Influence of Mulches on the Colonization by Adults and Survival of Larvae of the Colorado Potato Beetle (Coleoptera: Chrysomelidae) in Eggplant[1]

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ABSTRACT Six treatments (no mulch, black plastic mulch, black plastic painted with reflective aluminum paint, straw mulch, black plastic plus straw, and a living mulch of rye growing between the rows) were used to grow eggplant and to observe the effects on movement of adult Colorado potato beetles, *Leptinotarsa decemlineata* (Say); oviposition; and density and survival of larvae. Straw mulch and rye treatments reduced movement of overwintered beetles into the plots and also reduced the growth of the plants compared to black plastic mulch. Survival from the egg to small larva (first and second instar) was lower in the plots with straw mulch and black plastic plus straw than in plots with rye, bare ground or aluminum-painted mulch. None of the treatments had an effect on movement of the first generation adults, which was primarily determined by the proximity of the plots to the source field of potatoes. It may be possible to combine the positive effects of black plastic on early season growth and straw mulch on reducing the survival of potato beetle larvae by transplanting the eggplants into black plastic mulch, then adding straw as the egg masses of the potato beetle begin to hatch.

KEY WORDS straw mulch, plastic mulch, eggplant, *Solanum melongena*, Colorado potato beetle, *Leptinotarsa decemlineata*

Mulches are commonly used in both home gardens and in commercial production of vegetable crops. Each type of mulch has its own characteristic effects on soil moisture, the soil temperature profile, mineralization of nutrients, leaching, gas exchange, and control of weeds, and thus on yield of the desired crop (Waggoner et al. 1960, Ashworth and Harrison 1983), independent of any effect on insects.

Most studies of the effects of mulches on insect populations have dealt with the well-known reduction in alighting and spread of viral disease by aphids in plots with white or reflective mulches (Kring 1972). Reflective mulches also have been shown to reduce the abundance of other insects, such as *Diabrotica* spp. in squash (Schalk et al. 1979).

In potatoes, previous studies have shown that straw mulch affects the density of Colorado potato beetle, *Leptinotarsa decemlineata* (Say), adults or larvae (Zehnder and Hough-Goldstein 1990, Stoner 1993, Brust 1994, 1996). Zehnder

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and Hough-Goldstein (1990) showed that straw mulch reduced the density of adults, egg masses, and larvae early in the season in both rotated and non-rotated fields, reduced the number of insecticide treatments required to keep populations below the economic threshold, and increased soil moisture and tuber yield. Stoner (1993) found that straw mulch reduced the density of first generation larvae and the proportion of plants heavily defoliated by the beetle compared to leaf mulch and both irrigated and non-irrigated controls. Effects on the movement of overwintered adults were not significant. Brust (1994, 1996) found no effect of straw mulch on the movement of overwintered or first generation adults into the field, but found higher predation on larvae in mulched plots in both generations, with resulting lower densities of fourth-instar larvae, lower defoliation, and higher yield. While these studies consistently found that straw mulch reduced the density of and defoliation by larvae in potatoes, the authors reached different conclusions about whether these reductions are due to effects of straw on colonization by adults or to decreased survival of larvae.

While the practical and economical options for mulching potatoes are limited, there are many different possibilities for mulching two other hosts of Colorado potato beetle, eggplants and tomatoes. Mulches that have been used on these crops include many types and colors of plastic, straw, cover crop residues, and other plant materials (Ashworth and Harrison 1983, Carter and Johnson 1988, Elmer and Ferrandino 1991, Abdul-Baki et al. 1992, Abdul-Baki and Teasdale 1994). Black plastic mulch increases the earliness, number of fruit, and total yield of eggplant (Carter and Johnson 1988, Elmer and Ferrandino 1991) and tomato (Abdul-Baki et al. 1992) compared to plots without mulch.

The objective of this study was to examine the effects of several different mulches on the movement of Colorado potato beetle adults into eggplant plots, and their oviposition and the density of small larvae in the plots. I chose to use eggplant as the host because eggplant is a more highly preferred host than tomato, and thus would be more likely to attract large numbers of adults. By removing adult beetles as they were counted, I studied movement of new migrants into the plots, rather than the equilibrium densities of established beetle populations. Also, first generation large larvae were controlled with a microbial pesticide, in order to keep the plants from being defoliated for as long as possible, so that the effects of the mulches on movement could be measured on first generation as well as overwintered adults.

Materials and Methods

A field of 320 m^2 at Lockwood Farm in Hamden,CT adjacent to a larger potato field was divided into four blocks with six treatments per block: black plastic mulch, black plastic painted with aluminum spray paint, black plastic covered with straw mulch, straw mulch alone, a living mulch of rye planted between rows, and bare ground. Each plot consisted of four rows, with 0.9 m spacing, and six plants ('Classic') per row, with 0.6 m spacing within the row, transplanted on 1 June 1994. The black plastic mulch was in strips 0.6 m wide, buried along the edges and centered over the row with holes cut for each plant at transplanting. The aluminum treatment was black plastic sprayed with Rustoleum Aluminum #7715 paint before application. Straw was applied at a rate of one bale (15 kg) per plot on 3 June. Rye was planted on 3 May in a strip 0.3 m wide, centered between rows, at a rate of 25 g of seed per m^2. All plots were fertilized with 100g/m^2 of 10-10-10 (NPK) banded in the row on 22 May and side-dressed on 11 July with 30 g of 10-10-10 per plant, applied at the base. The strips of rye were also fertilized with 100g/m^2 of 10-10-10 at seeding. No fungicides were used, and weeds were controlled by hand-cultivation.

Adult Colorado potato beetles were removed and counted once per week from all plants. Egg masses and larvae were not removed. First and second instars were counted as small larvae, and third and fourth instars as large larvae. The number of eggs per egg mass was counted for every fifth egg mass. On 28 June and 6 July, Novodor (*Bacillus thuringiensis* Berliner var. *tenebrionis*) was applied at the lowest recommended rate (4.7 l of formulated product per ha) to prevent damage from first generation Colorado potato beetle larvae. Novodor was applied with a Solo 475 hand-operated backpack sprayer with a single flat fan nozzle at a pressure of 4.2 kg/cm^2 in a volume of 470 l/ha.

In order to get a quick index of plant size, the width of the plant from leaf tip to leaf tip across the widest point, the measurement across the plant perpendicular to the width, and the height of the center eight plants in each plot was measured on 28 June, and the number of branches and flowers per plant also were noted. Yield was measured for each plant, harvesting as needed from 21 July to 14 September, and the final fresh weight of the plants was measured on 14 September for the center eight plants of each plot.

Because movement of the first generation of Colorado potato beetle adults was dramatically different from that of the overwintered adults, the beetle counts up to 12 July were analyzed separately from those for the rest of the season. The mean numbers of Colorado potato beetles per plant within each plot were transformed as ln (X+1) and analyzed using a repeated measures analysis of variance (Wilkinson et al. 1992) using treatment and block as the factors between plots, and date and the interactions of treatment and block with date as the factors within plots for each insect stage. Only when this overall analysis showed a factor to be significant was it analyzed further with an ANOVA for each date and a protected least significant difference test to determine which treatments had differences.

Results

Early Season. The plots with a living mulch of rye and with straw mulch had the lowest numbers of overwintered adults moving into the plots overall (Table 1). Block was not significant for the overwintered adults ($F = 1.593$; df = 3,15; $P = 0.233$). The black plastic mulch had the highest numbers, more than both the straw mulch and the rye. The black plastic with straw and bare ground also had more adults overall than the rye. The numbers of egg masses early in the season were not significantly affected by block ($F = 0.620$; df = 3,15; $P = 0.613$) or treatment (Table 1). Although the differences were not significant, the trend among treatments was similar to the trend for adults, with rye and straw mulch lower than the other treatments.

There were more small larvae in the plots with aluminum or black plastic alone than in those with black plastic plus straw or straw mulch (Table 1), and

Table 1. Early season counts of Colorado potato beetles per plant with removal of adults, averaged over the plot and summed from 9 June until the date specified. Means by treatment (and standard deviation for the four plots within each treatment). Hamden, CT, 1994.

Treatment*	Adults** to 7 July	Egg masses† to 7 July	Small larvae†† to 12 July	Large larvae§ to 19 July
aluminum	0.52 (0.2) abc	0.7 (0.2)	18 (6) a	0.49 (0.5)
bare	0.68 (0.1) ab	0.9 (0.4)	15 (5) ab	0.57 (0.4)
black plastic	0.84 (0.4) a	0.8 (0.3)	17 (10) a	0.62 (0.4)
black plastic plus straw	0.72 (0.1) ab	0.9 (0.2)	8 (3) bc	0.23 (0.3)
rye	0.31 (0.07) c	0.5 (0.2)	11 (3) ab	0.30 (0.3)
straw mulch	0.41 (0.3) bc	0.4 (0.2)	3 (2) c	0.031 (0.04)

* Treatments not followed by the same letter are significantly different at $\alpha = 0.05$ by protected Fisher's LSD test.
** Treatments significantly different by ANOVA ($F = 3.615$; df = 5,15; $P = 0.024$).
† Treatments not significantly different by ANOVA ($F = 2.503$; df = 5,15; $P = 0.077$).
†† Treatments significantly different by ANOVA ($F = 6.838$; df = 5,15; $P = 0.002$).
§ Treatments not significantly different by ANOVA ($F = 1.750$; df = 5,15; $P = 0.184$).

also more in bare ground and rye than in plots with straw mulch. Differences between the aluminum and bare ground treatments in the timing of peak numbers of small larvae (Fig. 1) accounted for the interaction of treatment and sample date ($F = 2.856$; df = 15,45; $P = 0.003$). The overall numbers of large larvae were not different among blocks ($F = 0.743$; df = 3,15; $P = 0.543$) or treatments (Table 1), which probably reflects the efficacy of the *B. thuringiensis* applied and the consequent low numbers of large larvae in all plots. It should be noted, however, that the mean density of large larvae in the straw was one-eighth the density in the other treatments.

The ratio of egg masses to adults did not differ significantly among treatments (Table 2), and neither did the number of eggs per egg mass. The ratio of small larvae to egg masses, however, was higher in the rye, aluminum, and bare ground than in the straw and black plastic plus straw. Black plastic alone was intermediate between the two groups statistically, but still had twice the ratio of small larvae to egg masses as black plastic plus straw (Table 2).

The mulches affected plant height, width, branching and volume in the first month of growth. Regardless of the measure of plant size used, on 28 June the plants were largest in the aluminum and black plastic mulches, smallest in the straw mulch, and intermediate in size in the other treatments (Table 3).

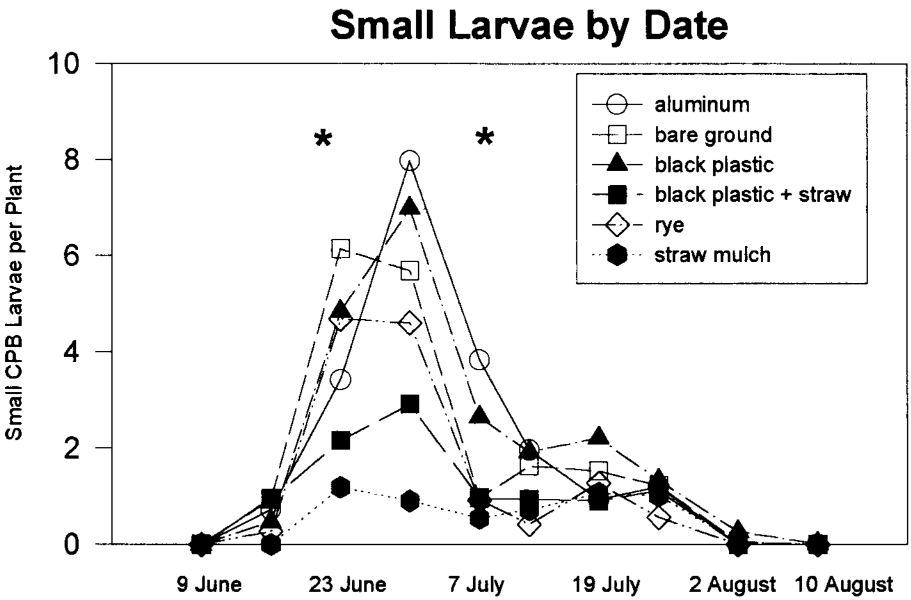

Fig. 1. Number of small larvae per plant averaged by treatment. The dates for which differences were significant are indicated with asterisks: 23 June (F = 5.424; df = 5,15; P = 0.005) and 7 July (F = 5.298; df = 5,15; P = 0.005). On June 23, straw mulch had significantly fewer small larvae than all other treatments except the combination of black plastic plus straw mulch. On July 7, straw mulch had fewer than all other treatments.

Late Season. Treatment did not significantly affect numbers of any stage of Colorado potato beetle in the late season. Adult Colorado potato beetles moved into the field from the north and east edges in large numbers in late July (Table 4). There was a larger potato field on the north side of the eggplant plot, which extended beyond the length of the eggplant plot to the east. The beetles making up this wave completely defoliated the eggplants in their path by clipping all the leaves at the petiole, and then feeding on the dropped leaves at the base of the plant. For the following 3 wks adult beetles advanced into the plot from these edges, moving just beyond the border of completely defoliated plants. The plots mulched with straw alone did have relatively low numbers of adults in the three blocks not on the northern edge of the field (Blocks B, C, and D), but this could be an artifact due to the position of the straw plots away from the eastern edge (Table 4).

Yield and Final Plant Size. The yield of eggplant and final plant size were significantly reduced in Block A by the complete defoliation by adult beetles in late July and August ($P < 0.001$ for total weight, number of fruit, and final plant weight by Fisher's protected LSD). This block was eliminated in considering the

Table 2. Ratios between stages of Colorado potato beetle. Each ratio is derived from the numbers per plant, averaged over the plot, and summed over the early seasons as in Table 1. Means by treatment (and standard deviation for the four plots with each treatment). Hamden, CT, 1994.

Treatment	Egg masses per adult*	Eggs per egg mass**	Small larvae per egg mass†
aluminum	1.6 (0.7)	28 (7)	25 (5) a
bare	1.2 (0.4)	29 (4)	21 (10) a
black plastic	1.2 (0.8)	30 (3)	19 (6) ab
black plastic plus straw	1.2 (0.3)	31 (8)	9 (4) bc
rye	1.5 (0.6)	33 (12)	25 (6) a
straw mulch	1.2 (0.4)	32 (8)	9 (6) c

* Treatments not significantly different by ANOVA ($F = 0.328$; df = 5,15; $P = 0.888$).
** Treatments not significantly different by ANOVA ($F = 0.204$; df = 5,15; $P = 0.956$).
† Treatments significantly different by ANOVA ($F = 4.155$; df = 5,15; $P = 0.014$).
Treatments not followed by the same letter are significantly different at $\alpha = 0.05$ by protected Fisher's LSD test.

effects of treatment. Rye plots had significantly fewer fruits per plant, lower total yield, and smaller final plant size than all other treatments (Table 5).

Discussion

While rye and straw mulch decreased colonization of the plots by overwintered beetles, they also reduced plant growth early in the season. The plants mulched with straw overcame this early setback enough to produce yields comparable with the other treatments, but the living mulch of rye, and the weeds that were difficult to eliminate in this treatment, continued to reduce eggplant growth and yield throughout the season. Straw mulch alone, and also straw spread over plastic mulch, reduced the rate of survival of Colorado potato beetles from egg mass to small larvae. Predation was not measured directly in this study, but increased predation in the straw plots would be one possible mechanism for this lower rate of survival, and straw mulch has been found in other studies to increase the density of predators of Colorado potato beetle eggs and larvae (Brust 1994, 1996). For first generation Colorado potato beetle adults, mulch was not a barrier to colonization by beetles on the spatial scale of this experiment, and geographical proximity to the source field determined the pattern of infestation.

Table 3. Size and branching of eggplants growing in different mulches, measured on 28 June 1994.

Treatment*	Width** (cm)	Height† (cm)	No. branches††	Volume index§ (m^3)
aluminum	63 (5) a	33 (6) ab	4.8 (1.0) a	0.128 (0.042) ab
bare	58 (4) b	28 (5) cd	2.9 (1.0) bc	0.088 (0.030) cd
black plastic	65 (5) a	35 (6) a	5.4 (0.7) a	0.146 (0.041) a
black plastic plus straw	58 (2) b	31 (1) bc	3.7 (0.3) b	0.105 (0.012) bc
rye	58 (7) b	31 (4) bc	2.0 (1.0) cd	0.093 (0.024) cd
straw mulch	53 (3) c	26 (3) d	1.4 (0.5) d	0.071 (0.017) d

* Treatments not followed by the same letter are significantly different at $\alpha = 0.05$ by protected Fisher's LSD test for all variables in this table.

** Treatments significantly different by ANOVA ($F = 8.514$; df = 5,15; $P < 0.001$).

† Treatments significantly different by ANOVA ($F = 5.997$; df = 5,15; $P = 0.003$).

†† Treatments significantly different by ANOVA ($F = 21.832$; df = 5,15; $P < 0.001$).

§ Volume index is the width X radius perpendicular to width X the height. Treatments significantly different by ANOVA $F = 8.695$; df = 5,15; $P < 0.001$).

In summary, although straw mulch alone had a small effect on colonization by overwintered adults, the main effect of straw on Colorado potato density and defoliation was probably due to reduced larval survival.

Because the beetle density and damage was kept artificially low in all treatments by removing adult beetles and treating larvae with a microbial insecticide, the lower density of beetles and larvae in plots with straw was not reflected in the size of the plants or the yield. Cotty and Lashomb (1982) found that densities above 8 larvae per plant, maintained until pupation in the first generation, damaged flower production and reduced yield of eggplant for the few weeks of harvest. In this experiment, after removing the adults and the first microbial treatment, the density of small larvae in all the aluminum plots, half the black plastic plots, and a few plots with the bare ground and rye treatments approached 8 larvae per plant on 30 June. None of the plots mulched with straw or with the combination of black plastic and straw exceeded 4 larvae per plant for the same date. Another microbioal treatment brought densities in all mulch treatments well below this threshold the following week (Fig. 1).

Plastic alone and plastic painted with aluminum paint had positive effects on plant growth early in the season, but no effect on colonization by Colorado potato beetle adults or survival of larvae. One way to combine the advantages of black plastic with straw might be to transplant the eggplants into black plastic

Table 4. Number of Colorado potato beetles in each row of each plot on 25 July 1994. Each number represents the adult beetles counted and collected on six plants, located by row and section of row. (A section of row in the four adjacent rows within a block is one plot.) Row 1 of Block A was on the north side of the field, with section 6 on the east.

		Section of row					
Block	row	1	2	3	4	5	6
A	treatment*	blpl	rye	straw	alum	bare	blst
	1	206	311	768	2303	1507	2276
	2	24	66	40	357	2292	4464
	3	14	20	11	35	2058	3309
	4	11	10	7	15	115	**
B		blst	blpl	straw	alum	rye	bare
	1	8	6	2	15	77	315
	2	10	5	2	13	31	302
	3	2	0	4	5	24	117
	4	5	0	3	12	18	155
C		alum	straw	blst	blpl	bare	rye
	1	7	1	4	8	17	87
	2	9	0	4	11	10	227
	3	6	2	2	4	12	182
	4	15	3	6	4	6	49
D		rye	blpl	alum	straw	bare	blst
	1	3	1	2	2	2	28
	2	6	4	1	1	4	18
	3	2	3	0	2	5	15
	4	2	5	4	1	4	12

* blpl, black plastic; alum, plastic painted with aluminum paint; blst, black plastic plus straw.
** Not counted on this date.

Table 5. Yield of eggplant fruit per plant in Blocks B, C, and D, and mean final fresh weight per plant for the center two rows of the same three blocks. Mean by treatment (and standard deviation for the three plots within treatment).

Treatment*	Total yield** (kg)	No. of fruit†	Final Plant Weight†† (kg)
aluminum	3.86 (0.57) a	7.79 (1.38) a	0.96 (0.15) a
bare	3.32 (1.35) a	6.67 (1.79) a	1.02 (0.31) a
black plastic	3.83 (0.59) a	8.67 (1.12) a	1.20 (0.08) a
black plastic plus straw	3.91 (0.56) a	8.60 (1.62) a	1.10 (0.10) a
rye	1.74 (0.73) b	4.10 (1.10) b	0.50 (0.22) b
straw mulch	3.45 (0.54) a	7.82 (0.75) a	1.01 (0.20) a

* Treatments not followed by the same letter are significantly different at $\alpha = 0.05$ by protected Fisher's LSD test for all variables in this table.
** Treatments significantly different by ANOVA ($F = 5.260$; df = 5,10; $P = 0.013$).
† Treatments not significantly different by ANOVA ($F = 4.702$; df = 5,10; $P = 0.018$).
†† Treatments significantly different by ANOVA ($F = 10.164$; df = 5,10; $P = 0.001$).

mulch, get the plants off to a fast start, then add straw later, as the potato beetle larvae begin to hatch, in order to reduce the survival of these larvae. This strategy could be a useful adjunct to a biologically-based program of Colorado potato beetle management, particularly for those farmers who grow rye or wheat in their crop rotations and thus have straw readily available on their farms.

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