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Evaluation of color traps for *Lygus* spp.: Design, placement, height, time of day, and non-target effects

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Abstract

Lygus hesperus and *L. lineolaris* are two of the most economically important plant bugs in North America. Here we present results from field trials that evaluated effective trap characteristics for maximizing *Lygus* spp. and other herbivorous insects capture, while minimizing beneficial insect capture. The response of lygus bugs, several other key herbivore species and predators to hue (white, clear, black, yellow, orange, blue, purple, green and red) and value (black, white and two neutral grays) was examined in alfalfa over three seasons using traps coated with Pestick adhesive. *Lygus* spp. exhibited a broad response to trap hue, but showed no response to trap value or intensity. Additionally, we showed that time of day, trap height, and trap placement influenced the number of *Lygus* spp. captured. More *Lygus* spp. were trapped from late afternoon to dusk compared to all other times of the day, and more males than females were captured on sticky traps even though the sexes were at parity in field sweep net samples. In the alfalfa setting, male lygus were more likely to be captured on traps placed 20 cm above the ground; traps placed 50 and 100 cm above the ground caught similar numbers of males and females. The highest number of plant bugs was captured when traps were placed in a cleared area between two alfalfa fields; lower numbers were captured on traps at the edge and in the center of the field. All other herbivores exhibited distinct preferences to trap hue and in some cases, trap value or intensity. Predators were rarely trapped, but did exhibit preferences to trap color (i.e., hue and value) characteristics. The potential of using sticky traps with specific hue and value characteristics to effectively monitor *Lygus* spp. is discussed.

Key words: Western tarnished plant bug; Visual cues; Alfalfa; Sticky traps; Natural enemies; Spectroradiometer

1. Introduction

In the southwestern United States, the western tarnished plant bug, *Lygus hesperus* Knight, is considered to be a serious pest. In Arizona, it is currently ranked as the most important pest in cotton (Ellsworth and Barkley, 2000). Before the widespread use of *Bt* (*Bacillus thuringiensis*) cotton, this insect occasionally caused significant damage, but with increasing *Bt* cotton acreage there have been fewer applications of broad-spectrum insecticides, which previously helped suppress populations of *L. hesperus*. Although conventional pesticides are still effective in controlling this pest, repeated use often leads to resistance problems and disruption of the natural enemy complex. Environmentally sound control options are limited and a long search for the sex pheromone of this species, and the closely related *Lygus lineolaris* (Palisot de Beauvois), has proven disappointing as field trials failed to attract males in adequate numbers (Gueldner and Parrott, 1978; Hedin et al., 1985; Aldrich et al., 1988; McLaughlin, 1998; Ho and Millar, 2002).

We have taken a complimentary approach that involves identifying pertinent host-plant cues that might be used for monitoring and/or mass trapping *Lygus* spp. Detection of host plants by phytophagous insects often involves visual recognition.

This recognition may include responses to color, size, shape or silhouettes (Prokopy and Owens, 1983). Color is three dimensional and is defined by its hue (dominant wavelength emitted), value (=intensity, is the total amount of light reflected over a range of wavelengths), and chroma (spectral purity of the reflected light).

In designing a trap for monitoring or mass trapping insect pests, it is often important that these visual variables be considered. Traps based on color characteristics have been used extensively in the field and greenhouse for a variety of pests (Moffitt, 1964; Kirk, 1984; Brødsgaard, 1989; Gillespie and Vernon, 1990; Matteson and Terry, 1992; Teulon et al., 1999; Blackmer et al., 2004a, 2006; Demirel and Cranshaw, 2006). The advantages of traps that employ visual cues are that their presence is instantaneously established, they function independent of air movement, and they are generally effective from a distance and from any direction, providing there are no obstacles between the trap and insect (Miller and Strickler, 1984).

Previous studies with plant bugs have demonstrated attraction to various colors, but the response appears to be species specific and in some cases, habitat dependent. Landis and Fox (1972) examined the response of *L. hesperus* and *Lygus elisus* Van Duzee to colored water-pan traps and found that significantly more *Lygus* spp. were trapped in light-orange yellow and deep-chrome-yellow pans than in green, red or pink water traps. For *L. lineolaris*, Prokopy et al. (1979) found that non-UV reflecting gloss white, Zinc (Zn) white, Zoecon yellow and clear Plexiglas rectangles captured equivalent numbers of adults, but significantly greater numbers than other hues of yellow, green, orange, blue, red, aluminum foil, black and Lead (Pb)-white rectangles. In peach orchards, Legrand and Los (2003) found that *L. lineolaris* was captured in higher numbers on pink sticky traps than on white traps. The pink trap closely mimicked the color of peach flower petals; however, most insects were trapped after peach petals were gone. Clearly, there is a lot of variation in response in the group and each monitoring scheme may require independent verification of trap design and color.

A few studies have examined the effect of trap design (Prokopy et al., 1979; Villavaso, 2004), height (Prokopy et al., 1979; Boivin and Stewart, 1984; Rancourt et al., 2000), placement (Boivin et al., 1982), time of day (Rancourt et al., 2000), and time of year (Boivin et al., 1982) for *L. lineolaris*. None of these parameters have been examined with sticky traps for *L. hesperus*. Landis and Fox (1972) examined the late autumn and early spring movement of *L. hesperus* using a yellow mechanical trap, and Butler (1972) examined their movement relative to time of day using a truck mounted net. Knowledge of how these various trap characteristics impact lygus bug capture will enhance our ability to monitor and/or mass trap these important economic pests.

Here we examined the response of *L. hesperus* and *L. lineolaris* to visual cues (trap hue and value) in alfalfa, *Medicago sativa* L. (cv Mecca II). Concurrently, we monitored the response of additional key herbivores and predators. By examining the pest and beneficial complex in alfalfa, we hope to identify trap characteristics that will be selective. We also present results on the effect of time of day, trap height, trap placement and daily vs. weekly collection intervals on *Lygus* spp. capture.

2. Materials and methods

2.1. Trap design

Trap material for studies on response to hue was purchased from GE polymershapes, Phoenix, AZ. Trap colors were white, yellow, orange, red, blue, purple, green, clear and black, and all colors were translucent (reflectance spectra; red, green, blue [RGB] and hue, saturation and luminosity [HSL] values of these colors are provided below). They were fabricated from 0.02-mm thick rigid vinyl plastic sheeting and were cut into 60 x 30 cm rectangles. One additional color, opaque yellow, was cut from high-density plastic sheeting (Cat. No. 01-4000-1; Hummert International, Earth City, MO). This is a standard yellow sticky trap color used in greenhouse monitoring of whiteflies and aphids (Muirhead-Thomson, 1991). For all colors, a 1-cm diameter hole was punched into each of the four corners of the 60 x 30 cm rectangles using a Rotex punch press (Rotex Punch Co, Inc., San Leandro, CA). Traps were then hand rolled on one side with a thick coating of Pestick adhesive (Hummert International, Earth City, MO).

To hang traps, lath screws (8 x 1) with 1-cm diameter heads were screwed into wooden laths (120 cm tall). The top screw was placed 11 cm from the top of the lath and the bottom screw was placed 25 cm below the top screw. The lath was then pounded into the ground and a sticky trap was placed onto the screws and wrapped around the lath to form an 18-cm diameter cylinder, where the bottom and top of the cylinder were ~ 50 and 80 cm above the ground, respectively. At this height, the trap bottoms were always at or slightly above canopy height in alfalfa. In all trials, traps were placed 10 m apart.

Traps for studies on value (or intensity) used 0.03-mm thick Kydex thermoplastic sheeting (Kleerdex Co., Reno, NV). Trap values were determined by matching trap color to the Liquitex value finder, which is based on Munsell value standards (Anonymous, 2001). Trap colors were polar white (#62000) with a value of 9, pewter gray (#52001) with a value of 6, dark gray (#52002) with a value of 4, and black (#52114) with a value of 1. Plastic sheeting was cut into 60 x 30 cm rectangles and treated as described above.

2.2. Measurement of color attributes

Reflected light and RGB values of the colored traps (with and without Pestick) used in these experiments were measured in the field between 1030 and 1200 h under sunny conditions (~100,000 lux) on 31 October 2005. Reflectance spectra were measured by a USB2000 spectroradiometer using OOIBase32 version 2.0.2.2 software (Ocean Optics Inc., Dunedin, FL). A solarization-resistant, UV transparent, optical fiber (400 µm) probe with an adjustable collimating lens was held perpendicular to the trap surface to capture the spectral reflection. Reflectance intensity readings from the near UV through the visible wavelengths (300-850 nm) were automatically scanned using an integration time of 4 ms. Spectroradiometers are commonly used to record the wavelengths in a spectrum of light reflected from an object. However, there are some drawbacks to their use (Byers, 2006a). An inexpensive and readily available alternate method that can be used to describe organisms objectively and quantitatively involves the use of a digital camera where pixels make up the images, and the pixels are colored based on an RGB system. Each pixel combines the three components in ranges from 0 to 255 in intensity. Any shade or color can be reproduced reliably with the RGB system, which is the most common color system used by computers. To determine the RGB values, the sticky-coated traps were photographed in the field using a Nikon Coolpix 2100 digital camera at the macro setting and at 1,600 by 1,200 pixel resolution. The resulting JPEG images were analyzed for color with the software described in Byers (2006a). RGB values were also converted to HSL values with internet software.

2.3. Visual preferences of Lygus spp.*, key phytophages and predators relative to hue and value*

Field trials were conducted between 2004 and 2006 in commercial alfalfa fields located on the University of Arizona, Maricopa Agricultural Center in Maricopa, AZ. Prior to all trials, four sets of 25 sweeps using a 38-cm diameter by 84-cm heavy duty sweep net (7212CM BioQuip Products, Inc., Gardena, CA) were made to determine species composition, density and sex ratios of resident *Lygus* spp. Females from the sweeps were dissected to determine reproductive status by counting number of mature eggs, and mating status by counting number of spermatophores in the seminal depository (Blackmer et al., 2004b; Villavaso, 2006)

In the autumn of 2004, on 28 September and 4 October, the preferences of *Lygus* spp., and other key herbivores and predators to hue (white, clear, black, yellow, orange, blue, purple, green and red) were examined using a randomized complete block design (RCB; N=4). Traps were left in the field for 24 h and then returned to the laboratory where lygus bugs were identified, counted, and sex determined. Other key phytophagous insects that are sometimes damaging: *Colias* spp. (Lepidoptera: Pieridae), *Conotelus mexicanus* Murray (Coleoptera: Nitidulidae), *Spissistilus festinus* (Say) (Homoptera: Membracidae, *Bemisia tabaci* (Gennadius) (Homoptera: Aleyrodidae), and *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae), as well as key predators: *Hippodamia* spp., (Coleoptera: Coccinellidae) and *Chrysoperla carnea* (Stephans) (Neuroptera: Chrysopidae) were counted and identified to species when possible. Because numbers were exceptionally high for *B. tabaci* and *F. occidentalis*, we estimated their numbers by counting the number found on three randomly selected, 4-cm^2 sections of each trap. These values were averaged and then multiplied by 112.5 to arrive at the total per trap.

In the spring and summer of 2005, the same colors plus opaque yellow (in August only) were tested. Traps were left up for 1 (24 May), 7 or 14 days (12-25 August) depending on the experiment. In all trials, *Lygus* spp. and *Colias* spp. were counted and removed from the traps daily; *Colias* spp. quickly obscured the surface of the trap if left in place. *Lygus* spp., phytophagous insects and predators were recorded at the end of the trapping period. Additionally, from 11-18 August in 2005, we conducted separate trials to examine insect response to trap value or intensity using black, white and two neutral grays as described above (RBC; N=4). *Colias* spp. were counted and removed daily and the remaining phytophagous and predatory insects were counted at the end of the trial.

2.4. Effect of time of day

Time of day effect on number of *Lygus* spp. captured was determined using sticky traps placed on 120-cm tall laths (RCB; N = 4). Traps were monitored over two 24-h periods beginning at 0900 h on 29 September and 5 October 2004. Counts were made at time intervals representing early morning (0700-1100 h – sunrise at 0625 h), midday (1100-1500 h), dusk (1500-1900 h – sunset at 1810 h), and overnight (1900-0700 h).

2.5. Effect of trap placement

To determine whether trap placement influenced trap catch, clear sticky traps were placed on 120-cm laths along the outside edge of an 8 ha alfalfa field, in the center of the field, or in a cleared buffer zone (2 m wide) between two 8 ha alfalfa fields. Eight traps were placed at each location and at the end of five days (22-27 June 2006) traps were covered with wax paper and returned to the laboratory where *Lygus* spp. were identified, counted and sex determined.

2.6. Trap height effect

Trap height effect was examined over a five-day period (25-30 July 2006) using wooden stakes that were 90-, 120-, and 180-cm tall (RCB; N = 6 for each trap height). The trap bottoms were located ~ 20, 50, and 100 cm above the ground, which corresponded to below canopy level, at canopy level, and above canopy level in alfalfa. Clear traps were used for this study and were placed in a buffer area (2 m wide), consisting of bare ground, between two 8 ha alfalfa fields. One field was flowering and the other field was in a vegetative state. After five days, traps were covered with wax paper and returned to the laboratory for processing. *Lygus* spp. from the traps and sweeps were identified, counted, and sex determined.

2.7. Effect of daily vs. weekly collections

Trapped *Lygus* spp. could potentially release defensive chemicals as well as sex, aggregation, or alarm pheromones and these compounds could influence subsequent trap catch. For this experiment, clear sticky traps were placed on 120-cm tall laths (N = 12) that were left up for a five-day period beginning on 25 July 2006. *Lygus* spp. were removed on a daily basis for one-half of the traps, while on the remaining traps lygus bugs were counted at the end of the five-day period.

2.8. Statistical analysis

For experiments on visual preferences in 2004, sampling dates (28 September and 4 October) were analyzed by an analysis of variance (ANOVA) using SigmaStat Software (version 2.0) with replication, sampling date and color as main factors. In 2005, spring and summer counts for hue and value experiments for *Lygus* spp., other herbivores and predators were analyzed separately by ANOVA. For time of day effect, trap counts were nearly identical for 29 September and 5 October, so they were combined for analysis. Counts were adjusted to reflect the longer sampling interval overnight, and then analyzed by ANOVA. For trap placement and trap height effect, *L. hesperus* and *L. lineolaris* were analyzed separately by ANOVA. Counts were transformed by $\sqrt{(y+0.5)}$ or ln (y+0.5) when needed to meet the assumptions of normality and homogeneity of variance. When data could not be normalized with these transformations, data were ranked and then analyzed. When F-statistics were significant means were separated by Tukey HSD tests. To determine if trap captures were affected by previous collections of lygus bugs, cumulative trap catches for daily versus weekly counts were compared for male and female *L. hesperus* and *L. lineolaris* by *t*-tests.

3. Results

3.1. Trap reflectance intensity, RGB and HSL values

Intensity counts relative to wavelength (nm) are represented for each trap color in Figure 1. The black

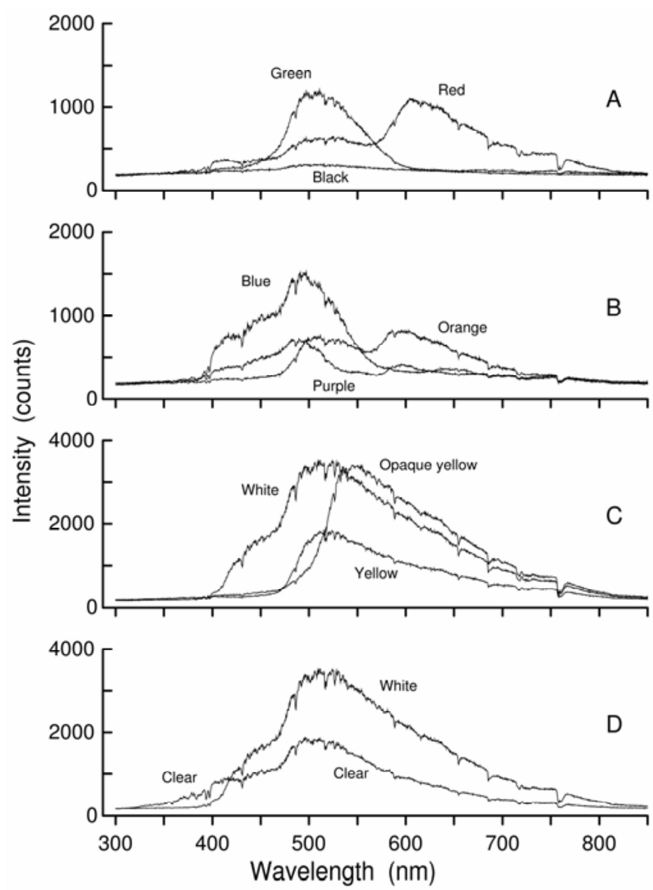

Fig. 1. Spectrograms of sunlight reflected from sticky traps of various hues: A) black, green and red spectrograms, B) blue, orange and purple spectrograms, C) white, opaque yellow and translucent yellow spectrograms, and D) white and clear spectrograms. Reflectance measurements were taken in an alfalfa field with a USB2000 spectroradiometer at ~ midday, under clear skies in Maricopa, AZ.

trap had very low intensity counts across all wavelengths measured. The other colored traps had complex intensity-wavelength curves relative to one another. Green had a dominant peak in intensity from 490-525 nm, and a second much smaller peak at approximately 410 nm, and red had a dominant peak from 595-635 nm, with a smaller peak from 490-550 nm (Fig. 1A). The blue traps increased in intensity above 395 nm culminating at 495 nm before decreasing, purple had two peaks of lower intensity, similar to opaque yellow that had a peak at

530-570 nm, while translucent yellow was lower in intensity with a peak from 495-540 nm (Fig. 1C). The clear traps reflected less light than white but in a similar pattern with most reflectance from about 485-535 nm; however, clear traps reflected more than white between 330-417 nm in the near UV range (Fig. 1D). Pestick adhesive had virtually no effect on reflected spectra since the spectrograms of each color with or without adhesive were similar (data not shown). RGB and HSL values corresponded well with spectral data (Table 1). one at about 490-515 nm and another at 580-610 nm, while orange also had two peaks with one at 475-540 nm and a second somewhat larger peak at 575-625 nm (Fig. 1B). White traps were of higher intensity and similar to blue from 400-500 nm (broad peak at 490-540 nm) and then gradually decreased in intensity.

3.2. Visual preferences of Lygus spp.*, key phytophages and predators relative to hue*

In late September to early October 2004, the majority of lygus bugs in sweeps were *L. hesperus* (97.1%). There was an average of 0.75 ± 0.25 (mean ± SEM) individuals per sweep and a sex ratio of 2.1:1.0 (male:female). Approximately 57% of the females had eggs with an average of 8.9 ± 1.7 eggs. Forty-seven percent of the females had one or more spermatophore. Trap hue played a significant role in trap catch (Fig. 2A; $F = 3.90$; df = 8, 71; $P = 0.004$). More *Lygus* spp. were trapped on green than on red and black traps, but other trap hues were not significantly different from one another (Fig.2A). All other phytophagous insects trapped showed distinct trap hue and sometimes value preferences. *Colias* spp. preferred translucent yellow over all other colors (Fig. 3A; $F = 16.80$; df = 8, 71; $P < 0.001$). *C. mexicanus* showed a strong preference to white that was significantly different from all other colors (Fig. 3A; $F = 104.60$; df = 8, 71; $P < 0.001$). *S. festinus* demonstrated a preference for translucent yellow that was different from all other colors except orange and green (Fig. 3A; $F = 8.32$, df = 8, 71; $P < 0.001$). *B. tabaci* also showed a strong response to translucent yellow over all other colors (Fig. 3A; $F = 71.19$, df = 8, 71; $P < 0.001$). *F. occidentalis* demonstrated a distinct preference for white and blue over all other colors (Fig. 3A; $F = 20.58$; df = 8, 71; $P < 0.001$). Very few predators were trapped, but *Hippodamia* spp. preferred translucent yellow, orange and white traps over red and black traps (Fig. 4A; $F = 5.15$; df = 8, 71; $P < 0.001$) and *C. carnea* showed a preference for red traps over clear and black traps (Fig. 4A; $F = 4.74$; df = 8, 71; $P = 0.001$).

Table 1
Mean (± SEM) red (R), green (G), blue (B), trichromatic percentages (R, G, B%), and hue (H), saturation (S) and luminosity (L) values from areas of digital photos of colored sticky traps taken under field conditions on 31 October 2005. Areas analyzed in pixels (N = 1216) and by Java software from Byers (2006a).

Trap color	R ± SEM	R% [a]	G ± SEM	G%	B ± SEM	B%	H:S:L
Yellow	182 ± 18	38.9	199 ± 16	42.5	87 ± 19	18.6	46:120:135
Opaque yellow	216 ± 15	46.1	200 ± 19	42.6	53 ± 16	11.3	36:162:127
Orange	223 ± 10	54.3	130 ± 12	31.6	58 ± 12	14.1	17:173:132
Green	53 ± 13	14.4	192 ± 14	52.0	124 ± 17	33.6	100:136:115
Purple	135 ± 16	33.7	101 ± 15	25.2	165 ± 17	41.2	181:63:125
Blue	84 ± 14	18.8	163 ± 15	36.4	201 ± 16	44.9	133:125:134
Red	236 ± 7	67.2	58 ± 10	16.5	57 ± 11	16.2	0:198:138
Clear	141 ± 20	32.0	161 ± 19	36.6	138 ± 26	31.4	75:26:141
Black	61 ± 13	32.4	65 ± 13	34.6	62 ± 12	33.0	90:8:59
White	209 ± 13	33.2	212 ± 12	33.7	208 ± 12	33.1	70:11:198

[a] Represents the percent red (R/ (R + G + B) x 100), G% and B% defined similarly.

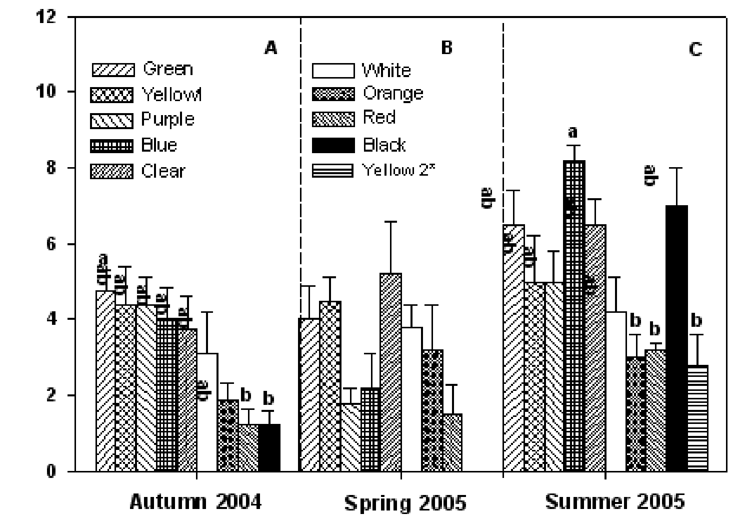

Fig. 2. Mean number (± SEM) of *Lygus* spp. trapped on sticky traps of various hues in alfalfa in the A) autumn of 2004, B) spring of 2005, and C) summer of 2005. Means followed by the same lowercase letter are not significantly different (Tukey test at $P \leq 0.05$). .* yellow 2 = opaque yellow, was used only in the summer of 2005.

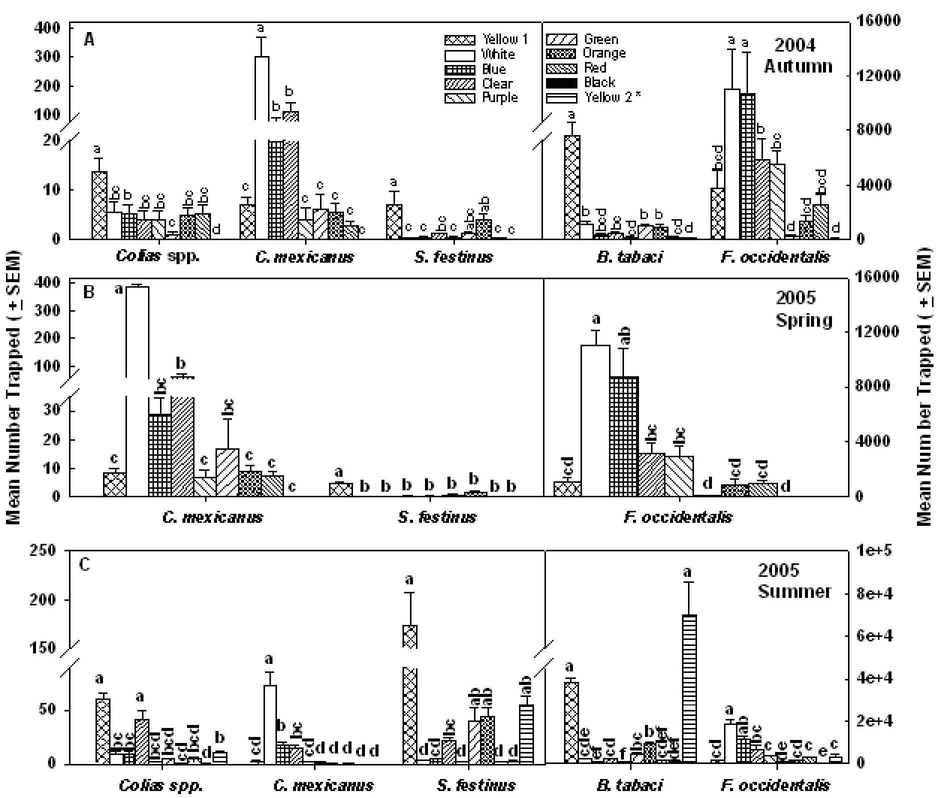

Fig. 3. Mean number (± SEM) of *Colias* spp., *C. mexicanus*, *S. festinus*, *B. tabaci* and *F. occidentalis* trapped on sticky traps of various hues in alfalfa in the A) autumn of 2004, B) spring of 2005, and C) summer of 2005. Means followed by the same lowercase letter are not significantly different (Tukey test at $P \leq 0.05$). * yellow 2 = opaque yellow, was used only in the summer of 2005.

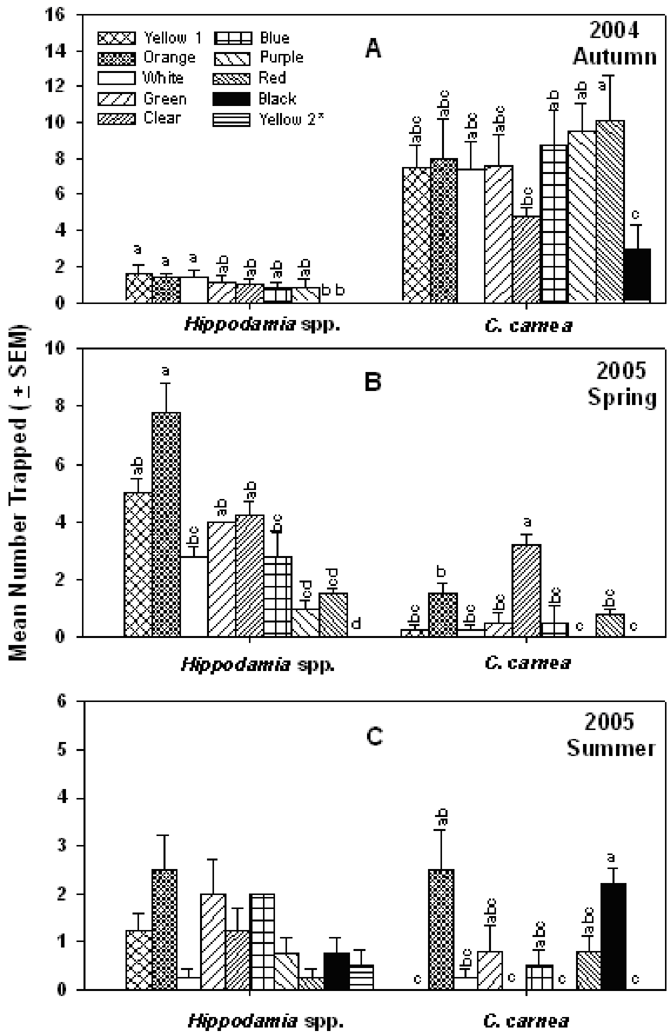

Fig. 4. Mean number (± SEM) of *Hippodamia* spp. and *C. carnea* trapped on sticky traps of various hues in alfalfa in the A) autumn of 2004, B) spring of 2005, and C) summer of 2005. Means followed by the same lowercase letter are not significantly different (Tukey test at $P \leq 0.05$). * yellow 2 = opaque yellow, was used only in the summer of 2005.

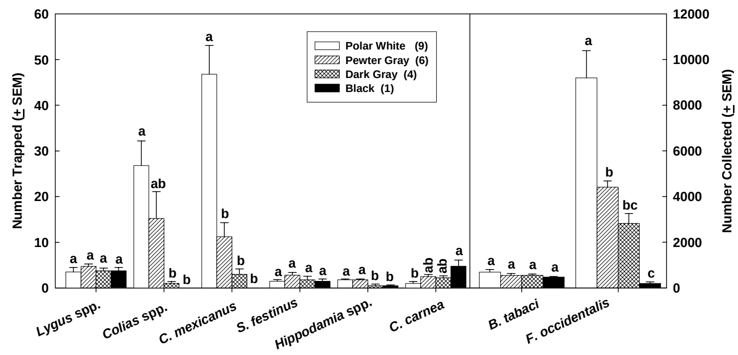

Fig. 5. Mean number trapped (± SEM) of *Lygus* spp., *Colias* spp., *C. mexicanus*, *S. festinus*, *Hippodamia* spp., *C. carnea*, *B. tabaci* and *F. occidentalis* relative to value (1, 4, 6, 9). Means followed by the same lowercase letter are not significantly different (Tukey test at $P \leq 0.05$).

In late May of 2005, the majority of lygus bugs in sweeps were again L. Hesperus (96.2%). There were 2.91± 0.36 individuals per sweep and the sex ratio was 1.0:1.0. Females had on average 7.82 ± 0.55 eggs and approximately 84% had eggs. Seventy-eight percent of the females had one or more spermatophore. Trap hue did not significantly affect *Lygus* spp. trap catches in the spring of 2005 (Fig. 2B; $P = 0.07$). Trap catches for *Colias* spp., *B. tabaci* and *C. quadrimaculatus* were too low for analyses in May; however, *C. mexicanus* showed a strong preference to white that was significantly different from all other colors (Fig. 3B; $F = 149.4$; df = 8, 35; $P < 0.001$). *S. festinus* demonstrated a distinct preference for translucent yellow that was different from all other colors ($F = 11.51$, df = 8, 35; $P < 0.001$). *F. occidentalis* demonstrated a distinct preference for white over all colors except blue, and blue was preferred over all colors except purple and clear (Fig. 3B; $F = 17.62$; df = 8, 35; $P < 0.001$). For predators, *Hippodamia* spp. were trapped more frequently on orange than on all colors except translucent yellow, green and clear (Fig. 4B; $F = 14.08$; df = 8, 35; $P < 0.001$). *C. carnea* was trapped more frequently on clear than on all other colors (Fig. 4B; $F = 11.27$ df = 8, 35; $P < 0.001$). .

On 12 August of 2005, the majority of lygus bugs in sweeps were *L. hesperus* (86.8%). There were 0.38 ± 0.02 individuals per sweep and the sex ratio was 1.5:1.0. Females had on average 10.5 ± 1.7 eggs and approximately 93% had eggs.

Sixty-four percent of the females had one or more spermatophore. The seven day trap catches did not show a significant difference relative to trap catch ($P = 0.34$); however, there were significant preferences demonstrated in the 14-day collections (Fig. 2C; $F = 4.41$; df = 9, 39; $P < 0.001$). Blue was preferred over orange, red and opaque yellow. *Colias* spp. showed a strong preference to translucent yellow that was different from all other colors except clear, and clear was preferred over all remaining colors (Fig. 3C; $F = 30.01$; df = 9, 39; $P < 0.001$). *C. mexicanus* showed a strong preference to white that was significantly different from all other colors (Fig. 3C; $F = 23.13$; df = 9, 39; $P < 0.001$). *S. festinus* demonstrated a distinct preference for translucent yellow that was different from their response to most other colors (Fig. 3C; $F = 26.59$, df = 9, 39; $P < 0.001$). *B. tabaci* showed a strong response to opaque yellow over all other colors except translucent yellow (Fig. 3C; $F = 56.95$, df = 9, 39; $P < 0.001$). *F. occidentalis* demonstrated a distinct preference for white over all colors except blue, and blue was preferred over all colors except clear (Fig. 3C; $F = 22.96$; df = 9, 39; $P < 0.001$). For predators, *Hippodamia* spp. showed no significant preference among colors ($P = 0.12$). *C. carnea* preferred black and orange over most other colors (Fig. 4C; $F = 5.78$; df = 9, 39; $P = 0.001$).

3.3. Visual preferences of Lygus spp.*, key phytophages and predators relative to value*

Lygus spp. showed no preference relative to trap value (Fig. 5; $P = 0.86$). *Colias* spp. demonstrated a strong preference for high intensity traps; white was preferred over black and dark gray, but not pewter gray ($F = 5.44$; df = 3, 15; $P = 0.02$). *C. mexicanus* also demonstrated a strong preference to white over all other traps (Fig. 5; $F = 24.24$; df = 3, 15; $P < 0.001$). The two homopteran species, *S. festinus* and *B. tabaci* did not demonstrate a preference relative to intensity ($P = 0.68$ and $P = 0.67$, respectively). *F. occidentalis* demonstrated a distinct preference for white over all colors, and pewter gray was preferred over black ($F = 22.46$; df = 3, 15; $P < 0.001$). For predators, *Hippodamia* spp. showed a slight preference for high intensity traps, with white and pewter gray being preferred over black and dark gray ($F = 4.41$; df = 3, 15; $P = 0.04$). *C. carnea* was trapped more frequently on low intensity traps, with black preferred over white traps ($F = 4.13$; df = 3, 15; $P = 0.04$).

3.4. Effect of time of day

Although *Lygus* spp. were caught in small numbers throughout the day and night, time of day had a significant effect on trap catch (Fig. 6; $F = 30.53$; df = 3,31; $P < 0.001$). Approximately 50% of the trapped individuals were caught in the 4-h interval between late afternoon and dusk (1500-1900 h).

3.5. Effect of trap placement

During this trial, sex ratios of trapped individuals were male biased, with *L. hesperus* at 10:1 and *L. lineolaris* at 8.3:1. Sweeps prior to and following the trial indicated that the sex ratio in the field was ~ 1:1, so either females were better at evading the traps or males were much more active at this time of year in late June. All females, both pre- and post-trial had mature, fully chorinated eggs, with a mean of 13.1 ± 0.77 eggs and 66% had one or more spermatophore. Of the individuals trapped, 76% were *L. hesperus* and both males and females of this species were influenced by the location of the trap. Significantly more individuals were captured when traps were placed between the two 8-ha alfalfa fields ($F= 5.11$; df = 2, 23; $P = 0.02$ for females and $F = 47.04$; df = 2, 23; $P < 0.001$ for males), than when placed in the center or at the outside edge of the alfalfa field. Very few *L. lineolaris* females were trapped and differences in capture relative to placement were not detected ($P = 0.33$); however male *L. lineolaris* were caught more frequently on traps placed between the two alfalfa fields ($F = 4.98$, df = 2,23; $P = 0.02$) than on traps placed on the outside edge of the alfalfa field.

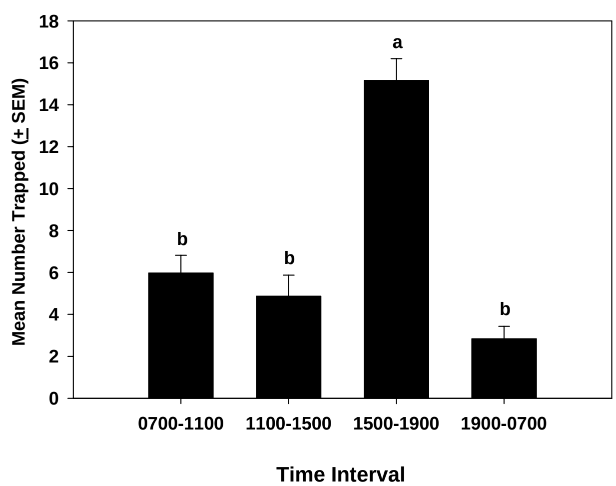

Fig. 6. Mean number (± SEM) of *Lygus* spp. trapped on sticky traps in alfalfa relative to time of day during two 24-h collections on September 29 and October 5, 2004. Means followed by the same lowercase letter are not significantly different (Tukey test at $P \leq 0.05$).

3.6. Trap height effect

At the time of these collections in late July, the number of *Lygus* spp. per sweep averaged 0.72 ± 0.18 in the flowering alfalfa and 0.57 ± 0.10 in the vegetative alfalfa. The sex ratio was 1.6:1.0 in the flowering alfalfa and 1.0:1.0 in the vegetative alfalfa. Approximately 75% of the females in flowering alfalfa had eggs with a mean of 10.0 ± 0.36 and 46% had at least one spermatophore. In vegetative alfalfa, 97% of the females had eggs with a mean of 11.4 ± 0.46 and 66% had at least one spermatophore. On the traps, the sex ratio was 2.4:1.0, indicating that males were more likely than females to be trapped; however, sex ratio varied considerably with height. At mid-canopy (90-cm stakes), the sex ratio was 3.5:1.0, while at canopy (120-cm stakes) and above canopy (180-cm stakes) the sex ratio was 1.0:1.0. *L. hesperus* accounted for 72.6% of the collection, the remainder were *L. lineolaris*. For *L. hesperus* more individuals were trapped on 90-cm stakes than on the 120- and 180-cm stakes (F = 24.32; df = 2, 35; P < 0.001), and regardless of height more males than females were trapped (F = 15.62; df = 1, 35; P = 0.003). For *L. lineolaris* more individuals were trapped on the 90-cm stakes than on the 180-cm stakes (F = 8.56; df = 2, 35; P < 0.007), but 90- and 120-cm stakes caught similar numbers. There was not a significant difference in trap catch for male and female *L. lineolaris* (P = 0.27).

3.7. Effect of daily vs. weekly collections

Similar numbers of *Lygus* spp. were trapped regardless of whether they were removed on a daily basis for five days and then totaled, or counted at the end of the five day period (t = 1.0, df = 46, P = 0.32). The response was similar for female *L. hesperus* (t = 1.26, df = 10, P = 0.24) and *L. lineolaris* (t = 1.52, df = 10, P = 0.16), as well as for male *L. hesperus* (t = -0.05, df = 10, P = 0.96) and *L. lineolaris* (t = 0.34, df = 10, P = 0.74). Defensive volatiles and sex, aggregation and alarm pheromones apparently were either not released by trapped *Lygus* spp., were of too short duration, were masked by the Pestick or were ineffective from a distance.

4. Discussion

Many phytophagous insects respond positively to light reflectance patterns of their host plant, and these responses can be quite specific. Very often substrates that reflect maximally between 500-580 nm elicit the greatest response; however, in some cases, the response may be associated with a particular stage of the host plant (i.e., flowering or fruiting stage) where reflectance is maximal in other regions of the spectrum (Prokopy and Owens, 1983). Knowledge of these behaviors has allowed us to effectively monitor many economically important pests. Here we examined the response of several key alfalfa herbivores and predators to trap hue and intensity. Particular emphasis was placed on the response of the generalist herbivore, *L. hesperus*, which has become a significant pest in recent years. *L. hesperus* made up a large percentage (> 85%) of all lygus bugs collected, and in general, their response to trap hue was broad and not very discriminating; however, over the three seasons the top four hues in terms of numbers trapped were green, clear, blue, and translucent yellow. Although males were trapped more frequently, no gender related differences in response to trap hue were detected. Male biases on sticky traps, despite 1:1 ratios in the field, have been reported previously for *L. lineolaris* (Prokopy et al., 1979; Boivin et al., 1982; Boivin and Stewart, 1984). Male trap catch biases for *L. hesperus* have not been reported previously, but our findings together with previous findings for *L. lineolaris*, suggest that either males are more active fliers or are more attracted to sticky traps. This latter alternative is less likely. Prokopy et al. (1979) found no differences in preferences by male and female *L. lineolaris* among the various hues tested, and neither did we for *L. hesperus* (J.L.B., unpubl. data). Given the high percentage of females with eggs over all three seasons, it seems likely that they were trapped less frequently because they were engaged in egg laying behavior. In previous studies, we found no evidence that having mature eggs negatively affected their ability to fly (Blackmer et al. 2004b), although this needs to be examined more closely in the field. In terms of trap value or intensity, *Lygus* spp. exhibited no preference; high intensity traps (white) caught as many lygus bugs as low intensity (black) traps.

In contrast, all other insect species monitored during these studies demonstrated distinct preferences to hue, and in some cases, intensity. Neither of the homopteran species, *S. festinus* and *B. tabaci*, responded to trap intensity, but did show a strong response to yellow. Todd et al. (1990) obtained similar responses with the leafhoppers, *Dalbulus maidis* (DeLong and Wolcott), *D. gelbus* DeLong and *D. quinquenotatus* DeLong and Nault, which responded strongly to yellow, but not to neutral grays indicating that their responses were primarily due to hue and not value or intensity.

Colias spp., *C. mexicanus*, and *F. occidentalis* all showed a strong response to high intensity traps, but their response to hue differed. *Colias* spp. responded strongly to translucent yellow, whereas *C. mexicanus* and *F. occidentalis* both responded strongly to white, blue and clear traps. Several researchers have reported that blue or white traps are attractive to *F. occidentalis* (Yudin et al., 1987; Vernon and Gillespie, 1990; Matteson and Terry, 1992; Roditakis et al., 2001), while Chen et al. (2004) reported a stronger attraction to blue or yellow traps than to white traps. Direct comparisons between studies are difficult, however, because trap hue, design and deployment varied among studies. No other studies have examined the response of *Colias* spp. or *C. mexicanus* to visual cues, but in both cases, as well as for *F. occidentalis*, these insects were responding to both hue and intensity.

Few predators were trapped during our studies, but *Hippodamia* spp. did show a preference for translucent yellow and orange traps and responded to traps of higher intensity. *C. carnea,* on the other hand, preferred low intensity traps and had a variable seasonal response to orange, red, black, and clear hues. Maredia et al. (1992) obtained similar responses to trap hue (red, orange, black, white, blue, yellow and green tested) by two predators. Although numbers were low, they found *Coccinella septempunctata* (L.) consistently responded to yellow traps regardless of location. *C. carnea* also responded to yellow, but green, red, black and orange trapped similar numbers depending on the location. In trapping *Lygus* spp., inadvertent trapping of beneficial predators could be reduced by utilizing green, blue, or clear sticky traps.

In addition to testing response to trap visual cues, we examined the effect of time of day, trap height, trap placement, and whether insect-associated pheromones and defensive compounds might influence subsequent trap catch of *Lygus* spp. Most lygus bugs were trapped between late afternoon and sunset in alfalfa. Mueller and Stern (1973) also found that *L. hesperus* was most active at dusk. Butler (1972) reported that *L. hesperus* actively engaged in flights 1 h before sunrise and 1 h after sunset; however, this study only covered a three-day period during the summer and all collections were made between 1 and 3 m above ground. *L. lineolaris* was reported to be most active at midday (Rancourt et al., 2000). In our studies, the number of *L. lineolaris* captured was too low to accurately determine time of day effect. The other three parameters measured (trap height, trap placement and effect of pheromones), have not been examined for *L. hesperus*. However, for *L. lineolaris* several researchers reported that, similar to our findings, most individuals were trapped less than 1 m above the ground (Prokopy et al., 1979; Boivin and Stewart. 1984; Rancourt et al., 2000). For several insect species, host plants surrounded by bare ground are more often visually apparent and consequently these plants receive more visits (Smith, 1976; Rausher, 1981). These findings support our results that trap placement over bare ground between two alfalfa fields trapped more *Lygus* spp. than traps placed in the center or at the edge of the field. For presumed pheromones (aggregation, alarm and/or sex) or defensive volatiles (Byers, 2006b), we found no evidence that trapped *Lygus* spp. released any chemicals that influenced subsequent trap collections.

In conclusion, *Lygus* spp. exhibited a broad response to hue, as predicted for a generalist herbivore (Prokopy et al., 1982; Prokopy and Owens, 1983), and their response varied relative to trap placement, height and time of day. If the intent is to maximize *Lygus* spp. collections while minimizing beneficial predator capture, our trials suggests the use of green, clear or blue traps, placed between alfalfa fields over bare ground, with traps less than 1 m high. Yellow traps have been used in the past, but over longer trapping periods we found that the preference to yellow by other key herbivores (i.e., *S. festinus* and *B. tabaci*) interfered with lygus bug captures (J.L.B., unpubl. data). The presence of *Colias* spp. during the summer and autumn would further interfere with trap catch if not removed on a daily basis. This is obviously not feasible in commercial practice. One option for dealing with this large insect would be to surround the trap with a finer mesh screen that would allow the target insect in, but prevent larger insects from being trapped. Such trap capture interactions will likely depend on the cropping system, because the species complex will vary. Future studies will focus on enhancing male and female response to our sticky traps, and this will likely involve looking at the role of plant phenology, insect reproductive status and the interaction between visual and volatile plant cues which we found to be important in the laboratory setting (Blackmer et al., 2004c; Blackmer and Cañas 2005).

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