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Biodegradable mulch films performance for autumn-winter strawberry production

Cláudia Santos Andrade[a], Maria da Graça Palha[b,*] and Elizabeth Duarte[c]
[a]*Casa Prudêncio, Quinta de S. Roque, Almeirim, Portugal*
[b]*Instituto Nacional de Investigação Agrária e Veterinária, Quinta do Marquês, Oeiras, Portugal*
[c]*Instituto Superior de Agronomia, Tapada da Ajuda, Lisboa, Portugal*

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Abstract. An enormous amount of plastic waste resulting from the agricultural activities is produced every year. Part of this plastic remains in the fields, while the other part is sent to recycling or landfill. The use of biodegradable (BD) mulch films can play a key role towards a sustainable development in agricultural sector because they can be plugged in the soil, after its use, together with the crop residues. The aim of this study was to evaluate the performance of white-on-black biodegradable mulch films in contrast to the conventional polyethylene (PE) mulch film in autumn-winter cycle strawberry production, monitoring the variation on soil warming, lifetime of the films in the field as well as the effects on fruit yield. Soil temperatures showed differences among treatments during summer period under open field conditions and autumn-winter season under tunnel. Although the degradation rate of BD mulch films varied along the crop cycle, they provided adequate bed cover and weed suppression until crop end. Plants had similar monthly crop yield distribution, and percentage of commercial and uncommercial fruits between mulch treatments. From the overall results obtained, biodegradable mulch films may be a promising alternative to PE mulching but there should be economic incentives for growers to implement this sustainable practical as its price at present are not yet competitive.

Keywords: Soil mulching, white-on-black films, sustainability, agriculture biodegradable polymers, long cycle crop

1. Introduction

From a crop production perspective, plastic mulches can increase yields, extend the growing season, reduce weed pressure, increase fertilizer use efficiency, conserve soil moisture, and increase soil temperature [1]. For these reasons, polyethylene (PE) mulches have been used in agriculture for over half a century [2]. The major limitation of polyethylene mulch involves disposal of mulch material after use due to high molecular weight and hydrophobic properties. Current disposal options as reviewed by Hayes et al. [3] include burning, incineration, recycling, composting and using landfills; each have major economic or environmental disadvantages [4].

Recently, biodegradable mulch films (BD) have been seen as a more sustainable and ecological alternative to polyethylene mulch [5]. Although some commercially available biomulchfilms are compostable, reliable in-soil biodegradation of mulches has not yet been fully understood. One of the main challenges of this biodegradable mulch is to be able to respond to all the functional requirements, during its lifetime, as the conventional ones [5]. At the end of the crop cycle the BD mulches are buried into the soil with the crop residues and are expected to be fully biodegraded within a reasonable time under real field conditions. BD films theoretically can save significant labour and disposal costs through incorporation via soil tillage operations rather than disposal in landfills [6].

*Corresponding author: Maria da Graça Palha, Instituto Nacional de Investigação Agrária e Veterinária (INIAV), Quinta do Marques, 2784-505 Oeiras, Portugal. Tel.: +351 214403692; E-mail: graca.palha@iniav.pt.

The replacement of traditional plastics, with renewable and biodegradable polymers has been particularly welcome. Several approved brands of totally or partially biodegradable mulches have already proven reliable in terms of agricultural performance [7] in several crops, including strawberry [5, 8–11].

Strawberry crop production is a very high consumer of agricultural plastics in Southern Europe either for covering the crop (low and high tunnels) or the soil (mulching). Plants are grown in intense annual production systems in raised beds covered with polyethylene film, drip irrigation underneath and high planting density [12]. In Portugal the consumption of PE mulches in strawberry production, is estimated in 138 t per year [13]. In autumn-winter cycles plants are typically grown on raised beds covered with white on black plastic mulches in a long crop cycle (6 to 9 months). This kind of production cycle is unusual being very challenging for farmers by its adding value. Mulch films are used only in one growing season as consequence of their prolonged exposure to climatic agents that lead to a decrease on mechanical properties [14] and due to cultural practices that include soil preparation - and sometimes soil disinfection - in order to achieve good conditions to install the next crop/crop cycle.

Biodegradable mulch (BD) films are so a promising new material providing a more convenient, environmentally friendly alternative for this crop, showing enhanced biodegradability [11] but having as main constrain to the farmer's acceptance the high cost [6]. However, it is important to analyze carefully all the costs associated to the recovery/recycle and disposal of the conventional mulch. In several European countries, there are economic incentives to the use of these new environmentally friendly materials, avoiding the negative impact of the PE mulches residues. In Portugal, these incentives exist but are not selected as a priority by farmers, mainly due to the lack of information about the performance of these new materials.

The aim of this study was to assess the performance of three BD white on black mulches, in comparison with one PE mulch, in order to assess if BD films are viable substitutes to PE in an autumn-winter strawberry crop cycle, reducing the environmental impact. To achieve the main objective were monitored the variation on soil warming, lifetime of the films, crop yield and degradation rate of the exposed and buried BD mulch films.

2. Material and methods

2.1. Experimental field trial

Field trial was conducted in a commercial strawberry farm (Casa Prudêncio Sociedade Agro-pecuária Lda), located in the central area of Portugal, in the Ribatejo region (39° 10'N, 8° 39'W, 10 m above sea), from June 14th 2010 till January 11th 2011, in a sandy-loam soil.

The experiment was set up in a randomized block design with 4 plots and 4 mulch film treatments in an area of 325.0 m^2 (6.5 m wide × 50 m long). Each plot consisted of one raised bed with 11.55 m^2 (1,1 m wide and 10.5 m long) with 66 plants.

The BD mulches were of starch-based raw material supplied by Polivouga enterprise (M1-Biomind) and by Silvex (M2 and M3Mater-Bi); the conventional mulch film was a low-density polyethylene (PE) purchased from Polivouga (M4). The characteristics of the mulch treatments are described in Table 1. All mulches were bicolor: white on upside and black on downside sheet.

Table 1

Characteristics of white-on-black mulch films treatments

	M1	M2	M3	M4
Raw material	Biomind	Mater-Bi®	Mater-Bi®	PE
Thickness (μm)	31	20	25	40
Film width (mm)	1500	1400	1400	1400
Density (g/cm^3)	1.35	1.20	1.20	0.92
Elongation at break (%)	450	335	390	375
Tensil strength (MPa)	18	23.6	23.5	18

In June 2010, planting beds were performed with a standard bed maker machine 0.50 m wide and 0.40 m high and were covered with white on black PE mulch film of 40 μm thickness. Beds were fumigated with 400 L·ha^{-1} of metam sodium through drip irrigation system to eliminate soil borne diseases, nematodes, and weeds in the soil. Beds covering remained for one month. After on M1, M2 and M3 plots the PE mulch was replaced with the corresponding biodegradable films treatments by hand.

On July 14th strawberry frigo plants were set in double rows per bed with plant distance 0.30 m between plants and 0.30 m between rows, giving a plant density of 6 plants per m^2. After plantation, sprinkler irrigation along with drip irrigation was used during 45 days for better plant establishment, followed by drip irrigation.

The crop was conducted in open field during July, August and September and under tunnel from October till December. High multi-tunnels of metal structure were mounted with an opening in each of the tops, oriented in NE-SW direction. The tunnels were covered on September 30th with transparent thermal polyethylene of 200 μm thickness. The use of high tunnel during autumn is mainly to protect strawberry from rain and fungal diseases and to enhance fruit appearance [12]. After end of fruit harvesting (December 20th) tunnels were removed from the experiment.

Fertilizers were provided by a drip computerized system and fertigation and pest control were done according to established practice. Phytosanitary treatments for *Oidium* sp., *Botrytis* sp., caterpillars, thrips and spider mites were applied.

2.2. Mulch films performance

The performance of the mulch films was assessed during three stages of the experiment: stage 1 – open field (from plantation to beginning of harvesting); stage 2 – tunnel (harvesting period); and stage 3 – open field (Table 2). The degradation of the exposed mulch films was evaluated every two weeks by visual observations. The measurements were performed according to a visual scale evaluation 0–9 [15] where 0 was 0–9% mulch cover and 9 was 90–100% mulch cover. Degradation of 8 to 9 correspond to mulch film in very good condition, 6 to 8 in good condition, 4 to 6 in satisfactory condition and less than 4 in bad condition.

In stage 3, after harvesting season, tunnels were dismantled and the aerial part of the plants was cut. Before the incorporation of the biodegradable mulch films a final measurement of the mulch films degradation was made by photographs and with the help of AUTOCAD program (2004 version). The images were flattened and the area of uncovered soil bed of each treatment was measured, taking in account the subtraction of plantation holes area.

At the end of the trial, drip irrigation system and the conventional mulch film were removed manually from the experiment. The biodegradable films were tilled together with soil and plant residues by a harrow in order to break up and to bury them. After the conclusion of the study the experimental area was left uncultivated.

2.3. Meteorological data and soil temperature

Air temperature, relative humidity, precipitation, and total solar radiation were hourly collected at an automatic weather station (iMETOS, Pessl Instruments). These data were collected during open field and tunnel environment conditions.

In order to determine the effect of the mulch treatments on soil temperature under field conditions, measurements of temperature were recorded at 0.15 m soil depth, every hour, with Soil Temperature Probe IM 5041D sensor SMT160-30 (Pessl Instruments), from August 2nd till end of the crop cycle. The sensors were located underneath the mulch of each plot, in the middle of the bed.

Table 2
Stages of the experimental field trial for mulch film degradation analysis

Stage	Period	Beginning – end	Environment
1	14 July–29 Sept.	Mulching installation – high tunnel collocation	Open-field
2	30 Sept.–20 Dec.	High tunnel collocation – end of harvesting season	Tunnel
3	21 Dec.–10 Jan.	End harvesting season – film buried	Open-field

2.4. Plant productivity

Fruits at commercial ripening stage were harvested from each plot (30 plants) three times a week between September 17th and December 20th. At each harvest, the number and the fresh weight of the fruits were recorded separately for marketable and non-marketable (deformed and diseases) fruits. Total yield, average fruit weight and number per plant were calculated for all treatments.

2.5. Costs analysis

A cost analysis per hectare of biodegradable mulch films in comparison to the conventional PE mulch was made based on current prices for 2010, on quantity of plastic used and on incorporation, removal and disposal costs. A comparison of costs was also made applying the Portuguese financial support for the application of BD mulches, which is 31.3% of product cost.

2.6. Statistical analysis

Fruit yield data were subjected to analysis of variance (ANOVA) and a LSD range test ($P < 0.05$) was applied to the significant results, using the program STATISTICA version 6.0 software.

3. Results and discussion

3.1. Soil temperature

Soil temperature decreased throughout the crop cycle, with mean values higher than air temperature, except at the end of the season (Fig. 1).

Soil temperatures showed some differences between PE and BD materials during summer period under open field conditions and in autumn-winter period under tunnel protection. The values recorded under BD films, especially M2 treatment, were always higher than those under PE mulch (Table 3). This was also related in previous report [16]. Following this period, differences in soil temperature among treatments became practically undetectable.

PE mulch film have lower water vapor permeability than BD mulch films and remains practically constant for longer periods due to its good chemical stability [17]. As consequence, in mulches with same film thickness, it is expected to find higher soil temperatures under PE due to the higher permeability of the biodegradable films to water vapor [10, 11, 17]. In this experiment, the higher film thickness of PE (40 μm) resulted in less soil heating. Besides, according to Vox and Schettini [16] mulch films with different thicknesses have different radiometric properties which also affect soil temperature.

Differences in soil temperature among treatments were more evident early in the growing season during summer because plants shaded less the mulches and the crop was conducted in open field environment. In late crop season covering the crop with high tunnel and the higher foliage shading contributed to reduce these differences [18].

3.2. Mulch films performance

From July till December, the mulches were exposed to different air temperature, relative humidity, rainfall and water sprinkler irrigation, and solar radiation conditions (Table 4).

The first signs of degradation of the exposed mulch film appeared in stage 1 and were presented by M1 with longitudinal tears on both sides of the beds, four weeks after application. M2 film degradation started later on, followed by M3 that initiated to degrade only in the beginning of stage 2, under tunnel environment (Fig. 2). M2 and M3 films also showed tears especially near the planting holes, with the M3 degradation starting later. The PE mulch film remained intact during this stage and during subsequent phases until the end of the experiment.

At the beginning of stage 2 (tunnel protection) the degradation rate of BD mulch films stabilized. Covering the crop with high tunnels reduced the detrimental effects of high doses of UV radiation on the elongation at break of

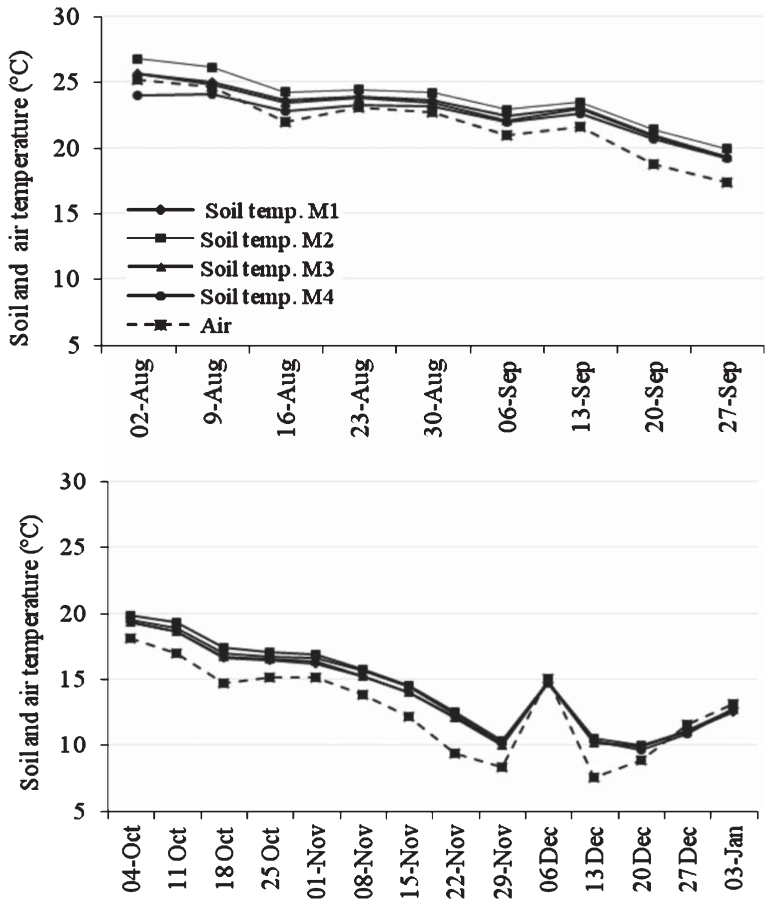

Fig. 1. Evolution of weekly soil and air mean temperatures during crop cycle in summer (a) and autumn-winter periods (b). M1 – Biomind, 31 μm thick; M2 – Mater-Bi®, 20 μm thick; M3 – Mater-Bi®, 25 μm thick; M4 – PE, 40 μm thick.

Table 3

Variation of weekly mean soil temperature (°C) under biodegradable mulch treatments relative to PE mulch, during summer and autumn-winter periods

	Summer period											
	02Aug	9Aug	16Aug	23Aug	30Aug	06Sep	13Sep	20Sep	27Sep			
M1-M4	1.71	0.98	0.82	0.60	0.45	0.48	0.46	0.22	0.09			
M2-M4	2.78	2.07	1.43	1.17	1.03	0.98	0.82	0.70	0.70			
M3-M4	1.69	0.78	0.59	0.51	0.28	0.16	0.31	0.11	0.02			
	Autumn-winter period											
	04Oct	11Oct	18Oct	25Oct	01Nov	08Nov	15Nov	22Nov	29Nov	06Dec	13Dec	20Dec	27Dec
M1-M4	−0.18	−0.25	−0.33	−0.26	−0.44	−0.45	−0.43	−0.21	−0.17	−0.07	−0.10	0.29	0.11
M2-M4	0.40	0.43	0.47	0.27	0.27	0.11	0.09	0.17	0.15	0.04	0.16	0.36	0.11
M3-M4	−0.17	−0.25	−0.30	−0.19	−0.27	−0.42	−0.44	−0.25	−0.23	0.04	−0.15	0.28	0.21

M1 – Biomind, 31 μm thick; M2 – Mater-Bi®, 20 μm thick; M3 – Mater-Bi®, 25 μm thick; M4 – PE, 40 μm thick.

Table 4
Monthly average values of the mean (T_{mean}), minimum (T_{min}) and maximum (T_{max}) air temperatures, relative humidity (RH), water (W) and solar radiation (SR) during the crop cycle

	T_{mean} (°C)	T_{min} (°C)	T_{max} (°C)	RH (%)	W (mm)	SR ($W \cdot m^{-2}$)
July	23.4	15.4	32.9	63.6	35.4*	5708
August	23.6	15.7	33.0	65.7	96.8*	8434
September	20.1	12.6	29.2	74.0	13.4*	6543
October	16.4	10.5	26.0	83.0	6.2	3194
November	12.3	7.3	20.4	87.0	4.2	2100
December	10.4	6.3	16.4	90.6	74.2	1540

*Rainfall and sprinkler water irrigation.

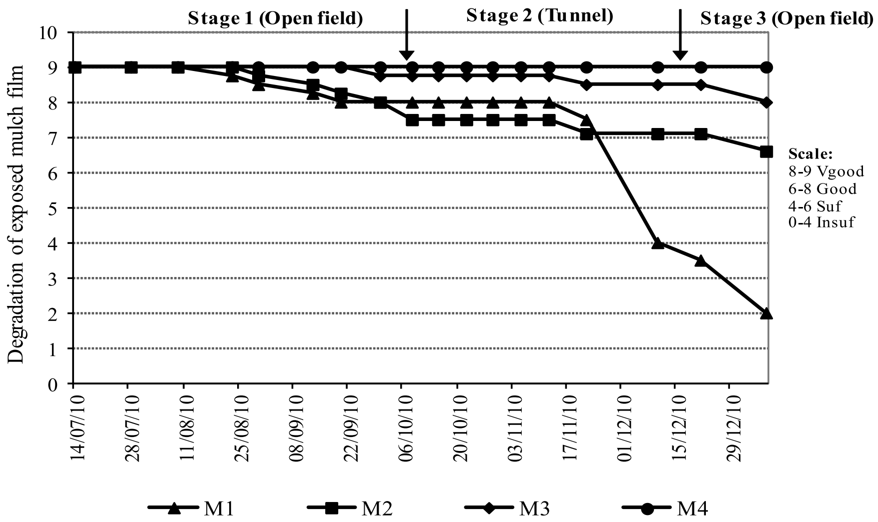

Fig. 2. Degradation of the exposed biodegradable mulches (M1 – Biomind, 31 μm thick; M2 – Mater-Bi®, 20 μm thick; M3 – Mater-Bi®, 25 μm thick) and of conventional mulch (M4 – PE, 40 μm thick) during open field (stages 1 and 3) and tunnel (stage 2).

BD mulching films [8]. However, in the middle of November the degradation process of M1 accelerated until the end of crop cycle. M1 was highly fragmented at the slightest touch, beginning to break into small pieces, with a texture similar to paper. This fact may be attributable to the composition of the M1 mulch film as M2 and M3 films only started to degrade after the removal of tunnel protection. The higher degradation of M2 was mainly due to its lower film thickness in comparison to M3. Although the occurrence of the BD mulch films degradation throughout the experiment, this did not impair the general appearance of the plants. In addition, they provided adequate weed suppression as illustrated in Fig. 3.

Concerning the degradation of the buried edges of the mulch films, M1 had a very rapid degradation during July and August while for M2 and M3 treatments this process was only observed in December (Fig. 4).

At the end of the crop cycle and before the incorporation of the biodegradable mulch films the final measurement of the mulch films degradation were performed and the mean values of degraded area per mulch treatment are presented in Table 5. The percentage of soil mulching surface with M1 was lower (20%) compared with the M2 (70%) and M3 (86%) mulching surface. These measurements are in agreement with the final values of visual scale used.

The results obtained suggest that the different performance of M1 in relation to M2 and M3 films may be due to the composition of its material, although films thicknesses were different among them [16]. Between M2 and M3 mulch performance was influenced by films thickness, as they have the same composition and the differences were only in the exposed mulch.

Fig. 3. Performance of mulch films at the end of crop season. a) M1 – Biomind, 31 μm thick; b) M2 – Mater-Bi®, 20 μm thick; c) M3 – Mater-Bi®, 25 μm thick; d) M4 – PE, 40 μm thick.

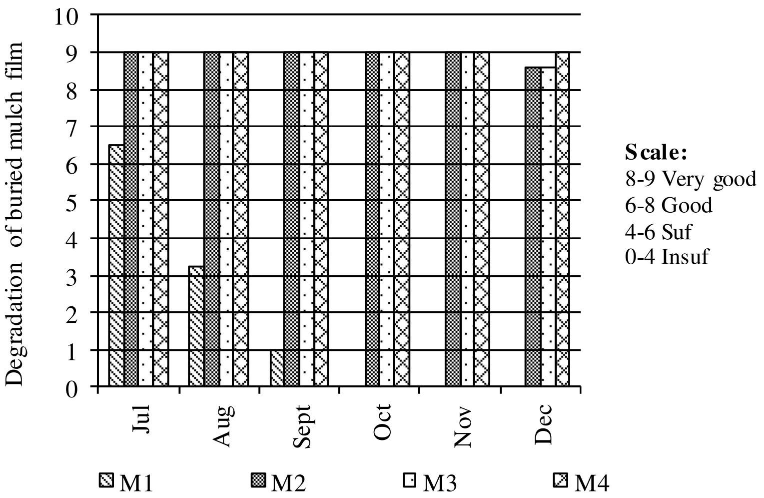

Fig. 4. Degradation of buried edges of biodegradable and of conventional mulch along the strawberry crop cycle. (M1 – Biomind, 31 μm thick; M2 – Mater-Bi®, 20 μm thick; M3 – Mater-Bi®, 25 μm thick; M4 – PE, 40 μm thick).

Table 5
Mean degraded area (±Standard Deviation) and initial and final covering area per mulch film treatment, before its incorporation into soil

	Treatment			
	M1	M2	M3	M4
Initial covering area (m^2)	10.4	10.4	10.4	10.4
Mean degraded area (m^2)	8.3 ± 1.3	3.2 ± 1.2	1.5 ± 0.8	0.0 ± 0.0
Final covering area (%)	20.4	70.1	85.9	100

M1 – Biomind, 31 μm thick; M2 – Mater-Bi®, 20 μm thick; M3 – Mater-Bi®, 25 μm thick; M4 – PE, 40 μm thick.

Table 6
The effect of mulch film (M) on yield performance

Treatment	Total yield (g/plant)	Percent crop harvested per month				N° fruit/plant	Fruit weight (g)
		Sept.	Oct.	Nov.	Dec.		
M1	317.7 b	12.7 a	55.8 a	25.9 a	5.6 a	24.6 b	13.7 a
M2	390.8 b	10.5 a	51.7 a	28.4 a	9.5 a	29.8 b	13.7 a
M3	415.4 b	12.1 a	54.4 a	25.1 a	8.4 a	31.6 b	13.8 a
M4	508.7 a	12.9 a	53.9 a	25.3 a	7.8 a	40.1 a	13.3 a

M1 – Biomind, 31 μm thick; M2 – Mater-Bi®, 20 μm thick; M3 – Mater-Bi®, 25 μm thick; M4 – PE, 40 μm thick. Values within column followed by the same letter are not significantly different at $P \leq 0.05$.

3.3. Fruit yield

Yields for all biodegradable mulch films were significantly lower than for PE mulch film (Table 6). The mean loss of crop yield was about 20% for M2 and M3 and 37% for M1 compared to PE mulch film (M4). No significant differences were observed on fruit yield among biodegradable mulch films. The highest fruit production occurred during October and November.

The highest yield on M4 may be related to the lowest soil temperature of this plot, mainly during the beginning of the trial (July and August), when the air temperature was very high. With these high temperatures, plant growth and development may have been favored by a soil temperature more adequate to their development [19], leading to a better crop yield.

Despite the differences in the total yield among mulch treatments, no significant differences were found in the percentage of commercial and uncommercial fruits, which was about 82% and 18% respectively. Mulch treatment had no effect on fruit production per month.

The number of fruits was significantly higher on M4 than in the biodegradable mulch films plots with no differences among the last ones (Table 6). The highest number of fruits on M4 led to highest fruit yield as average fruit weight was not affected by mulch treatment. These findings agree with Himelrick [20].

3.4. Cost analysis

Costs of BD and PE films, including product, removal and disposal costs are presented in Table 7. The use of BD films increases the amount of input costs for the strawberry grower because of its high price which is practically three times the PE cost.

The costs of removing and of the transport for disposal of the conventional polyethylene much film was nearly nine times more expensive than the costs of burying the biodegradable mulch films together with the crop residues into the soil (Table 7). These high costs are mainly due to human labor and machinery which totalized 106 h/ha for

Table 7
Comparison between the costs of BD and PE mulch films per hectare for autumn-winter strawberry production

Variables	Biodegradable mulch film			PE mulch
	M1	M2	M3	M4
Plastic cost (€/kg)	5.85	6.25	6.25	1.95
Quantity of plastic (kg/ha)	510	305	382	438
Plastic cost (€/ha)	2984	1906	2388	854
Average incorporation cost (€/ha)	60	60	60	0
Average removal and disposal costs (€/ha)	0	0	0	548
Overall costs (€/ha)	3044	1966	2448	1402
Overall cost difference (%) (base: PE)	117.1	40.2	74.6	–
Government incentive for BD plastic (%)	31.3	31.3	31.3	0
Plastic cost with incentive (€/ha)	2050	1310	1640	1402
Overall cost with incentive	2110	1370	1700	1402
Overall cost difference with incentive (%) (base:PE)	50.5	−2.3	21.3	–

M1 – Biomind, 31μm thick; M2 – Mater-Bi®, 20 μm thick; M3 – Mater-Bi®, 25 μm thick; M4 – PE, 40 μm thick.

polyethylene mulch removal and transport operations in contrast to 4 h/ha for biodegradable mulch film incorporation in the soil.

Comparing the total costs of using these two types of plastic mulch it is clearly evident that using BD mulch films remains expensive due to its high prices, which has been already reported [21]. However, in order to accomplish sustainable agriculture practices, Portuguese government gives financial support for the application of these kinds of mulches. Applying this incentive the use of BD mulch represented a less investment for the farmers.

4. Conclusions

The purpose of this study was to evaluate the performance of white-on-black biodegradable (BD) mulch films in autumn-winter cycle strawberry production and its effects on soil heating and plant productivity. Soil temperature and mulch films performance were affected by film thickness and material composition.

Biodegradable mulch films M2 and M3 (made from Mater-Bi® raw material) underwent to a lower degradation showing 78% of soil coverage at the end of the crop cycle in contrast to M1 BD mulch film (Biomind raw material) that had 20% of soil coverage. This last one also had a fast degradation of the buried edges. Although these changes in the film structure BD mulch films provided adequate bedcover during the growing season over five months.

The differences in soil temperature between BD and polyethylene (PE) mulch films were more evident in the summer period. The BD mulches warmed soils more than PE mulch during summer which might have contributed to less number of fruits produced and consequently to lower plant productivity.

From the overall results obtained, the use of biodegradable plastic materials for mulching may be a promising alternative to PE mulching due to their progressive degradation throughout the growing season and because they provided an adequate ground cover and an efficient control of weeds as well as retaining fruits free from the soil. However there should be governmental economic incentives in order to implement this practical as the plastic cost remains still too expensive.

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