Optical Properties of Paper and Polyethylene Mulches Used for Weed Control in Lettuce

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Abstract. Optical properties of paper and plastic mulches were determined in experiments on mulched head lettuce (*Lactuca sativa* L.) grown in organic soil in 1997–98. Mulches used in 1997 were a coextruded white/black polyethylene, a beige paper coated with latex on both sides and a black paper coated with latex on both sides. Three supplementary mulches were added in the 1998 experiment: beige paper coated with a biodegradable polymer either coated on the underside, on the top side or on both sides. Optical properties of the polyethylene mulch remained stable over the course of the experiment. As the paper mulches aged, they changed structurally, spectrally, or both, but remained in place until harvest. The black paper was the only mulch that offered complete weed control, although the weeds under the other mulches did not develop beyond the cotyledonary or two-true-leaf stage.

Three aspects of weed control create major economic constraints in lettuce production. First, weed control is an expensive, time-consuming operation. In the United States, hand hoeing can account for 35% to 40% of a grower's preharvest production costs (Naegely and Greenleaf, 1999). In Quebec, head lettuce growers control weeds by applying a pre-emergence herbicide coupled with manual and mechanical weeding throughout the season. This last operation can cause injuries to the root system and reduce both yield and quality (Roberts et al., 1977; Shreffler et al., 1996). Finally, standard weed control methods can be phytotoxic to the crop and are not always effective. For example, a number of Quebec lettuce fields have been abandoned or allocated to different crops because of yellow nutsedge (*Cyperus esculentus* L.) infestation. Yellow nutsedge is very difficult to control, as a single tuber may, within one year, give rise

to 601 plants and 2172 tubers/m² (Tumbleson and Kommedahl, 1961). Also, yellow nutsedge can reproduce both from seed and rhizomes each year (Alex, 1992).

Mulches may reduce the costs of weed management. They provide weed control while minimizing root damage and maintaining soil temperatures favorable for crop growth and development. The widely used black polyethylene mulch tends to warm the soil and may not be the most appropriate for a cool-season crop such as lettuce (Clarkson, 1960; Loy and Wells, 1990). White polyethylene and paper mulch may be more appropriate for this crop. The latter has not been extensively used, since it has a tendency to degrade, often before the end of the crop's growing season (Anderson et al., 1995; Hutchins, 1933; Schonbeck and Evanylo, 1998).

The experiment was undertaken to deter-

mine the weed control effectiveness of a coextruded white/black polyethylene mulch and various types of paper mulches (color and coating) in the production of head lettuce.

Materials and Methods

Location. This experiment was conducted during the summers of 1997 and 1998 in Sherrington, Quebec (lat. 45°10'N; long. 73°31'W), and in Napierville, Quebec (lat. 45°11'N; long. 73°25'W), respectively. The lettuce seedlings were planted in a well decomposed organic soil (humisol) in commercial lettuce fields. Barley and turf crops preceded the 1997 and 1998 plantings, respectively. No herbicide was used.

Experimental layout. Mulches used during the experiment in 1997 were a coextruded white/black polyethylene, a beige paper coated on both sides with latex, and a black paper coated on both sides with latex (Table 1). Three mulch treatments were added to the experiment in 1998. They were beige paper coated with a biodegradable polymer on the underside, on the topside, or on both sides. Mulch treatments were compared with weeded and nonweeded controls. Treatments were replicated four times in a randomized complete-block design. Mulches were laid by hand 9 July and 3 June in 1997 and 1998, respectively. One day after the mulches were laid, lettuce plants cv. Ithaca (29 d and 25 d old in 1997 and 1998, respectively) were transplanted in 3.2-cm-wide holes on raised beds 0.15 m high and 0.76 m wide. Plots were 10.26 m long in 1997 and 12.7 m long in 1998. Plants were staggered in adjacent rows with 35.6 cm within and 44.5 cm between rows. Beds and blocks were spaced 1.27 m and 1.0 m apart, respectively. A section of 4.27 m in each plot was used for weed counts and spectroradiometric measurements. Plots were sprinkler irrigated immediately pre- and postplanting following the standard practice for the region.

Mulch decomposition measurements. Degradation measurements were undertaken in 1998. Degradation was evaluated weekly by measuring the percentage of degradation at the mulch air/soil interface. Degradation below the soil surface or under the lettuce leaves near the end of the experiment was not taken into account.

Table 1. Mulch treatments used in 1997–98.

Material	Color	Coating	Lettuce plants		
			1997	1998	
			With	With	Without
<i>Mulched treatments</i>					
Polyethylene ^c	White/Black		x	x	x
Paper ^b	Black	Latex double-sided	x	x	x
Paper	Beige	Latex double-sided	x	x	x
Paper	Beige	Biodegradable polymer underside		x	x
Paper	Beige	Biodegradable polymer topside		x	x
Paper	Beige	Biodegradable polymer double sided		x	x
<i>Nonmulched treatments (controls)</i>					
Nonweeded			x	x	x
Weeded			x	x	

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^cCoextruded 1.1 mL, 137 cm wide, white topside, supplied by Plastitech Culture, St-Rémi, Québec.

^bKraft paper 83 g·m⁻², 122 cm wide, supplied by Cascades Multi-Pro, Drummondville, Québec.

Optical property measurements. Weekly, a 25 × 25-cm mulch sample was cut between the rows of lettuce in the plot. The hole was covered with a soil-filled plastic bag to secure the cut edges and prevent wind from lifting the mulch. The mulch sample was then labelled, cleared of dirt with a small paintbrush, dried at room temperature, sealed in an envelope, and placed in the dark. Subsamples for all mulches were used to analyze their optical properties in laboratory. Reflection and transmission of light were measured in 10-nm increments over the 400–1100 nm range with a LI-1800 spectroradiometer (LI-COR, Lincoln, Nebr.). Absorption was calculated using the equation $1 = a + r + t$, where a is absorption, r is reflection and t is transmission (Rosenberg et al., 1983). Results were an average of four sub-samples per treatment and were quite stable within the treatments.

Weed population measurements. Weekly, weeds with stems within the 25 × 25-cm area were counted and the aboveground biomass was evaluated. Weeds were separated into monocotyledonous or dicotyledonous groups and dried at 70 °C for 24 to 48 h. In 1998, an additional experiment was undertaken in a nutsedge-infested field in Sherrington, Quebec, to evaluate the effectiveness of the mulches against yellow nutsedge (*Cyperus esculentus* L.). With the exception of a weeded control, the treatments of the 1998 Napierville experiment with lettuce (Table 1) were repeated for this experiment. Mulches were laid by hand 8 May and removed 61 d later. Beds were 0.15 cm high, 1 m long, and 0.76 m wide. Treatments were replicated four times in a randomized complete-block design. At the time the mulch was laid, no weeds were visible. No holes were made in the mulch and no crop was cultivated. At the end of the experiment, the mulches were removed and the weeds on the complete bed were harvested. Weeds collected during the experiment were separated into two groups: yellow nutsedge and other weeds. Weeds within each group were counted and the aboveground biomass was dried for a period of 48 h at a temperature of 70 °C.

Statistical analysis. Results were analyzed statistically using the Statistical Analysis System (SAS Institute, Cary, N.C., 1998). When treatment effects were significant ($P < 0.05$), differences among means were detected using the Student–Newman–Keuls (SNK) test.

Results and Discussion

Decomposition of the paper mulch in 1998. Degradation along the edges of the paper became visible 21 d after the mulch was laid (Fig. 1). Degradation of the beige papers coated on either both sides or on the underside with biodegradable polymer was negligible (<0.1%) or nil for the duration of the 1998 experiment, whereas the degradation was between 3% and 5% for all other papers.

Visible degradation for the paper coated with latex occurred where the edges of the papers were in contact with the soil. Similar results had been found with a black asphalted paper mulch (Hutchins, 1933) and a plain

Fig. 1. Percentage of degradation along the mulch air/soil interface 0, 7, 14, 21, 28, and 35 d after mulch placement in 1998. Mean separation within sampling day using a Student–Newman–Keuls test at $P < 0.05$. Results are means for four blocks.

Fig. 2. Percentage of light transmission through polyethylene and paper mulches, after 0, 21, and 42 d in the field.

paper mulch (Anderson et al., 1995). Paper decomposition was also observed 2 to 3 cm below soil level but was not evaluated to avoid manual damage to the mulch.

The biodegradable polymer coating of the paper coated on the topside started to peel away from the paper 14 d after mulch placement. Once a crack or break appeared on the top surface of the bed, degradation was rapid and complete areas of the paper started to decompose after 21 d for this mulch (data not shown).

At the end of the experiment, the polyethylene mulch was removed by hand and landfilled, whereas the paper mulches were disc-harrowed into the soil.

Spectroradiometry: Transmission of light. Mulch samples taken 0, 21, and 42 d from the start of the experiment were spectrally analyzed in the laboratory. Minimal light was transmitted through the coextruded white/black mulch (average of 2%) and black paper mulch (average of 0.08%) (Fig. 2 A and B). Transmission in the infrared (IR) range (775 to 1100 nm) was less than 10% for the coextruded white/black polyethylene mulch and <1% for the black paper mulch.

An average 4.3% of light in the photosynthetically active radiation (PAR) range (400–700 nm) was transmitted through the beige paper mulch coated on both sides with latex (Fig. 2C). This percentage increased over time reaching 9.4% after 42 d. Light transmission in the near IR range was >20% during the first 21 d of the experiment and decreased slightly at 42 d.

The three papers coated with biodegradable polymer (Fig. 2D–F) had initial light transmission patterns similar to those of the beige paper coated with latex (Fig. 2C). Less than 10% of the light was transmitted in the PAR range at the beginning of the experiment. Light transmission in the PAR region through the paper treated with polymer on the topside was >10% after 42 d (Fig. 2E). Paper treated with either the polymer on the underside or on both sides maintained their transmission patterns throughout the course of the experiment (Fig. 2D and F). Since paper mulch generally decomposes during the cropping season, it was expected that the optical properties of the paper mulch would change over time.

Spectroradiometry: Reflection of light. The quantity of light reflected off the white upper surface of the coextruded white/black polyethylene decreased as the wavelength increased (Fig. 3A). The mean values for light reflection within the 400–1100 nm range was 45%. Other researchers have found similar, but slightly higher results. Kluitenberg et al. (1991) found that a highly reflective, white/black polyethylene mulch reflected 50% of the incoming light within the 400–1100 nm range. The coextruded white/black polyethylene mulch used in the present experiment was not a pure, bright, white but was grayish due to the black color underneath. This appearance of the mulch may have been further reduced by a fine coating of organic soil that collected on the surface of the mulch.

Fig. 3. Percentage of light reflection by polyethylene and paper mulches, after 0, 21, and 42 d in the field.

Light reflection from the black paper mulch coated with latex was minimal (6% in PAR range to 9% in the near IR range) and remained stable over time (Fig. 3B). The beige paper mulch coated with latex reflected an average of 33% of the light in the PAR range at the beginning of the experiment, and an average of 50% after 42 d (Fig. 3C). The percentage of light reflected by papers coated with polymer on the topside and on both sides increased over time (Fig. 3E and F). Beige paper coated with biodegradable polymer on the underside reflected more light at 21 d than at 42 d (Fig. 3D). A possible explanation for this is that while the surface of this paper was being exposed to the bleaching action of the sun, it simultaneously was becoming ingrained with dirt. Indeed, dirt stuck to the exposed paper surface.

Spectroradiometry: Absorption of light. Absorption levels of the coextruded white/black polyethylene were stable throughout the observation period and varied from 40% in the

PAR range to 60% in the IR range (Fig. 4A). The black paper coated with latex absorbed more than 90% of the light in all of the wavelengths studied (Fig. 4B). This mulch exhibited no change in absorption over the time. In general, light absorption of the beige paper decreased with longer wavelengths as the reflection and transmission values increased (Fig. 4C–F).

Weed growth. A minimal number of monocotyledonous weeds were observed and no significant ($P < 0.05$) differences were noted among treatments in 1997 (Table 2). Although, a few dicotyledonous weeds (four and one) were visible under the black paper mulch at the first and second sampling, no weeds were visible at subsequent sampling dates. Dicotyledonous weeds were found under the beige paper treated with latex and white/black polyethylene at each sampling date. These weeds did not develop beyond the cotyledonary or two-leaf stage; their dry

weights were always <0.1 g compared with 0.11 g (7 d) and 13.3 g (35 d) for the nonweeded control (data not shown).

Temperature, moisture, and light are the three main factors affecting seed germination (Leblanc et al., 1998). The low level of light transmitted by the beige paper mulches (0% to 20% of the light transmitted in the PAR range) could explain the poor weed emergence and growth. The lettuce architecture also influenced weed growth. The wrapper leaves of the lettuce, which completely covered the planting holes by the end of the experiment, reduced light to understory plants, and consequently prevented weed growth. The experimental field used in 1998, which has been under turf production for a number of years, had minimal weed growth and no significant differences among the treatments were detected, including the nonweeded control (data not shown).

In the nutsedge experiment, the population of nutsedge in the nonweeded control ranged from 1.3 to 23 shoots/m² at 14 and 42 d, respectively (data not shown). The dry weights of the nutsedge and other weeds were significantly greater in the nonweeded control than in all other treatments except for the paper mulch coated on the topside (Table 3).

A single, etiolated nutsedge plant (dry weight <0.1 g) was discovered under the white/black polyethylene upon removal of the mulch. Growth of other weeds under this mulch was also minimal. The black paper mulch coated with latex completely prevented the growth of weeds. Weeds started to force their way through the beige paper coated with a biodegradable polymer on the top 42 d after placement. The paper underside tended to degrade with time leaving only the translucent coating on top. The weeds then grew freely as reflected by the dry weights, which were heavier (significantly so in the case of other weeds) than those in the other mulch treatments.

The other beige papers used transmitted <20% of the light in the PAR range after 42 d (Fig. 2). The average dry weight of yellow nutsedge found under the beige mulches (excluding the beige paper mulch coated on the topside) was calculated to be 1.2 g·m⁻² (Table 3). The dry weight of the other weeds was lowest in the paper treated with polymer on both sides. These papers may be analogous in terms of PAR transmission to an infrared transmitting (IRT) plastic mulch used by Majek and Neary (1991). They reported average nutsedge shoot weights of 16.6 g·m⁻² (60 shoots/m²) under IRT mulch 117 d after the mulch was laid and, as in our experiment, yellow nutsedge shoots under the mulch were etiolated.

This experiment clearly shows that paper mulches can maintain their integrity and be successfully used to control weeds for the duration of a fast growing crop such as lettuce. All the mulches (except the beige paper coated with a biodegradable polymer on the topside) controlled weeds, including yellow nutsedge, for 42 d. When working with paper mulches the protective coating, and not the paper itself, should come in direct contact with the soil. Indeed, mulch treated with coating on the

Fig. 4. Percentage of light absorbed by polyethylene and paper mulches, after 0, 21, and 42 d in the field.

Table 2. Effect of mulch type on number of monocotyledonous and dicotyledonous weeds² in a randomized 25 × 25-cm area, 7, 14, 21, 28, and 35 d after transplanting lettuce in 1997. Values are means of four blocks.

Time after transplanting (d)	Monocotyledonous weeds					Dicotyledonous weeds				
	7	14	21	28	35	7	14	21	28	35
White/black polyethylene	0.0	0.0	0.5	0.3	0.3	15 a ²	10 ab	3 b	7 ab	2 bc
Black paper latex double sided	0.0	0.0	0.0	0.0	0.0	4 b	1 b	0 b	0 b	0 c
Beige paper latex double sided	0.3	0.8	0.0	0.5	0.0	15 a	10 ab	10 b	9 ab	7 ab
Nonweeded control	0.0	0.3	0.0	0.3	0.3	10 ab	20 a	19 a	16 a	12 a

²Mean separation within columns by Student–Newman–Keuls (SNK) test at $P < 0.05$.

topside only degraded faster than all other mulches, allowing light to pass through it resulting in weed growth. After a rainy period, the unprotected surface of the paper coated only on the underside remained wet longer than the other papers. Although not a problem in this experiment, this moist environment might encourage disease development. Paper or coextruded white/black mulches may be

suitable alternatives to the manual and mechanical weeding that is currently employed in lettuce. However, an economic study should be conducted to compare the costs use of using mulches with the existing methods of weed control. Decomposition measurements should also be under taken over a number of years to assess the durability of paper mulches under a range of climatic conditions.

Table 3. Effect of mulch type on the dry weight (g) of yellow nutsedge and other weeds found in 1 × 0.76-m size experimental plots under the mulches, 61 d after the start of the 1998 experiment.

Material	Color/Type	Dry wt (g) ^z	
		Yellow nutsedge	Other weeds
Polyethylene	White/black	0.1 c ^y	0.1 d
Paper	Black, latex double-sided	0.0 c	0.0 d
Paper	Beige, latex double-sided	1.1 bc	11.3 c
Paper	Beige, biodegradable polymer underside	0.5 bc	4.9 cd
Paper	Beige, biodegradable polymer topside ^x	5.6 ab	150.1 b
Paper	Beige, biodegradable polymer double-sided	1.2 bc	2.9 cd
Nonweeded control		11.9 a	214.3 a

^zData were square-root transformed prior to analysis of variance. Means for four blocks.

^yMean separation within columns by Student–Newman–Keuls (SNK) test at $P < 0.05$.

^xMulch was torn by the weeds 42 d after installation.

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