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Effect of different biodegradable and polyethylene mulches on soil properties and production in a tomato crop

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Abstract

The use of plastic materials for mulching is a very common practice for vegetable crops. Black polyethylene is the most widely used due to its excellent properties and low cost. However, the massive use of these materials supposes an environmental risk. In the last few years, the use of starch-based biodegradable films has been introduced as an alternative to conventional mulches. These materials can be incorporated into the soil at the end of the crop season and undergo biodegradation by soil microorganisms. A 2-year study was conducted to determine the response of a tomato crop to seven mulch materials (polyethylene and biodegradable) in open fields in Central Spain. Biodegradable films underwent early decomposition, but in general remained functional during use and did not affect yield and the fruit quality attributes (total soluble solids, firmness, dry weight, juice content and shape). The temperatures reached under polyethylene films were always higher than under biodegradable films, which could be a disadvantage in certain circumstances, especially in hot climates, although may be advantageous in cool conditions. The use of polyethylene films resulted in the lowest values of soil microbial biomass C and soil organic matter mineralization, probably due to the increase of temperature registered under mulches. The analysis of the marketable yield components indicates that the variability in yield mainly depended on the number of fruits, with mean fruit weight being practically constant in the different treatments and seasons, which suggests the strong varietal character of this parameter.

Keywords: Soil temperature; Microbial activity; Yield; Quality; *Lycopersicon esculentum* Mill.

1. Introduction

Historically, vegetable growers have employed plastic films for mulching to reduce the growth of weeds, soil erosion from wind or water, leaching of fertilizers, especially on light, sandy soils, and the development of plant diseases coming from the soil (Green et al., 2003; Scarascia-Mugnozza et al., 2006). 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). The decrease in soil water evaporation results in a more uniform soil moisture content and a reduction in the amount of irrigation water, which is very important in summer crops in dry areas. Mulching avoids the fluctuations in temperature in the first 20–30 cm depth in soils. This favours root development, and the soil temperature in the planting bed is raised, promoting faster crop development and earlier harvest (Lamont, 1993). The linear low density polyethylene (LLDPE), especially black PE, is mainly used due to its easy processing, excellent chemical resistance, high durability, flexibility and odourless as compared to other polymers (Wright, 1968; Espí et al., 2006).

The main negative consequence of the use of plastics in agriculture is related to handling the plastic wastes and the associated environmental impact. Only a small percentage of the constantly rising amount of agricultural plastic waste is currently recycled because the process of recycling is expensive and time-consuming due to the high labour cost for the proper collection of the plastic films at the end of cultivation. A large portion of plastic films is left on the field or burnt uncontrollably by the farmers, emitting harmful substances with the associated negative consequences to the environment (Briassoulis, 2006; Scarascia-Mugnozza et al., 2006).

A solution to the disposal of plastic mulches could be the use of films produced with biodegradable polymers. These

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biodegradable materials, called biopolymers (polymers formed from renewable resources), are basically composed of polysaccharides such as cellulose and starch. Starch films, mainly from corn, potato and rice crops, possess low permeability and are mineralized into harmless products (carbon dioxide and methane, water and biomass) when placed in contact with the soil moisture and microorganisms (fungi and especially bacteria) in a reasonable time frame (Chandra and Rustgi, 1998; Scarascia-Mugnozza et al., 2004, 2006). Therefore, these materials do not contaminate the environment and disposal could be accomplished simply by incorporating them into soil by plowing the field after their use, instead of removing them from the field (Stapleton and Summers, 2002).

In recent years, coloured mulches in vegetable crops have been used for increasing yield and quality of produce. Altered microenvironments around plants can be created, depending on the colour of the mulch and local climate conditions, which can be beneficial for crop growth and yield. Use of darker colour mulches increases soil temperature, while lighter colours reflect more solar radiation and tend to minimize changes in soil temperature while increasing the irradiance around the plant canopy. Also, specific mulch colours can cause qualitative and quantitative differences in reflected light wavelengths, which have been shown to affect the growth and yield characteristics of plants (Decoteau et al., 1990; Mahmoudpour and Stapleton, 1997) and the presence of pests or pathogen populations (Csizinszky et al., 1997; Greer and Dole, 2003). The influence of mulch colour on crop growth and productivity has been postulated to be highly specific, and may vary with plant taxa, climate and seasonal conditions (Decoteau et al., 1988; Mahmoudpour and Stapleton, 1997).

In relation to soil quality, understood as the capacity of soil to function as a vital living system able to fulfill all its functions (Pompili et al., 2006), microorganisms play a leading role. Soil microorganisms and the processes they govern are essential for long-term fertility of soil. Soil microbiological properties have the potential to be early and sensitive indicators of soil stress or productivity changes, and there is considerable evidence they can be used to evaluate the influence of management and land use of soils (Jinbo et al., 2007). Microbial activity, which relies on the availability of decomposable material, plays an important role in regulating soil fertility and transforming organic matter (Marinari et al., 2007). Soil microorganisms respond directly to environmental changes and they are able to grow very fast if the conditions are appropriate (Xu et al., 2006). However, the increase in soil moisture and temperature due to plastic film mulching can change the biological characteristics of the soil and may have a negative impact on soil quality (Li et al., 1999).

The objective of the present study was to assess the effect of seven coloured film mulches of different composition (biodegradable and polyethylene) on soil temperature and microbiological properties, as well as the effect on yield and fruit quality in an open-air tomato crop.

2. Material and methods

2.1. Research site

Field experiments were conducted at the experimental farms of the University of Castilla-La Mancha (4°2′W, 38°59′N, altitude 640 m) in 2004 and of the Agrarian Research Service of Castilla-La Mancha (3°56′W–39°0′N, altitude 640 m) in 2005, Ciudad Real, Spain.

The region is characterized by having a continental mediterranean climate. The total rainfall and mean temperature during the cropping seasons (June to October in 2004 and May to October in 2005) were 96.1 mm and 21.2 °C in 2004, and 49.4 mm and 20.6 °C in 2005, respectively (Fig. 1). The main physical and chemical properties of the experimental soils are shown in Table 1.

2.2. Experimental design

Trials were designed as randomised complete blocks with seven mulch treatments [four biodegradable (BD) and three low density polyethylene (PE) mulches of different colours] replicated three times in plots 4 m long in 2004 and 5 m long in 2005, by 1.5 m wide. Distance between plants within the row was 0.5 m. The characteristics of the mulch treatments employed are summarised in Table 2. PE2 and PE3 were bicolour (blue and yellow) polyethylene sheeting: blue-side upwards in PE2 and yellow-side upwards in PE3.

2.3. Plant material and culture conditions

Fresh-market tomato (*Lycopersicon esculentum* Mill.) cv. Mina (Seminis seed company), characterized by a determinate growth habit, was transplanted in the open air on 1 June 2004 and on 11 May 2005, after placing mulches. Nursery seedlings with 3–4 mature leaves (5–6 weeks old) were used. The fragile consistency of the biodegradable films forced to prepare soil carefully and install them by hand.

Fertilization consisted of four applications of humic and fulvic compounds at 15-day intervals from transplanting, with a

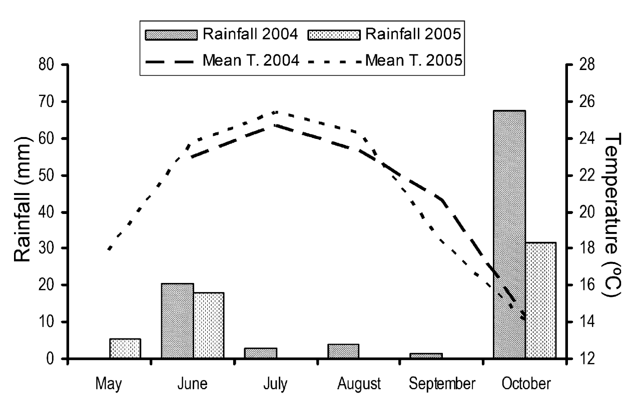

Fig. 1. Evolution of air temperature and rainfall throughout the growth cycles of the experiment (years 2004 and 2005).

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Table 1
Physical and chemical soil properties (years 2004 and 2005)

Soil property	2004	2005
Sand (2–0.05 mm) (%)	27.0	29.0
Silt (0.05–0.002 mm) (%)	46.0	35.0
Clay (<0.002 mm) (%)	27.0	36.0
Texture	Clay loam	Clay loam
pH (1:2.5 soil:water)	8.3	8.0
EC[a] (1:5 soil:water) (dS m^{-1})	1.5	2.0~~5~~
Total organic carbon (%) (Walkley-Black)	1.5~~1~~	0.7
Organic matter (%) (Walkley-Black)	2.6~~0~~	1.2
Total calcium carbonate (%) (Galet)	35.0	20.5
Active calcium carbonate (%) (Drouineau)	16.0	8.2
Nitrogen (%)	0.12	0.06
Phosphorous (ppm)	55.0	8.6~~2~~
Potassium (mequiv. 100 g^{-1})	1.8~~0~~	0.7
Magnesium (mequiv. 100 g^{-1})	6.2~~3~~	1.0
Calcium (mequiv. 100 g^{-1})	31.5~~2~~	28.0

[a] Electrical conductivity.

total dose of 40 kg ha^{-1}. No chemical fertilizers were applied. Lepidopterous (*Heliothis* sp.) larvae were controlled by weekly applications of *Bacillus thuringiensis*. The crops were daily irrigated by a trickle irrigation system. The crop cycle lasted 158 days after transplanting (1 June to 31 October) in 2004 and 168 days (11 May to 26 October) in 2005.

2.4. Evaluation of mulch degradation and soil temperature

The degradation of the exposed mulching films was evaluated throughout the crop cycles by means of a visual scale, ranging from 1 to 9, where "1" corresponded to the mulch material completely degraded, and "9" to the film practically intact. At the end of the each crop season, the four biodegradable materials were buried to favour their biodegradation by soil microorganisms.

In order to determine the effect of the different mulches on soil temperature under field conditions, measurements of temperature at 10 cm soil depth were recorded in each plot and in bare soil (no mulch) at 6:00 solar hour (sh) in 2004 (9 June to 29 September, 21 times) using a soil digital thermometer. In 2005, soil (10 cm depth) temperatures were recorded at 15 min intervals (12 May to 27 October) in the middle of the mulched beds (one plot per mulching treatment) and in bare soil with thermocouples linked to a data logger (model HI-141 GH, Hanna).

2.5. Harvesting and yield determinations

Ripe (pink to firm red) fruits were hand-harvested from 18 August (78 days after transplanting, DAT) to 31 October (152 DAT) in 2004 (11 harvests) and from 22 July (72 DAT) to 26 October (168 DAT) in 2005 (16 harvests). At each harvest, the weight and number of fruits were determined separately for marketable and non-marketable (damaged, deformed, undersized and affected by sunscald and blossom-end rot) fruits.

Four marketable fruits were selected at random from each plot to analyse fruit quality attributes such as total soluble solids, firmness, juice content, and shape, defined as the ratio between the equatorial (D) and the longitudinal (L) diameter. The measurements of total soluble solids and fruit firmness were conducted using a digital refractometer (PR-32, Atago Co. Ltd.), and a penetrometer (Bertuzzi FT-327, Facchini, Italia), with a 8 mm plunger, respectively.

2.6. Soil microbial biomass and microbial activity

In order to determine the effects of the different mulch materials on the soil biological attributes, soil samples (5–10 cm depth) were taken at two dates in 2004: prior to establishment of the treatments (3 May 2004) and once the crop cycle was finished and the biodegradable mulch materials were completely degraded (not visible) (21 April 2005). At the first date, only one sample composed of 10 subsamples taken at different points of the experimental field was analysed; at the second date, samples corresponding to bare soil with no crop, bare soil next to the crop and soil previously covered by each mulch material were taken. Each of these samples was composed of three subsamples corresponding to each replication of the different treatments.

The soil microbiological attributes analysed were calculated according to Maire et al. (1999). These parameters were the following:

(i) Soil microbial biomass C (SMBC), expressing the total amount of microbial biomass in soil, mainly from bacteria and fungi, measured as the ATP (adenosine triphosphate) content.
(ii) Soil organic matter mineralization (SOMM), representing the sum of CO_2 produced during the 15 days of incubation, expressed on an organic matter basis.

Table 2
Characteristics of the mulching films

Treatment	Material	Colour	Thickness (μm)	Width (m)	Supplier company
BD1	Biodegradable	Green	25	1.20	Barbier
BD2	Biodegradable	Brown	17.5	1.20	Deltalene
BD3	Biodegradable	Black	20	1.20	Deltalene
BD4	Biodegradable	Black	16	1.20	Barbier
PE1	Polyethylene	Black	15	1.20	Various
PE2	Polyethylene	Blue/Yellow[a]	30	1.35	Deltalene
PE3	Polyethylene	Blue/Yellow[b]	30	1.35	Deltalene

[a] Blue-side upwards.
[b] Yellow-side upwards.

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(iii) CO_2 production-to-ATP ratio, or specific activity of the microbial biomass. This ratio is similar to the more generally used metabolic quotient (qCO_2), and is related to the availability of nutrients, especially organic carbon, and it is often used as an indicator for assessing the influence of environment conditions on soil microbial communities (Anderson and Domsch, 1990).

2.7. Statistical analysis

Results were subjected to analysis of variance (ANOVA) and a Duncan's multiple range test ($P < 0.05$) was applied to the significant results (InfoStat 2006d.2).

3. Results

3.1. Behaviour of mulches

The first signs of biodegradable mulch degradation appeared 22 and 9 days after transplanting in 2004 and 2005, respectively. BD1 was the most affected in both years, showing large longitudinal cracks early in the growing season. In 2004, as result of the early breakages and the season climatic conditions, with strong windy summer storms, BD1 practically disintegrated at the middle of the crop season. However, in 2005, in spite of the large cracks, BD1 covered most of the crop soil until the end of the crop cycle.

The other biodegradable materials gradually degraded, especially BD3, and in spite of these early cracks, performed better by covering the soil until the crop shaded the mulches. The polyethylene mulches remained practically intact and had to be removed at the end of the crop cycles.

The spring following each crop season, the biodegradable films, previously buried at the end of the crop cycles, were not visible.

3.2. Soil temperature

Soil temperatures under the different mulches were affected by the composition of the mulch material employed in both years (Fig. 2, Table 3). This fact was evident among the black films, in which differences in soil temperature could not be attributable to mulch colour. The lowest values were obtained under the biodegradable and the highest under the polyethylene mulches. In all cases, the temperatures recorded in bare soil were always lower than those attained across all mulch materials, and followed a similar pattern to them.

In 2004, the differences between the polyethylene and the biodegradable materials were marked throughout most of the crop cycle, while the differences became practically undetectable at the end of the experiment. Soil temperatures increased slightly from the beginning of the season (following transplanting of the crop) to 46–60 DAT and underwent a gradual decrease afterwards, especially in the last period.

In 2005, grouping the mulches as BD mulches or PE mulches, the average mean soil temperatures varied between 26.6–14.8 °C in the BD mulches, 27.4–15.1 °C in PE mulches and 24.2–15.1 °C in bare soil (Table 3). In relation to the average minimum soil temperatures, the values ranged from 23.6–13.8 °C for BD, 24.9–14.1 °C for PE and 21.3–12.9 °C for bare soil.

Both BD and PE mulches increased soil temperature in relation to bare soil in all sampling dates (Table 4), especially PE. The highest increases in soil temperature took place during the first stages of the crop cycle (up to 5.9 °C and 6.9 °C in PE and 5.5 °C and 5.8 °C in BD, increases of mean and minimum soil temperature, respectively). The thermal effect of PE mulches remained until the end of the crop season; however, BD mulches behaved similarly to bare soil during the last period. The increases in minimum temperatures were more marked than those corresponding to mean temperature during most of the growing season.

3.3. Yield and fruit quality

The different mulches employed showed similar values of marketable yield and fruit number (Table 5), with the exception of BD1 in 2004, which resulted in the lowest yield values. This fact could be as result of the early degradation of this material, which caused a lower soil temperature and allowed weeds to grow. Marketable yield and number of fruits in 2005 were about 25% and 30% higher than those obtained in 2004. However, the marketable mean fruit weight was similar among mulch treatments in both years.

No significant differences among treatments were found in tomato fruit shape, firmness, juice content and solid soluble solids. However, fruits had increased values ($P < 0.05$) of juice content and total soluble solids in 2005, although in 2004 fruit had a more rounded shape (Table 6).

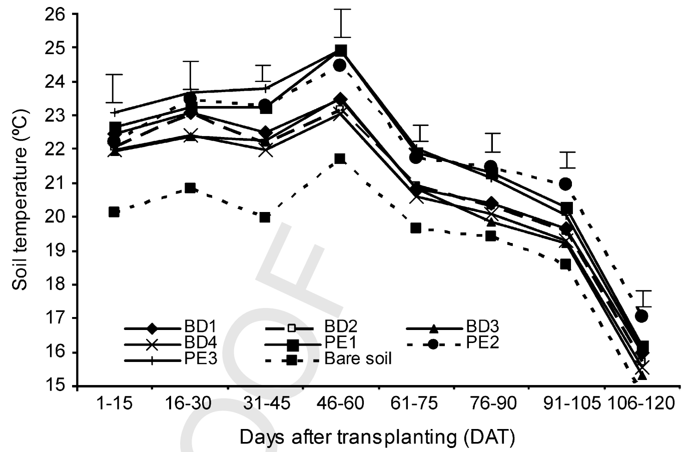

Fig. 2. Evolution of soil temperature over 15-day periods during the growth cycle in 2004. Data measured at 6.00 solar hour. Soil temperature at a depth of 10 cm: BD, biodegradable mulch (BD1: green, 25 μm thick; BD2: brown 17.5 μm thick; BD3: black, 20 μm thick; BD4: black, 16 μm thick); PE, polyethylene mulch (PE1: black, 15 μm thick; PE2: blue/yellow, blue-side upwards, 30 μm thick; PE3: blue/yellow, yellow-side upwards, 30 μm thick). Vertical bars represent LSD among treatments ($P < 0.05$).

Table 3
Average mean and minimum soil temperatures 10 cm depth over 15-day periods during the crop cycle in 2005

Mulch treatment	Days after transplanting (DAT)											Seasonal average
	1–15	16–30	31–45	46–60	61–75	76–90	91–105	106–120	121–135	135–150	151–165	
Mean												
BD1	22.5	26.3	25.2	25.4	25.8	24.2	23.6	22.6	18.5	17.6	15.2	22.4
BD2	22.7	26.4	25.2	25.3	25.4	24.0	23.4	22.2	18.3	17.4	15.1	22.3
BD3	23.2	26.6	25.3	25.5	25.2	23.9	23.2	22.1	17.5	16.4	14.8	22.2
BD4	22.0	25.5	24.8	25.1	25.0	23.3	22.8	21.9	18.0	17.4	15.2	21.9
Average BD	22.6	26.2	25.1	25.3	25.3	23.8	23.3	22.2	18.1	17.2	15.1	22.2
PE1	22.7	27.1	27.1	27.4	26.2	24.7	24.5	23.7	20.0	18.9	15.6	23.4
PE2	23.8	28.2	27.3	26.6	25.8	24.7	24.4	23.1	18.8	18.0	15.3	23.3
PE3	22.6	26.9	25.9	26.3	26.1	24.8	24.3	23.3	19.3	18.3	15.1	23.0
Average PE	23.0	27.4	26.8	26.8	26.0	24.7	24.4	23.4	19.3	18.4	15.3	23.2
Bare soil	17.1	21.5	22.7	24.2	23.4	22.2	22.0	21.4	17.7	17.1	15.0	20.4
Minimum												
BD1	18.7	23.1	23.3	23.7	23.4	22.0	21.6	20.8	16.4	15.5	13.9	20.2
BD2	18.3	22.0	22.5	23.5	23.4	22.6	21.7	20.6	16.2	15.3	13.9	20.0
BD3	18.3	23.0	22.7	23.4	23.0	21.7	20.8	19.8	15.2	14.3	13.3	19.6
BD4	17.7	22.0	23.2	23.7	23.4	22.2	21.4	20.6	16.4	15.7	14.0	20.0
Average BD	18.4	22.5	22.9	23.6	23.3	22.2	21.4	20.4	16.0	15.2	13.8	20.0
PE1	18.9	23.4	24.2	24.8	24.5	23.3	22.7	21.8	17.2	16.1	14.0	21.0
PE2	19.3	24.4	25.0	25.2	24.8	23.7	23.1	22.0	17.4	16.6	14.4	21.4
PE3	18.3	23.1	23.8	24.5	24.2	23.2	22.6	21.9	17.3	16.4	13.9	20.8
Average PE	18.8	23.6	24.3	24.9	24.5	23.4	22.8	21.9	17.3	16.4	14.1	21.1
Bare soil	12.9	16.7	19.1	21.2	21.3	20.7	20.2	19.3	16.2	15.1	13.7	17.8

BD, biodegradable mulch (BD1: green, 25 μm thick; BD2: brown 17.5 μm thick; BD3: black, 20 μm thick; BD4: black, 16 μm thick); PE, polyethylene mulch (PE1: black, 15 μm thick; PE2: blue/yellow, blue-side upwards, 30 μm thick; PE3: blue/yellow, yellow-side upwards, 30 μm thick).

3.4. Soil microbial biomass and microbial activity

The values of the soil biological attributes before transplanting (3 May 2004) and after the biodegradable materials were completely degraded (21 April 2005) are shown in Table 7.

At the beginning of the crop season, the soil presented a normal level of microorganisms (ATP, 1663 ng g^{-1}), clearly related with the high content of organic matter (2.6%) and clay (27%), and resultantly low SOMM (998 μg OM g^{-1} 15 day^{-1}). In relation to the quality of the active biomass, the CO_2 production-to-ATP ratio (3.8 μg CO_2 μg^{-1} ATP) indicates a certain equilibrium between the microorganisms responsible for mineralization and the humification of the soil organic matter.

At the second sampling, the ATP content was, in general, normal in all the cases in relation with the organic matter and clay contents, with values slightly higher in the no-mulched treatments, especially in bare soil next to the crop. In relation to the first date, ATP decreased slightly in all the samples analysed. A similar behaviour was observed in SOMM, the lowest values corresponding to the polyethylene mulches. The

Table 4
Increment of mean and minimum soil temperature under mulches relative to bare soil and biodegradable mulch materials (ΔT) in 2005

ΔT (°C)	Days after transplanting (DAT)										
	1–15	16–30	31–45	46–60	61–75	76–90	91–105	106–120	121–135	135–150	151–165
Mean											
BD-bare soil	5.5	4.8	2.4	1.1	1.9	1.6	1.3	0.8	0.3	0.1	0.1
PE-bare soil	5.9	5.9	4.1	2.5	2.7	2.5	2.4	2.0	1.6	1.3	0.3
PE-BD	0.4	1.2	1.6	1.4	0.7	0.9	1.1	1.2	1.3	1.2	0.3
Minimum											
BD-bare soil	5.6	5.8	3.9	2.4	2.0	1.5	1.2	1.1	−0.1	0.1	0.1
PE-bare soil	6.0	6.9	5.2	3.7	3.2	2.7	2.6	2.6	1.1	1.3	0.4
PE-BD	0.4	1.1	1.4	1.3	1.2	1.2	1.4	1.5	1.2	1.2	0.3

BD, biodegradable mulch; PE, polyethylene mulch.

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Table 5
Marketable yield, fruit number and mean fruit weight for the mulched-treatments: years 2004 and 2005

Year	Mulch treatment	Yield (kg m^{-2})		Fruits (m^{-2})		Mean fruit weight
		Marketable	Total	Marketable	Total	Marketable (g)
2004	BD1	9.2 b	10.3 b	47.8 b	59.8 b	193.2 a
	BD2	11.9 a	12.9 a	57.9 a	69.1 ab	205.9 a
	BD3	11.8 a	12.9 a	58.3 a	69.4 ab	202.7 a
	BD4	11.7 a	12.9 a	56.7 a	69.4 ab	206.8 a
	PE1	11.6 a	12.4 ab	61.2 a	71.8 a	188.9 a
	PE2	11.8 a	12.5 ab	57.7 a	68.2 ab	205.1 a
	PE3	10.2 ab	11.0 ab	53.9 ab	62.4 ab	188.3 a
2005	BD1	13.5 a	15.3 ab	67.1 a	82.5 b	201.1 a
	BD2	15.4 a	17.3 a	75.8 a	92.8 a	203.0 a
	BD3	13.8 a	15.6 ab	69.6 a	87.1 ab	197.9 a
	BD4	13.8 a	15.5 ab	69.4 a	85.3 ab	199.0 a
	PE1	13.6 a	15.7 ab	67.4 a	84.9 ab	201.8 a
	PE2	14.0 a	15.8 ab	71.9 a	89.1 ab	194.8 a
	PE3	13.4 a	15.0 b	70.2 a	85.2 ab	191.3 a
2004 average		11.2 b	12.1 b	56.2 b	67.2 b	198.7 a
2005 average		13.9 a	15.7 a	70.2 a	86.7 a	198.5 a
2004–2005 average		12.6	13.9	63.2	76.9	198.6

BD, biodegradable mulch (BD1: green, 25 μm thick; BD2: brown 17.5 μm thick; BD3: black, 20 μm thick; BD4: black, 16 μm thick); PE, polyethylene mulch (PE1: black, 15 μm thick; PE2: blue/yellow, blue-side upwards, 30 μm thick; PE3: blue/yellow, yellow-side upwards, 30 μm thick). Values within columns followed by different letters are significantly different ($P < 0.05$) according to Duncan's test.

Table 6
Average quality attributes of marketable yield for the mulched-treatments: years 2004–2005

Year	Shape (D/L)	Firmness (kg cm^{-2})	Juice content (%)	Total soluble solids (°Brix)
2004	0.85 a	6.00 a	57.21 b	4.46 b
2005	0.80 b	6.02 a	60.19 a	4.82 a
2004–2005 average	0.83	6.01	58.70	4.64

Values within columns followed by different letters are significantly different ($P < 0.05$) according to Duncan's test.

CO_2 production-to-ATP ratio presented low values in all the treatments, and also experimented a decrease in relation to the first sampling data.

4. Discussion

The effect of coloured mulches on soil temperature has been widely documented (Locher et al., 2005; Lorenzo et al., 2005). In general, plastic mulches increase soil temperature in relation to bare soil, these increases resulting higher in clear and dark colours than in the reflective ones such as white or silver/aluminium (Rangarajan and Ingall, 2001). In this experiment, the differences in the soil temperatures among black films could only be attributable to the composition of the mulch material. In the same way, the results obtained suggest that the differences in soil temperature among mulches were mainly due to the

Table 7
Soil microbial attributes for the mulched-treatments: year 2004

Date	Mulch treatment	SMBC (ATP, ng g^{-1})	SOMM (μg OM g^{-1} 15 day^{-1})	CO_2 to ATP ratio ~~(ratio~~ (μg CO_2 μg^{-1} ATP)~~)~~
3 May 2004	–	1663	998	3.8
21 April 2005	BD1	1210	499	2.2
	BD2	1319	502	2.0
	BD3	1183	588	2.7
	BD4	1348	562	2.3
	PE1	1005	451	2.1
	PE2	1048	480	2.8
	A	1703	558	1.9
	B	1512	556	2.4

SMBC, soil microbial biomass carbon; SOMM, soil organic matter mineralization. BD, biodegradable mulch (BD1: green, 25 μm thick; BD2: brown 17.5 μm thick; BD3: black, 20 μm thick; BD4: black, 16 μm thick); PE, polyethylene mulch (PE1: black, 15 μm thick; PE2: blue/yellow, blue-side upwards, 30 μm thick); A, bare soil next to the crop; B, bare soil with no crop.

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composition of the film. The lowest soil temperatures were always reached under the BD mulches, which could be explained by the composition of these materials, which permits increasing gas exchange with the open air as result of their higher permeability (Chandra and Rustgi, 1998).

The highest increments of soil temperature under the different mulches in relation to bare soil occurred during the early crop season, when tomato plants shaded less the soil surface, is in agreement with previous reports (Schales and Sheldrake, 1963; Streck et al., 1995; Brault et al., 2002). In the BD mulches, this fact linked to their progressive degradation throughout the growing season, caused that the differences in temperature in relation to bare soil were undetectable at the end of the cycle.

According to Díaz-Pérez and Batal (2002), the optimum soil temperature for tomato yield and fruit number is about 26 °C, while mean seasonal root-zone temperature >27 °C causes stress, resulting in plants with a lower vigour and fruit yield (Díaz-Pérez et al., 2007). In this experiment, mean seasonal soil temperature at 10 cm depth never exceeded 27 °C. Mean soil temperature only reached this value in PE1 (16–60 DAT) and PE2 (16–45 DAT) in 2005, during the vegetative growth. During the harvest period, mean soil temperatures were always <27 °C. Thus, soil temperature probably was not harmful to the tomato plants in the different treatments.

Differences in yield can be attributed to differences in soil temperature when temperature is a limiting factor (Brown et al., 1992). When soil temperatures are high but do not reach the maximum threshold for each crop, mulches do not influence yield (Streck et al., 1995; Lorenzo et al., 2005). The results obtained in this experiment support the previous studies, so the range of temperatures under the different mulches did not have a marked effect on the crop yield.

Marketable yield and number of fruits were only affected when mulches underwent an early degradation (as for BD1 in 2004). This ~~which~~ could increase the water losses by evaporation from the soil surface and allowed the weeds to grow, competing with the crop for light, water and nutrients. As was the case for soil temperature, tomato yield was not affected by the colour of the mulch, in agreement with Orzolek et al. (1993) and Lamont (1999). However, other studies (Brown et al., 1992; Csizinszky et al., 1997; Mahmoudpour and Stapleton, 1997) show differences in crop growth and yield as a function of mulch colour, although the final conclusions they exposed are very different according to the experimental location, cultivar, climate, seasonal conditions, etc.

The fact that the specific environmental conditions in each season influenced marketable yield and number of fruits but not mean weight per fruit, indicates that the differences in yield depended primarily on the number of fruits, while mean fruit weight depended on the cultivar and was little affected by the environment. Similar results were obtained by Brown et al. (1992).

The type of mulch employed had no effect on the fruit quality attributes in agreement with the report of Martín-Closas et al. (2003) in processing tomato fruits grown under black polyethylene and biodegradable mulches.

In relation to the soil microbial biomass and activity, soils mulched with PE films had the lowest values of SMBS and SOMM, while bare soils had the highest SMBC values.

ATP content, an indicator of SMBC, and SOMM, and indicator of soil global catabolic activity and related with the mineralizable soil organic matter (Maire et al., 1999), are biochemical quantities that bear a direct link with the living soil microorganisms. In the experiment, mulching resulted in decreased ATP in the top soil in relation to bare soil, probably due to the increased temperature under mulches, which could limit soil microbial activity, in agreement with Li et al. (1999). For this reason, the abundancy of SMBC greatly depended on the composition of the cover material employed, suffering a more marked decrease in the PE materials. However, in studies by Li et al. (2004) consisting of comparing the effect of plastic mulch on soil biological attributes, the highest SMBC contents were found in the mulched treatments, although in that case the highest temperatures reached were <28 °C. As ATP content, SOMM rate showed a decrease in the PE treatments compared to both bare soil and BD treatments, which supposes a lower enrichment of soil nutrients as result of a lower mineralization of soil organic matter.

The low values of the CO_2 production-to-ATP ratio reached in all cases, especially at the second sampling date, indicate a progressive impoverishment in soil organic matter and decreased activity of microorganisms responsible for the humification process.

5. Conclusions

This study demonstrates that the use of biodegradable plastic materials for mulching may be an alternative to the polyethylene films, because BD mulches fulfill successfully all the functions of the traditional plastic mulches. These biodegradable materials did not decrease marketable yields and fruit quality attributes in tomato crops, but in contrast to PE mulches, BD mulches degrade in a short time, instead of being left or burnt without any control, and reduce the contamination of the soil. Biodegradable films warm soils less than polyethylene mulches, which could be favourable in areas and seasons characterized by high temperatures responsible for damages to the crops, although PE may be advantageous in areas with cool conditions.

Mean fruit weight is a yield component with a marked varietal character and tends to remain about constant in different environments. The differences in yield observed each season could be the result of the different number of fruits formed.

In general, mulches affected the microbiological properties of the soil. However, PE had more negative effect on soil microbiological properties than the BD films.

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