INFLUENCE OF COLOUR AND TRAP HEIGHT ON CAPTURES OF ADULT PEA LEAFMINER, *LIRIOMYZA HUIDOBRENSIS* (BLANCHARD) (DIPTERA: AGROMYZIDAE), IN CELERY

A. D. MARTIN, R. S. VERNON[1], R. H. HALLETT[2]
Department of Environmental Biology, University of Guelph,
Guelph, Ontario, Canada, N1G 2W1
email: rhallett@uoguelph.ca

Abstract *J. ent. Soc. Ont.* 136: 25–35

Sticky trap colour preference and spatial distribution of adult pea leafminer in celery were evaluated in 2001 and 2002 for use in developing an integrated approach to managing this pest. Colour preference was determined by exposing traps of various colours (red, blue, violet, green, white, and yellow) and materials (cardboard and acetate) to leafminer populations in celery for 24-48 hours. To evaluate the vertical distribution of flying adults, yellow sticky cards were positioned at standard heights (10, 30, 50, 70, and 90 cm) within celery crops of varying height for 24-48 hours. All cards were returned to the lab where sex and total number of adult pea leafminer were determined. Both sexes of adult pea leafminer were preferentially attracted to yellow opaque or translucent sticky cards, with highest captures occurring about 20 cm below the crop the top of the celery crop canopy.

Introduction

The pea leafminer, *Liriomyza huidobrensis* (Blanchard), was initially identified in the Holland Marsh region of Ontario in 1999 after causing significant economic loss in leafy vegetable crops (McDonald et al. 2000). This polyphagous pest is established in the sub-tropical and temperate regions of North and South America, Europe, and Asia (Spencer 1973; Weintraub and Horowitz 1995). Since its discovery in Ontario, the pea leafminer has remained geographically isolated within the Holland Marsh region, where it appears to survive the winter within greenhouses (Martin et al. 2005). Local crops experiencing damage include lettuce (*Lactuca sativa* Linnaeus), spinach (*Spinacia oleracea* Linnaeus), celery (*Apium graveolens* Linnaeus), Asian crucifers (*Brassica* spp.), greenhouse ornamentals, greenhouse cucumbers (*Cucumis sativus* (Linnaeus)), and onions (*Allium cepa* Linnaeus).

Insect monitoring is an important management practice required to track pest presence within a field effectively and time control measures accurately. Sampling methods used for monitoring leafminers include adult counts on sticky traps, pupal collections, counts

[1] Pacific Agri-Food Research Centre, Agriculture and Agri-Food Canada, Agassiz, BC, Canada, V0M 1A0
[2] Author to whom all correspondence should be addressed.

of mines, and live larval counts within leaves (Levins et al. 1975; Poe et al. 1978; Johnson et al. 1980). Not all of these techniques are reliable or efficient, as large errors in estimation may occur, counts of adult and pupal stages are not representative of larval populations, and a detrimental time delay in implementing control measures may occur by attempts to forecast future populations (Zehnder and Trumble 1984; Heinz and Chaney 1995). In the Holland Marsh, pea leafminer monitoring in celery, *Apium graveolens* Linnaeus, occurs indirectly from systems in place for established pests or by visual damage assessments. Although sticky card captures may not provide enough information to accurately time pest control programs, this is the simplest and most efficient monitoring method used in the area and it provides growers with information about levels of adult infestation in their crops. The potential for severe economic losses make early detection and continued monitoring of this pest particularly important. The purpose of this research was to determine the most effective colour and placement of sticky traps within the celery canopy to maximize adult pea leafminer captures.

Materials and Methods

All experiments were conducted in plots of celery cv. Florida 683 grown on muck soil (60% organic matter) at the University of Guelph Muck Crops Research Station, Kettleby, ON.

Trap Colour. Card stock (white poster board, Hilroy, Toronto, ON) was painted with two to three coats of exterior or interior acrylic latex paint (The General Paint Store, Cambridge, ON), and cut into 28 x 10 cm cards. Cards were folded in half (14 x 10 cm) with the painted surface exposed. Just prior to placement in the field, traps were coated with medium grade Sticky Stuff® (Olson Products, Medina, OH). Commercial, translucent yellow sticky traps (Cooper Mill Ltd., Madoc, ON) were also included as a standard (14 x 10 cm). All traps were fastened to wooden stakes using bullclips and were oriented facing north/south between the two centre rows of a four row celery bed.

In 2001, six colours (paint formulations provided in parentheses) were evaluated: white (71-011: A1/2, T1/2), violet (81-054: E44, L2, V1Y40), blue (71-052: AC079N), green (71-054: A2Y, T1, Kx6), yellow (71-054: A2Y10, T1, Kx8), and red (15-101). Traps were placed at the top of the canopy (approximately 62 cm). All treatments were replicated six times on three consecutive days (28-30 August) in a completely randomized design. After each 24 hour exposure period, cards were collected and the sex and number of all pea leafminers on the total trap surface were determined using a dissecting microscope (25x).

In 2002, the heights of 30 randomly selected celery plants were measured and the average crop height was determined prior to each experimental period. All traps were placed at half of the average crop height for that experimental period, and were arranged in a completely randomized design with five replications per exposure period. In order to examine the effect of light transmission through traps on pea leafminer captures, paints were applied to both card stock and plastic (overhead transparency film, Basics Office Products, Kitchener, ON) cards to create opaque and translucent traps, respectively. Due to low captures on red, blue, and violet traps in 2001, only white, green, and yellow were included. Traps were established in the field on 6 and 20 August, 5 September, and 2 October 2002 for 48 hours after which they were returned to the lab where sex and total number of adult pea leafminer were determined.

Spectral reflectance curves of all trap colours and types were determined by spectrophotometer (DataFlash 100 spectrophotometer, Datacolour, Lawrenceville, NJ) and are presented in Figure 1. For translucent and commercial yellow traps, reflectance values were determined for traps placed against both white and black backgrounds; spectral reflectance curves were created using the mean percent reflectance values from both

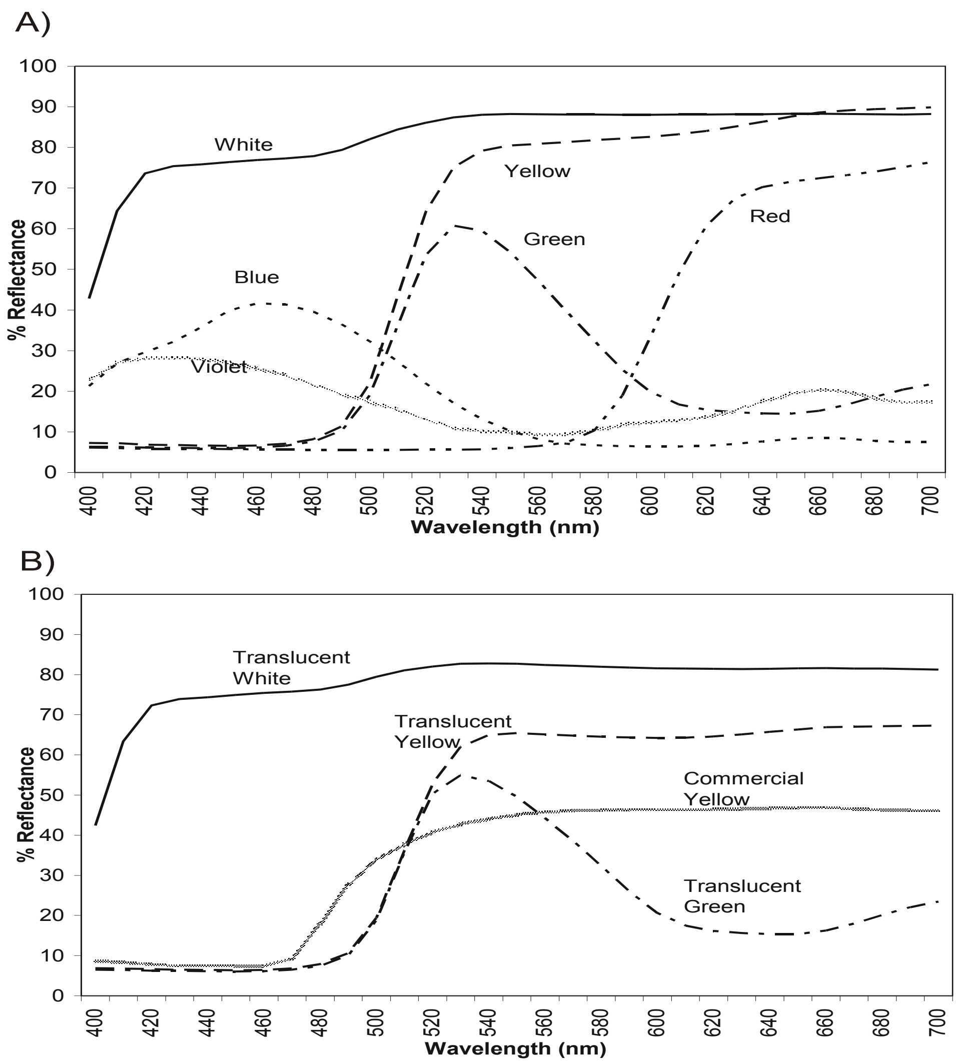

FIGURE 1. Spectral reflectance curves of A) opaque trap colors and B) translucent trap colors, determined by DataFlash 100 spectrophotometer.

backgrounds (Figure 1B).

Trap height. In 2001, yellow commercial sticky traps measuring 14 x 10 cm were fastened individually to wooden stakes using bullclips at heights of 10, 30, 50, 70, or 90 cm from the soil to the bottom of the trap and positioned between the two centre rows of a four row celery bed. Sticky cards were arranged in a completely randomized design with nine replications per day for two days. On 3 and 6 September 2001, traps were exposed for 24 hours, after which the sex and total number of pea leafminer adults on each trap were determined. Average crop height was approximately 65 cm throughout this experiment.

In 2002, yellow commercial individual sticky cards were fastened to wooden stakes at 10, 30, 50, 70, and 90 cm above the soil, using a completely randomized design with eight replications. Traps were positioned between the two centre rows of a four row celery bed on 1 and 14 August, and 17 September 2002, when mean crop heights were 30, 50 and 70 cm, respectively. Traps were exposed for 48 hours after which sex and total number of pea leafminer adults on each trap were determined.

Statistical analyses. Colour data from both years and height data from 2001 were analyzed by analysis of variance (ANOVA) using PROC GLM (SAS Institute, 1999) after transformation by log (x + 0.5). In 2002, numerical heights were renamed according to their relative placement within the canopy (i.e., 60 cm below, 40 cm below, 20 cm below, at, 20 cm above, 40 cm above, and 60 cm above the crop canopy); data for all exposure periods were pooled and analysed as described above. Since trap placement was based on crop height at the time of trap exposure not all relative trap positions could be tested at each exposure period (i.e. 60 cm below the canopy was not applicable when crop height was 50 cm). Two basic assumptions of ANOVA, i.e. 1) independent treatment and model effects and 2) random, independent, and normally distributed errors, were verified prior to analysis. Height and colour were ranked in order of attractiveness by males, females, and total using Tukey's Honestly Significant Difference test. In all cases, $\alpha = 0.05$ and actual, rather than transformed, data are presented.

Results

Trap colour. In 2001, the commercial yellow sticky card captured the most female ($F = 85.26$; df = 6, 109; $P<0.0001$) and male ($F = 87.06$; df = 6, 109; $P<0.0001$) pea leafminers, followed by painted yellow and green sticky cards (Table 1). More males were captured on white than violet sticky cards, but there were no significant differences in captures of females on white, blue, red, and violet sticky cards. Significant date (F = 5.55; df = 2, 109; $P = 0.0051$) and replicate ($F = 4.80$; df = 5, 109; $P = 0.0005$) effects were observed.

In 2002, significantly more males ($F = 10.53$; df = 6, 107; $P<0.0001$) and females ($F = 18.60$; df = 6, 125; $P<0.0001$) were captured on yellow sticky cards than on all other trap types (Table 2). For females, commercial and translucent yellow sticky cards were significantly more attractive than opaque yellow cards, but for males there was no difference between the three types of yellow cards. Translucent green and white traps did not capture more pea leafminer than their opaque counterparts. There were significant date*treatment interactions for males ($F = 2.69$; df = 18, 107; $P = 0.0009$) and total pea leafminer captured

TABLE 1. Effect of trap color on the number of male, female, and total adult pea leafminer, *Liriomyza huidobrensis*, captured on sticky traps in three 24-hour trapping sessions between 28 and 30 August 2001. Data for all trapping sessions were combined.

	Mean (± SE) Number of Pea Leafminer Adults Captured[1]		
Trap Colour	**Male**	**Female**	**Total**
Commerical Yellow	138.73 ± 14.85 **a**	48.73 ± 4.48 **a**	187.47 ± 16.19 **a**
Yellow	32.83 ± 7.60 **b**	15.39 ± 3.58 **b**	48.22 ± 11.02 **b**
Green	19.56 ± 2.41 **b**	8.33 ± 0.90 **b**	27.89 ± 3.15 **b**
White	5.50 ± 1.02 **c**	3.22 ± 0.67 **c**	8.22 ± 1.82 **c**
Blue	5.00 ± 1.25 **cd**	2.56 ± 0.37 **c**	7.72 ± 1.43 **c**
Red	2.78 ± 0.45 **cd**	2.22 ± 0.36 **c**	5.33 ± 0.62 **c**
Violet	1.94 ± 0.38 **d**	1.94 ± 0.76 **c**	3.89 ± 1.06 **cd**

[1]Means in the same column followed by the same letter are not significantly different, ANOVA and Tukey's HSD comparisons of means, α= 0.05.

TABLE 2. Effect of trap color and translucence on the number of male, female, and total adult pea leafminer, *Liriomyza huidobrensis*, captured on sticky traps in 2002. Data for all dates were combined.

	Mean (± SE) Number of Pea Leafminer Adults Captured[1]		
Trap Colour	**Male**	**Female**	**Total**
Commercial Yellow	14.95 ± 5.20 **a**	40.40 ± 14.46 **a**	55.35 ± 19.21 **a**
Translucent Yellow	10.90 ± 3.52 **ab**	34.00 ± 11.68 **a**	44.90 ± 14.84 **a**
Opaque Yellow	9.10 ± 2.76 **ab**	17.00 ± 5.71 **b**	26.20 ± 8.24 **b**
Translucent Green	6.95 ± 2.94 **bc**	12.20 ± 4.57 **bc**	19.15 ± 7.38 **bc**
Opaque Green	4.05 ± 1.23 **bcd**	6.85 ± 1.91 **bc**	10.90 ± 2.89 **bc**
Translucent White	2.74 ± 1.52 **d**	10.00 ± 3.76 **bc**	12.74 ± 5.10 **cd**
Opaque White	1.85 ± 0.61 **cd**	4.55 ± 1.36 **c**	6.40 ± 1.79 **d**

[1]Means in the same column followed by the same letter are not significantly different, ANOVA and Tukey's HSD comparisons of means, α= 0.05.

(*F* = 2.02; df = 18, 107; *P* = 0.0142). These interactions were apparently due to low insect captures on 6 and 20 August, which led to a lack of significant model effects on 6 August for males. As patterns of capture on the remaining dates (5 September and 1 October) were almost identical to those for all dates combined, all data were pooled (Table 2).

Trap height. In 2001, captures of both males (3 September: *F* = 65.90; df = 4, 32; *P*<0.0001, 6 September: *F* = 54.01; df = 4, 32; *P*<0.0001) and females (3 September *F* = 121.62; df = 4, 32; *P*<0.0001, 6 September: *F* = 135.49; df = 4, 32; *P*<0.0001) were significantly higher on traps placed at either 30 cm or 50 cm height than at other heights, with more males than females being captured at 30 cm on 3 September (Table 3). Male and female captures at 10 cm trap height were low to intermediate and captures decreased with increasing trap heights above 50 cm. A significant date*treatment interaction for both males (*F* = 10.56; df = 4, 72; *P*<0.0001) and females (*F* = 7.00; df = 4, 72; *P*<0.0001) captured prevented the pooling of data from both experimental periods. On 3 September, precipitation likely reduced male and female captures at 50 cm relative to the more sheltered placement at 30 cm.

In 2002, male (*F* = 37.60; df = 6, 98; *P*<0.0001) captures were significantly higher on traps placed between 20 cm below and 20 cm above the crop canopy, than on traps at lower or higher positions (Table 4). Female (*F* = 32.80; df = 6, 104; *P*<0.0001) captures were significantly higher on traps placed below the crop canopy than on traps placed at or above the crop canopy. Total (*F* = 17.08; df = 6, 98; *P*<0.0001) captures were highest on traps placed at canopy height or below. There were significant date*treatment interactions for males (*F* = 8.59; df = 6, 98; *P*<0.0001) and total (*F* = 3.26; df = 6, 98; *P* = 0.0058) captured. These interactions were apparently due to low insect captures on 1 August, leading to lack of a significant treatment effect for males (*F* = 0.65; df = 4; 98; *P* = 0.6342). As patterns of capture on the remaining dates (14 August and 17 September) were almost identical to those for all dates combined, pooled data are presented here.

Discussion and Conclusions

The effect of colour on specific behaviours of insects is not well known, but it is generally accepted that attractive colours elicit more alighting by insects (Bernays and Chapman 1994). Adult pea leafminer, both male and female, are attracted to yellow and green sticky traps but not to white, blue, red and violet traps. Previous studies of other leafminers, as well as other dipterans, have shown an attraction for yellow and green, with yellow being the most common colour when sticky cards are used for monitoring (Chandler 1981; Affeldt et al. 1983; Harris and Miller 1983; Zoebisch and Schuster 1990; Jones and Schreiber 1994; Degen and Städler 1996). It is uncertain why so many insects respond strongly to yellow; however, these wavelengths are in the range of 560 to 580 nm and are not far from the peak sensitivity of an insect's green sensitive pigment (540 nm). The reflectance intensity of peak yellow wavelengths between 560 and 580 are also generally much higher than the peak wavelengths reflected by green pigments, and it has been hypothesized that yellow simply represents a 'supernormal', or more highly attractive version of green to certain insects (Bernays and Chapman 1994). In contrast, *Delia antiqua*, the onion fly, is more attracted to white painted surfaces than yellow cardboard in the field

TABLE 3. Effect of trap height on the number of male, female, and total adult pea leafminer, *Liriomyza huidobrensis*, captured on yellow sticky card traps in celery in 2001. The mean crop canopy height was 65 cm.

			Mean (± SE) Number of Pea Leafminer Adults Captured[1]		
Date	**Height above ground (cm)**	**n**	**Male**	**Female**	**Total**
3 September 2001	90	9	7.11 ± 1.36 **e**	3.78 ± 0.64 **d**	10.89 ± 1.58 **e**
	70	9	18.89 ± 1.30 **d**	9.44 ± 1.17 **c**	28.33 ± 1.94 **d**
	50	9	76.56 ± 7.71 **b**	57.22 ± 2.80 **a**	133.78 ± 8.30 **b**
	30	9	175.56 ± 24.45 **a**	88.44 ± 8.70 **a**	264.00 ± 32.50 **a**
	10	9	30.67 ± 8.79 **c**	27.89 ± 2.34 **b**	58.56 ± 9.49 **c**
6 September 2001	90	9	11.11 ± 1.47 **c**	9.78 ± 1.41 **c**	20.89 ± 2.24 **c**
	70	9	33.11 ± 2.93 **b**	31.56 ± 3.29 **b**	64.67 ± 5.25 **b**
	50	9	141.67 ± 16.30 **a**	115.67 ± 11.53 **a**	257.33 ± 21.86 **a**
	30	9	109.56 ± 15.65 **a**	108.78 ± 6.12 **a**	218.33 ± 17.34 **a**
	10	9	11.78 ± 2.68 **c**	37.22 ± 5.55 **b**	49.00 ± 7.75 **b**

[1]Means in the same column followed by the same letter are not significantly different, ANOVA and Tukey's HSD comparisons of means, $\alpha = 0.05$.

TABLE 4. Effect of trap placement relative to the celery canopy on the number of male, female, and total adult pea leafminer, *Liriomyza huidobrensis*, captured on yellow sticky card traps in 2002. Data for three dates combined (1 and 14 August, and 17 September 2002; mean crop height was 30, 50 and 70 cm, respectively).

		Mean (± SE) Number of Pea Leafminer Adults Captured[1]		
Position relative to crop height	n	Male	Female	Total
60 cm above	8	0.50 ± 0.27 **b**	0.12 ± 0.12 **d**	0.63 ± 0.26 **c**
40 cm above	16	0.81 ± 0.43 **b**	0.19 ± 0.14 **d**	1.00 ± 0.56 **c**
20 cm above	24	4.79 ± 1.29 **a**	2.83 ± 0.93 **c**	7.62 ± 2.11 **b**
At crop height	24	13.79 ± 3.69 **a**	6.59 ± 1.75 **b**	20.29 ± 5.25 **a**
20 cm below	24	11.76 ± 4.00 **a**	16.20 ± 3.86 **a**	27.96 ± 5.51 **a**
40 cm below	16	0.87 ± 0.31 **b**	13.47 ± 2.97 **a**	13.33 ± 2.95 **a**
60 cm below	8	0 ± 0 **b**	14.50 ± 3.79 **a**	14.50 ± 3.79 **a**

[1]Means in the same column followed by the same letter are not significantly different, ANOVA and Tukey's HSD comparisons of means, $\alpha = 0.05$.

(Vernon and Bartel 1985) and insects attacking the flowers of plants, such as *Frankliniella occidentalis*, are frequently attracted to blue sticky traps (Gillespie and Vernon 1990).

In 2002, captures of adult pea leafminers were numerically higher on traps that allowed for the transmission of light as opposed to opaque traps of the same colour. Translucent traps appear brighter than their opaque counterparts, due in part to the combined reflectance of yellow wavelengths from, and the transmission of yellow wavelengths through, the trap.

In the 2001 trap colour experiment, approximately twice as many males as females were captured, while more than three times as many females as males were trapped in 2002. This result is likely due to the placement of traps within the canopy (top in 2001 and middle in 2002) rather than a reflection of the sex ratio present in the field. In 2001, the sex ratios of the trap height (1 : 0.43 males to females) and colour (1 : 0.80) experiments were more similar than in 2002, when the sex ratio in the colour experiment (1 : 4.15) was more strongly biased towards females than height experiment (1 : 1.18) for three similar dates. Even though sex ratios of adults emerging from colony-reared pupae indicate a 1:1 sex ratio (Parrella 1987), Jones and Parrella (1986) captured 83.5% males and 16.5% females in a greenhouse when traps were placed 0.3 m above the canopy. In potatoes, about twice as many females as males were caught on sticky traps 10 cm above the ground, but relatively equal sex ratios were found at heights up to 70 cm, which was 20 cm above the crop canopy (Weintraub and Horowitz 1996).

In the trap height experiments, captures of female pea leafminers were highest when traps were positioned within the celery canopy. Male pea leafminers were most frequently captured on traps that were located within 20 cm above or below the top of the canopy despite the mean height of the crop changing over 40 cm throughout the duration of the experiment. In contrast, captures of male *Liriomyza* spp. were highest in the middle and lower portions of a tomato canopy in a study by Zehnder and Trumble (1984), which may be related to canopy architecture. Increased captures of pea leafminer males in the upper portion of the celery canopy may be explained by high flight activity as they actively search for food and mates, while females spend more time on leaves for oviposition. This interpretation is supported by the finding that significantly more pea leafminer larvae were found in cucumber leaves within the lower canopy than at higher positions on the plant (Abou-Fakhr Hammad and Nemer 2000). Our findings suggest that trap height studies should be designed, and recommendations expressed, in relation to the height of the crop canopy rather than height above the ground to more accurately reflect insect behaviour.

Combined captures of male and female pea leafminer adults were highest in the middle portion of the celery canopy. These results correspond with other studies on the spatial distribution of *Liriomyza* within plants when sex is not considered. In potato, more pea leafminer were captured at or just below crop height than closer to the ground (Weintraub and Horowitz 1996). More *L. trifolii* and *L. sativae* adults were captured by placing cards at low to middle canopy heights in tomatoes and peppers (Zehnder and Trumble 1984; Chandler 1985; Zoebisch and Schuster 1990), possibly indicating host-dependent spatial distributions. There are several reasons for high captures of adult *Liriomyza* in the middle of the crop canopy. Adult longevity is prolonged at cooler temperatures (Parrella 1987), and due to an absence of direct sunlight, temperatures are cooler within the crop canopy than above it. Maximum daily air temperatures at the time of the experiment in 2001 were 27°C with temperatures frequently rising above 30°C in 2002. Female fecundity of *L. trifolii* is greatly reduced as temperatures approach 35°C, with maximum fecundity at 30°C (Leibee 1984). Female pea leafminers may remain within the crop canopy in order to maximize their fitness. Larvae developing lower within the canopy may also be protected from temperature extremes and parasitoids by the dense foliage.

In the Holland Marsh region of Ontario, pea leafminer populations remain low through July and August but rapidly reach economically damaging levels from early September to October (Martin et al. 2005). Adult pea leafminer have a high attraction to sticky cards that reflect through the yellow portion of the spectrum, as opposed to blue. Translucent yellow sticky cards placed 20 cm below the top of the crop canopy are most efficient at capturing both male and female adult pea leafminer in celery. Although sticky trap captures cannot as yet be used to adequately time chemical sprays to target larvae, they can be used as an indicator of pea leafminer presence and movement of adults throughout a field (Zehnder and Trumble 1984; Heinz and Chaney 1995). In addition, a rapid increase in adults on sticky traps can be used to herald the need for more extensive larval monitoring within the crop.

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