Coleomegilla maculata, *Coccinella septempunctata* (Coleoptera: Coccinellidae), *Chrysoperla carnea* (Neuroptera: Chrysopidae), and *Macrocentrus grandii* (Hymenoptera: Braconidae) Trapped on Colored Sticky Traps in Corn Habitats

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ABSTRACT Behavioral responses of 4 species of natural enemies to 4 colors were examined by capturing adults on colored sticky cards placed at 2 locations (edge and interior) in corn, *Zea mays* L., fields. Cards were placed at 2 heights (1.8 and 0.3 m) in 1993 and in 2 habitats (sweet and field corn) in 1994, using a split-split plot design. Natural enemies studied included the coccinellids *Coleomegilla maculata* (DeGeer) and *Coccinella septempunctata* L., the chrysopid *Chrysoperla carnea* (Stephens), and *Macrocentrus grandii* Goidanich, a braconid larval parasitoid of *Ostrinia nubilalis* (Hübner). Compared with red, green, and white cards, yellow cards trapped greater numbers of all natural enemies, except *C. carnea,* which was trapped equally on cards of all 4 colors. Few significant interactions were observed between the effects of color and those of location and height or habitat, which are perhaps indicative of microhabitat preferences. Captures on cards provided information on abundance of each natural enemy species during different periods in the summer. It also revealed the pattern of adult flights of *M. grandii,* which is useful for determining whether its life cycle is synchronized with that of its host. The study suggests that, besides studying behavioral responses, color cards may be useful for monitoring natural enemy populations.

KEY WORDS *Coleomegilla maculata*, *Coccinella septempunctata*, *Chrysoperla carnea*, *Macrocentrus grandii*, color stimuli, natural enemies

ENTOMOPHAGOUS INSECTS RESPOND to diverse cues as they seek shelter, food, oviposition sites, or mates. Signals may emanate from conspecifics or from other biotic or abiotic sources in the environment in which the natural enemy is located. Various stimuli and diverse sensory modalities may be used by predators and parasitoids during different stages of resource location (Prokopy 1986). The influence of chemical stimuli in elicitation of forage and reproductive behaviors of natural enemies is well recognized, but visual cues, which are likely to be important for diurnal natural enemies, have received less attention.

Compound eyes of insects possess specialized receptors that detect color (wavelength of light reflected or transmitted), patterns, contrast, and movement (Allan et al. 1987). If color stimuli from biotic or abiotic elements in the surroundings elicit responses in natural enemies, it may be possible to exploit these responses in biological control programs. Examination of the patterns of responses of natural enemies to color stimuli under field conditions will help monitor populations and better understand their habitat-location, host-searching, and dispersal behaviors (Weseloh 1972). Color stimuli may be useful for manipulating natural enemy behaviors in ways that would improve their efficacy and performance thus leading to greater reductions in population levels of pest species.

The current study was conducted to determine responses of selected natural enemies to color by trapping on sticky cards placed in corn, *Zea mays* L., habitats. We were interested in determining whether color traps had potential for use for monitoring natural enemy populations through the growing season of corn and for determining microhabitat preferences, if any, of each species. The study was limited to 4 natural enemy species that are frequently encountered in corn (Mason et al. 1996). Predators included in the study were the aphidophagous *Coleomegilla maculata* (DeGeer) and *Coccinella septempunctata* L., and the green lacewing *Chrysoperla carnea* (Stephens), which in

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the larval stages is a predator of a wide variety of small insects and eggs (Hoffman and Frodsham 1993). We were interested in trapping the parasitoid *Macrocentrus grandii* Goidanich, which is an introduced larval parasitoid that was mass-released in Delaware between 1941 and 1946 (MacCreary and Rice 1949) for biological control of the European corn borer, *Ostrinia nubilalis* (Hübner). There is renewed interest in *M. grandii* as a biological control agent for control of *O. nubilalis* (Sreenivasam et al. 1991) and it has been the focus of several behavioral studies (Swedenborg and Jones 1992; Udayagiri and Jones 1992, 1993).

Materials and Methods

The study was conducted at the Agricultural Experiment Station Farm of the University of Delaware at Newark, in 1993 and 1994. Sticky traps were prepared by application of Tanglefoot (Grand Rapids, MI) to colored polyethylene cards that were obtained from Great Lakes IPM (Vestaburg, MI). Colors were obtained from Benjamin Moore (Montvale, NJ), and included green (custom mix color), red (safety red 07121), yellow (canary yellow 133-12), and white (safety white 07108). A Chroma-Meter (Model CR-221, Minolta, Ramsey, NJ) that measures color (hue) on a scale ranging from 0 (black) to 100 (white) was used to measure the color on each card. Chroma-Meter measurements of cards used in the study were 5.95 ± 0.06 for green, 9.33 ± 0.07 for red, 78.18 ± 0.38 for yellow, and 90.05 ± 0.55 for the white cards.

In 1993, the experiment was conducted in 2 field corn ('Agway 797') plots that were >0.5 ha. Tanglefoot was applied to 1 side (10 by 15 cm) of cards that were set up in the 2nd wk of July and replaced on a fortnightly basis until the 3rd wk of August when the experiment had to be discontinued because the corn was harvested. Color cards were placed at 2 locations: at the edge (between the outermost 2 rows at the edge of the field) and in the interior (at least 25 m away from the edge). At each location, cards of the 4 colors were placed randomly at least 25 m apart between corn rows. Initially, the cards were attached to 30 cm stakes but, after 2 wk, the cards were attached to bamboo poles at 2 heights: 0.3 and 1.8 m above the ground. The experiment was set up as a split-split plot design with 8 replicates. Each replicate consisted of 1 card of each of the 4 colors randomly distributed and placed at each of the 2 locations and heights. Sticky cards were monitored every week; at the end of a 2-wk period, the cards were removed, covered with clear polyethylene sheets, and brought to the laboratory. Each card was examined carefully and the number of adults belonging to each of the 4 natural enemy species was recorded. Voucher specimens of each natural enemy species have been placed in the Insect Museum, University of Delaware.

The study was repeated in 1994 in field corn (Agway 797) and sweet corn ('Silver Queen') plots using larger cards, which, when folded in half, represented double-sided 14 by 23-cm cards. Instead of using bamboo poles, which tended to fall during major storms in 1993, the cards were folded around corn stems and secured with staples effectively allowing both sides for insect captures. The experiment was set up at 2 sites (1 field corn and 1 sweet corn habitat). As before, sticky cards of the 4 colors were set up at each of 2 locations (edge and interior) using a split-split plot design. All sticky cards were placed at a height of 1.2 m above the ground. The cards were set up in the 1st wk of June and replaced on a weekly basis for 12 wk until the end of August. The duration of the experiment was increased in 1994 to cover the entire growing season of corn.

Statistical Analysis. An analysis of variance was performed for the split-split plot experiments conducted in 1993 and 1994. In 1993, location (edge or interior) was the main plot factor, while color (red, yellow, green or white) was the split plot factor and height (1.8 or 0.3 m) was the split-split plot factor. In 1994, habitat (sweet or field corn) was the main factor, location was the split plot factor, and color was the split-split plot factor. The variable analyzed was the total number of adults of each of the 4 natural enemy species. Because there were 3 response variables evaluated each year, caution was used for interpreting P values that were close to 0.05. Profile plots were examined for detecting patterns when interactions between factors were found to be significant. The Ryan multiple-range test was used to separate the means for the main effect of color whenever the F test was significant at an α level of 0.05. Computations were performed using the general linear model (GLM) procedure of SAS (SAS Institute 1989).

Results

Sticky cards captured adult *C. maculata, C. carnea,* and *M. grandii* in 1993 and in 1994, but *C. septempunctata* was captured in 1994 alone. Captures of each natural enemy species were not uniform and appeared to be affected by certain factors and interactions between them.

Of the 4 factors examined, trap color had the greatest impact on natural enemy captures. The effect of color was significant in both years for *C. maculata* (1993: $F = 6.95$; df = 3, 42; $P = 0.0007$; 1994: $F = 41.5$; df = 3, 12; $P < 0.0001$) and for *M. grandii* (1993: $F = 13.4$; df = 3, 42; $P < 0.0001$; 1994: $F = 8.59$; df = 3, 12; $P = 0.0026$) (Fig. 1 A and B). It was also significant for *C. septempunctata* in 1994 ($F = 81.19$; df = 3, 12; $P < 0.0001$) (Fig. 1B). For these 3 species, yellow cards captured more adults than cards of the other 3 colors (Ryan multiple-range test, $P < 0.05$). Although *C. carnea* was captured in both years, no significant differences were observed in the numbers cap-

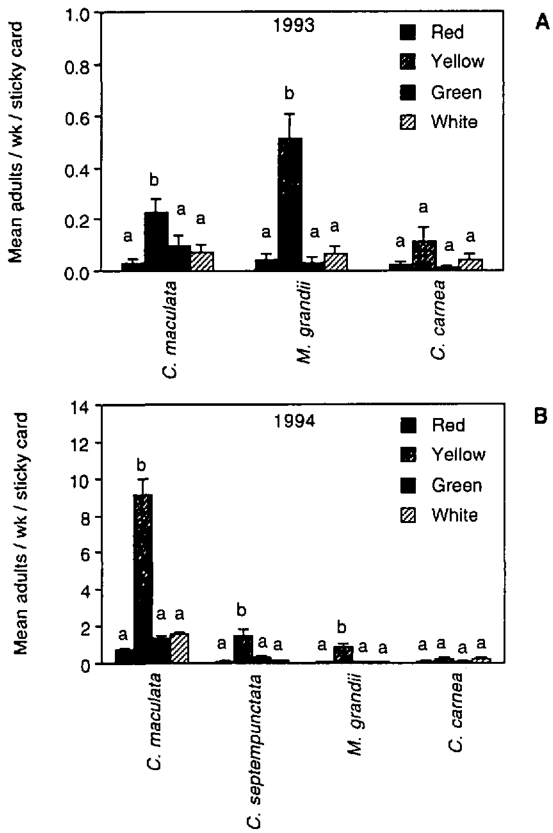

Fig. 1. Effect of color on mean ± SE captures of *C. maculata*, *C. septempunctata*, *C. carnea*, and *M. grandii* on sticky cards. (A) 1993 (n = 32). (B) 1994 (n = 8). Within a natural enemy species, bars with different letters are significantly different (Ryan multiple-range test, P < 0.05).

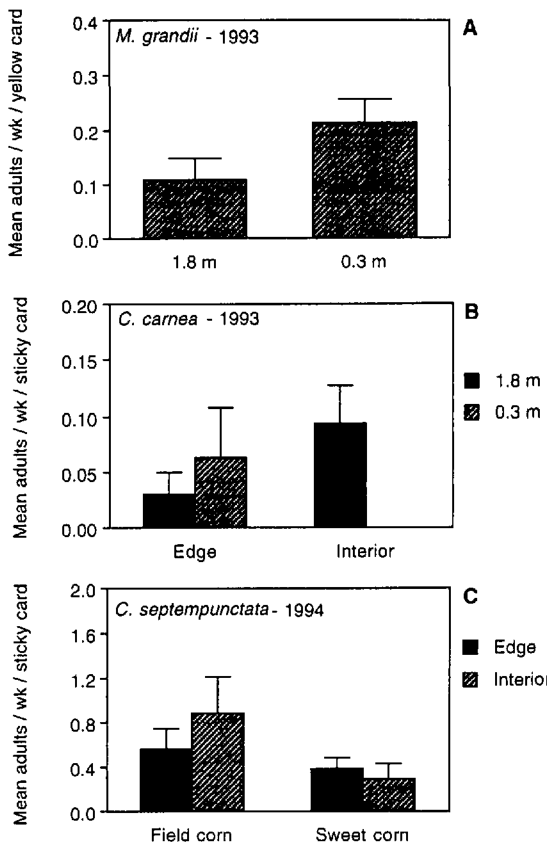

Fig. 2. Influence of interactive effects on mean ± SE captures of natural enemies on sticky cards. (A) *M. grandii* captures on yellow cards at 2 heights in 1993 (n = 16). (B) *C. carnea* captures on sticky cards of all colors at 2 locations and 2 heights in 1993 (n = 32) (the value for interior, 0.3 m, was 0). (C) *C. septempunctata* captures on sticky cards of all colors at 2 locations in 2 habitats in 1994 (n = 8).

tured on cards of all 4 colors in 1993 (F = 2.29; df = 3, 42; P = 0.09) (Fig. 1A). In 1994 the effect of color was marginally significant (F = 3.88; df = 3, 12; P = 0.0376), but few adults were captured and differences in captures on cards of the 4 colors were not significant (Ryan multiple-range test, P > 0.05) (Fig. 1B).

Significant interactions between color and the other 3 factors were observed occasionally. An interaction between height and color was observed for *M. grandii* in 1993 (F = 11.28; df = 3, 56; P < 0.0001). Yellow cards placed at 0.3 m captured more adults than cards placed at 1.8 m (Fig. 2A). In 1993 the 3-way interaction among location, color, and height was marginally significant for *C. carnea* (F = 2.95; df = 3, 56; P = 0.04). Numbers were low but, for all colors, although sticky cards placed at the edge captured more adults at 0.3 m than at 1.8 m, in the interior of the fields, *C. carnea* was captured only at 1.8 m (Fig. 2B). In 1994, the 3-way interaction among habitat, location, and color was significant for *C. septempunctata* (F = 5.52; df = 6, 12; P = 0.006). In field corn habitats, sticky cards placed in the interior captured more adults than cards placed at the edge of the field but in sweet corn the pattern was reversed (Fig. 2C). In 1994, the 2-way interaction between color and location was significant for *C. carnea* (F = 5.21; df = 3, 12; P = 0.016) but profile plots indicated no clear patterns in the interactions.

Location of the sticky cards influenced the number of *C. maculata* captured in 1993 (F = 9.91; df = 1, 7; P = 0.016) (Fig. 3). Cards placed in the interior captured more adults than cards placed at the edge of the fields. However, in 1994, the effect of location was not significant for *C. maculata* (F = 0.98; df = 1, 2; P = 0.43).

Height at which sticky cards were placed did not have an impact on natural enemy captures except in the interactions listed earlier. Similarly habitat alone was not a significant factor influencing natural enemy captures. Greater numbers of *C. maculata* and *C. septempunctata* were trapped in field corn, whereas *C. carnea* captures were higher in sweet corn habitats but the differences were not statistically significant.

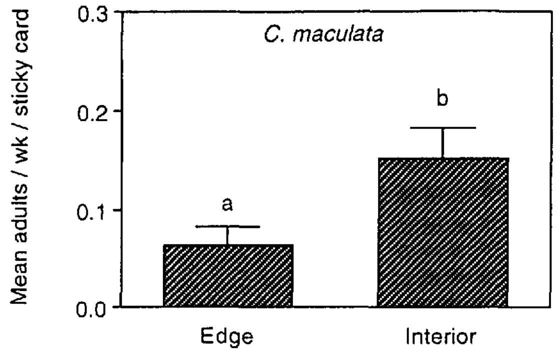

Fig. 3. Effect of location on mean ± SE captures of *C. maculata* on sticky cards of all colors in 1993 (n = 64). Bars with different letters are significantly different ($P < 0.05$).

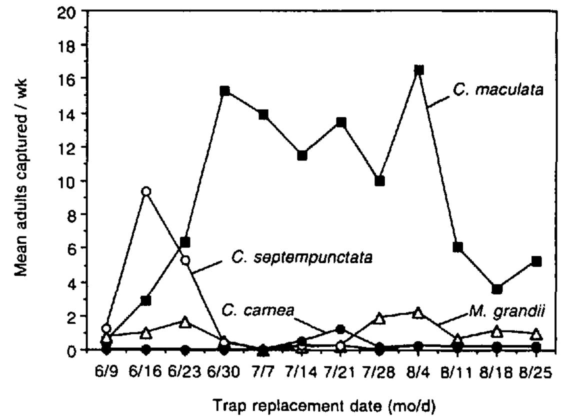

Fig. 4. Mean number of adult *C. maculata* (—■—), *C. septempunctata* (—○—), *C. carnea* (—●—), and *M. grandii* (—△—) trapped on yellow sticky cards weekly through the growing season of corn in 1994.

Captures of each of the 4 natural enemy species varied through the growing season of corn (Fig. 4). *C. septempunctata* numbers were highest at the beginning of the growing season but after June its numbers declined. The number of *C. carnea* captured on yellow cards was low and occurred primarily in July. Adult *M. grandii* populations appeared to peak twice through the growing season, once in the middle of June and again toward the end of July and the beginning of August. Overall, *C. maculata* was the most abundant natural enemy captured on the sticky traps and it was present in corn fields through the growing season.

Discussion

Sticky cards placed in corn habitats provided a simple mechanism for determining responses of 4 natural enemy species to color stimuli. In our study, of the 4 colors tested, yellow cards trapped the greatest numbers of 2 predatory and 1 parasitoid species (Fig. 1). Although it was not unexpected, there were strong positive responses of *C. maculata* and of *M. grandii* to yellow. Yellow is known to be attractive to insects and its positive effects on other natural enemy species have been documented by Weseloh (1972, 1986), Dowell and Cherry (1981), Neuenschwander (1982), Ridgway and Mahr (1986), Vargas et al. (1991), and Maredia et al. (1992b). Studies with phytophagous insects suggest that yellow constitutes a super-normal foliage-type stimulus for foliage feeding insects (Prokopy and Owens 1983). Yellow could have a similar effect on parasitoids and predators of insects that frequent foliage and it may constitute an important stimulus for habitat-location behavior in several natural enemy species.

Yellow sticky cards were, however, not effective for drawing significantly greater numbers of adult *C. carnea* compared with cards of the other 3 colors. These results are in agreement with observations by Capinera and Walmsley (1978) and Maredia et al. (1992b) on *C. carnea* captures in sugar beet, *Beta vulgaris* L., and alfalfa, *Medicago sativa* L., habitats, respectively. Cues other than those of color may be critical for elicitation of habitat-location and other behaviors in *C. carnea* adults.

Yellow cards provided a simple means of monitoring the population of each natural enemy species. Our study indicated that *C. maculata* was present in corn fields through the growing season (Fig. 4). Numbers of adults increased considerably toward the end of June and remained high until the beginning of August. In 1994, up to 45 adults were captured in a week on a single card. However, *C. septempunctata* was captured primarily during June, and the maximum number of *C. septempunctata* caught in a week was 25. In a study by Maredia et al. (1992b) conducted in alfalfa fields in Michigan, the maximum number caught on an individual trap in a fortnight was 16. Movement of adult *C. septempunctata* to other habitats later in the season was also observed by Maredia et al. (1992a). In 1993, our experiment was commenced in the 2nd wk of July and this could account for the absence of any *C. septempunctata* trapped on the cards.

Differences in the densities of the 2 species of coccinellids may be a reflection of differences in feeding patterns. Both species are aphidophagous predators (Gordon 1985), but *C. maculata* also feeds extensively on pollen, which can constitute up to 50% of its diet (Hoffman and Frodsham 1993). High densities of *C. maculata* have been observed in sweet corn habitats during pollen production (Groden et al. 1990, Coll and Bottrell 1991). When corn pollen is not present, *C. maculata* is an important predator of *O. nubilalis* egg masses (Andow 1990, Zheng 1993). The presence of either pollen or *O. nubilalis* egg masses at different periods may be responsible for retaining *C. maculata* in corn habitats through the summer in Delaware. High captures on yellow cards compared with other colored cards could be caused by its attraction to plant pollen or to corn leaves containing egg masses of *O. nubilalis*.

Information on stimulatory cues for parasitoids is needed for development of effective monitoring systems. Parasitoids like *M. grandii* are known to be attracted to habitat-related odors (Udayagiri and Jones 1992, 1993), but visual cues may also be involved in habitat and host location in this species. Attraction of *M. grandii* to yellow may be caused by the presence of its host in foliage or within stems of corn plants. *M. grandii* is a larval parasitoid of *O. nubilalis*, and captures of adult parasitoids on sticky cards provided information on adult flight peaks that can be used to estimate the number of generations per year (McClain et al. 1990), and to determine whether adult flights coincide with availability of larval hosts. Existing population estimates of *M. grandii* in Delaware are based on records of parasitoid emergence from overwintering host larvae collected in the fall (Mason et al. 1994), and tactics are required for determining periods of adult emergence in the summer for correlation with seasonal occurrence of larval stages of *O. nubilalis*. Weekly trap catches in 1994 indicated that flight peaks for *M. grandii* occurred twice during the summer demonstrating that it undergoes 2 generations in Delaware (Fig. 4). A study by Peng (1994) on *O. nubilalis* captures in pheromone traps in the same region indicated that it also has 2 generations and that its larval stages coincide with periods when *M. grandii* adults were captured on sticky cards in our study. Thus, yellow sticky cards provided evidence that the life cycle of *M. grandii* was synchronized with that of its host in Delaware.

Placement of cards may be critical for capturing natural enemies and hence, in the current study, cards were placed at 2 locations and at 2 heights. Within a habitat, natural enemies are expected to be found in areas where their prey or hosts are likely to be present, but they may also be attracted to other regions that provide shelter from biotic and abiotic elements. In our study, greater numbers of *M. grandii* were captured on yellow cards placed at 0.3 m compared with cards placed 1.8 m above the ground (Fig. 2A), although *O. nubilalis* larvae are present all along a corn plant. In 1993, there were more captures of *C. maculata* in the interior than at the edge but the same pattern was not observed the following year. However, in 1993 the experiment was limited to the end of July and early August when temperatures were high, and perhaps during this period, *C. maculata* prefers the interior of the habitat. *C. carnea* captures in the interior were limited to cards placed 1.8 m above the ground (Fig. 2B). It is a predator in the larval stage only, and captures of adults on cards may have been limited to those occurring during flight. Variation in captures of natural enemies at different heights and locations is perhaps an indication of their microhabitat preferences and reveals areas within a habitat where color cards should be placed for attraction of specific natural enemies to hosts or prey that may be present in these regions.

In conclusion, responses of natural enemies to color stimuli have potential for exploitation in biological control programs. Yellow cards provide a simple means of monitoring populations of natural enemies like *C. maculata, C. septempunctata,* and *M. grandii*; this can be used for estimating population sizes and for timing insecticide sprays so as to maximize pest control but minimize natural enemy mortality. It can also be used for studying various aspects of the biology of natural enemies, such as determining emergence or dispersal patterns, locating overwintering sites, or evaluating parasitoid–host synchronization (Udayagiri 1996). It is possible that yellow cards could also be employed for orienting natural enemies to hosts or prey during rearing operations or for drawing them to particular habitats or specific locations within a habitat where their hosts or prey are located; this application needs investigation. The potential disadvantage would be inadvertent attraction of certain pest species that may also be attracted to yellow. However, if a pest species and its natural enemy are attracted to the same color, it will be possible to simultaneously estimate densities of both species for timing releases of the natural enemies (Vargas et al. 1991). Additionally, the benefits from attraction of natural enemies may be greater than the negative impact of attracting a few pest species, but this needs to be tested. In a mass-trapping experiment by Neuenschwander (1982), the overall ratio of parasitoids and predators to the pest species trapped on yellow cards was 16:1.

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