.5 a	7.12 a	11.1 a	64.19 a	173.6 a	162.1a
Aluminized photodegradable	44.44 a	85.7 a	1.81 a	3.5 a	5.61 a	10.8 a	7.42 a	14.3 a	51.86 a	156.8 a	146.7 a
Black polyethylene	53.56 a	86.8 a	0.89 b	1.4 b	7.22 a	11.7 a	8.11 a	13.2 a	61.67 a	163.9 a	151.8 a
Mean	51.69	87.2	1.02	1.8	6.53	11.0	7.55	12.9	59.24	164.8	153.6

Means followed by different letters in the same column are statistically different at $P < 0.05$ (LSD test).

under the biodegradable film in all the cases, which could be explained by the composition of this material, which permits increasing gas exchange with the open air as result of its higher permeability to water vapour (Chandra and Rustgi, 1998). Moreno and Moreno (2008) obtained similar results by comparing some biodegradable and polyethylene mulches of different colours, indicating that the differences in soil temperature among mulches were firstly due to the composition of the film.

The greatest soil temperature differences among treatments occurred early in the growing season (Fig. 1), before plant growth became sufficient to shade the row surface, in agreement with previous researchers (Schales and Sheldrake, 1963; Streck *et al.*, 1995; Brault *et al.*, 2002). Thus, the lowest incident solar radiation due to the progressive covering of the mulch by the crop and the gradual deterioration of the mulch materials throughout the crop cycle could have reduced the influence of the type of mulch on soil temperature. These aspects, linked to the end of the summer season, caused that these values tended to be similar to those obtained in bare soil at the end of the growing season.

Marketable and total yields were similar in both black biodegradable and polyethylene mulches, in agreement with Martín-Closas *et al.* (2003) in a tomato crop. The increased yield was the result of a slight increase in the number of fruits, which were also slightly heavier and larger, especially in the biodegradable treatment, than those obtained in the photodegradable mulch.

The range of temperatures registered under the different mulches in this experiment did not have a marked effect on the crop yield. Tindall *et al.* (1991) and Grass-

Table 5. Distribution of marketable yield into the standard sizes according to the mulch treatments for a tomato crop grown in Central Spain. MM: 47-57 mm, M: 57-67 mm, G: 67-82 mm, GG: 82-102 mm, GGG: >102 mm

Mulch treatment	MM		M		G		GG		GGG	
	kg m $^{-2}$	%	kg m $^{-2}$	%	kg m $^{-2}$	%	kg m $^{-2}$	%	kg m $^{-2}$	%
Black biodegradable	0.33 a	3.34 a	1.84 a	18.78 a	5.18 a	52.81 a	2.40 a	24.47 a	0.06 a	0.60 a
Aluminized photodegradable	0.63 a	9.13 a	1.56 a	22.83 a	3.37 a	49.22 a	1.29 b	18.83 a	0.00 a	0.00 a
Black polyethylene	0.37 a	4.31 a	2.04 a	23.58 a	4.72 a	54.49 a	1.48 b	17.06 a	0.05 a	0.57 a
Mean	0.44	5.59	1.81	21.73	4.42	52.17	1.72	20.12	0.04	0.39

Means followed by different letters in the same column are statistically different at $P < 0.05$ (LSD test).

Table 6. Average quality parameters of marketable yield according to the mulch treatments for a tomato crop in Central Spain

Mulch treatment	Shape (D/L)	Total soluble solids (ºBrix)	Firmness (kg cm $^{-2}$)	Dry weight (%)	Juice content (%)
Black biodegradable	0.83 a	4.14 a	5.15 a	4.14 a	64.3 a
Aluminized photodegradable	0.84 a	3.92 a	5.17 a	4.01 a	66.9 a
Black polyethylene	0.84 a	4.01 a	5.09 a	3.84 a	66.4 a
Mean	0.84	4.02	5.14	4.00	65.87

D/L: ratio between the equatorial (D) and the longitudinal (L) fruit diameter. Means followed by different letters in the same column are statistically different at $P < 0.05$ (LSD test).

baugh *et al.* (2004), testing organic and inorganic mulches in a tomato crop, observed that although plastic mulches produced the maximum soil temperatures, they were probably harmful to the plants, resulting in the lowest marketable and total yield compared to the organic treatment. Similar results were obtained by Streck *et al.* (1995) with different plastic mulch materials in a tomato crop. However, Decoteau *et al.* (1989) and Abdul-Baki *et al.* (1992) attributed the highest tomato yields, in part, to the highest temperatures reached under the mulches tested.

The lowest marketable and total yield obtained in the reflective photodegradable mulch could be attributed to its early breakage, showing important cracks, which allowed the weeds to grow, competing with the crop for light, water and nutrients. Another aspect derived from the early degradation of this material could be the increase in water losses by evaporation from the soil surface. Suwwan *et al.* (1988) and Streck *et al.* (1995), when comparing opaque and reflective mulches, observed that tomato yield was not significantly affected by the type of mulch employed. Csizinszky *et al.* (1997) and Mahmoudpour and Stapleton (1997), however, obtained significantly higher yields in reflective mulches than in all the other treatments, probably due to the fact that the materials tested in those experiments were not photodegradable and covered completely the soil until the end of the crop cycle. Csizinszky *et al.* (1997) also associated the highest yield in silver mulch to lower soil temperature and greater photosynthetically active radiation reflected from the mulch onto the plants, also reducing the high populations of whitefly-transmitted *Tomato mottle virus* (TMoV).

The small and sharp cracks presented in the biodegradable film only allowed a little spread of weeds, so this factor did not exert the same influence on this material.

In relation to the non-marketable production, the aluminized photodegradable film resulted in the highest incidence of sunscald, in agreement with Suwwan *et al.* (1988). It could be explained by the property of these materials to reflect an important ratio of the incident solar radiation, as previously noted, which could increase fruit pericarp temperatures exceeding 40ºC, temperatures which are considered as critical by Kinet and Peet (1997) for sunscald in tomato fruits. In despite of the early deterioration of this material, remained fragmented on the soil during the harvest period and its reflective effect could favour sunscald in fruits.

The calculated percentages of marketable and non-marketable yield and fruit number relative to the total values were similar in all treatments. Thus, the treatments more productive (black biodegradable and polyethylene) increased the marketable and non-marketable yield and number of fruits in a similar manner as compared with the less productive (aluminized photodegradable), in concordance with Suwwan *et al.* (1988).

The type of mulch employed had no effect on the fruit quality parameters measured, in concordance with Martín-Closas *et al.* (2003), who neither found significant differences in shape nor soluble solid content in processing tomato fruits by comparing black polyethylene to biodegradable mulches.

The results obtained suggest that the use of biodegradable films as mulching could be a good alternative to the traditional plastic films widely used in Central Spain, especially in spring-summer crops, as long as the early deterioration does not prevent them performing correctly all their functions. These materials do not cause a reduction of the productive capacity of the plants and degrade rapidly, avoiding all the problematic aspects derived from the use of polyethylene as mulch. For the other hand, the use of aluminized photodegradable mulches in these conditions seems not very advisable because they reduce marketable yield and the size of fruits, and could increase the incidence of sunscald.

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