

Effects of different paper mulches on soil temperature and yield of cucumber (*Cucumis sativus* L.) in the temperate zone

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The effect of different paper mulches and two different biodegradable plastic mulches on the yield of field-grown cucumber (*Cucumis sativus* L.) was examined. The studies were conducted during two climatically different growing seasons 2011 and 2012 in Southern Finland. All the mulches increased the yield as compared to bare ground. In 2011, cucumbers on all the mulches with a dark upper surface produced higher yields than those on kraft paper alone. In 2012, when the average temperatures were lower than in 2011, there were no differences in yield between different types of mulches. Soil temperatures of the experimental plots were monitored throughout the growing seasons. The mulches with a dark-colored upper surface increased the soil temperature more than the ones with a light-colored upper surface. The soil warming effect of the mulches was greater during early season and diminished when the plants grew larger and their leaves covered most of the mulch surface. There was no need for weed control except in uncovered plots. In conclusion, during both years dark-colored paper mulch was comparable to biodegradable film in yield production and could replace it as a mulch material in cucumber production.

Key words: biodegradable plastic mulch, kraft paper, weeds, yield, soil temperature

Introduction

Low temperatures and particularly low soil temperatures limit early cucumber production in Finland and in other countries in the temperate zone with similar climate conditions. The minimum root-zone temperature for cucumber growth is 10–12 °C (Salokangas 1973). In Finland, especially in spring, the soil temperature is too low for cucumbers (Salokangas 1973) and other species with a high temperature requirement. Different mulches may improve the soil temperature, as they absorb solar radiation and thereby heat the soil (Anderson et al. 1995). The quality, transparency and color of mulch film have a significant impact on the soil temperature, and thereby on crop growth. When different mulches were tested, the soil temperature was highest under clear polyethylene, intermediate under black polyethylene and lowest when the ground was not mulched (Salokangas 1973, Nimah 2007). Paper mulches also increased the soil temperature, but not as much as clear PE sheet (Salokangas 1973). In a study by El-Nemr (2006) conducted in Cairo, Egypt, a kraft paper saturated with paraffin wax in order to increase its transparency gave the highest soil temperature and moisture compared to transparent, silver or black polyethylene mulches. The best growth and highest cucumber yield were obtained by using black polyethylene or kraft paper saturated with paraffin as mulch. Ibarra-Jiménez et al. (2008), who tested eight different colored plastic mulches in cucumber production in Mexico, suggested that the optimal color of plastic mulch needs to be determined in each specific region, as the color affects the upper soil temperature profile and the soil heat accumulation.

Weed control is an important aspect to be considered when planning vegetable production. Whether done manually, mechanically, or chemically, it accounts for a major part of the pre-harvest cost (Jenni et al. 2004). Mulches may provide weed control (Anzalone et al. 2010, Coolong 2010). Furthermore, mulching can significantly reduce the demand for irrigation and improve water use efficiency in cucumber production (Kirnak and Demirtas 2006), and may also help to control harmful insects or pests (Necibi et al. 1992).

Polyethylene is widely used as a mulch in agriculture and horticulture (Espí et al. 2006), and black-colored film has been the most popular in production (Moreno and Moreno 2008). However, there have been efforts to find alternative products for polyethylene (PE) because of the disposal problems. Minuto et al. (2008) found that starch-based biodegradable film can substitute conventional PE films for short-duration crops. They believed the cost of the biodegradable film to be comparable with that of PE film when removal and disposal costs are considered. If removal expenses are not considered, the cost of materials for growers using biodegradable mulches is 2 to 3 times higher than that of PE mulch films (Halley 2001, Sarnacke and Wildes 2008).

In processing tomato production, the economic benefit of different biodegradable plastic mulch treatments was 52 to 76 % of that for polyethylene mulch (Cirujeda et al. 2012). For paper mulch treatments, the benefit was 64 to 65 % compared to polyethylene. Both paper and biodegradable films are made of renewable materials, but the raw materials for biodegradable films could also be used as food for humans or feed for animals, thus making paper mulch a more sustainable option. This option is even more sustainable if and when material for paper production is taken from certified forests and/or the paper material is recycled.

The aim of our study carried out in southern Finland was to examine the effects of different paper mulches on the yield of cucumber, the soil temperature, and weed emergence, and to assess whether paper mulches could substitute biodegradable film mulch in cucumber production. Because paper materials and biodegradable film have not proven to be durable enough alone (Hochmuth and Hochmuth 1994, Moreno and Moreno 2008), we also tested papers coated with biodegradable films.

Materials and Methods

The study was conducted in the experimental field of the Faculty of Agriculture and Forestry of the University of Helsinki (latitude, 60°13'N; longitude, 25°01'E) in 2011 and 2012. Average monthly temperatures and rainfall during these years are presented in Table 1. Growing season of 2011 was warmer than the average during the years 1981-2010.

Plant material

Cucumber (*Cucumis sativus* L., cv. Dirigent) seeds were sown in a greenhouse on 27 May in 2011, and on 22 May in 2012. The seedlings were grown for 24 days according to commercial practice before transplanting for the field trial.

Mulches

In both years, four paper mulches, a biodegradable film and bare ground (BG) as a control were used. In 2011, the paper mulches were: brown kraft paper 70 g m⁻² (K), brown kraft paper 70 g m⁻² with the underside coated with black biodegradable film (K1), brown kraft paper 70 g m⁻² with both sides coated with black biodegradable film (K2), and brown kraft paper 70 g m⁻² with the upper side colored black by using carbon black (KB). The biodegradable film (BDF) was black and made of maize starch (thickness 30 µm, commonly used in Finland). K, K1, K2, and KB were under development by different paper manufacturers, and BDF was a commercial product. In 2012, the paper mulches were: brown kraft paper 70 g m⁻² with the upper side colored black (KB), MimGreen kraft paper 85 g m⁻² with black upper side (MIMGROUP, Spain) (MG), creped brown kraft paper 60 g m⁻² (CK), and creped brown kraft paper 60 g m⁻² with wax coating (CKW). The biodegradable film (BIO) was made of maize starch (thickness 18 µm) (Bioska, Plastiroll, Finland). KB, CK, and CKW were under development, whereas MG and BIO were commercial products.

Field trial

The clay loam soil of the trial area was prepared by ploughing and harrowing. The trial area was fertilized with 130 kg N ha⁻¹, 43 kg P ha⁻¹ and 173 kg K ha⁻¹ in 2011. In 2012 the trial area was fertilized with 116 kg N ha⁻¹, 39 kg P ha⁻¹ and 155 kg K ha⁻¹, and 11 kg N ha⁻¹, 6 kg P ha⁻¹ and 17 kg K ha⁻¹ were added through drip irrigation two times during the growing season. Four 0.7-m-wide and 0.10-m-high beds that served as blocks in the experimental design were formed with a laying machine (Avagro, Finland). Experimental plots (0.7 x 1.5 m in size) were arranged in a randomized complete block design within four blocks (=beds). Paper mulches were laid on the beds manually and their edges were buried in soil just before planting the cucumber seedlings. Mulches were applied manually due to the complicated lay-out of the experiment which did not allow mechanical application. Transplantation was carried out manually on 20 June in 2011, and on 15 June in 2012 in two interlaced rows with a distance of 30 cm between the plants. There were five plants in each plot and one buffer plant between the plots.

Throughout the growing season of 2011, the average temperatures were higher than in 2012 (Table 1). Furthermore, rainfall in August 2011 was much greater than in August 2012. The plots were watered when needed with an overhead sprinkler in 2011 and through drip irrigation in 2012. All the treatments received equal amount of irrigation water. In 2011, weeding of the uncovered control plots was carried out once during the growing season. In 2012, the plots were weeded 45 days after transplanting and the total dry weight of all the weeds harvested from the whole plot was measured.

Cucumbers were harvested twice a week starting on 19 July and on 20 July, and finishing on 23 September and on 19 September, in 2011 and 2012, respectively. The cucumbers were weighed immediately after harvesting with a precision scale and their diameter was measured to determine if it was within the industrial standard (25–45 mm). The commercial yield as kg m⁻² was calculated so that 10% of cucumbers could exceed the 45-mm size limit, as is determined in the standard.

Temperature and moisture monitoring

The soil conditions of all plots were monitored at 10-cm depth with temperature and moisture sensors (Decagon 5TM, USA) connected to data loggers (Decagon Em50) once in every 30 minutes (moisture measurement data not included in this article).

Statistics

The data were subjected to analysis of variance in PASW Statistics 18 (IBM SPSS Inc.). Treatment means were separated using Student-Newman-Keuls (S-N-K) test at $p < 0.05$.

Table 1. Average monthly temperature and rainfall during the experimental years 2011 and 2012, and the average during 1981-2010

	Temperature (°C)			Rainfall (mm)		
	2011	2012	1981-2010	2011	2012	1981-2010
June	16.7	13.7	14.6	49	88	57
July	20.6	17.8	17.7	56	54	63
August	17.5	16.0	16.3	173	39	80
September	13.6	12.5	11.5	88	160	56

Results and Discussion

In 2011, the average soil temperature under the double-coated black kraft paper (K2) was on average 1°C higher than under kraft paper (K), kraft paper coated on the underside with black biodegradable film (K1), or that of bare ground (BG) (Table 2). In June and July, soil temperatures were highest under K2 and lowest under K1, other mulches being intermediate between these two (Fig. 1). In June, soil under the black-surfaced mulches (K2, BDF and KB) was warmer than under K1 or bare ground. In general, those of our mulches that had a dark color on the upper surface increased the temperature of soil more than the ones with a light-colored upper surface. Dark colors reflect and transmit less shortwave radiation than light colors and also absorb more shortwave radiation. This increases the soil temperature in the upper soil profile (Ibarra-Jiménez et al. 2008). The differences between the mulches diminished during the season, as the cucumber leaves covered all of the mulch, and mulch color no longer played any role. In July, soil temperature under K2 was still higher than that of bare ground and under paper with a brown surface (K and K1). In August, only K2 significantly increased soil temperature as compared to bare ground.

Cucumbers on all of the mulches with dark upper surfaces (KB, BDF, K2) produced higher yields than kraft paper alone (Table 2). All the mulches produced significantly higher yields than when the soil was left bare. All paper mulches, except untreated kraft paper, were equally good as compared with biodegradable mulch film.

Table 2. Number of fruits and yield of cucumbers grown on different mulches, and average soil temperatures (T) under the mulches in 2011. BG = bare ground, KB = brown kraft paper with the upper surface colored black, BDF = biodegradable film, K = brown kraft paper, K1 = brown kraft paper coated on the underside with black biodegradable film, K2 = brown kraft paper coated on both sides with black biodegradable film.

Mulch	Fruits (no m ⁻²)	Yield (kg m ⁻²)	T June to Sept. (°C)
BG	104 ^y ± 1 c	9.5 ^y ± 0.2 c	18.0 b
KB	148 ± 4 a	14.3 ± 0.7 a	18.3 ab
BDF	153 ± 4 a	14.2 ± 0.5 a	18.7 ab
K	125 ± 8 b	11.7 ± 0.6 b	18.1 ^y b
K1	141 ± 5 ab	13.2 ± 0.3 ab	18.0 ^y b
K2	155 ± 6 a	15.2 ± 0.6 a	19.1 ^y a
<i>p</i>	< 0.001	< 0.001	0.023

Values are means of four replicates and followed by ± SEM. Values within columns followed by different letters are significantly different (*p* < 0.05) according to SNK test.

^y n = 3

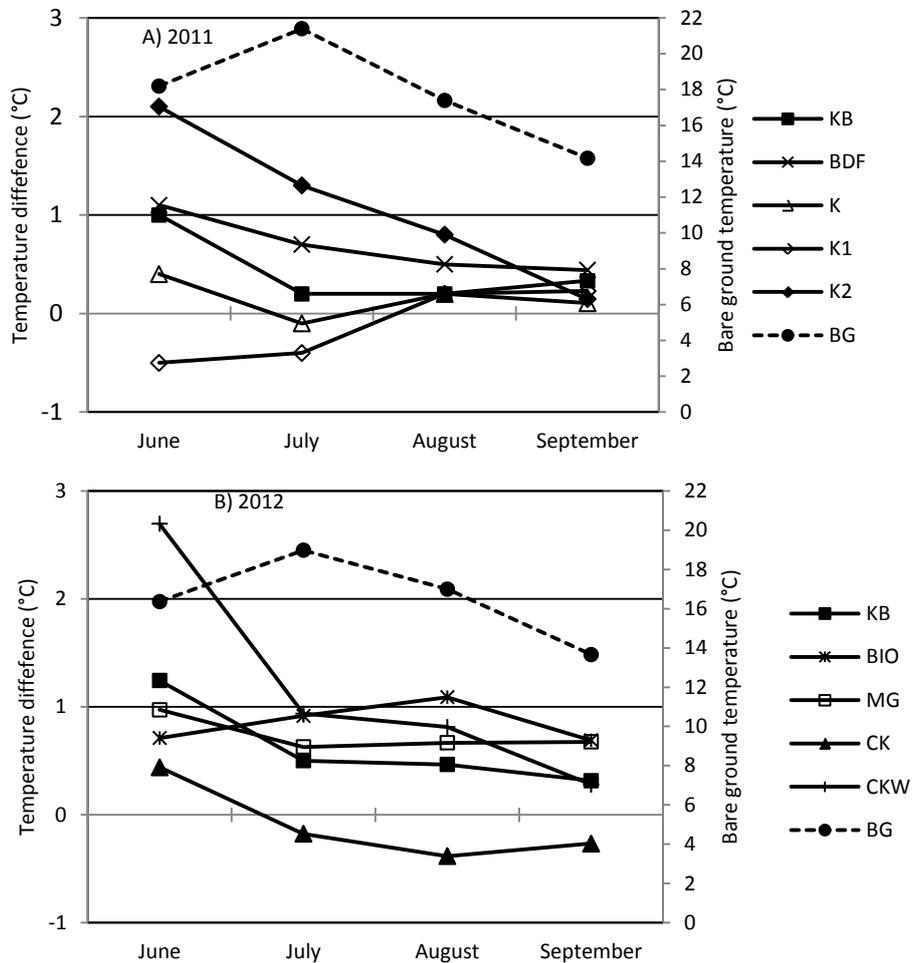


Fig. 1. Mean soil temperature difference under the different mulches as compared to bare ground (left Y-axis) and the mean bare ground temperature (BG) (dotted line, right Y-axis). A) In 2011, KB = brown kraft paper with the upper surface colored black, BDF = biodegradable film, K = brown kraft paper, K1 = brown kraft paper coated on the underside with black biodegradable film, K2 = brown kraft paper coated on both sides with black biodegradable film. B) In 2012, KB = brown kraft paper with the upper surface colored black, BIO = biodegradable film Bioska, MG = MimGreen kraft paper with black upper side, CK = creped kraft paper and CKW = creped kraft paper with wax coating.

In 2012, biodegradable film (BIO) and creped kraft paper with wax coating (CKW) increased the average soil temperature as compared to bare ground (Table 3). The average soil temperature was lower under creped kraft paper (CK) than under BIO, kraft papers with black upper side (KB and MG), or CKW. In June, CKW increased the soil temperature by 2.7°C, the temperature under the other mulches being lower (Fig. 1). This transparent mulch transmitted more solar radiation warming the soil under the mulch. In July and September, none of the mulches significantly increased soil temperature. In August, only BIO increased soil temperature.

Table 3. Number of fruits and yield of cucumbers grown on different mulches, and average soil temperatures (T) under the mulches in 2012. BG = bare ground, KB = brown kraft paper with the upper surface colored black, BIO = biodegradable film Bioska, MG = MimGreen kraft paper with black upper side, CK = creped kraft paper, and CKW = creped kraft paper with wax coating

Mulch	Fruits (no m ⁻²)	Yield (kg m ⁻²)	T June to Sept. (°C)
BG	40 ± 4 ^b	4.3 ± 0.4 ^b	16.9 ^{y bc}
KB	74 ± 6 ^{ab}	8.3 ± 0.6 ^a	17.5 ^{ab}
BIO	81 ± 6 ^a	9.1 ± 0.6 ^a	17.8 ^a
MG	72 ± 3 ^{ab}	7.9 ± 0.4 ^a	17.6 ^{ab}
CK	74 ± 12 ^{ab}	8.2 ± 1.4 ^a	16.6 ^{x c}
CKW	72 ± 12 ^{ab}	8.0 ± 1.4 ^a	17.9 ^a
<i>p</i>	0.032	0.028	0.006

Values are means of four replicates and followed by ± SEM. Values within columns followed by different letters are significantly different ($p < 0.05$) according to SNK test.

^y n = 3

^x n = 2

Cucumbers on all the mulches produced higher yields than on bare ground (Table 3). The tested paper mulches (KB, MG, CK, CKW) and biodegradable mulch film did not differ significantly from each other in yield production. In both years, mulching increased the yield due to increased fruit numbers. The average fruit weight was 94.6 g in 2011, and 110.5 g in 2012, and was not affected by mulch treatment.

Mulching can increase the soil temperature and moisture content, and also the yield (El Nemr 2006), and in some studies mulching has improved the growth and earliness of cucumber plants (Salokangas 1973, Pessala and Hårdh 1977). Some studies have indicated that a low root temperature restricts water uptake and top growth of cucumber plants, and may cause wilting and a long-term retardation of stem and leaf growth (Karlsen 1980, Krug and Thiel 1985, Lorenzo et al. 1999). The lower root temperature may also decrease the cucumber yield (Lorenzo et al. 2005), whereas a higher soil temperature has been observed to promote the stem and leaf growth of cucumbers (Krug and Thiel 1985). According to Ibarra-Jiménez et al. (2008), yield increments caused by mulching are partly due to an increase in soil temperature and photosynthesis.

Transparent or black polyethylene or straw as mulching materials increased the yield of pickling cucumber as compared to bare ground in a study by Gebologlu and Saglam (2002). In an earlier study conducted in Finland, an increase in soil temperature caused by polyethylene mulch clearly improved the cucumber yield, more than doubling it in summers with low temperatures (Salokangas 1973). Gosselin and Trudel (1985) demonstrated that an increased soil temperature in Quebec, Canada, may improve the cucumber yield in spring, but has minor effects in the fall. Likewise, in our study, the greatest effect on soil temperature was observed in the spring, leading to increases in early yields (data not shown). In Germany, cucumber yields were increased when the soil temperature increased from 16 to 18 °C (Krug and Thiel 1985). However, in Poland, no difference in the total or marketable yield of cucumbers or the quality of fruits was observed when grown on black polyethylene mulch or in unmulched soils (Spizewski et al. 2010). Similarly, although Hanna (2000) observed higher soil temperatures under black plastic than under white plastic mulch, the growth of cucumber plants was not affected.

In our study, black printed kraft paper produced higher total and early yields (data not shown) than kraft paper alone in the 2011, when the summer was warmer than the year after. This observation is supported by the study of Hallidri (2001), in which black, silver or transparent polyethylene films or wheat straw were used as mulches in a greenhouse. Black film increased the soil temperature more than other mulching materials, and gave the highest early production of cucumber.

Weeding was carried out only once in the uncovered control plots in both years. Cucumber growth was vigorous and leaves shaded the soil surface so that further weeding was not necessary. All the mulches controlled the growth of weeds so efficiently that weeding was not needed. Mulches with a black color were not even lifted by the weeds due to their total growth suppression. The light colored paper mulches and especially the waxed one allowed growth of weeds under the mulches (Fig. 2). The weeds did not penetrate the mulches, but grew through the planting holes. However, their number was that low and size small and they were quite equally distributed to all the plots that we do not think that they significantly affected the results. In earlier studies, black-colored paper mulch (Brault et al. 2002) and black paper mulch coated with latex (Zhang et al. 2008a, b) have offered complete weed control in cucumber production. Under beige paper mulches, dicotyledonous weeds were found, but they did not develop beyond the cotyledonary or two-leaf stage (Zhang et al. 2008a, b).

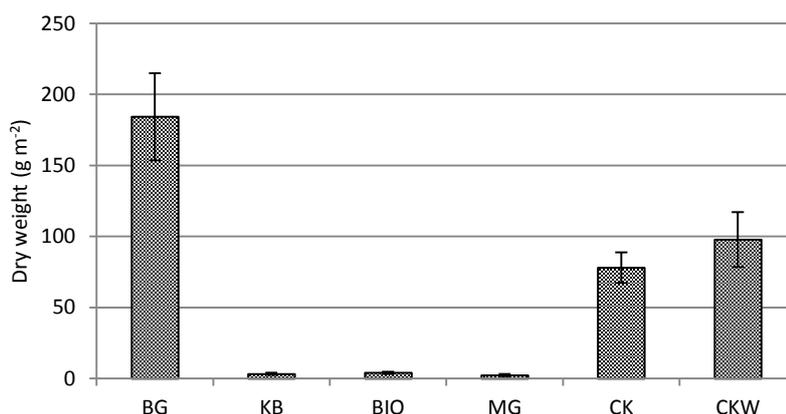


Fig. 2. Dry weight of the weeds harvested 45 days after transplanting (30 July, 2012) from cucumber plots covered with different mulches. BG = bare ground, KB = brown kraft paper with the upper surface colored black, BIO = biodegradable film Bioska, MG = MimGreen kraft paper with black upper side, CK = creped kraft paper and CKW = creped kraft paper with wax coating. Vertical bars present \pm SEM (n=4).

Many of the paper mulches, especially the ones not coated with biodegradable film, degraded on their sides, detaching them from the soil, whereas the coated ones remained intact for much longer. Brault et al. (2002) observed that even though the mulches used in cucumber production aged and degraded, they remained in place until harvest. We assume that the vigorous growth of the cucumber plants helped to keep the mulches in place. The paper mulches coated with the biodegradable film were clearly more durable than the film alone. In the case of cucumbers, the most important characteristic of the mulch material is that it increases the soil temperature and is durable enough to last in place and control weeds until the crop plant has sufficiently covered it and shades the ground to control weeds. A clear advantage of biodegradable material is that it can be left on ground and ploughed under, or collected and burnt or composted once the crop is finished. This makes it environmentally much more acceptable than the use of plastic.

In conclusion, mulching with paper or biodegradable plastic, and especially the mulches with a dark upper surface increased the yield of cucumber. These dark-colored mulches also had the greatest soil warming effect and controlled the weeds efficiently. Based on our results, black-printed paper mulch was comparable to biodegradable film in yield production and could replace it in cucumber production

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