Nonwoven Fiber Barriers for Control of Cabbage Maggot and Onion Maggot (Diptera: Anthomyiidae)

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ABSTRACT We investigated the use of nonwoven fiber barriers for control of cabbage maggot, *Delia radicum* (L.), and onion maggot, *D. antiqua* (Meigen). The barriers consist of arrangements of minute fibers loosely intertwined in "web" form. Results from a greenhouse experiment showed that manually applied graphite fibers placed at the base of broccoli plants reduced the number of *D. radicum* eggs by 64–98%, and that efficacy increased with greater fiber density. Using a melt extrusion process, we devised a method for on-site creation of nonwoven fibers of ethylene vinyl acetate (EVA). In field trials with broccoli and onion plants, EVA fibers significantly reduced the number of cabbage and onion maggots infesting plants. Fiber barriers provided comparable control to standard insecticide applications. The addition of blue, yellow, red, or black pigments, as well as optical brighteners that absorb UV light did not enhance fiber efficacy. Incorporation of capsaicin olfactory repellent to EVA also did not enhance fiber efficacy. Nonwoven fiber barriers may offer an alternative to insecticides for control of cabbage maggot and onion maggot and possibly other insect pests. Additional research is needed to improve the application process and to identify economically feasible and biodegradable compounds for fibers.

KEY WORDS *Delia antiqua, Delia radicum,* mechanical control, cultural control

CABBAGE MAGGOT, Delia *radicum* (L.), and onion maggot, *D. antiqua* (Meigen), are serious worldwide pests of cruciferous and *Allium* crops, respectively (Finch 1989). They are particularly damaging in the northeastern United States and Canada, where several generations occur each season. Crops attacked by cabbage maggot include cabbage, broccoli, cauliflower, radish, turnips, kale, collards, and brussels sprouts (Finch and Thompson 1992). Onion maggots attack onions, garlic, chives, shallots, and leeks (Straub and Emmett 1992). Females of both species lay their eggs near the base of plants and emerging larvae (maggots) infest the underground structures of plants. When infested in the seedling stage, plants may wither and die. Secondary decay can occur in the maggot feeding area, which can result in infection by pathogenic organisms, such as *Fusarium* spp. (McDonald and Sears 1992). Under heavy pressure, up to 90% of plants may be destroyed by cabbage maggot if control measures are not taken (Finch and Thompson 1992). Losses of untreated onion plants to *D. antiqua* are estimated to be ≈24–40% (Finch 1989).

For both pests, growers rely heavily on the use of insecticides for control. Fields are treated prophylactically with soil insecticides (granules, seed treatments, and soil drenches) at planting to control the first generation of maggots. Foliar insecticide sprays for adults are used to control subsequent generations (Finch et al. 1986a) but often are not effective (Whitfield et al. 1985, Finch et al. 1986b). Both cabbage maggot and onion maggot have become resistant to a wide range of insecticides (Harris and Svec 1976, Carroll et al. 1983, Harris et al. 1988), and relatively few compounds remain effective for control of these pests (Hayden and Grafius 1990, Finch and Thompson 1992). Furthermore, registration of most of the currently used compounds (organophosphates and carbamates) could be lost in the United States pending regulatory action of the Food Quality Protection Act of 1996 (Stivers 1999a, 1999b). Thus, the need for alternative control measures for cabbage maggot and onion maggot is critical.

The use of physical barriers has been investigated as a control measure for *D. radicum* and *D. antiqua* because they lay their eggs at the base of plants and require tactile stimulation with the plant before oviposition (Finch 1980, Prokopy et al. 1983, Harris and Miller 1991). Successful results have been shown with crop-protecting covers and collars placed around the base of the plant (Skinner and Finch 1986, Matthews-Gehringer and Hough-Goldstein 1988, Evans et al. 1997) and with hydromulch applications (Liburd et al.

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1998). Most of these approaches are expensive, labor-intensive, difficult to dispose of, or pose problems for plant development and pollination (Finch 1989).

Hough-Goldstein (1987) studied the effectiveness of spunbonded (nonwoven mesh) polyester as a barrier against seedcorn maggot and lepidopteran pests of cabbage. Results showed that the row cover dramatically reduced feeding damage by lepidopteran pests but was ineffective in preventing infestation of seeds by seedcorn maggot because eggs and/or larvae were already present in the field before planting. The polyester row cover would probably work as an effective barrier against cabbage maggot and onion maggot because these pests lay eggs after crops have been planted and seedlings have emerged (Finch 1989). Row covers, however, are expensive and may increase the risk of bacterial rot to the crop by increasing relative humidity (Hough-Goldstein 1987).

We report here our research on the use nonwoven fiber barriers, intertwined in "web" form, and applied in situ for control of cabbage maggot and onion maggot. In addition, we evaluated the potential to enhance fiber efficacy with the incorporation of color pigments, optical brighteners, and capsaicin repellent.

Materials and Methods

We conducted several greenhouse and field experiments on the use of nonwoven fibers as an oviposition deterrent for *D. radicum* on broccoli and *D. antiqua* on onions. All greenhouse studies were conducted at the Cornell University Insectary Building under a combination of daylight and grow-lights on a photoperiod of 16:8 (L:D) h and ambient temperatures from 24 to 30°C. All field experiments, with the exception of on-farm trials for onion maggot, were conducted at the Cornell University Entomology Research Farm near Freeville, NY.

All *D. radicum* and *D. antiqua* used in the experiments were obtained from colonies maintained at the Department of Entomology, New York State Agricultural Experiment Station, Geneva, NY. As needed, pupae were placed in separate 0.3-m^3 emergence cages at 23°C, 40% RH, and a photoperiod of 16:8 (L:D) h. Emerged adult flies were provided a 10% sucrose solution with a cotton dental wick in a flask, Holland Dry Diet, and Brewers yeast ad libitum and allowed to mate. Female *D. radicum* or *D. antiqua* were aged 7–9 d posteclosion (reproductively mature) before their use in trials.

Manually Applied Graphite Fibers: Cabbage Maggot Experiment. To initially test the concept of nonwoven fiber barriers as a control method for *D. radicum*, we manually applied graphite monofilaments to the base of potted broccoli plants and evaluated oviposition by the flies. The experiment was a randomized complete block design choice test with four replicates conducted in the greenhouse in May 1996. Each block was a 0.3-m^3 cage containing one potted three-leaf stage 'Southern Comet' broccoli seedling for each of four treatments.

Fibers (6–7 μm diameter) were obtained by teasing apart strands of a 5-cm section (=tow) of graphite twine composed of ≈3,000 monofilaments per tow (Hercules Fibers, Wilmington, DE). Density of fibers was determined by the number of 5-cm tows used. The fiber tows were interlaced at the base of the plant. Treatments included three, six, and nine tows of graphite plus a nontreated control.

Ten female *D. radicum* flies were released into each cage and provided with a 10% sucrose solution as a food source. Plants were removed from cages after 72 h and sampled for eggs by washing the soil, plant material, and fibers through a No. 70 USA standard testing sieve (W. S. Tyler, Mentor, OH). Eggs were rinsed onto a petri dish and counted over a grid. Total number of eggs per plant was recorded. Data were analyzed using PROC GLM in SAS (SAS Institute 1999). Fisher's least significant difference (LSD) was used to separate treatment means at the 0.05 level of significance.

Development and Optimization of a Fiber Delivery System. To generate fibers in situ, we fabricated a small-scale prototype machine that produced fibers of ethylene vinyl acetate (EVA) (Elvax 200 W or 205 W; DuPont Polymers, Wilmington, DE) by a melt extrusion process. Hydraulic pressure was used to extrude molten EVA through a small orifice and the fibers were carried to the target by a stream of air. The melt-extrusion apparatus consisted of a metal reservoir (160 by 100 mm) that was heated to ≈150–180°C and pressurized to ≈172.4 kPa with CO_2. The pressure forced the molten EVA through a 2-mm i.d. nozzle orifice located near the base of the reservoir. Fibers from this prototype unit ranged from 20 to 250 μm in diameter.

Subsequently, we obtained commercial equipment to generate EVA fibers via melt extrusion. The equipment, which was manufactured by ITW Dynatec (Hendersonville, TN) was designed to apply hot melt glue in industrial settings. We selected it for our trials because it allowed us to easily generate a range of fiber characteristics by varying temperature, pressure, and nozzle configuration. The equipment consisted of a Dynamini adhesive supply unit fitted with a pneumatic piston pump, and a 3.7-m Dynaflex hose and a Dynagun hot melt applicator MODEL 155 fitted with a 0.787-mm Dynaswirl nozzle orifice. The unit required an air compressor and was powered in the field by a generator. The EVA fibers generated ranged from 5 to 50 μm in diameter.

When used in trials, fibers produced by the Dynatec system were applied directly to the soil around the plant's base with coverage patterns similar to that of hand-teased commercially available fibers. The hose, spray gun, and hopper containing EVA were maintained at ≈170°C during application. The resulting nonwoven barriers were three dimensional, bound coarse web mats of varying strand number and amount of reticulation. The Dynatec unit also permitted us to produce fibers made from various compound mixtures and of various colors.

EVA Fibers: Onion Maggot Field-Cage Experiment. In mid-June 1998, the effectiveness of in situ-generated EVA was tested against onion maggots in a large field cage (2.7 by 3.7 by 2.4 m) covered with natural-color Lumite (HDPE) (Hansen WeatherPort, Gunnison, CO). Ten to 11 greenhouse-grown three-leaf stage 'Stuttgart' onion plants were transplanted into each of four plastic rain gutters (2.74 m long by 0.10 m wide by 0.07 m deep), which were buried in trenches and filled with a 10:4 sand:top soil mixture to match the existing soil level in the cage. Plants were spaced ≈25 cm apart in the gutters, with 0.6 m between the gutters.

Within each gutter, four randomly chosen plants were treated with EVA and another four not treated. Plants located at the ends of rows were not used. EVA treatments were applied with the Dynatec melt extrusion unit with pneumatic pressure to the fluid pump at 413.7 kPa and air supply to the nozzle set at 275.8 kPa. Fiber applications were completed in ≈3 s and ranged from 1 to 2 g per plant.

Twenty female *D. antiqua* flies were released into the cage and provided with a 10% sucrose solution. After 72-h onion maggot egg numbers were sampled by removing a cylinder of soil (5.0 cm radius by 7.6 cm in deep) around each plant and washing and sieving the soil and plant material as described previously. Total number of eggs per plant was recorded. Data were analyzed using PROC GLM in SAS (SAS Institute 1999). Fisher LSD was used to separate treatment means at the 0.05 level of significance.

Fiber Color: Onion Maggot Experiments. One greenhouse experiment was conducted in December 1998 and another in March 1999. Each experiment was a randomized complete block design choice test with five replicates. Each block was a 0.3-m^3 cage containing one potted three-leaf stage Stuttgart onion seedling for each treatment.

Colored fibers were created through the addition of Colormatch plasticizer pigments (Plasticolors, Ashtabula, OH) at a rate of 4 g of pigment per 450 g of EVA. For experiment 1, treatments consisted of unpigmented, blue, and yellow EVA plus a nontreated control; experiment 2 consisted of unpigmented, red, and black EVA plus a nontreated control. Fiber treatments were applied using the same protocol as in the previous experiment.

Five *D. antiqua* adult females were introduced into each cage and allowed to oviposit for 4 d. Counts of eggs were made by removing each potted plant from the cages and washing and sieving the plant and soil mixture as described previously. Data were analyzed using PROC GLM in SAS (SAS Institute 1999). Fisher's LSD was used to separate treatment means at the 0.05 level of significance.

Fibers + Optical Brightener: Cabbage Maggot Field-Cage Experiment. Optical (fluorescent) brighteners are widely used in paints, fabrics, plastics and detergents, wherein they enhance the apparent brightness of the material by absorbing UV radiation and emitting light in the blue visual spectrum (Martinez et al. 2000). These brighteners were feasible to use with our existing technology and could potentially increase fiber effectiveness. Thus, in mid-May 2000, we tested the efficacy of optical brighteners added to EVA fibers against cabbage maggots in four large Lumite field cages (3.7 by 3.7 by 1.8 m). The experiment was a randomized complete block design with four replicates (cages).

Within each cage, six rows (3 m long) were formed ≈0.3 m apart by hand plowing. Greenhouse-grown two-leaf stage Southern Comet broccoli was transplanted into the six rows within each cage at a plant spacing of 15 cm. One row of broccoli represented a single treatment within each cage. The six treatments were as follows: (1) EVA at low rate (3.7 g/3-m row); (2) EVA at high rate (7.4 g/3-m row); (3) EVA at low rate + 0.05% Optiblanc SPL-10 optical brightener (Lenape Industries, Hillsborough, NJ); (4) EVA at high rate + Optiblanc; (5) chlorpyrifos applied as a soil drench at 0.033 kg (AI)/100 row meter (grower standard); and (6) a nontreated control. Fiber treatments were applied with the Dynatec melt extrusion unit at a pump pneumatic pressure of 138 kPa and nozzle pneumatic pressure of 552 kPa. Once applied, fibers encompassed a 15- to 20-cm band at the base of the broccoli seedlings.

On 21 May, ≈175 *D. radicum* pupae were placed into each of the four cages and 10% sucrose solution was provided as a food source for emerging adults. After ≈2 wk, broccoli plants were sampled for cabbage maggot larvae and pupae by digging up roots and soil around each plant and washing the material through a No. 60 USA standard testing sieve. Total number of larvae and pupae per plant was recorded. Data were analyzed using PROC GLM in SAS (SAS Institute 1999), which included partitioning the treatment source of variation into four orthogonal contrasts (Little and Hills 1978): (1) EVA versus control; (2) EVA + optical brightener versus pure EVA; (3) high rate of fiber versus low rate; and (4) chlorpyrifos versus fiber.

Fibers + Optical Brightener: Onion Maggot On-Farm Experiments. In spring 2000, the effectiveness of EVA fibers with and without optical brighteners was tested against *D. antiqua* on two commercial onion farms, one in Potter, NY, and the other near Oswego, NY. The same treatments were tested at each location in a randomized complete block design with four replicates.

In early April, 'Gazette' onions were planted on "muck" soils by using a push-behind Earthway Precision Garden seeder model 1001-B (EarthWay Products, Bristol, IN). Individual plot sizes were two rows by 4.6 m. Plants were ≈10 cm apart within rows. The six treatments were as follows: (1) EVA at low rate (3.7 g/3-m row); (2) EVA at high rate (7.4 g/3-m row); (3) EVA at low rate + 0.05% Optiblanc SPL-10 optical brightener; (4) EVA at high rate + Optiblanc; (5) Fipronil seed treatment at 50 g (AI)/kg seed, which is currently the most efficacious insecticide treatment for onion maggot (Eckenrode et al. 2000); and (6) an untreated control. All EVA treatments were applied when onion plants were 3–6 cm high (early to mid-

May) by using the Dynatec melt extrusion unit as described previously. Once applied, fibers encompassed a 15- to 20-cm band at the base of the onion seedlings.

Cumulative readings of damaged and wilting plants, plus onion maggot numbers were made weekly from late May to late June. Data were collected from the center 3 m of row in each plot. At each sample date, the number of total plants, number of wilted plants + dead seedlings, and the number of maggot larvae in dead seedlings were counted. Data were analyzed using PROC GLM in SAS (SAS Institute 1999), which included partitioning the treatment source of variation into four orthogonal contrasts (Little and Hills 1978): (1) EVA versus control; (2) EVA + optical brightener versus pure EVA; (3) high rate of fiber versus low rate; and (4) fipronil seed treatment versus fiber.

Fibers + Capsaicin: Cabbage Maggot Field Experiment. Capsaicin is present in an oleoresin mammal repellent made from piquant chili peppers. We added oleoresin capsaicin to EVA fibers and tested it against *D. radicum* in a field experiment. The experiment was a completely randomized design with eight replicates.

On 26 June, 2000, land at the Freeville farm was cultivated, fertilized with 15-15-15, and four rows (beds) were made 1 m apart. Greenhouse-grown two-leaf stage Southern Comet broccoli was transplanted into the rows at a plant spacing of ≈0.2 m. Individual plot size was one row by 4.8 m. Six treatments were tested and were as follows: (1) EVA at low rate (3.7 g/3-m row); (2) EVA at high rate (7.4 g/3-m row); (3) EVA at a low rate + capsaicin oleoresin (1:6 ratio, 1.6 M-Scoville Heat Units); (4) EVA at high rate + capsaicin; (5) chlorpyrifos applied as a soil drench at 0.033 kg (AI)/100 row m; and (6) an untreated control. Fiber treatments were applied as described previously.

On 21 July, five randomly chosen broccoli plants from each plot were dug up. The root systems of each plant plus ≈1,200 ml of surrounding soil were sampled for cabbage maggot larvae and pupae by washing and sieving as described previously. Data were analyzed using PROC GLM in SAS (SAS Institute 1999), which included partitioning the treatment source of variation into four orthogonal contrasts (Little and Hills 1978): (1) EVA versus control; (2) EVA + capsaicin versus pure EVA; (3) high rate of fiber versus low rate; and (4) chlorpyrifos versus fiber.

Results

Manually Applied Graphite Fibers: Cabbage Maggot Experiment. There was a significant treatment effect of manually applied graphite fibers on oviposition by *D. radicum* on broccoli ($F = 3.65$; df = 3, 9; $P \leq 0.057$). Three 5-cm tows of monofilaments placed at the base of plants reduced the number of maggot eggs by 64%, six tows reduced egg numbers by ≈77%, and nine tows reduced egg numbers by ≈96% (Fig. 1).

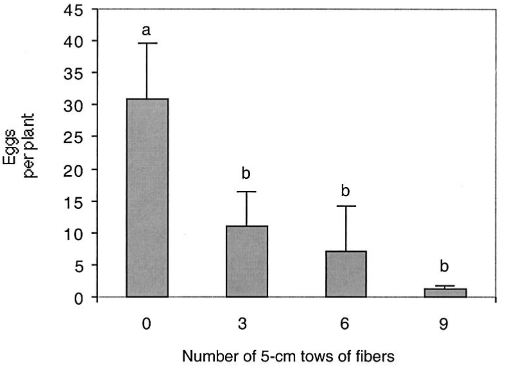

Fig. 1. Effect of graphite fibers applied manually to the base of broccoli plants for control of *D. radicum* in a choice field-cage experiment. One tow of fibers represents a 5-cm section of graphite twine composed of ≈3,000 monofilaments. Columns with the same letter are not significantly different according to Fisher LSD at the 0.05 level of significance.

EVA Fibers: Onion Maggot Field-Cage Experiment. Applying EVA fibers to onion plants and the surrounding soil surface significantly reduced the number of onion maggot eggs found ($F = 15.62$; df = 1, 27; $P \leq 0.0005$). EVA-treated plants had a mean ± SE of 1.4 ± 0.6 eggs compared with 10.4 ± 2.1 eggs for the untreated plants. Fibers did not restrict growth of the onion plant or cause any apparent phytotoxicity.

Fiber Color: Onion Maggot Experiments. There was a significant treatment effect in experiment 1 ($F = 3.66$; df = 3, 12; $P \leq 0.05$) and experiment 2 ($F = 7.36$; df = 3, 12; $P \leq 0.005$). In both experiments, EVA fiber treatments had 70–90% fewer eggs than the non-treated control (Table 1). In experiment 1, no differences were found among blue, yellow, and clear EVA treatments. Similarly, in experiment 2, no differences were found among black, red, and clear treatments. Thus, the addition of these color pigments to EVA fibers did not increase efficacy for control of onion maggot in these experiments.

Table 1. Effect of EVA fibers of different colors on number of eggs deposited at the base of onion plants by *D. antiqua* in greenhouse choice experiments

Trial	EVA fiber treatment	*D. antiqua* eggs per plant (mean ± SE)
Experiment 1	Untreated	204.80 ± 73.26a
	Clear	38.60 ± 23.87b
	Yellow	57.80 ± 22.06b
	Blue	17.40 ± 2.93b
Experiment 2	Untreated	132.60 ± 34.4a
	Clear	35.80 ± 18.42b
	Red	24.00 ± 10.62b
	Black	14.00 ± 5.48b

EVA treatments were applied at a rate of 1–2 g per plant by using a melt extrusion applicator. Values followed by the same letter are not significantly different according to Fisher's protected LSD at the 0.05 level of significance.

Table 2. Effect of EVA fiber treatments applied at the base of broccoli plants for control of *D. radicum* in a field-cage experiment by using artificially released flies

Treatment	Rate	*D. radicum* larvae per 3-m row of broccoli
Nontreated control		11.8 ± 3.1
EVA	3.7 g/3-m row	7.8 ± 1.3
	7.4 g/3-m row	3.8 ± 0.6
EVA + optical brightener[a]	3.7 g/3-m row	7.8 ± 2.7
	7.4 g/3-m row	5.5 ± 2.4
Chlorpyrifos drench	0.033 kg (AI)/100-m row	6.0 ± 2.3
Orthogonal contrasts		
EVA vs control		($P < 0.0714$)
EVA + optical brightener vs pure EVA		NS
High rate of EVA vs low rate		NS
Chlorpyrifos vs EVA		NS

ANOVA treatment source of variation was not significant ($F = 1.11$; df = 5, 15; $P = 0.394$).

NS, not significant.

[a] Optiblanc SPL-10 optical brighteners (Lenape Industries) were mixed with melted EVA at a rate of 0.05%.

Table 3. Effect of EVA fiber treatments with and without capsaicin applied at the base of broccoli plants for control of *D. radicum* in a field experiment

Treatment	Rate	*D. radicum* larvae per plant
Nontreated control		4.4 ± 0.6
EVA	3.7 g/3-m row	0.6 ± 0.4
	7.4 g/3-m row	1.0 ± 0.3
EVA + capsaicin[a]	3.7 g/3-m row	1.4 ± 0.5
	7.4 g/3-m row	1.4 ± 0.4
Chlorpyrifos drench	0.033 kg (AI)/100-m row	0.3 ± 0.2
Orthogonal contrasts		
EVA vs control		($P < 0.001$)
EVA + capsaicin vs pure EVA		NS
High rate of EVA vs low rate		NS
Chlorpyrifos vs EVA		NS

ANOVA treatment source of variation was highly significant ($F = 10.42$; df = 5, 40; $P < 0.001$).

NS, not significant.

[a] Capsaicin oleoresin (1.6 M-Scoville Heat Units) was mixed with melted EVA at a 1:6 ratio.

Fibers + Optical Brightener: Cabbage Maggot Field-Cage Experiment. Applying EVA fibers to two-leaf stage broccoli plants and the surrounding soil appeared to restrict leaf unfurling for a period of time (1–2 wk), but as plants grew, the leaves broke through the fiber barrier and were subsequently unaffected by the fiber mat. Treatment effect was not significant on number of cabbage maggots found on broccoli plants ($F = 1.11$; df = 5, 15; $P = 0.396$). Nonetheless, orthogonal contrasts revealed a marginally significant difference in maggot numbers between fiber treatments and the nontreated control (Table 2). No differences were found between high and low rates of fiber or between fibers and chlorpyrifos drench. Addition of Optiblanc brightener did not increase fiber efficacy.

Fibers + Optical Brightener: Onion Maggot On-Farm Experiments. Onion maggot population levels were low in New York in 2000. The two on-farm experiments did not have sufficient *D. antiqua* pressure to adequately evaluate the fiber treatments. No maggots were found at the Oswego site, and at the Potter location, there was no significant treatment effect on number of maggots ($F = 1.56$; df = 5, 15; $P = 0.231$) or percentage of wilted plants ($F = 1.97$; df = 5, 15; $P = 0.142$). Although these experiments were not an adequate evaluation of onion maggot control, on-farm testing did provide us with some qualitative information on the feasibility of applying fibers in the field. We observed some initial restriction of plant growth by the EVA fiber mat, but most of the onion seedlings poked through the fibers by the second or third true-leaf stage and were subsequently not affected by the fibers.

Fibers + Capsaicin: Cabbage Maggot Field Experiment. Applying EVA fibers to broccoli plants and the surrounding soil had a highly significant effect on number of cabbage maggots infesting the plants ($F = 10.42$; df = 5, 40; $P \leq 0.001$). Two plots were removed from the data set because of human error during the wash and sieving process. Fiber treatments had significantly fewer maggots per plant compared with the untreated control and were not significantly different than the chlorpyrifos application (Table 3). No differences were seen between high rate and low rate of fiber. The addition of capsaicin oleoresin did not significantly improve the efficacy of the EVA fibers.

Discussion

Nonwoven fiber barriers hold considerable potential for the management of *D. radicum* and *D. antiqua.* Results of our greenhouse and field experiments showed that nonwoven fibers applied to the base of plants substantially reduced the number of eggs or larvae of *D. radicum* on broccoli and *D. antiqua* on onions. In the field, fiber barriers provided comparable control to standard insecticide applications.

Using a commercial melt extrusion applicator (Dynatec system), we devised a method for on-site creation of nonwoven fiber barriers. In our trials, we used ethylene vinyl acetate, a relatively inert and nondegradable polymer. This material is too expensive and impractical for large-scale agricultural use because the resulting fiber mat requires removal from the field and disposal after each use. We hope to use fibers with the proper characteristics for pest repellence and timed degradation so that they remain intact only as long as necessary for efficacy. The development of degradable polymers is a research area that is currently receiving much attention (Swift 1995, Croteau 1998, Shaw 1999). For insect pest management purposes the optimal fiber would protect plants from pests, yet degrade into inert ingredients before harvest and would need to be relatively inexpensive.

The incorporation of visual enhancements to fibers also should be further investigated. Research has shown that color and shape are important cues for *Delia* spp. to find host plants (Harris and Miller 1983, Prokopy et al. 1983, Tuttle et al. 1988). Moreover, reflectance of visible and UV light can act as a repellent to numerous insect species (Chalfant et al. 1977, Schalk et al. 1979, Prokopy and Owens 1983, Conway et al. 1989), including *D. radicum* (Liburd et al. 1998). In our trials, the addition of blue, yellow, red, or black pigments, as well as optical brighteners that absorb UV light did not enhance fiber efficacy. However, it is possible that the fiber density used in our experiments may have masked the effects of the various optical enhancers.

Incorporation of olfactory repellents is another approach to enhancing the effectiveness of fiber barriers. Several compounds have been shown to suppress *D. antiqua* oviposition, including phenolics and monoterpenoids (Cowles and Miller 1992), and pungent spices such as dill, paprika, black pepper, chili powder, ginger, and red pepper (Cowles et al. 1989). In addition, the mammal repellent capsaicin deterred *D. antiqua* oviposition by 95% when present at 320 ppm in the top 1 cm of soil (Cowles et al. 1989). In our studies, the addition of capsaicin oleoresin to EVA fibers did not increase efficacy against *D. radicum* in the field; however, all fiber treatments significantly reduced maggot numbers compared with nontreated broccoli plants.

Although the research presented in this article focused on *D. radicum* and *D. antiqua* control, nonwoven fibers may be useful for managing other pests in other crops. The fiber barrier concept has recently been patented (Hoffmann et al. 2000) and additional studies are currently being conducted on the use of fibers to control other pest organisms.

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