Evaluation of Various Color Hydromulches and Weed Fabric on Broccoli Insect Populations

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ABSTRACT We evaluated the potential for variously colored hydromulches (sprayed-on wood fibers plus adhesive) and weed fabric to suppress populations of the cabbage maggot, *Delia radicum* (L.), cabbage aphid, *Brevicoryne brassicae* (L.), and other insects in broccoli, *Brassica oleracea* L. Weed control also was evaluated. Commercial hydromulches were evaluated in their standard formulations or modified by adding corn starch, plaster of paris, lamp black, and latex blue or yellow paint. *D. radicum* populations were significantly lower in plots treated with hydromulch and blue paint than in unmulched control plots. This treatment was equal to or better than diazinon in suppressing *D. radicum. B. brassicae* populations were significantly higher in plots treated with hydromulch and yellow paint than in unmulched control plots. Weed fabric significantly reduced weed populations, but the levels of flea beetle *Phyllotreta cruciferae* (Goeze) in those plots were 6 times higher than in control plots. Early-season populations of *D. radicum* and *B. brassicae* could be suppressed simultaneously if the appropriate combinations of hydromulch and color were used.

KEY WORDS cabbage maggot, cabbage aphid, flea beetle, hydromulch, color

The cabbage maggot, *Delia radicum* (L.), and the cabbage aphid, *Brevicoryne brassicae* (L.), are major pests of crops in the genus *Brassica* (Gehringer and Goldstein 1988, Ellis et al. 1996). Control of *D. radicum* usually involves a soil drench applied at transplanting for larval control, or plant sprays directed at adults. Visual traps are used to monitor and time insecticide applications (Finch 1990). Insecticides also are applied frequently against *B. brassicae* to prevent them from moving into developing broccoli flower buds. When pest densities are high, growers may spray 4–6 times to prevent populations from reaching economically damaging levels (Costello and Altieri 1994). Additional integrated pest management alternatives are needed for both of these pests.

Soil barriers have been explored for control of *D. radicum*. Tarred felt disks (Wadsworth 1917), foam rubber collars (Finch and Wheatley 1980), plastic and straw mulches, and row covers (Gehringer and Goldstein 1988) have been used against this pest with some success. Similarly, living and reflective mulches have been used to reduce the incidence of aphids and aphid-borne viruses (Chalfant et al. 1977, Andow et al. 1986, Schalk and Robbins 1987, Costello and Altieri 1994). Benefits derived from the use of such barriers include increased yields, moderation of soil temperature extremes (Schalk and Robbins 1987), reduction of plant diseases (Chalfant et al. 1977), and reduced dependency on chemical pesticides (Gehringer and Goldstein 1988). Several drawbacks are associated with barriers currently used for pest control. Weed fabric and aluminum foil are expensive and create disposal problems at the end of the growing season. Insect suppression gained from the use of living mulches may be offset by yield reduction from competition between the main crop and a living mulch (Andow et al. 1986).

Visual cues are important for host location by both cabbage maggot flies and cabbage aphids. Prokopy et al. (1983a), using real and artificial leaves, showed that *D. radicum* can discriminate among host plants on the basis of leaf color. Radish leaves elicited the greatest number of landings, followed by green and red cabbage leaves, respectively. Landings on artificial mimics were similar to those on real leaves. In another study, Roessingh and Städler (1990) reported that *D. radicum* laid significantly more eggs on bright green and yellow surrogate paper leaves than on red or blue.

Kring (1967), using a flight chamber, found that 3 species of aphids, including *B. brassicae*, landed more frequently on yellow cards than on cards that contained yellow mixed with orange and green. When white was added to yellow at different proportions, aphids landed most frequently on cards having the least white and the most yellow.

One mulch product that has not been tested for insect-control properties against pests of field crops is hydromulch, a by-product from the timber and paper industry consisting mainly of ground paper or wood fibers. Hydromulch is marketed under several trade names (Soil Guard, Silva Blend, and Silva Fiber Plus) and has been used since the 1960s primarily for preventing erosion on slopes and for establishing vegetation (Wakefield et al. 1974). Mulch adhesives (tacifiers), generally starch or latex, are often added to the hydromulch mix before application. Commercially available hydromulches are yellow, green, or blue-green.

Our primary hypothesis was that hydromulches or weed fabric would reduce populations of cabbage maggots by inhibiting oviposition by flies or preventing larvae from reaching the root system. Other objectives were to evaluate the effects of various color hydromulches and weed fabric on *D. radicum*, other cabbage insects, and weeds.

Materials and Methods

Experiments were conducted in 1994 and 1995 at a University of Rhode Island research farm in Kingston, RI. Broccoli, *Brassica oleracea* L., seedlings ('Southern Comet', Agway, Syracuse, NY) used in all experiments were started in the greenhouse and transplanted into the field on 9 May 1994 and 26 April 1995. All treatments were applied the day after broccoli seedlings were transplanted into the field.

The experimental design was a randomized complete block with 4 replications. There were 8 treatments: 5 hydromulch/tacifer combinations, weed fabric, diazinon, and a control. Plots were 10 by 8 m and consisted of 4 rows of 8 plants per row (32 plants per plot). Broccoli plants were spaced 40 cm apart within rows and 45 cm between rows. Plots were separated by 10 m of cultivated soil. Four yellow sticky Pherocon AM traps (Great Lakes IPM, Vestaburg, MI) were placed at cardinal positions in buffer areas of the field to detect emergence of *D. radicum* and to monitor adult population levels. Some plots were spray painted with blue or yellow latex paint (Country Blue and Chiffon Yellow, respectively, Long Island Paint Company, Glen Cove, NY) by using a Solo backpack sprayer equipped with a Tee-Jet 8015-SS nozzle. The paint to water ratio was 2.8:13.2 with a total spray mix application volume of 500 liters/ha.

Treatments (1994). Hydromulch treatments consisted of Soil Guard (yellow), Soil Guard (painted yellow), Soil Guard (painted blue), Silva Blend (blue-green), and Silva Fiber Plus (green) (Weyerhaeuser, Engineered Fiber Products, Snoqualmie, WA). Other treatments included weed fabric (black) (Model 1198, Atlantic Construction Fabrics, Richmond, VA), diazinon (Ciba, Greensboro, NC), and an untreated control.

Treatments (1995). Treatments consisted of Soil Guard (yellow), Soil Guard (painted yellow) plus starch (The Dial Corporation, Food Division, Phoenix, AZ), Soil Guard (painted blue) plus starch, Soil Guard plus lamp black (Empire Blended Products, Bayville, NJ), and starch (gray), Soil Guard plus lamp black and plaster of Paris (Bondex, St. Louis, MO) (gray). Other treatments included weed fabric, diazinon, and an untreated control.

Hydromulch/tacifer combinations were thoroughly mixed (68 kg of mulch per 0.15 kg tacifer per 557 liters of water) and applied at a rate of 700 kg/ha with a Bowie 1890 hydromulcher (Victor model, Bowie Industries, Bowie, TX). In 1995, plaster of paris and commercial corn starch were added to hydromulch treatments at a rate of 14 and 58 kg/ha, respectively, to improve cohesiveness. Lamp black was added at a rate of 9 kg/ha to change the color of the mulch from yellow to gray. Diazinon AG 500 (0.375 ml) was applied in 300 ml of water to each plant (0.01 g [AI] per plant) as a soil drench.

Insect Sampling. In 1994, aphids were counted twice per week from 23 May to 8 July by counting all of the aphids on every 3rd plant (16 plants) within each plot. On 20 July, all broccoli plants (32) in each plot were dug up and soil removed (10 cm diameter by 15 cm deep) and the cabbage maggots (larvae and pupae) on and around each plant were counted in the field. In 1995, we sampled the entire broccoli pest complex, including cabbage maggots (pupae and larvae); cabbage aphids (nymphs and adults); flea beetle adults of *Phyllotreta cruciferae* (Goeze); cabbage worm larvae, *Pieris rapae* (L.); cabbage looper larvae, *Trichoplusia ni* (Hübner); and diamondback moth larvae, *Plutella xylostella* (L.). Aphid and flea beetle populations were evaluated 3 times per week for 6 wk, starting 19 May, by counting all of the aphids and flea beetles on every plant (16 plants) in the 2 outer rows in each plot. Outer rows were used in 1995 to prevent disturbance of the treated surfaces of the plots. Lepidopterous pests were assessed weekly for 6 wk beginning 19 May by counting individuals on the 16 plants in the 2 outer rows of every plot. Cabbage maggots were sampled on 15 May by digging (10 cm diameter by 15 cm deep) the 4 end plants in the 2 inner rows and counting the larvae and pupae on the root system and in the adjacent soil. On 10 July, the 16 plants in the 2 outer rows were dug up and the larvae, pupae, and empty pupal cases were counted.

Weed Sampling. Weeds were assessed on 24 May and 15 June in 1994 and on 5 May and 5 June in 1995. Sampling was done by randomly placing a square frame (0.2 m^2) at 2 locations within each plot and visually estimating percent weed cover by each weed species. Total weed cover was used for analysis.

Harvested Yields. Broccoli was harvested weekly from the 2 outer rows of each plot from 28 June to 20 July in 1994 and from 19 June to 10 July in 1995. For the initial harvest, all central stems were cut 2 cm below the lowest branch of the head. In subsequent samples, all florets were cut with a 2-cm stem. The yield from each plot was placed in a bag and weighed in the field.

Statistical Analysis. The data were subjected to an analysis of variance (ANOVA). Least significant dif-

Table 1. Effect (mean ± SEM) of hydromulch and weed fabric on *D. radicum* larvae and pupae, *B. brassicae* nymphs and adults, weeds, and yield in broccoli (1994)

Treatment	*D. radicum*/plant 20 July	*B. brassicae*/plant 23 May–8 July	% weeds/0.4 m^2 24 May	% weeds/0.4 m^2 15 June	Yield/g/plant 28 June–20 July
Soil Guard (Yellow)	1.9 ± 0.3a	11.0 ± 1.1b	3.3 ± 0.4	28.8 ± 7.1a	107.9 ± 5.0
Soil Guard + Yellow paint	2.0 ± 0.4a	18.8 ± 1.8a	3.9 ± 0.6	29.0 ± 3.1a	108.3 ± 14.7
Soil Guard + Blue paint	0.8 ± 0.1cd	5.8 ± 0.6c	4.2 ± 1.0	26.8 ± 5.9a	93.5 ± 7.9
Silva Blend (Blue-green)	1.2 ± 0.1bc	6.7 ± 0.3c	7.1 ± 4.1	43.5 ± 15.2a	111.3 ± 5.1
Silva Fiber Plus (Green)	1.7 ± 0.4ab	9.7 ± 0.5bc	3.3 ± 0.7	37.5 ± 6.9a	110.4 ± 19.0
Weed Fabric (Black)	0.8 ± 0.2cd	7.8 ± 0.8bc	0.0 ± 0.0	0.0 ± 0.0b	91.1 ± 22.3
Diazinon	0.3 ± 0.2d	9.5 ± 0.7bc	5.2 ± 2.2	27.3 ± 5.5a	109.9 ± 6.9
Control	2.0 ± 0.1a	7.9 ± 0.9bc	5.8 ± 3.7	32.5 ± 4.2a	110.0 ± 10.8
F	8.87	24.05	0.88	4.34	0.39
P	0.0001	0.0001	0.5412	0.0041	0.8975

Means within columns followed by the same letter are not significantly different, (P = 0.05, LSD test). For each column, df = 7, 21.

ference (LSD) tests were used to show mean treatment differences (P = 0.05), (SAS Institute 1989).

Results

Cabbage Maggots. In 1994, the mean numbers of *D. radicum* larvae in plots treated with Soil Guard (painted blue), weed fabric (black), Silva Blend (blue-green), and diazinon were significantly ($P <$ 0.01) lower than in control plots (Table 1). There was no significant difference between plots treated with Soil Guard (yellow), Soil Guard (painted yellow), Silva Fiber Plus (green) and the control plots. On 15 May 1995, mean numbers of larvae in plots treated with Soil Guard plus starch (painted blue), weed fabric (black), and diazinon were significantly (P = 0.01) lower than in control plots (Table 2). During both years, the highest number of cabbage maggots was recorded in plots treated with Soil Guard (painted yellow) and in control plots. On 10 July 1995, larvae in plots treated with Soil Guard (painted blue) and Soil Guard (now faded yellow) were significantly (P = 0.05) lower than in the control plots. Diazinon was effective in controlling 2nd generation *D. radicum* in 1994, and the 1st generation in 1995 (Tables 1 and 2). However, by 10 July 1995, the highest number of 2nd-generation maggots was recorded in the diazinon-treated plots (Table 2).

Aphids. In 1994, the mean number of *B. brassicae* in plots treated with Soil Guard (painted yellow) was significantly ($P <$ 0.01) higher than in control plots at the end of our 6-wk counts (Table 1). Similarly in 1995, mean numbers of *B. brassicae* in plots treated with Soil Guard (painted yellow) plus starch were significantly ($P <$ 0.01) higher than in control plots at the end of our 6-wk counts (Table 2). During both years, aphid populations gradually increased, peaked, and then declined. In plots treated with Soil Guard (yellow) and Soil Guard (painted yellow) plus starch, we recorded an average ± SEM of 76.8 ± 13.2 and 70.3 ± 18.2 aphids per plot, respectively, during the peak population period in 1995 (Fig. 1). During the same period, only an average ± SEM of 18.5 ± 5.9 and 39.3 ± 8.6 aphids was recorded in plots treated with Soil Guard (painted blue) plus starch and the control, respectively (Fig. 1).

Flea Beetles. *P. cruciferae* densities in plots treated with weed fabric were 6 times greater than in control plots and at least 2 times higher than in other treated plots at the end of our 6-wk sample period (Table 2). Highly significant ($P <$ 0.0001) differences in mean densities were recorded between weed fabric and all other treated plots throughout the season. Flea beetle damage was noticeable early in the season but did not significantly affect yields in weed fabric plots (Table 2).

Lepidopterous Pests. There were no significant differences (F = 0.53; df = 7, 21; P = 0.79) in populations of lepidopterous pests among the treated plots and control. Therefore, it appears that the treatments used in this experiment had no direct effect on populations of imported cabbage worm, cabbage looper, and diamondback moth. Larval and pupal densities were low and the mean number for all 3 pests rarely exceeded 35 larvae per plot at any time during the growing season.

Weeds. The use of weed fabric resulted in no weed growth in treated plots (Tables 1 and 2). None of the other treatments suppressed weed growth in 1994. Total weed growth in plots treated with Silva Blend and Silva Fiber Plus exceeded that in control plots on the 15 June 1994 sample, but the differences were not significant (Table 1). Because of the lack of any weed suppression by these 2 treatments, they were eliminated in 1995. On the 5 May 1995 sample only plots treated with Soil Guard (plus yellow paint and starch) had significantly ($P <$ 0.01) fewer weeds compared with control plots. However, by 5 June, 4 of the 5 Soil Guard treatments had significantly ($P <$ 0.01) suppressed weed cover compared with control plots (Table 2). The weed species that accounted for >70% of the weeds were quackgrass, *Agropyron repens* (L.) Beauvois; field bindweed, *Convolvulus arvensis* L.; chickweed, *Stellaria media* (L.); purslane, *Portulaca oleracea* L.; lambsquarters, *Chenopodium album* L.; and ragweed, *Ambrosia artemisiifolia* L.

Table 2. Effect (mean ± SEM) of hydromulch, hydromulch combinations and weed fabric on *D. radicum* larvae and pupae, *B. brassicae* nymphs and adults, weeds, and yield in broccoli (1995)

Treatment	*D. radicum*/plant 15 May	*D. radicum*/plant 10 July	*B. brassicae*/plant 19 May–30 June	*P. crucifera*/plant 19 May–30 June	% weeds/0.4 m² 5 May	% weeds/0.4 m² 5 June	Yield/g/plant 19 June–10 July
Soil Guard (Yellow)	2.5 ± 0.9bcd	0.3 ± 0.1c	10.2 ± 1.4ab	15.6 ± 3.0c	3.8 ± 1.0ab	34.7 ± 4.2bc	94.9 ± 17.3ab
Soil Guard + Yellow paint + starch	5.2 ± 0.8a	1.1 ± 0.3abc	14.7 ± 3.4a	9.9 ± 4.6c	2.0 ± 0.4c	26.5 ± 1.7bc	50.2 ± 5.6b
Soil Guard + Blue paint + starch	1.3 ± 0.4d	0.3 ± 0.1c	4.0 ± 0.6c	14.1 ± 3.3c	3.3 ± 0.3abc	26.0 ± 0.8bc	111.1 ± 2.8a
Soil Guard + Lampblack + starch	2.5 ± 0.9bcd	0.6 ± 0.1bc	4.6 ± 0.5c	23.3 ± 3.5bc	2.5 ± 0.5bc	24.7 ± 2.4c	81.7 ± 19.4ab
Soil Guard + Lampblack + plaster of paris	4.0 ± 0.9abc	0.7 ± 0.2abc	5.6 ± 1.7bc	20.7 ± 3.9bc	3.9 ± 0.6ab	37.0 ± 4.6ab	69.8 ± 13.9ab
Weed Fabric (Black)	1.8 ± 0.8cd	1.4 ± 0.7ab	5.8 ± 2.1bc	66.5 ± 10.8a	0.0 ± 0.0d	0.0 ± 0.0d	100.5 ± 19.1a
Diazinon	1.8 ± 0.9cd	1.5 ± 0.4a	8.6 ± 1.3bc	33.7 ± 3.0b	4.3 ± 0.6a	46.8 ± 5.4a	109.5 ± 19.7a
Control	4.4 ± 0.2ab	1.3 ± 0.2ab	8.2 ± 0.7bc	10.9 ± 2.0c	4.0 ± 0.3ab	47.8 ± 8.2a	69.3 ± 13.8ab
F	3.50	2.41	3.78	12.99	6.41	15.80	1.98
P	0.0120	0.0563	0.0083	0.0001	0.004	0.0001	0.106

Means within columns followed by the same letter are not significantly different, (P = 0.05, LSD test). For each column, df = 7, 21.

Discussion

Cabbage Maggots. Plots treated with Soil Guard (painted blue) and weed fabric were as effective as diazinon-treated plots in suppressing *D. radicum* populations. The increase in *D. radicum* populations early in the season in plots treated with Soil Guard (yellow) and Soil Guard (painted yellow) may have been the result of a super foliage stimulus (Prokopy 1972) produced by the yellow mulch eliciting ovipositional and food-seeking responses. A higher population of larvae also was seen in plots treated with Silva Fiber Plus (green) (Table 1). These results are consistent with those of Roessingh and Städler (1990) who reported that *D. radicum* females laid significantly more eggs on yellow and bright green paper models.

The reduction of cabbage maggots in diazinon-treated plots in 1994 (Table 1), was likely caused by the treatment just 4 wk before 2nd generation of maggots appeared. A similar reduction is apparent in the 1st-generation maggot count on the 15 May 1995 (Table 2). The high counts of *D. radicum* in the diazinon-treated plots on 10 July 1995 may be the result of the partial degradation of the insecticide (Wauchope et al. 1992) and its movement away from the root zone (Chapman and Eckenrode 1973) by the time 2nd-generation maggots were present.

Aphids. During both years, significantly more aphids were recorded in plots painted yellow than in control plots. Yellow is believed to influence *B. brassicae* alighting on plants of the appropriate physiological type (Kennedy et al. 1961). In 1995, broccoli attained its maximum height approximately 14 June, just before harvest, averaging ± SEM 49.4 ± 8.6 cm per plant (n = 350). At that time the foliage canopy had almost completely covered the plots. That fact, combined with the fading of the naturally yellow Soil Guard plots compared with Soil Guard painted yellow, may partially explain the differences in aphid populations in those treatments after 14 June (Fig. 1).

Flea Beetles. Significantly more flea beetles were found in plots treated with weed fabric. There are a number of possible explanations for this including relative attractiveness of the black substrate, elevated temperatures in the plots, and reduced predation. The significant increase in flea beetles in diazinon-treated plots may lend credence to the predation concept, but we did not measure any of these parameters.

Harvested Yields. In 1994, trap monitoring data indicated that the 1st generation of maggot flies was already on the decline when broccoli seedlings were transplanted in the field. When the 2nd generation appeared, the broccoli root system was well established. During both years, populations of *D. radicum* were relatively low. Under these conditions, adequate soil moisture and a vigorous root system can enable a brassica crop to tolerate a moderately high maggot infestation (as observed in our yellow painted and control plots) and still produce accept-

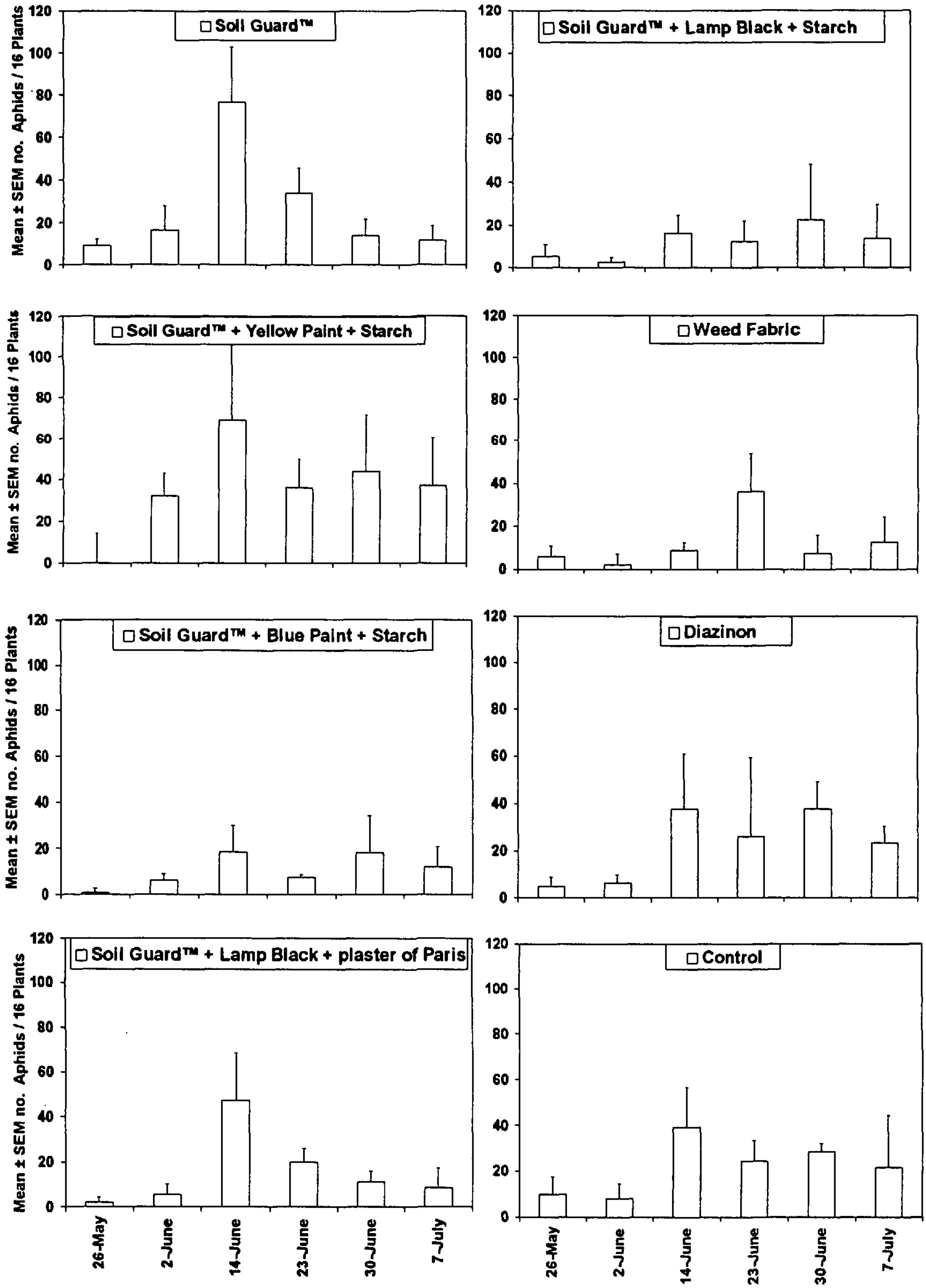

Fig. 1. Weekly mean ± SEM number of aphids per 16 broccoli plants (1995).

able marketable yields (Gehringer and Goldstein 1988). This may account for the nonsignificant differences in yields in 1994 and 1995 (Tables 1 and 2).

Color. Saturated blues such as the one used in our experiment have low reflectance energy in the green region (Koätál 1991) and are apparently less attractive to or do not arrest *D. radicum* or *B. brassicae*. Our results are similar to Moericke (1955) who reported that aphids were turned away from ground patches covered with blue material. Prokopy et al. (1983a, b) showed that landing by *D. radicum* is determined by a peak green reflectance between 500 and 600 nm. Kennedy et al. (1961) also recorded similar results for aphids.

Hydromulch. Treatments formed a physical barrier around the base of broccoli plants. Hydromulches were ≈5 mm thick and had the approximate texture when dry of a cardboard egg carton. Spray-painted plots remained distinctly colored throughout the season. Other colored treatments faded noticeably after 2–3 wk. In preliminary greenhouse tests, hydromulches appeared quite effective against weeds, particularly when lampblack and starch were added to the mix, giving it a rigid surface. However, in the field, regular rainfall and high humidity resulted in a soft surface that was penetrated readily by cabbage maggots and weeds. Some potential exists for control of insects and weeds if an adhesive could be found that would keep the hydromulch rigid in moist conditions.

In situations where densities of *D. radicum* and *B. brassicae* are high, choosing a mulch material with the appropriate color could simultaneously regulate both pest populations. At the application rate we used (700 kg/ha), Soil Guard costs approximately $1,500/ha for material, which is considerably more expensive than other hydromulches. The latex paint costs $220/ha at our application rate and diazinon costs approximately $56/ha for 1 application. The average cost of laying, removing, and disposing of weed fabric is about $2,434/ha for Agri-Tex landscape fabric (Agri-Tex, Danbury, CT) (Merwin et al. 1992) compared with a cost of $1,512/ha for plastic films (Wiggen 1995).

Soil Guard (painted blue) and starch applications resulted in lower populations of insects and weeds. Our results demonstrate that the color of the substrate in the broccoli cropping system influences the behavioral responses of *D. radicum, B. brassicae,* and *P. cruciferae*. In addition, our results suggest that populations of *D. radicum* and *B. brassicae* could be suppressed simultaneously if the appropriate soil barrier and color are adopted. The need for early-season chemical treatments for these pests could thereby be reduced. Further work needs to be done to understand the behavioral mechanism underlying the effects of color on pest populations.

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