Degradable Mulch as an Alternative for Weed Control in Lettuce Produced on Organic Soils

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Keywords: biodegradable mulch, crisphead lettuce, *Lactuca sativa* L., organic soils, paper mulch, polyethylene, soil moisture

Abstract

Lettuce in Quebec is primarily grown on organic soils, where weed control accounts for 30% of the pre-harvest production cost. As no efficient post-emergence herbicide is available, weeding is done mechanically and manually. Using mulch could be a possible alternative to current practices. Degradable paper mulches (pale, pale/black, black/pale) were compared with polyethylene mulches (white/black or black) and a manually weeded unmulched control. The experiment designed as a randomized complete block with 4 blocks was carried out in 1999 and 2000. Polyethylene or paper mulches with at least one black side were effective in controlling weed growth in both seasons. During a warm season in 1999, air and soil temperatures of the paper-mulched plots were similar to those of the control. Day temperatures for the white/black polyethylene mulch were reduced by 2.8°C for air and 0.9°C for soil compared with the control. Soil humidity was highest under the polyethylene followed by the paper and finally the unmulched control. Lettuce grown on paper or polyethylene mulches had 25% greater marketable yield, with heads significantly heavier than those of unmulched lettuce. In 2000, the air temperatures for all mulches were similar to and 1°C above those of the control. When the black side of mulches was exposed to the sun, the soil temperature increased by 2.8°C compared with treatments where the pale side of the mulch was exposed. Lettuce grown in treatments with higher soil temperatures had longer stems. Soil moisture was similar in mulched and unmulched plots during the cool and rainy 2000 season. Growing lettuce on paper or polyethylene mulches increased marketable yield by 7% and resulted in significantly heavier heads compared with the control. Although similar yields were obtained with both paper and polyethylene mulches, the former has the environmental and practical advantage of being able to degrade in the soil at the end of the season.

INTRODUCTION

Quebec lettuce, valued at CAN $34 million and accounting for 77% of Canada's total production, is the province's leading vegetable crop (Statistics Canada, 2002). Lettuce is mainly grown on organic soils in the southwestern part of the province. A major challenge in producing lettuce on organic soil is weed control, since no efficient post-plant herbicide is available. Mechanical and hand weeding may represent up to 40% of pre-harvest production costs (Naegely and Greenleaf, 1999). Paper mulch has been a well-known method of weed control for close to a century (Flint, 1928; Smith 1931). The discovery of plastics brought a new era in the horticulture industry. Emmert (1955) developed many principles of plasticulture with his research on mulches and row covers. The benefits of using polyethylene in vegetable crop production include easy mechanical installation, conservation of soil moisture, reduction of soil compaction, as well as weed control if the plastic is opaque to photosynthetically active radiation (Waggoner et al., 1960). These many benefits resulted in the rapid adoption of polyethylene by growers. Clear and infrared transmitting types of plastic mulch have been adapted to promote earliness in warm-season crops (Loy and Wells, 1990; Jenni et al., 1998). A highly reflective mulch such as coextruded white/black polyethylene may be better suited to cool-season crops such as lettuce, since the upper surface of the mulch reflects incoming light, thereby reducing surface temperatures (Carnell, 1996).

Although there are many benefits associated with the use of plastic mulches, increasing costs and concerns about plastic removal and disposal has sparked a renewed interest in biodegradable paper mulches (Anderson et al., 1995; Cappelletto et al., 1998; Schonbeck and Evanylo, 1998; Shogren, 2000). Paper mulches have not yet been widely adopted for commercial field production, primarily because of their rapid degradation in an unprotected environment (Anderson et al., 1995; Schonbeck and Evanylo, 1998). New paper mulches with polymer coating have been developed to improve the resistance of the material to breakdown. Previous papers mulches were either pale or black in color (Brault et al., 2002b). Black (paper or polyethylene) mulches offer complete weed control and increase the temperature of the air and soil environment close to the plant as a result of the mulch's absorption of solar radiation. Brault et al. (2002a) found weed growth under pale paper mulch. They attributed this to light transmitted in the PAR range, which increased from 4% at mulch placement to 10% after 42 days of field exposure. The development of a paper mulch with a black side for weed control and a pale side to reduce solar radiation absorption may offer the best overall combination to enhance growth of this cool-season crop.

The general objective of this work was to compare the agronomic performance of paper mulches with a black side and a pale side to that of a coextruded white-over-black polyethylene mulch in head lettuce crops grown on organic soil. More specific objectives were: (1) to evaluate whether having the black side or the pale side of the paper mulch as the upper surface affects the air and soil temperature around the plant, and hence the yield and maturity of cripshead lettuce; (2) to compare soil moisture levels under paper and polyethylene mulches; and (3) to evaluate the field degradation of paper mulches with a polymer coating on one or two sides.

MATERIALS AND METHODS

The experiments were carried out in Napierville, Quebec, Canada (lat. 45°11’N, long. 73°25’W) in a well-decomposed organic soil (humisol). The paper mulch used in the treatments was a kraft paper (83 $g{\cdot}m^{-2}$, Cascades Multi-Pro Inc., Drummondville, Quebec), either pale on both sides or black on one side and pale on the other, with a polymer coating on one side (coating in contact with the soil) or two sides. In 1999, the mulches consisted of a pale-colored (P) paper with a coating (C1) on one side only, pale-over-black (P/B) papers with three types of polymer coatings (C2, C3, C4), and a white-over-black (W/B) coextruded polyethylene (0.028 mm, Plastitech Culture, Saint-Rémi, Quebec). Since the paper mulches rapidly degraded in 1999, a new series of three papers with a polymer coating on both sides were tried in 2000. The mulches included a pale-colored (PC1) paper, pale-over-black (P/B) paper with three types of polymer coatings (C5, C6, C7), two black-over-pale (B/P) paper mulches with two types of polymer coatings (C5, C6), white-over-black (W/B) polyethylene and black (B) polyethylene (0.025 mm, Plastitech Culture, Saint-Rémi, Quebec). Weeded and non-weeded controls were included in both years to evaluate weed populations. Treatments were replicated four times in a complete randomized block design. Plots consisted of raised beds 14.6 m long, 0.15 m high and 0.76 m wide. A pre-plant herbicide (paraquat) was applied in 1999, but none was used in 2000. Mulches were laid manually onto wet soil on June 10, 1999 and June 5, 2000. Planting holes (5.0 cm diameter) were made manually at 35.5 cm intervals in two rows spaced 30.5 cm apart. ‘Ithaca’ crisphead lettuce was seeded in a greenhouse on May 20, 1999 and May 11, 2000 and transplanted in the field on June 15, 1999 and June 14, 2000. Plants were irrigated once after transplanting and then depended on natural rainfall.

Air and soil temperatures were measured in one block using copper-constantan thermocouples connected to an AM-416 multiplexer and a CR-10 data logger (Campbell

Scientific Canada, Edmonton, Alberta). Air temperature in the field was measured using two protected thermocouples per plot installed 1 cm above the soil/mulch surface. Three soil thermocouples per plot were placed at a depth of 10 cm between two lettuce plants. Air and soil temperature readings taken at 10-minute intervals were averaged over each hour. Soil moisture under selected mulch treatments in one block was measured in the first 10 cm using Soil Water Reflectometers (Campbell Scientific Canada, Edmonton, Alberta) connected to the data logger, along with a rain gauge (Texas Electronics Tipping Bucket Rain Gauge).

Weeds with stems within a quadrat (25cm X 25 cm) were counted weekly, harvested dried at 70°C for 24 to 48 h and weighed. Degradation of the paper mulches was evaluated weekly by measuring the percentage of degradation at the mulch air/soil interface. Degradation below the soil surface was not taken into account.

Twenty plants per treatment per block were harvested when more than 80% of the lettuce heads in at least one treatment had reached acceptable firmness and weight for the market. The fresh weight of the heads was recorded once the wrapper leaves were removed. The heads were then halved and the length of the stems measured. Data were statistically analyzed using the Statistical Analysis System (SAS Institute Inc., 2000). Data were subjected to an arcsin transformation when necessary in order to satisfy homogeneity of variance and normality. When treatment effects were significant, differences between means were detected using orthogonal contrasts.

RESULTS AND DISCUSSION

Temperatures

The growing season was warmer in 1999 than in 2000: mean air temperature was 2.4°C higher in control plots from planting to the 10-leaf stage and 2.2°C warmer from the 10-leaf stage to harvest. Mulch effect on air and soil temperatures was more definite during the early part of the growing period (i.e. before the 10-leaf stage) than in the latter part of the growing season, when the lettuce foliage covered most of the mulch (data not shown).

In 1999, plots with paper and no mulch had similar mean air (21.7° to 22.0°C) and soil temperatures (20.1° to 20.8°C, Table 1). The coolest mean air (20.8°C) and soil temperatures (19.5°C) were observed with the white/black polyethylene treatment, primarily because of the lower maximum temperature. This treatment lowered the maximum air and soil temperatures by 2.8°C and 0.9°C respectively compared with the control (Table 1).

In 2000, mean air temperatures above paper and polyethylene mulches were similar and consistently higher than those of the control (0.6° to 1.4°C, Table 1). Mulch had a greater effect on soil than on air temperature during this cool growing season. Independent of the type of mulch (paper or polyethylene), mean soil temperatures were consistently higher under the pale mulches (19.2° to 19.4°C) and the black mulches (22.1° to 22.2°C) than in the control (18.7°C). A black upper surface (paper or polyethylene) increased soil temperature by 2.8°C compared to a pale upper surface (paper or polyethylene) and by 3.4°C compared to the control.

Rainfall and Soil Humidity

Rainfall was less evenly distributed in 1999 than in 2000 (Figure 1). During the period from June 15 to July 23, plants in 1999 received 2.1 times more water than in 2000 (400 and 188 mm respectively). Mulched soil was moister than uncovered soil. Soil humidity under polyethylene was consistently higher than under paper, the former being less permeable to water. In 1999, average soil humidity was 30% under polyethylene, 21% under paper and 19% for the control. In 2000, soil humidity of mulched and control plots was very similar although the soil humidity of the control was less stable over time (Figure 1).

Mulch Degradation

In 1999, P/B paper mulch with various coatings (C3, C4, C5) degraded faster than the pale paper mulch C1. More than 75% of the mulched perimeter had degraded after 8 days, compared to just 4% for the pale paper C1. Two major factors were identified for this rapid degradation of the P/B paper mulches. The first factor was the method of application. The mulch was laid tight to the soil with the edges buried in V shape as recommended for plastic mulch. The soil was wet when the mulch was laid and as the soil dried the mulch contracted and tore along the edge of the V. In contrast with plastic mulch, paper mulch should be laid loose on the soil. The second factor involved a failure in the coating process, as a result of which uncoated sections of the paper were directly exposed to the soil surface. This problem was resolved and in 2000 the first signs of degradation were visible only after 36 days. The coatings protected the paper and for those mulches with coatings on both sides, only a 3 % degradation of their perimeter was observed after 50 days.

Weeds

Very few weeds were present in plots that received a pre-plant herbicide in 1999. After 36 days, a few (1.8) large (9.0 g dry weight) weeds were present in the quadrats of the unweeded plots. No herbicide was used in 2000 and more (169.0 weeds) but smaller (16.3 g dry weight) weeds were present in the unweeded controls. In 2000, all black-coated paper mulches (P/B or B/P) effectively controlled the growth of weeds (0 to 1.3 weeds weighing less than 0.01 g), but the pale paper C1 mulch allowed some weed growth (15 weeds weighing 0.046 g). Therefore, using black-coated paper mulch may be important when the weed pressure is high.

Lettuce Yield

The rate of plant mortality was less than 10% in all plots for both years, and no significant difference was observed between treatments (data not shown).

In 1999, the lettuce plants were as uniform in all treatments with coefficients of variation ranging from 21 to 27% (Table 2). Although there was no significant difference in head weight of mulched and unmulched plots, plants grown on paper or polyethylene mulch with a black side were 26% heavier than those in the control (557 g and 443 g respectively). These treatments significantly increased ($P<0.05$) marketable yield by 25% to 51%.

In 2000, plants grown on mulch had a tendency ($P<0.10$) to be more uniform (CV=28%) than the controls (CV=36%, Table 2). The most uniform crop was that grown on a black polyethylene mulch (CV=21%). Lettuce grown on black-sided paper or polyethylene mulches (mean 784 g) had significantly ($P<0.05$) heavier heads than the lettuce grown without mulch (704 g). Similarly, the percentage marketable yield tended to be higher ($P<0.1$) in black-sided mulch treatments (81.8%) than in the control (75.0%).

Lettuce heads were harvested at an earlier stage in 1999 than in 2000, as reflected by the lighter heads and shorter stems. For example, lettuce in the control plots weighed 443 g in 1999 and 704 g in 2000, with stem lengths of 3.7 cm in 1999 and 6.2 cm in 2000 (Table 2). Stem length is an important character for lettuce quality particularly during warm growing conditions, when the plant tends to develop rapidly and bolt. Using a black-sided mulch had no effect on stem length in 1999 but it had a significant effect ($P<0.05$) in 2000 (Table 2). Furthermore, lettuce grown on B/P paper mulches in 2000 had significantly longer ($P<0.001$) stems (8.2 cm) than the lettuce grown on P/B paper mulches (6.4 cm). Although not significant, the same trend was observed for polyethylene: stem length on black mulch was 7.4 cm versus 6.6 cm for white/black mulch. Exposing the black side of the mulch had the effect of enhancing maturity of the lettuce and possibly reducing its quality particularly during warm periods.

CONCLUSIONS

Black-sided paper or polyethylene mulches effectively controlled weeds in lettuce crops grown on organic soil. For summer lettuce, bicolored mulch with a pale upper side may be the more appropriate. As a matter of fact, a black surface increased soil temperature by 2.8°C and accelerated maturity, as reflected by a longer stem. Pale-over-black paper and white-over-black polyethylene mulches produced lettuce with similar head weights and marketable yields. Although not as effective as polyethylene, paper mulches were able to conserve soil moisture, particularly during drier periods. Conversely, paper mulches are more porous to rain or irrigation water, and this may be an advantage in allowing water to directly reach the roots. The obvious advantage of paper over polyethylene mulch is that there is no need for collection and disposal of the material at the end of the growing season. The paper mulch degrades rapidly after a simple disking. Paper mulches may be more adapted to cool-season crops or mid-season production of warm-season crops, since this product lacks the soil heating capacity of clear or infrared transmitting polyethylene mulches necessary for earliness. The successful adoption of paper mulch by growers will depend on cost and availability. Work still needs to be done to tailor the rate of paper mulch degradation to the needs of the crop.

ACKNOWLEDGMENTS

This project was supported by a grant from the Matching Investment Initiative (MII) of Agriculture and Agri-Food Canada in collaboration with Cascades Multi-Pro Inc., Les Fermes Hotte et Van Winden, Innotag Inc, and McGill University.

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Tables

Table 1. Mean air temperatures 1 cm above the surface of paper and polyethylene mulches and soil temperatures at a depth of 5 cm from planting to the 10-leaf stage. Planting dates were June 15, 1999 and June 14, 2000. The 10-leaf stage was 6 July for both years. Temperature data were the mean of two thermocouples readings per plot.

	1999						2000					
	Air Temp. (°C)			Soil Temp. (°C)			Air Temp. (°C)			Soil Temp. (°C)		
Treatments	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Pale paper	13.6	31.2	22.0	19.1	22.3	20.8	12.5	28.4	20.0	17.8	20.9	19.2
Pale/black paper	13.0	31.0	21.7	18.9	21.2	20.1	12.7	29.4	20.6	17.8	21.5	19.4
Black/pale paper	-	-	-	-	-	-	13.1	29.7	20.8	19.7	25.2	22.1
White/black poly.	13.4	28.2	20.8	18.3	20.5	19.5	12.7	29.0	20.4	17.9	21.2	19.3
Black polyethylene	-	-	-	-	-	-	12.7	29.9	20.6	19.5	25.7	22.2
Weeded control	13.4	31.0	21.8	18.8	21.4	20.2	12.2	27.1	19.4	16.8	20.9	18.7

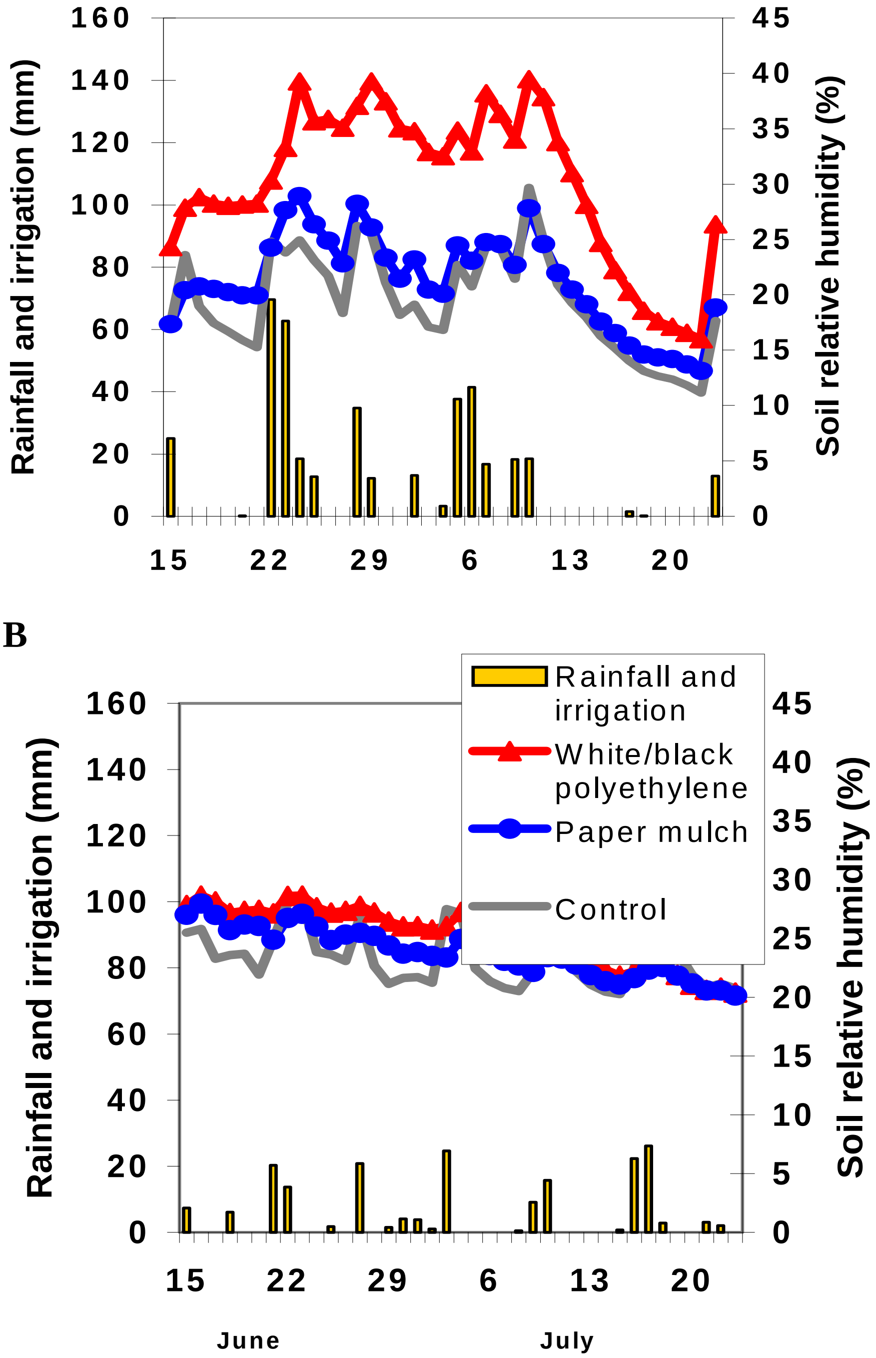
Table 2. Coefficient of variation (CV, %), trimmed head weight (g), marketable heads (yield, %) and stem length for head lettuce grown on paper and polyethylene mulches. Data are averages of four blocks.

Treatments[z]	CV (%)[y]		Head weight (g)		Yield (%)		Stem length (cm)	
	1999	2000	1999	2000	1999	2000	1999	2000
P paper C1	23.4	37.1	512	654	48.8	61.3	3.8	5.3
P/B paper C2	27.4	-	557	-	67.5	-	4.3	-
P/B paper C3	20.8	-	565	-	43.8	-	4.1	-
P/B paper C4	24.6	-	549	-	53.8	-	4.3	-
P/B paper C5	-	30.1	-	751	-	78.8	-	6.6
P/B paper C6	-	23.4	-	791	-	86.3	-	6.2
P/B paper C7	-	32.8	-	753	-	72.5	-	6.5
W/B polyethylene	22.5	23.5	558	768	38.8	90.0	4.0	6.6
B/P paper C5	-	29.6	-	840	-	82.5	-	8.7
B/P paper C6	-	35.3	-	751	-	75.0	-	7.6
B polyethylene	-	21.1	-	836	-	87.5	-	7.4
Weeded control	21.7	36.1	443	704	26.3	75.0	3.7	6.2
Treatment probability	0.91	0.10	0.15	0.02	0.10	0.0005	0.55	0.0001
Orthogonal contrasts[x]								
All mulches-(C1&C7[v]) vs control	NS	+	NS	*	*	+	NS	*
P/B paper[u] vs W/B polyethylene	NS	NS	NS	NS	NS	NS	-	-
B/P papers vs B polyethylene	-	*	-	NS	-	+	-	-
P/B papers C7vs P paper C1	-	NS	-	+	-	*	-	-
P/B pap C5+C6 vs B/P pap C5+C6	-	-	-	-	-	-	-	***
Black polyethylene vs W/B poly.	-	-	-	-	-	-	-	NS
P/B paper C7 vs P paper C1	-	-	-	-	-	-	-	*

[z] Mulches were black (B), pale over black (P/B), black over pale (B/P) or white over black (W/B)
[y] Data were arcsin-transformed before analysis.
[x] NS, +, *, **, ***, not significant or significant at P<0.10, 0.05, 0.01, or 0.001, respectively.
[v] C7 is not included in 1999.
[u] P/W papers refers to C2, C3, C4 in 1999 and C5 and C6 in 2000.

Figures

1999 A



2000 B

Fig. 1. Water received (rainfall and irrigation) and soil moisture under paper and polyethylene mulches for head lettuce crops grown on organic soil in 1999 (A) and 2000 (B).