An Evaluation of the Potential for the Use of Trap Cropping for Control of the Striped Cucumber Beetle, *Acalymma vittata* (F.) (Coleoptera: Chrysomelidae)

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ABSTRACT Experiments were conducted to evaluate the potential for controlling striped cucumber beetle (StCB), *Acalymma vittata* (F.), on cucumber, *Cucumis sativa* (L.), using a squash trap crop. A squash, *Cucurbita maxima* (Duch.) cv. 'NK530', was identified in greenhouse choice assays as being exceptionally attractive to StCB. Trap crop experiments were conducted using 50% and 15% of experimental plots planted to the trap crop. In both sets of experiments, plots which contained squash were more attractive than plots which did not. In 50% experiments, at least 70% of beetles found in plots were found on squash plants throughout the sampling period, with 90% on squash during the first 5 d. The use of a feeding deterrent on cucumbers did not significantly enhance the attractiveness of squash. In 15% experiments, over 70% of beetles were found on squash plants initially, although this number declined after 3 d. Two planting arrangements were tested and found not to differ. These experiments demonstrate strong potential for the use of this control strategy.

KEY WORDS *Acalymma vittata*, striped cucumber beetle, trap crop, cultural control, *Cucumis sativa*, *Cucurbita maxima*, colonization, aggregation, Coleoptera, Chrysomelidae.

The use of trap crops has been suggested as a control strategy for agricultural pest insects since the idea was advanced by Stern (1969) in the use of alfalfa interplanted with cotton for control of western lygus bugs (*Lygus hesperus* Knight and *L. elisus* Van Duzee) on cotton. Hokkanen (1991) surveyed the literature on trap cropping and noted two general strategies: 1) early planting of a trap crop to coincide with emergence of the pest, prior to establishment of the main crop and 2) establishment of trap and commercial crops simultaneously. The latter relies on a trap crop with stronger attractive qualities to the pest than the commercial crop.

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Management factors that may affect trap crop performance include: the choice of trap species, the size and location of the stands, establishment and growing operations (fertility levels, tillage practices), possible manipulations to increase their attractiveness (use of antifeedants on commercial crop, application of attractants to the trap crop), and pesticide treatments (Hokkanen 1991). Based on their extensive work on the chemical ecology of pests, Rhodes et al. (1980) suggested the use of trap crops to control pests of the genus Diabrotica. The present study evaluates the potential of a squash (Cucurbita spp.) trap crop to control striped cucumber beetle (StCB), Acalymma vittata (P.), on cucumber, Cucumis sativa (L.).

There is evidence that StCB has a marked preference for certain genera of the Cucurbitaceae, specifically for Cucurbita spp. relative to Cucumis spp. Gould (1944) noted that StCB’s would feed on zucchini-type squashes, Cucurbita pepo (L.), before feeding on cucumbers (Cucumis sativa). Lower (1972) found that degree and frequency of feeding damage on cucumber were greater when ‘Zucchini Elite’ squash (C. pepo) was the surrounding cultivar than when any of three cucumber cultivars were the surrounding plants, suggesting attractiveness of squash. Elsey (1988) supported this with his observation of higher numbers of StCB’s in patches of zucchini than patches of cucumber. In a ranking of preference for several genera of the Cucurbitaceae, Howe et al. (1972) found strong preference by StCB for species of Cucurbita, with C. maxima Duch. the most preferred, although Cucumis sativa was the second-most preferred. However, leaf disk choice assays in petri dishes were used in this study, and it is possible that using injured tissue may alter the volatile chemical environment in the dishes (Carrol and Hoffman 1980, Risch 1985).

Preference has been demonstrated both within and between species of Cucurbita. Wiseman et al. (1961) showed that StCB has strong preference for seedlings of certain cultivars within Cucurbita pepo over others of the same species. Further study of feeding by Diabrotica spp. on intact cotyledons of various Cucurbita cultivars resulted in near-maximum damage ratings on zucchini-types and near-zero damage on scallop and acorn squashes, all of which are cultivars of C. pepo (Ferguson et al. 1983). Likewise, among hundreds of wild and cultivated cucurbits screened for feeding resistance, zucchinis (C. pepo) were rated among the most damaged from feeding of StCB and southern corn rootworm (SCR), Diabrotica undecimpunctata howardi Barber, while some of the pumpkins (C. pepo) were least damaged (Baker and Robinson 1985). Howe and Rhodes (1976) documented a strong attraction of StCB to nine Cucurbita spp. tested in the field, with the highest numbers of beetles attacking C. maxima. Thus, both preference for Cucurbita spp. over Cucumis spp., and preferences for certain species within Cucurbita are well documented.

Cucurbitacins, triterpenoid compounds common to the family Cucurbitaceae, have been shown to strongly influence the behavior of Diabrotica spp. beetles. Although most of the work with cucurbitacins has been done with members of the genus Diabrotica, similar activity has been demonstrated in the StCB (Metcalf et al. 1979, Rhodes et al. 1980). Cucurbitacins may function only as an arrestant and feeding stimulant, while the combination of volatiles emanating from cucurbit seedlings functions as the long range attractant, causing the
sudden infestations typical of this pest. Lewis et al. (1990) confirmed that such effective host finding involves olfactory cues received from seedlings. In a field experiment designed to deprive beetles from reception of visual or tactile cues, significant numbers of StCB's were trapped on veiled sticky cups containing concealed *Cucurbita maxima* seedlings. Cucurbitacins could influence the ability of a squash trap crop to hold StCB's for an extended period of time through their arrestance effect, though their function of attraction is in doubt.

Based on these previous studies on StCB attraction and preference, a series of experiments was conducted in 1990 and 1991, designed to evaluate the potential for a trap crop strategy for controlling StCB in cucumber fields. Objectives of this study included: 1) identifying a cultivar of squash which is strongly preferred over cucumber, 2) examining two field characteristics hypothesized to have an effect on beetle tenure in cucumber plots: a) plot shape and b) soil texture, and 3) testing trap crop configurations in the field.

### Materials and Methods

All field studies were carried out at the University of Maine Sustainable Agriculture Research Station in Stillwater, Maine.

**Host preference among cucumber and squash cultivars.** Choice tests were conducted comparing cucumber, *Cucumis sativa*, with several squash cultivars of *Cucurbita pepo* and *C. maxima*. These squash species were chosen because of their high levels of cucurbitacin B (Ferguson et al. 1983), as well as their high feeding damage ratings (Wiseman et al. 1961, Ferguson et al. 1983, Baker and Robinson 1985).

**Assays.** Assays were conducted in a greenhouse. Each assay arena consisted of a Plexiglas™-sided cage with screened top and bottom, measuring 20 by 20 by 40 cm (length, width, height), and contained a seedling of one of the trap plant candidates at one end of the cage and a cucumber seedling (cv. 'Score', a variety grown commercially in Maine) at the other end. Squash cultivars tested included: *Cucurbita maxima* cvs: 'Sweet Mama' and 'INK530', and *C. pepo* cvs: 'Ambassador', 'Caserta', 'Chefini', 'Gold Rush', and 'Black Jack'. In addition, a low cucurbitacin cucumber (*Cucumis sativa*) cv 'Marketmore 80', was tested against 'Score' cucumber.

Plants were grown in 4.45 cm² Jiffy Strip™ peat pots in the glasshouse. Beetles, which were collected in the fall of 1990 and maintained in cages with cucumber plants (cv. 'Score') in the greenhouse, were held in plastic tubes 5 cm in length and starved for 24 h prior to assay. At the start of each assay, holding tubes were inserted into the center of the long wall of one side of each cage, at a point approximately equidistant from the two seedlings. Then, a cardboard gate which had been holding the beetle in the tube was lifted out, allowing the beetle to enter the cage and select a seedling. The temperature during the assays ranged from ca. 20 to 30°C, and natural daylight illuminated the assay arenas. Upward air flow was maintained by blowing a stream of air over the tops of the cages using a tabletop fan on low speed. This was done to prevent plant volatiles from building up in the cage and thus disorienting the beetle.
The experiment was a randomized complete block design and blocks were usually conducted 12 replicates at a time, although the first few trials consisted of only four replicates. The positions of beetles in cages were checked approximately every hour through the daylight hours. A beetle was recorded as having chosen a seedling if it remained on the originally chosen plant to the end of the day.

Analysis. Data were analyzed using one-way analysis of variance. Data were expressed as the proportion of cages in a trial in which a beetle made a clear choice of a particular seedling. Cages in which choices were not made were not included in the analysis. Such situations included: 1) the beetle never left the tube, and 2) the beetle left the tube but was never observed on a plant. Data from each trial were weighted according to the number of assay cages in which a particular combination of seedlings was tested. To correct for possible differences in choice based on the influence of leaf size, cotyledon length was measured and averaged for each trial (a strong correlation was found between total leaf area and abundance of a closely related tropical species, Acalyptus innubum (F.) (Bach 1984)). These cotyledon lengths were incorporated into the ANOVA as a covariate. The mean proportions chosen were separated using the Tukey compromise test (Zar 1984); paired t-tests were used to directly discern preference for each candidate squash (C. pepo and C. maxima) over 'Score' (Cucumis sativa) by comparing mean proportions chosen to 0.5, the hypothetical proportion at which there is assumed to be no preference.

Perimeter-to-area ratio. In 1990, a field experiment was designed to assess whether perimeter-to-area ratio of the planting affects a trap crop strategy. Four plots of equal area (25m²) were established on 26 May, using 100 cucumber (Cucumis sativa) seedling transplants (cv. 'Score') spaced at 0.5 m in both directions. Plots were separated by a minimum of 100 m from each other or any other crop plantings to avoid interplot movement. Two plot shapes (differing in area by 1 m²) which represented the extremes of perimeter-to-area ratios (5 by 5 m-square, and 16 by 1.5m long) were replicated twice. Plots were marked with numbered red flags along the perimeter to create a coordinate grid so that day-to-day movements of beetles could be tracked.

Sampling. Plots were sampled in the early morning for 4 or 5 consecutive days during three periods (25-28 June, 2-5 July, and 15-19 July), following a thorough examination of every plant and removal of all beetles from all plots during the previous evening. During sampling, each plant was examined, beetles were counted without disturbance, and their positions on the coordinate grid within the plots recorded.

Analysis. The effect of plot shape on total density of beetles was tested using a two-way ANOVA (plot shape, sampling period), treated as a randomized complete block design, with two replicates of each treatment per block. Power of the test (b) was determined for detection of a difference of 100% of the mean (Zar 1984). Indices of dispersion (I = s² / x̄) were calculated for each plot on each day for all three sampling periods. A t-test was used to test the null hypothesis I = 1. The effect of plot shape on colonization rate and dispersion (s² / x̄) of colonizing beetles were discerned using a two-way ANOVA (plot shape, sampling period), with time within each period used as a covariate. Colonization rate data were expressed as a proportion of the maximum number of beetles that colonized each plot to eliminate confounding differences in local populations over time.
Soil texture experiments. Early in the 1990 field season, it was observed that beetles spend a significant portion of time in the soil and often can be seen under soil clods and in soil cracks. Experiments were designed to test whether soil surface texture influenced the tenure of beetles on individual plants.

During the summer of 1990, an experiment was conducted in a 0.3-ha cucumber field planted with the hybrid cucumber, *Cucumis sativa*, cultivar 'Score' spaced 1 m between rows and 0.5 m within rows. Four adjacent seedlings within each of four nonadjacent rows were used. On the afternoon of 26 July 1990, three mating StCB pairs were released into each of sixteen 0.6-m³ field cages; each cage covered an individual cucumber seedling. Beetles were marked on their left elytra to indicate sex and on the right by one of four color groups. The purpose of using cages was to allow beetles to establish themselves on seedlings. Cages were then removed early the following morning without affecting the insect's behavior. Two treatments were replicated twice; two groups of four adjacent plants in which the soil surface was finely pulverized by hand, and two groups in which the soil was left in its natural state (frequent surface cracks, 2-3/m², 2-4 cm in depth).

Sampling. Cages were removed at 6:00 AM on 27 July, and beetles were counted on each plant. Plants were examined at 3-h intervals throughout the day. Observations were continued on the following 2.5 days, but only with morning and evening observations.

Analysis. The number of beetles per four adjacent plants were log (x + 1) transformed and analyzed as a completely random design using a one-way ANOVA with repeated measures (Wilkinson 1989).

A second experiment was conducted from 30 July to 7 August 1991. One 12-m² plot consisted of four blocks; each block consisted of four subplots, each containing 16 plants arranged in four rows. Two levels of two factors appeared once in each block: two plant types, squash (*Cucurbita maxima*) cv. 'Sweet Mama' and cucumber (*Cucumis sativa*) cv. 'Score'; and two soil treatments (soil pulverized using a rototiller and soil left in its natural state). Plants were grown from seed in polystyrene Pro Trays™ in the glasshouse and transplanted at a spacing of 0.75 m in both directions.

Sampling. Sampling was performed on six mornings during a 9-d period. Every plant in the plot was examined on every sample date. Data were analyzed as a randomized complete block design with split plots, with plant type and soil texture as the main plot factors and time as the subplot factor (Wilkinson 1989).

Trap crop field test. Two trap crop planting ratios were evaluated in 1991: a 50:50 (Experiment One) and an 85:15 (Experiment Two) cucumber (*Cucumis sativa*) to squash (*C. maxima*) ratio.

Experiment One, 50% cucumber - 50% squash. In the first experiment, a total of three treatments were used: 1) 50% trap squash - 50% cucumber; 2) an arrangement identical to the first except that cucumber plants were sprayed with a feeding deterrent in an attempt to increase the attractiveness of the squash trap plants; and 3) 100% cucumber. Margosan-O™ (W. R. Grace and Co., Columbia, Maryland, USA), an ethanol-based preparation of azadirachtin, is a commercially available antifeedant compound containing 0.3% azadirachtin. Azadirachtin, a secondary natural product from seeds of the neem tree, *Azadirachta indica* A. Juss., has been shown to have activity as a feeding
deterrent against StCB in laboratory and greenhouse feeding assays (Reed et al. 1982). Neem extract containing 0.3% azadirachtin applied at both 100 ppm and 1000 ppm to cantaloupe seedlings in the greenhouse did not cause total rejection of treated plants by StCB's, although feeding relative to the untreated control was significantly deterred (Reed et al. 1982).

**Plots.** Plants were grown from seed in Jiffy Strips peat pots in the greenhouse and transplanted into nine plots on 28 May. Varieties planted were 'Score,' a hybrid pickling cucumber and 'NK 530,' a hybrid variety of *Cucurbita maxima*. Three treatments replicated three times were assigned in a completely randomized design to nine 225-m² plots at a minimum distance of 100 m from each other, a maximum distance of 375 m, and turf grass in between plots. The neem oil spray was applied to runoff on three occasions (2, 6, and 13 d after planting) at 40 ppm. The third treatment consisted of 100% cucumbers to test if the overall long-range attractiveness of plots containing trap plants differed from plots that lacked them. Each plot contained 400 plants in a 20 row by 20 column array. Plants were spaced at 0.75 m in both directions. In plots containing both squash and cucumber, four alternating groups of five rows (each considered a subplot) were planted running north to south. The easternmost group was cucumber, followed by squash, cucumber, squash. This orientation was maintained through all nine of the plots.

**Sampling.** Samples were taken during the cool early morning hours just after sunrise to avoid disturbing the beetles. The four subplots of each plot were divided into four sub-subplots, each consisting of 25 plants arranged in a five row by five column array. This resulted in a total of 16 sub-subplots per plot. Plots were sampled on 14 occasions during a 23-d period starting on 2 June. On each sampling date, five plants were selected at random from each sub-subplot and the number of beetles per plant were recorded.

**Analysis.** Data were analyzed using one-way analyses of variance for three tests: 1) to test for overall differences in attraction between the three treatments on a beetle-per-plant basis, summed over the entire sampling period of 23 days; 2) to test for differences in the two trap crop treatments on a beetle-per-plant basis, both by sample day and over the entire sampling period; and 3) to test for differences between the two plant species within a plot on a beetle-per-plant basis, both by day and over the entire sampling period. The last test was contingent upon results of the second test; it was planned that if no differences were found between the trap crop plots with azadirachtin and those without azadirachtin, then the plots would be treated as six individual blocks with two treatments per block (squash and cucumber) for the last test. Otherwise, the azadirachtin treatment would be included as a separate factor. Comparison of overall attractiveness was made using the Tukey HSD multiple comparison test (Wilkinson 1989). Data were transformed for the comparison of trap crop treatments by calculating the ratio of beetles per squash plant to beetles per cucumber plant, and then the ANOVA was performed on the ranked data.

**Second Experiment** 85% cucumber - 15% squash. Plants were grown from seed in polystyrene Pro Trays™ and transplanted on 12 July 1991 to nine plots as in the 50% cucumber - 50% squash plots, except that plots were 182 m² and consisted of 18 row by 18 column arrays of plant, also spaced 0.75 m in both directions. Water soluble 20-20-20 fertilizer was applied at the time of
transplanting to all plots. Varieties planted were the same as in the 50% squash experiment. These plots differed from those above in that one in every six rows was planted to squash. Treatments were assigned at random. Three plots had five north-south running rows of cucumber (on the west side of the plot), followed by one row of squash, with this pattern repeated three times within an 18-row plot (single-row pattern); three plots had 15 north-south running rows (on the west side of the plot), followed by three rows of squash (group of three-row pattern); and three plots consisted entirely of cucumber plants, which served to compare overall long-range attractiveness of plots with trap plants.

**Sampling.** Plots were sampled on six occasions during a 11 d-period starting on 16 July. Stratified random sampling was performed in the early morning hours except that there were 54 sub-subplots per plot, each consisting of a row of six plants. One plant sample was taken randomly from each sub-subplot on the first two sampling dates, and after this, two plants per row of six were sampled, the average of the two being used as each data point. This was modified because it was observed that beetles were highly aggregated and it was felt that a higher sampling intensity was required to detect accurate population density.

**Analysis.** One-way analyses of variance were used to: 1) test for overall differences in attraction between the three treatments on a beetles-per-plant basis summed over the entire sampling period of 11 d; 2) test for differences in the two planting pattern treatments on a beetles-per-plant basis in the mixed plots, both by day and summed over the sampling period; 3) test for differences between the two plant species on a beetles-per-plant basis in the mixed plots, both by day and summed over the sampling period. Categorical grouping of treatments in the third test (for plant species) were based on results of the second test (for planting arrangement). Comparison of overall attractiveness was made using the Tukey HSD multiple comparison test (Wilkinson 1989). Data were log \((x + 1)\) transformed as above to compare the trap crop treatments.

**Results and Discussion**

**Host preference among cucumber and squash cultivars.** StCB's chose the *Cucurbita maxima* squash cultivar 'NK530' over the *Cucumis sativa* cucumber cultivar 'Score' with greater frequency than four of the six squash varieties tested (Table 1). Cotyledon size alone had no effect on preference \(F = 1.49, df = 1, 80; P > 0.05\), although a significant cotyledon size by cultivar interaction was found \(F = 2.35; df = 5, 80; P < 0.05\), indicating that some cultivar comparisons are differentially affected by size in cotyledon size.

Cucurbitacin B is present in cotyledons of most, if not all *Cucurbita maxima* and *Cucurbita pepo* cultivars but not in cotyledons of *Cucumis sativa* (Ferguson et al. 1983), and the cultivar 'Marketmore 80' was bred with low levels of all cucurbitacins specifically for resistance to cucumber beetle feeding. The fact that 'Marketmore 80' (*Cucumis sativa*) was chosen greater than 50% (61.2%) of the time over 'Score' (*Cucumis sativa*) \(t = 2.36; df = 18; P < 0.05\) supports earlier work which questioned the role of cucurbitacins as a long range attractant (Howe et al. 1976, Quisumbing and Lower 1978, Branson and Guss 1983). Because of these results, *Cucurbita maxima*, 'NK530', was chosen as the
Table 1. Mean proportion of beetles choosing a cultivar of squash or cucumber over the cucumber cultivar 'Score' in greenhouse choice tests. Letters indicate significant differences ($P < 0.05$) in frequency of choosing the test cultivar relative to 'Score' (Tukey compromise test). The $t$-values and probabilities are results from individual tests of mean proportion chosen versus no preference (proportion = 0.5).

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Mean Proportion</th>
<th>df</th>
<th>$t$</th>
<th>$P$</th>
</tr>
</thead>
<tbody>
<tr>
<td>squash 'Sweet Mama' (C. maxima)</td>
<td>0.502 a</td>
<td>21</td>
<td>-0.09</td>
<td>0.927</td>
</tr>
<tr>
<td>squash 'Chefini' (C. pepo)</td>
<td>0.545 ab</td>
<td>10</td>
<td>-0.58</td>
<td>0.575</td>
</tr>
<tr>
<td>squash 'Caserta' (C. pepo)</td>
<td>0.569 ab</td>
<td>6</td>
<td>-2.12</td>
<td>0.078</td>
</tr>
<tr>
<td>squash 'Ambassador' (C. pepo)</td>
<td>0.687 ab</td>
<td>12</td>
<td>-25.98</td>
<td>0.0001</td>
</tr>
<tr>
<td>squash 'NK 530' (C. maxima)</td>
<td>0.805 c</td>
<td>20</td>
<td>-13.15</td>
<td>0.0001</td>
</tr>
<tr>
<td>cucumber 'Marketmore 80' (C. sativa)</td>
<td>0.612 ab</td>
<td>17</td>
<td>-2.36</td>
<td>0.031</td>
</tr>
</tbody>
</table>

candidate trap crop for field evaluation and 'Score' was chosen over 'Marketmore 80' as the cucumber (Cucumis sativa) variety.

**Perimeter-to-area ratio.** No difference in density of colonizing beetles was found between the two plot shapes (long plots: $\bar{x} = 287 \pm 66.33$, square plots: $\bar{x} = 220.667 \pm 34.98$; $F = 0.55$; df = 1, 6; $P > 0.05$; $b = 0.35$ to detect 100% difference). Plot shape did not affect colonization over time (Fig. 1) within the three sampling periods ($F = 2.27$; df = 2, 54; $P > 0.05$) or over time among the three sampling periods ($F = 0.44$; df = 2, 54; $P > 0.05$).

The overall mean index of dispersion, 1.595, was found to be significantly greater than one ($t = 11.8$, df = 51; $P < 0.05$), indicating that StCB's occurred in a clumped distribution. The change in the index of dispersion over time decreased (population became less aggregated) as the season progressed ($F = 8.6$; df = 2, 43; $P < 0.05$; early season slope = $0.818 \pm 0.22$; middle season slope = $0.622 \pm 0.076$; late season slope = $-0.096 \pm 0.194$). The index of dispersion was affected by plot shape ($F = 3.99$; df = 1, 43; $P < 0.05$; long: $I = 1.55$, square: $I = 1.71$). The above results suggest that: 1) field plot shape does not affect the overall beetle densities which colonize a field, 2) colonization rate is independent of field shape and time of year in the spring in Maine, 3) beetles have a high degree of aggregation, as measured by the index of dispersion, upon initial colonization, but the degree of colonization decreases through time as beetles spread out within the plot, and 4) plot shape affects the degree of dispersion, square plots having a significantly higher degree of aggregation than narrow plots.

DaCosta and Jones (1971) first suggested that an aggregation pheromone might play a role in the characteristic sudden attack by StCB's, since many beetles were found to aggregate on single seedlings. Howe et al. (1976) also mentioned this possibility in the case of southern corn rootworm, Diabrotica undecimpunctata howardi Barber and western corn rootworm, Diabrotica
Fig. 1. Colonization of long and square plots during (A) 26-39 June, (B) 3-6 July, and (C) 16-20 July 1990. Solid line is regression for long plots and dashed line is regression for square plots.
virgifera virgifera LeConte. Raemisch and Turpin (1984) found no evidence of the production of aggregation pheromones by western corn rootworm actively feeding on freshly sliced high cucurbitacin-containing fruits of Cucurbita foetidissima or dried powdered fruits of high-cucurbitacin containing hybrid fruits of Cucurbita andreana x C. maxima. Guss et al. (1982) identified a female-produced sex pheromone of western corn rootworm, which was found to be a powerful attractant to males of western corn rootworm and northern corn rootworm, Diabrotica barberi Smith & Lawrence. While evidence of StCB pheromones has yet to be detected, early season sex ratios of 3:1 male:female (Lewis et al. 1990) and at least 1.5:1 male:female (Elsey 1988) imply attraction of males to females. No further investigations have explored this as a mechanism of mass attack. Nevertheless, the aggregative nature of StCB’s is a potentially useful attribute for control with a trap crop. The plot shape influence on aggregation, at least at the spatial scale that we studied the phenomenon should be incorporated as a design variable in a trap crop control practice.

**Soil texture experiments.** Beetle abundance was not affected by soil texture treatment in the first experiment conducted in 1990 \( (F = 6.32; \text{df} = 1, 9; P > 0.05) \). Similar results were obtained in the second soil texture experiment. There was no effect of soil texture \( (F = 0.46; \text{df} = 1, 1509; P > 0.05) \), but higher numbers of beetles were found on squash \( (F = 21.45; \text{df} = 1, 1509; P < 0.05) \). A significant plant by soil texture interaction \( (F = 12.14; \text{df} = 1, 1509; P < 0.05) \) was observed, with squash on unpulverized soil having the greatest number of beetles over time (Fig. 2).

The importance of the soil habitat, particularly when plants are in the small seedling stage in the spring, has been emphasized by Jewett (1927), who observed mating pairs in soil crevices. This is also a time when oviposition rate is high (Elsey 1988). Although manipulation of soil surface texture does not consistently affect where beetles are found in regards to plant species, the C. maxima cultivar (‘Sweet Mama’) used in the present studies was colonized by more StCB’s than cucumber when tested in the field, and this effect was enhanced when soil texture was in a crusty state.

**Trap crop field test.**

**First trial experiment.** Treatment differences over the season were found in numbers of beetles per plot \( (F = 8.77; \text{df} = 2, 6; P < 0.05; \text{Fig. 3a-c}) \). There were differences between cucumber and unsprayed plots and between cucumber and neem oil-sprayed plots, but not between unsprayed and neem oil-sprayed plots. Mean (± SD) number of beetles per plot, summed over the entire sampling period were 18.3 (± 15.7), 619 (± 353.1), and 412.4 (± 364.9), in 100% cucumber, 50% squash without neem oil, and 50% squash with neem oil treatments, respectively. This suggests that the presence of a trap crop in a plot either attracted beetles regionally from outside the plot boundaries or held beetles in the plots with trap crops longer so that the emigration rates in plots with trap crops was significantly less than the 100% cucumber plots.

The effect of spray treatments among the six plots containing the trap crop was measured by looking for enhancement in the ratio of beetles per squash plant to beetles per cucumber plant. A significantly higher ratio in the sprayed treatment would indicate an influence on host selection. Significant differences in beetles per plant for the spray treatments were not found over the entire
duration of the experiment ($F = 0.03; \text{df} = 1.64; P > 0.05$) or on any single day, even immediately following a spray treatment date ($P > 0.05$). The mean number of beetles per plant species in each treatment for each sample date is shown in Figs. 3a-c. Since spray treatments had no effect, each mixed plot was treated as a block containing both squash and cucumber for testing species preference of StCB. Significant differences ($P < 0.05$) were found on 8 of 11 sample dates, while a significant block effect occurred on only one date, indicating an even distribution of beetles on the farm. Beetles initially colonized squash plants and the majority remained on them throughout the 18-d sampling period when beetles were present (Fig. 4). The horizontal dotted line in Fig. 4 indicates the level at which equal numbers of beetles per plant occurred on squash and cucumber. Thus, the trap crop planting at a 50:50 ratio was effective in attracting and retaining the majority of colonizing beetles over the duration of the experiment.

*Second trial: 85% cucumber - 15% squash.* Treatment differences were found in the number of beetles per plot ($F = 7.13, \text{df} = 2, 6; P < 0.05$; Figs. 5a-c). Differences were not found between the single row pattern and the group of three row pattern, or between the all cucumber and group of three row pattern. However, a significant difference was found between the single row pattern and the all cucumber treatment ($P < 0.05$). Mean number ($\pm \text{SD}$) of beetles per plot, summed over the entire sampling period were 111.6 ($\pm 39.8$), 171.9 ($\pm 47.4$), and 249.4 ($\pm 46.8$) in 100% cucumber, group of three-row pattern, and single-row pattern treatments, respectively. Since a significant difference was not found between the cucumber and one of the squash treatments, it appears that a
Fig. 3. Beetles per plant in: A) 100% cucumber plots, B) 50% squash/50% cucumber without neem oil, and C) 50% squash/50% cucumber with neem oil. Error bars are standard errors.
Fig. 4. Percent of beetle population in 50% squash/50% cucumber plots on squash plants. Horizontal dotted line indicates equivalent densities of beetles on cucumber and squash which would be expected if there was no preference for squash. Error bars are standard errors.

potential exists for selecting a ratio of trap crop which does not result in higher densities of beetles per plot, but still aggregates the beetles on the attractive trap crop.

The effect of the planting pattern treatments among the six 15% squash plots was measured by looking for enhancement of the ratio of beetles per squash plant to beetles per cucumber plant. Significant differences were not found cumulatively, or on any single day ($F = 0.5; \text{df} = 1, 34; P > 0.05$). The mean number of beetles per plant species is shown in Figs. 5a-c. Since planting pattern treatments had no effect, each mixed plot was treated as a block containing both squash and cucumber for testing species preference of StCB’s. Significant differences were found on the first three sampling dates ($P < 0.05$), but following this, beetles became more evenly distributed over both plant species ($P > 0.05$). Colonization occurred suddenly and it was apparent at the first sampling that beetles had already colonized the plots, since severe feeding damage was observed on squash plants on the day prior to the first sampling. This suggests that greater than 70% of beetles were on squash prior to Julian day 197 (Fig. 6). The horizontal dotted line in Fig. 6 indicates the level at which equal numbers of beetles per plant occurred on squash and cucumber.

The results of these experiments suggest potential for the use of a squash trap crop for control of StCB on cucumber in that: 1) StCB’s exist in a highly aggregated distribution, which makes it biologically feasible to concentrate beetles on a small number of highly attractive plants, 2) preference for $C. \text{maxima} \ cv.$
Fig. 5. Beetles per plant in: (A) 100% cucumber plots, (B) 15% squash single row arrangement, and (C) 15% squash grouped row arrangement. Error bars are standard errors.
Fig. 6. Percent of total beetles in 85% cucumber/15% squash plots on squash plants. The horizontal dotted line indicates equivalent densities of beetles on cucumber and squash. Error bars are standard errors.

'NK530' was demonstrated in cages in the greenhouse and in the field, and 3) squash plants demonstrated the ability to concentrate StCB in trap plots.

In all three experiments in which squashes and cucumbers were planted together, including the soil texture experiment (Fig. 7), the majority of beetles initially colonized squash plants (86% of beetles in 50% squash plots, 70% of beetles in 15% squash plots, 90% of beetles in 50% squash soil-texture plot), which demonstrates the strong attractiveness of squash to colonizing beetles. Regional attractiveness of squash was clearly demonstrated in the 50% squash experiment: while no substantial feeding damage was seen in any of the 100% cucumber plots until Julian day 164, populations in the 50% squash plots were peaking on this date (Fig. 3). Vandermeer (1989) proposed that the concentration of trap crop should not be so high as to become a regional attractant, lest the infestation spill over onto the commercial crop. Such a situation was reduced greatly in 15% squash plots compared with 100% cucumber control plots. The difference in beetle numbers between the single row trap and the three row trap could be due to the concentration of the trap crop within a plot. If a difference in the size of individual areas devoted to the trap crop was responsible for this, then the group of three row pattern would be expected to have greater beetle density over time than the single row pattern. One-way analysis of covariance (planting arrangement as factor, time as covariate) demonstrated that the proportion of the total number of beetles in 15% squash plots found on squash plants over time was similar ($F = 0.21; \text{df} = 1, 32; P > 0.05$), which suggests that the size of the squash resource did not influence its ability to concentrate StCB's for a sustained period.
Another factor which may affect the ability to concentrate beetles is the overall length of interface between squash and cucumber plants. It has been suggested that borders of other plant species may affect StCB abundance in polyculture studies (Bach 1980) and patch size studies (Bach 1988 a,b). In the 15% squash experiment, the single row treatment had four times the length of squash/cucumber interface as the group of three row treatment, yet there was no difference in attractiveness of squash plants over time. The late-season soil texture experiment was a 50% squash/50% cucumber plot and when compared with the early-season 50% squash/50% cucumber plots, squash plants in the late season experiment were colonized by the majority of beetles for only 8 d (Fig. 7) while colonization lasted for at least 18 d in the early season experiment (Fig. 4). Since the lengths of the squash/cucumber interfaces were virtually the same (46.75 m in late season experiment, 45 m in early season experiment), this difference in beetle density over time is consistent with the lack of any such relationship between the two 15% squash planting arrangements.

Differences in the ability to concentrate beetles may be explained by the influence of temperature on activity. Movement is often affected by ambient temperatures. Lewis et al. (1990) reported highest StCB abundance on flats of squash plants and greatest amount of StCB flight activity when the temperature was over 18°C. Bach (1988a) found a difference in pattern of StCB abundance early and late in the season, with a change in movement behavior hypothesized as the reason. Since mean temperature ranges of the sampling
periods of the trap crop experiments differed (50% squash: 9.8° - 26.1°C; 15% squash: 15.4° - 31.8°C), the higher temperature during the 15% squash experiment may have influenced movement in these plots. A strong positive correlation (r = +0.89) was found between the change in number of beetles per squash plant and mean temperature on the prior date (Radin 1992). Since the critical time for control of StCB's is during the colonization of the first cucumber crop of the season when temperatures are lower, the pest may be less likely to spread itself onto the commercial crop. Even so, application of an insecticide to the trap crop to prevent infestation of the commercial crop may be necessary before the StCB population reaches a maximum.

Strong regional attractiveness of the trap crop was responsible for barely detectable populations in 100% cucumber plots in the spring of 1991, although a minority of beetles were found on cucumber plants in plots containing squash trap crop. While it could be argued that control of StCB's on cucumber was not achieved in these mixed plots, the spatial scale at which such a strategy is used commercially makes it feasible; a highly attractive trap crop in a large field of cucumbers would be expected to draw the majority of a StCB population to the vicinity of the trap crop, and density would be expected to decrease with distance from the trap crop. Isolated populations would not be expected on cucumber unless the trap crop was located beyond the range of detection of colonizing beetles. Furthermore, if a cucumber crop was growing on the experimental farm in the absence of a trap crop, there is no reason to believe that beetles would leave the farm while a suitable cucumber host was available. Thus, it can be assumed that the presence of the squash trap crop reduced the overall number of beetles per cucumber plant by concentrating beetles in the vicinity of squash plants.

The greater relative attractiveness of the single row treatment over the group of three row treatment of the 15% trap crop experiment may be due to the spatial manner in which StCB's colonize a resource patch. The arrangement in which beetles are most likely to encounter the trap crop may result in the most attraction. In order to characterize this, data from 100% cucumber plots of the 50% trap crop experiment were used in an analysis of covariance. Sub-subplot data were classified as either of two levels of a field location factor: "edge" refers to the 12 sub-subplots which border the edge of the plot; "center" refers to four sub-subplots which are at the center of the plot. No difference was found in the numbers of edge-colonizing and center-colonizing beetles over time in 100% cucumber plots (F = 0.29; df = 1, 189; P > 0.05). Therefore, colonization may be associated with the probability of encountering an attractive host, rather than the probability of encountering the edge of a plot. For this reason, the use of dispersed strips of the trap crop may result in a higher abundance of colonizing beetles on squash. An added benefit of this planting arrangement is the ease of its incorporation into a commercial cropping system.

The key components of a functional trap crop are 1) inherent biological potential for the use of a trap crop; 2) strong host preference for the trap crop over the commercial crop; and 3) ability of the trap crop to hold the pest population for at least a period of time in which it can be concentrated in a small area for the purpose of control. Striped cucumber beetles aggregate to a high degree, which makes their concentration on a trap crop feasible. Their
highly specialized host finding and feeding makes them vulnerable to a strongly attractive trap crop. Host preference for *C. maxima* cv. 'NK530' was clearly demonstrated in the greenhouse and the field. The effectiveness of the trap crop to concentrate StCB's was demonstrated, and found to be related to temperature. Thus, the successful use of a trap crop strategy has high potential early in the season, when StCB's have the greatest impact on cucumber production.

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