Numerical Responses of Natural Enemies to Artificial Honeydew in Utah Alfalfa

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ABSTRACT Artificial honeydews were applied to alfalfa plots in field experiments during the second (1992) and third (1991 and 1992) crops in northern Utah. Individual plots received a single application of sucrose dissolved in water; protein supplement and water; sucrose, protein supplement, and water; or water alone. Sweep samples were taken for entomophagous arthropods over a period of 4 d (second crop) or 10 d (third crop) after treatment spray applications. Application of sucrose, but not of protein supplement, resulted in reduced densities of aphids (relative to those in plots sprayed with water only). Adult lacewings and lady beetles consistently responded positively to application of sucrose. Lacewings during the second and third crops in 1992 and lady beetles during the third crop in 1991 also responded positively to application of protein supplement, with greatest densities occurring in plots sprayed with both materials. Positive responses to application of sugar by adults of the alfalfa weevil parasitoid, *Bathyplectes curculionis* (Thomson), and adult hover flies, bigeyed bugs, and minute pirate bugs (but not spiders or adult damsel bugs) were also detected in one or more experiments. None of these groups, however, responded consistently or clearly to application of protein supplement. In the absence of rain, positive responses by particular natural enemies to sugar, protein supplement, or both, persisted for up to 7 d after application. Our experimental results add to those of previous research indicating that local populations of a variety of entomophagous insects, including parasitoids with non-aphid hosts, can be increased in crops by application of artificial honeydew.

KEY WORDS alfalfa, artificial honeydew, biological control

ARTIFICIAL HONEYDEWS applied to crops have proved useful in attracting and retaining predatory insects that exploit honeydew as a supplemental food source (Hagen 1986). Hagen et al. (1971) developed an effective artificial honeydew for field use by mixing sucrose and protein supplement with water; variations on this basic mixture have been used on various crops to attract and retain adult lacewings, lady beetles, hover flies, and other predators (Butler & Ritchie 1971; Ben Saad & Bishop 1976a,b; Hagen et al. 1976; Nichols & Neel 1977; Tassan et al. 1979; Neuenschwander & Hagen 1980). Sucrose alone, dissolved in water, has also been used successfully to concentrate adult lady beetles and lacewings in treated crops (Ewert & Chiang 1966, Schiefelbein & Chiang 1966, Carlson & Chiang 1973). The degree to which protein supplement and sucrose act together in additive or synergistic fashion in retaining large numbers of predators has been relatively little studied (but see Hagen et al. [1971, 1976]; Nichols & Neel [1977]). Furthermore, only limited results for predators other than lacewings and lady beetles have been reported in field studies with artificial honeydew.

We have therefore engaged in field experiments in which sugar or protein supplement, or both, mixed with water have been applied as artificial honeydew in factorial fashion to plots in crop alfalfa grown for hay. Our studies were conducted in northern Utah, where pea aphids, *Acyrthosiphon pisum* (Harris) (Aphididae), occur regularly in moderate to large numbers in alfalfa; these aphids and their honeydew serve as important sources of nutrition for numerous arthropod natural enemies (Davis et al. 1976, Evans & Youssef 1992). We report here on the responses of abundant groups of predators in our alfalfa plots (as sampled by sweep net) to these treatments. We also examine the response to artificial honeydew by a parasitoid wasp, *Bathyplectes curculionis* (Thomson), a host-specific enemy of the alfalfa weevil, *Hypera postica* (Gyllenhal) (Curculionidae). With the exception of a parasitoid of hover flies noted by Hagen (1986), responses of parasitoids have not been reported by previous researchers in field studies of artificial honeydew. We have built on previous re-

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search by sampling our plots repeatedly over a period of up to 10 d after application of artificial honeydews, to assess whether and how treatment effects vary over time.

Materials and Methods

The study was conducted in an alfalfa field farmed by Utah State University in Logan, UT. The 4-ha field (seeded in 1989) was representative of cultivated alfalfa fields of northern Utah and was cut three to four times each year to harvest hay for dairy cows. Three similar experiments were conducted in the field; these were conducted in August 1991 and June and August 1992. For each experiment, 24 plots were used as experimental units. They were laid out in the northern half of the field as four rows by six columns; the alfalfa in these plots grew as a thick stand with few weeds or grasses present. Individual plots were rectangular, measuring 10 by 12 m, with 10 m separating adjacent plots (both in rows and in columns).

In partial compensation for any subtle spatial variability that might exist in the plant or insect community, the study area was considered as two sets of 12 plots (columns 1–3 versus columns 4–6) when treatments were assigned to individual plots. Each plot within a set of 12 was then assigned randomly to receive one of four treatments, yielding a total of six replicate plots per treatment for the experiment as a whole. The treatments consisted of a single application of an artificial honeydew or water alone (using a 9.5-liter hand sprayer with fine mist) at the start of each experiment. In particular, the treatment applications were as follows: sucrose dissolved in water; protein supplement and water; sucrose, protein supplement, and water; and water alone.

In August 1991, the artificial honeydew was prepared just before spraying by mixing 75 g of sucrose or 50 g of Wheast (obtained from Dadant and Sons, Hamilton, IL), or both, per liter of water; 1.5 liters were applied to each plot. Hagen et al. (1971) and subsequently other researchers have used Wheast as a protein source in artificial honeydews; Wheast is a dairy product that contains whole yeasts and their milk whey substrates (Hagen et al. 1976). Wheast was not available in 1992; in substitution we used a protein hydrolysate of brewer's yeast (Ardamine PH, obtained from Champlain Industries, Clifton, NJ). Previous research indicated that Wheast and the hydrolysate of brewer's yeast function very similarly as sources of nitrogen and amino acids in artificial honeydew (Hagen et al. 1976). For June and August 1992 experiments, the artificial honeydews were prepared by mixing 150 g of sucrose or 50 g of protein hydrolysate of brewer's yeast, or both, in 1 liter of water. During each period, 2 liters of artificial honeydew mixture or water alone was sprayed on each plot. Our mixtures of water, sugar, and protein supplement were similar in percentage composition to those of previous researchers, although considerable variability among honeydew field trials exists (e.g., Tassan et al. [1979] used 92 g sucrose per liter of water, whereas Hagen et al. [1976] used 350–700 g sucrose per liter of water).

In each of the three experiments, treatments were applied to plots on a clear, calm day. On the days following, insect samples were taken from each plot between 1000 and 1130 (August 1991), 1200 and 1500 (June 1992), and 1330 and 1600 (August 1992) h. On each sampling occasion (exact days of sampling after treatment application varied among experiments), predators were sampled by taking 15 sweeps of 180° with a net (38 cm diameter) through the upper canopy of the alfalfa in each plot. After 15 sweeps, the contents of the net were transferred to a plastic bag, chilled, and taken to the laboratory, where they were frozen until identified and counted. Because plots were sampled repeatedly over the course of each experiment, sweep samples were taken from new north–south transects through each plot on each sampling occasion; sampling on successive occasions was rotated among transects taken through the eastern, central, and western third of each plot.

In 1991, treatments were applied on 13 August. Sweep samples were then taken on 14, 15, 17, 20, and 23 August (i.e., on days 1, 2, 4, 7, and 10 after the treatments were applied). The alfalfa was in the third crop of the season (it had been cut most recently in mid-July) and stood 30–40 cm tall during the experiment. The weather was generally clear and warm (30°C at midday) throughout the experiment, with the exception of a brief, light rain in the afternoon of 16 August. In the first experiment in 1992, treatments were applied on 23 June. Sweep samples were taken on days 1, 2, and 4 (24, 25, and 27 June); the weather was clear and warm (25–27°C) during sampling. Sampling was discontinued thereafter after a heavy rain on 28 June. The alfalfa was in the second crop (it had been cut most recently in late May) and stood 40–50 cm tall during the experiment. In the second experiment in 1992, treatments were applied on 3 August. Sweep samples were taken on days 2, 4, 7, and 10 (5, 7, 10, and 13 August); again, the weather was clear and warm (30–35°C) during sampling in this experiment. The alfalfa was in the third crop (it had been cut most recently in early July) and stood 45–65 cm tall during the experiment.

Sweep samples were processed in the laboratory in 1991 by counting the number of adult individuals belonging to the following seven groups of entomophagous insects: (1) lady beetles (Coccinellidae; the most common species were *Hippodamia convergens* Guerin–Meneville, *H. quinquesignata* [Kirby], *H. sinuata* Mulsant, *Coccinella transversoguttata richardsoni* Brown,

and the recently introduced *C. septempunctata* L.); (2) lacewings (Chrysopidae; *Chrysoperla plorabunda* [Fitch] sensu lato [Henry et al. 1993] and *Chrysopa oculata* Say); (3) minute pirate bugs (Anthocoridae; *Orius tristicolor* White), and (4) bigeyed bugs (*Geocoris* spp., Geocorinae, Lygaeidae). In addition, adults of the following groups were counted in 1992 sweep samples: (5) damsel bugs (Nabidae; *Nabis americoferus* Carayon and *N. alternatus* Parshley) (Roe 1986); (6) hover flies (Syrphidae); and (7) the weevil parasitoid *Bathyplectes curculionis* (Ichneumonidae) (Hamlin et al. 1949). Finally, individuals of an eighth group, spiders, were also counted in 1992 samples. Only adult entomophagous insects were counted, because these individuals had greatest power to disperse and thereby respond to the experimental treatments during the sampling period. The number of pea aphids (all stages combined) was also determined for each sweep sample in 1992 experiments and for sweep samples taken in control plots in August 1991.

Statistical Methods. Results for individual groups in a given experiment (e.g., lady beetles in August 1991) were analyzed using repeated measures analyses of variance, with application of sugar or protein supplement serving as treatments in a 2 × 2 factorial design (PROC ANOVA; SAS Institute 1988). Individual plots were designated as the experimental units, with a blocking effect incorporated into the statistical design to reflect that equal numbers of plots were assigned to a treatment in each half of the study area (see above description of the spatial arrangement of plots). Before analysis, counts were log transformed [$ln(N+1)$] to reduce heterogeneity in variances. When significant interactions of treatments with date were detected, differences between treatments on individual sampling dates were tested for significance using Tukey's standardized range test (which controls for Type I experimentwise error rate; $\alpha = 0.05$). In a few cases, insufficient numbers of individuals of a given group were collected on one or more sampling dates to permit full analysis of date × sugar treatment × protein treatment. In these cases, either a repeated measures analysis was performed on the appropriate subset of the sampling occasions, or a two-way analysis of variance without repeated measures was performed on the combined results of several successive sampling occasions or on the results for a single sampling occasion for which sufficient individuals were sampled. In all cases, the P values reported are two-tailed.

Results

August 1991. Aphid populations were low in the study plots, averaging only three aphids per sweep throughout the experiment in control plots (the only plots sampled for aphids; means ± 1 SEM varied between 2.5 ± 0.4 and 3.7 ± 0.5 on individual dates). Adult lady beetles were present in moderate numbers at the outset, but densities of these predators dropped precipitously in all plots over the 10-d experimental period after treatment application (Fig. 1). Significantly larger numbers of lady beetles, however, occurred in plots with versus without sugar through day 7 (but not on day 10) after treatment application (Tukey's test; note the significant interaction of sugar treatment with date in Table 1). Lady beetles also responded positively to ap-

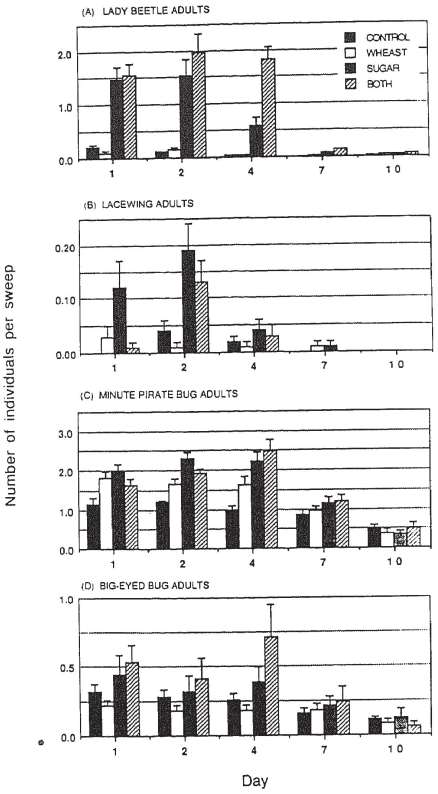

Fig. 1. Mean number of individuals per sweep (+1 SEM) in alfalfa plots treated with, from left to right, (1) water only (control), (2) Wheast, (3) sugar, and (4) Wheast + sugar (both), on each sampling day after treatment application in August 1991: (A) lady beetle adults, (B) lacewing adults, (C) minute pirate bug adults, and (D) bigeyed bug adults. Bar shadings for treatments for each insect group as illustrated for lady beetle adults (A).

Table 1. *P* values for effects of sucrose, protein supplement (Wheast), date of sampling, and their interactions, in two-way analyses of variance (with or without repeated measures) for log-transformed numbers of individuals [*ln*(*N* + 1)] of adult predatory insects per 15 sweeps in experimental plots in August 1991

Source of variation	df	Lacewings	Lady beetles	Minute pirate bugs	Bigeyed bugs
Block	1	—	—	—	—
Sucrose (S)	1	0.0001	0.0001	0.003	NS
Wheast (W)	1	0.050	0.017	NS	NS
S × W	1	0.050	0.008	NS	NS
Error a	19				
Date (D)	4	—	0.001	0.001	0.025
Error b	4				
D × S	4	—	0.0001	0.003	NS
D × W	4	—	0.030	NS	NS
D × S × W	4	—	0.034	0.004	NS
Error c	76				

NS: $P > 0.05$.

plication of protein supplement, such that the greatest numbers of adult lady beetles were recovered from plots treated with both sugar and protein supplement (Fig. 1; Table 1). In particular, significantly larger numbers of lady beetles occurred in plots with versus without protein supplement on days 4 and 7 (but not on other days) after treatment application (Tukey's test; note the significant interaction of protein treatment with date in Table 1).

Lacewing adults were uncommon in sweep samples taken from the experimental plots and had all but disappeared from the plots by day 7 after treatment applications (Fig. 1). An ANOVA restricted to combined sampling results for days 1, 2, and 4 revealed a positive response to application of sugar and a negative response to application of protein supplement (Table 1; Fig. 1).

Adult minute pirate bugs responded positively to the presence of sugar but not protein supplement. A significant interaction of sampling date with sugar treatment occurred (Table 1): significantly more bugs occurred in plots with versus without sugar on days 1, 2, and 4 after application, but not on days 7 and 10 (Fig. 1; Tukey's test). Densities of adult bigeyed bugs were also higher in plots with versus without sugar in the first week after treatment application (Fig. 1), but the results were only marginally significant ($P = 0.053$ for the effect of sucrose in the analysis reported in Table 1).

June 1992. Aphid densities were somewhat greater during the experimental period (Fig. 2) than they had been the previous August. Densities of these insects were significantly reduced (relative to densities on untreated plots) by application of sugar but not of protein supplement (Table 2). Reductions in aphid densities in plots with versus without sugar were particularly marked on days 2 and 4 after spray applications (Fig. 2).

As in August 1991, adult lady beetles responded strongly in positive fashion to application of sugar, but they did not exhibit a clear response to protein supplement (Fig. 2; Table 2). Lacewing adults were collected commonly in sweep samples in June 1992; they responded positively to both sugar and protein supplement, with particularly strong numerical response to application of both materials (Fig. 2; Table 2). There was a significant interaction of sugar treatment with date (Table 2): lacewing densities in plots treated with sugar increased dramatically over the 4-d experimental period (Fig. 2; Tukey's test: $P < 0.05$ on all dates for the effects of sugar treatment). This increase in densities likely reflects general attraction of lacewing adults from surrounding areas in response to presence of protein supplement in the experimental area (Hagen et al. 1976, Tassan et al. 1979).

Adult hover flies and adults of the alfalfa weevil parasitoid *B. curculionis* were captured in low numbers in sweep samples on all three sampling occasions (days 1, 2, and 4 after treatment applications; Figs. 2 and 3). ANOVAs for combined totals of adults on the three sampling dates revealed a positive response to sugar by both hover flies and weevil parasitoids, but no response to protein supplement, and no significant interaction between applications of sugar and protein supplement (Table 2).

Adult minute pirate bugs exhibited complex patterns of response to the honeydew treatments; significant interactions occurred between date of sampling and both sugar and protein supplement treatments (Fig. 2; Table 2). These predators were significantly less abundant in plots with than without sugar on day 1 after treatment application, but did not differ significantly in density on day 2 (Tukey's test). Greater numbers of individuals were collected from plots with versus without sugar on day 4 (Fig. 2), but the difference in mean densities was not quite significant (Tukey's test). Minute pirate bugs were also significantly less abundant in plots with versus without protein supplement on days 1 and 2, but did not differ significantly in density on day 4 after treatment (Tukey's test).

Adult bigeyed bugs responded to application of sugar, but not protein supplement. A significant interaction of sampling date with the sugar treatment occurred (Table 2), as significantly greater numbers of these predators occurred in plots with versus without sugar on day 4 but not on days 1 and 2 after treatment application (Fig. 2; Tukey's test). Adult damsel bugs were also common at the study site (Fig. 2). Densities of these predators in the experimental plots, however, were not affected by application of sugar or protein supplement (Table 2). Spiders were present in relatively low numbers (Fig. 2); ANOVA for combined totals of these predators

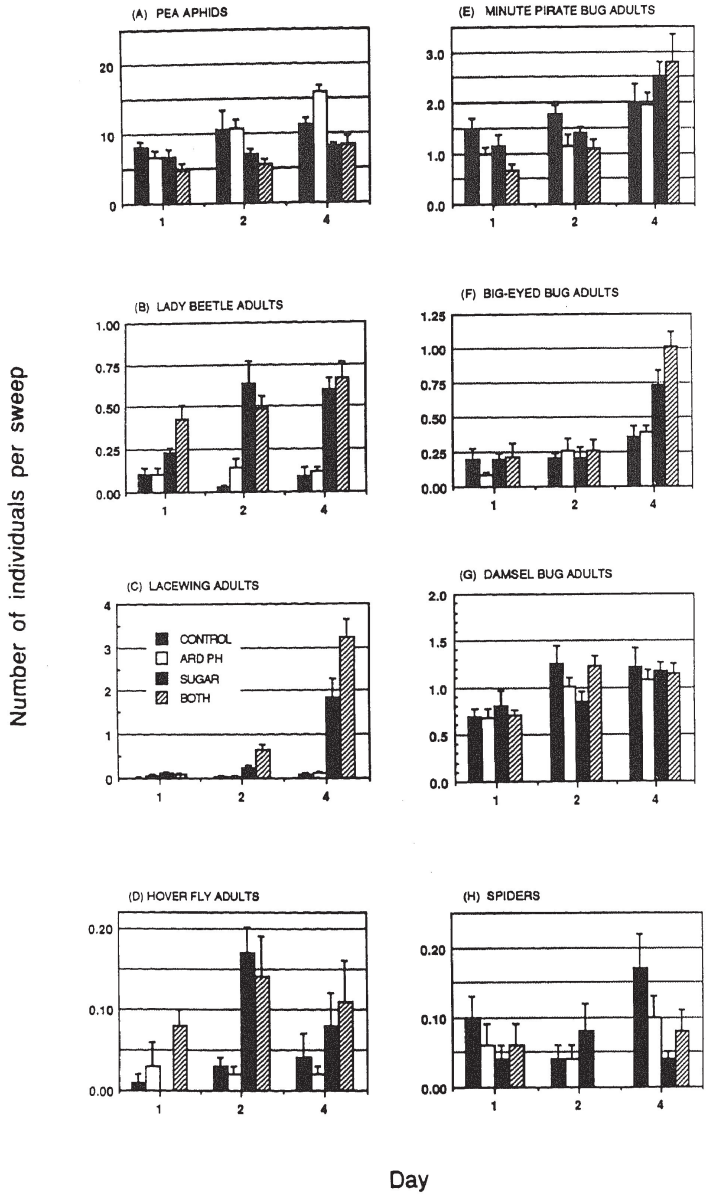

Fig. 2. Mean number of individuals per sweep (+1 SEM) in alfalfa plots treated with, from left to right, (1) water only (control), (2) ardamine PH (ard PH), (3) sugar, and (4) ardamine PH + sugar (both), on each sampling day after treatment application in June 1992: (A) pea aphids, (B) lady beetle adults, (C) lacewing adults, (D) hover fly adults, (E) minute pirate bug adults, (F) bigeyed bug adults, (G) damsel bug adults, and (H) spiders. Bar shadings for treatments for each group as illustrated for lacewing adults (C).

Table 2. *P* values for effects of sucrose, protein supplement (Ardamine PH), date of sampling, and their interactions, in two-way analyses of variance (with or without repeated measures) for log-transformed numbers of individuals [*ln*(N+1)] of aphids, adult entomophagous insects, and spiders per 15 sweeps in experimental plots in June 1992

Source of variation	df	Pea aphids	Lacewings	Lady beetles	Hover flies	Parasitoids[a]	Minute pirate bugs	Bigeyed bugs	Damsel bugs	Spiders
Block	1	—	—	—	—	—	—	—	—	—
Sucrose (S)	1	0.0001	0.0001	0.0001	0.0001	0.0011	NS	NS	NS	NS
Ard PH (A)	1	NS	0.013	NS	NS	NS	0.044	NS	NS	NS
S × W	1	NS	NS	NS	NS	NS	NS	NS	NS	NS
Error a	19									
Date (D)	2	NS	0.025	NS	—	—	0.005	0.05	0.05	—
Error b	2									
D × S	2	NS	0.0001	NS	—	—	0.005	0.033	NS	—
D × A	2	NS	NS	NS	—	—	0.016	NS	NS	—
D × S × A	2	NS	0.025	NS	—	—	NS	NS	NS	—
Error c	38									

NS: $P > 0.05$.
[a]*Bathyplectes curculionis* adults.

on the three sampling dates revealed no significant responses to sugar or to protein supplement.

August 1992. Very high densities of pea aphids were present during the experiment (Fig. 4). As in June, aphid densities were significantly reduced (relative to densities on untreated plots) by application of sugar but not of protein supplement (Table 3); densities were significantly lower in plots with versus without sugar on days 2 and 4 after treatment application, but not on days 7 and 10 (Tukey's test and Fig. 4; note the significant interaction of sugar treatment with date of sampling in Table 3).

The response of lady beetles to sugar varied over time (Fig. 4; note the significant interaction of date with sugar treatment in Table 3). On days 2 and 4 after treatment applications, lady beetle populations were significantly greater in plots with versus without sugar (Tukey's test; although the effect of protein supplement was not significant, greatest mean densities were again associated with plots sprayed with both sugar and protein supplement). The response to sugar treatment was reversed, however, by days 7 and 10 after treatment application, as lady beetles became significantly more numerous in plots not sprayed with sugar (Tukey's test; aphid densities in these plots had become high relative to densities in plots sprayed with sugar).

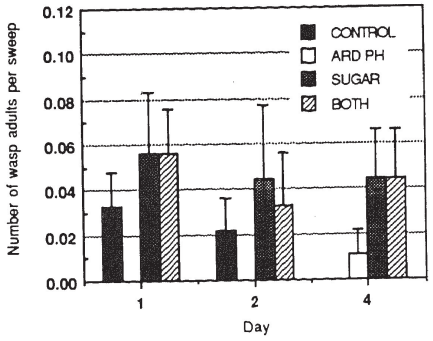

Fig. 3. Mean number of individuals of adult *Bathyplectes curculionis* (males and females combined) per sweep (+1 SEM) in alfalfa plots treated with, from left to right, (1) water only (control), (2) ardamine PH (ard PH), (3) sugar, and (4) ardamine PH + sugar (both), on each sampling day after treatment application in June 1992.

Lacewing adults also responded positively to application of both sugar and protein supplement (Table 3). Densities of these predators were relatively high on the first sampling occasion (day 2 after treatment application) and gradually declined thereafter (Fig. 4; Table 3). A significant interaction occurred between sampling date and sugar treatment (Table 3); lacewing densities were significantly greater in plots with versus without sugar on days 2, 4, and 7, but not on day 10 (Fig. 4; Tukey's test).

Meaningful numbers of adult hoverflies were captured in sweep sampling only on day 2 of the experiment (Fig. 4); ANOVA restricted to results from day 2 again revealed a significant, positive response to application of sugar but not protein supplement (Table 3). Too few adults of the alfalfa weevil parasitoid *B. curculionis* were recovered from sweep samples during the experiment to assess these insects' responses to the treatments.

Adult minute pirate bugs responded positively to sugar treatment, but this response was obscured by a complex interaction of sampling date × sugar treatment × protein supplement treatment (Table 3; Fig. 4). No response to application of sugar or protein supplement by adult bigeyed bugs, damsel bugs, or spiders was detected during the experiment (Table 3; Fig. 4).

Discussion

Previous researchers have probed especially the responses of adult lacewings and lady bee-

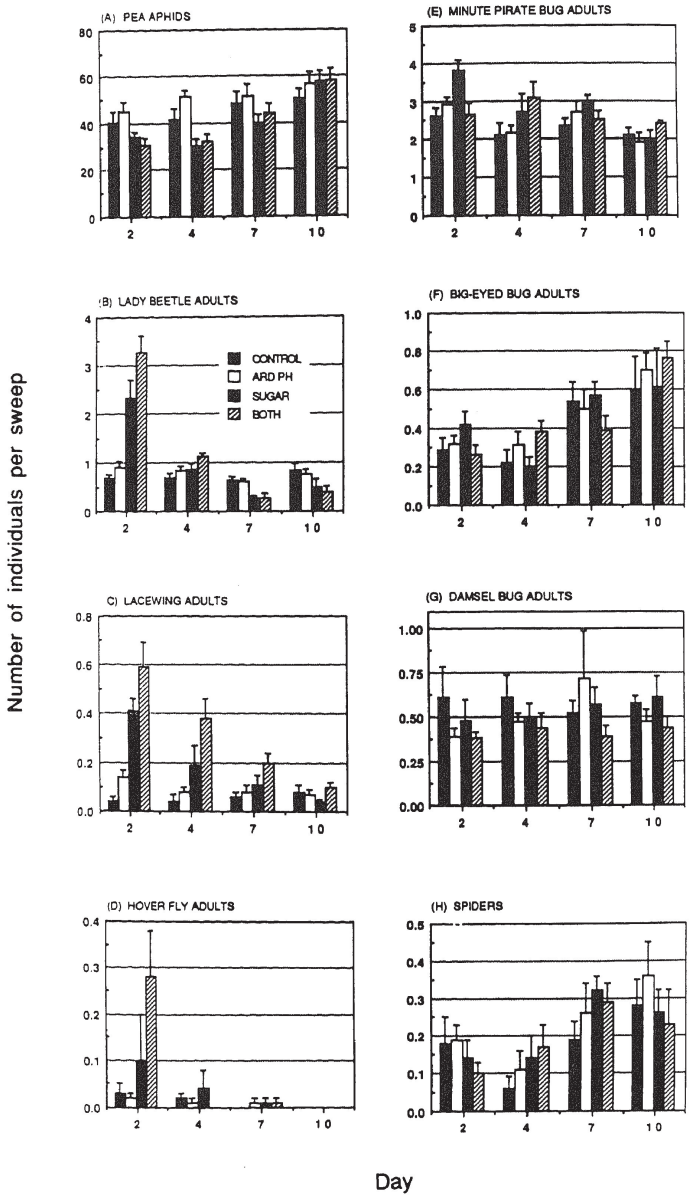

Fig. 4. Mean number of individuals per sweep (+1 SEM) in alfalfa plots treated with, from left to right, (1) water only (control), (2) ardamine PH (ard PH), (3) sugar, and (4) ardamine PH + sugar (both), on each sampling day after treatment application in August 1992: (A) pea aphids, (B) lady beetle adults, (C) lacewing adults, (D) hover fly adults, (E) minute pirate bug adults, (F) bigeyed bug adults, (G) damsel bug adults, and (H) spiders. Bar shadings for treatments for each group as illustrated for lady beetle adults (B).

Table 3. *P* values for effects of sucrose, protein supplement (Ardamine PH), date of sampling, and their interactions, in two-way analyses of variance (with or without repeated measures) for log-transformed numbers of individuals [$ln(N+1)$] of aphids, adult entomophagous insects, and spiders per 15 sweeps in experimental plots in August 1992

Source of variation	df	Pea aphids	Lacewings	Lady beetles	Hover flies	Minute pirate bugs	Bigeyed bugs	Damsel bugs	Spiders
Block	1	—	—	—	—	—	—	—	—
Sucrose (S)	1	0.013	0.0001	NS	0.0015	0.017	NS	NS	NS
Ard PH (A)	1	NS	0.0012	NS	NS	NS	NS	NS	NS
S × W	1	NS	NS	NS	NS	NS	NS	NS	NS
Error a	19								
Date (D)	3	0.05	0.025	0.005	—	0.05	0.005	NS	NS
Error b	3								
D × S	3	0.0013	0.0001	0.0001	—	NS	NS	NS	NS
D × A	3	NS	NS	NS	—	NS	NS	NS	NS
D × S × A	3	NS	NS	NS	—	0.033	NS	NS	NS
Error c	57								

NS: $P > 0.05$.

tles to application of artificial honeydews. Hagen et al. (1971) recorded spectacular increases in numbers of lacewing adults in alfalfa plots sprayed weekly or twice a week with protein supplement and sugar as compared with adjacent unsprayed plots; aphid densities were very low in the study fields during those experiments. In subsequent field experiments, lacewing densities were higher in plots sprayed with various protein supplements and sucrose than in plots sprayed with sucrose alone on both days 1 and 4 after spray applications; densities in the sucrose plots were in turn higher than in unsprayed plots (Hagen et al. 1976). Other field experiments, in which small plots of alfalfa were sprayed and insects were sampled by sticky traps attached to the exterior surfaces of screen cages placed over the plots, revealed that lacewings were attracted over long distances by the application of protein supplement (and in particular, tryptophan), but not by application of sucrose (Hagen et al. 1971, 1976). Population buildup of lacewings on alfalfa treated only with sugar therefore presumably resulted from simple arrestment of foraging individuals in these areas after contacting sugar on plant surfaces.

Butler & Ritchie (1971) found that densities of lacewing adults were consistently significantly greater in sprayed versus unsprayed plots of cotton when sampled 2 to 7 d after application of a mixture of Wheast, honey, and glycerine. Ben Saad & Bishop (1976a,b) also reported that lacewings responded positively to mixtures of sugar and Wheast sprayed on potatoes (furthermore, food sprays were particularly effective in concentrating lacewings when honey or molasses was added to the Wheast and sugar food spray). Schiefelbein & Chiang (1966) and Carlson & Chiang (1973) recorded significantly higher densities of lacewing adults on corn plants sprayed with a simple sugar solution than on unsprayed plants, but only when corn leaf aphid populations were low.

Our experimental results from June 1992 (the only period in our studies during which adult lacewings were abundant) are generally consistent with those of previous researchers. In particular, large numbers of lacewings apparently were attracted to the study area by application of artificial honeydew containing protein hydrolysate of brewer's yeast, and these adult lacewings responded positively both to the protein supplement and to sucrose, with greatest densities occurring in plots with prior application of both protein supplement and sucrose. Similar positive responses to protein supplement and sucrose were also apparent at low lacewing densities in August 1992; these responses were still evident a week after treatment application. It is unclear why the low number of lacewings present in August 1991 responded positively to application of sugar but not application of protein supplement (Wheast versus protein hydrolysate of brewer's yeast in 1992); pea aphids were present in relatively low numbers in the plots during this experiment (particularly as compared with August 1992).

Lady beetles have also been shown by previous research to be very responsive to food sprays of sucrose and protein supplement. Except when corn leaf aphids were present in high numbers, densities of *Hippodamia* spp. and *Coleomegilla maculata* (Degeer) were much greater on corn plants sprayed with sucrose solution than on unsprayed plants (Ewert & Chiang 1966, Schiefelbein & Chiang 1966, Carlson & Chiang 1973). Similarly, greater numbers of Coccinellidae occurred in experimental plots sprayed with protein supplement and sugar than in unsprayed plots in alfalfa (Hagen et al. 1971, 1976), potatoes (Ben Saad & Bishop 1976a), and corn (Nichols & Neel 1977). When Wheast and sugar were applied both in combination and separately to cotton plots, densities of *Coleomegilla maculata* were significantly greater in plots sprayed with

both Wheast and sugar than in other plots (Nichols & Neel 1977).

We found that with one exception, consistently higher numbers of adult lady beetles occurred in plots sprayed with sugar solution versus with water alone; the positive effects of sugar persisted for as long as 7 d after application. The exception occurred during the second half of the experimental period in August 1992, when lady beetles became most numerous in plots not sprayed with sugar, where aphid numbers were then higher than in sprayed plots. As did Nichols & Neel (1977), we also recorded significantly higher densities of lady beetles in plots sprayed with versus without protein supplement in August 1991, with highest densities in plots sprayed with both sugar and protein supplement.

Cage experiments indicate that lady beetle adults are not attracted by applications of protein supplement or sugar, or both, to alfalfa and cotton (Hagen et al. 1971, 1976; Nichols & Neel 1977); however, Ben Saad & Bishop (1976b) reported that greater numbers of adult lady beetles were trapped on cages placed over potato plots sprayed with honey, molasses, or tryptophan than on cages placed over unsprayed plants. Sugar and (on at least some occasions) protein supplement therefore presumably serve as arrestants in concentrating adult lady beetles in plots sprayed with artificial honeydew (see also Carter & Dixon [1984], who demonstrated that natural aphid honeydew serves as an arrestant for coccinellid larvae).

Of the other predators sampled in our experiments, none responded consistently or clearly to application of protein supplement. Adult hover flies, bigeyed bugs, and minute pirate bugs responded positively to application of sugar in one or more experiments. Previous researchers have reported positive responses of adult hover flies to application of protein supplement and sugar combined (Hagen et al. 1971, Ben Saad & Bishop 1976a). Bigeyed bugs appeared to be attracted to artificial honeydews incorporating sugar, protein supplement, honey, or aphid juice when sprayed on potatoes (Ben Saad & Bishop 1976b). These predators did not occur in greater numbers, however, in plots sprayed with a mixture of sugar and protein supplement than in unsprayed plots in alfalfa (Hagen et al. 1971) or in cotton (Butler & Ritchie 1971). Similarly, Ben Saad & Bishop (1976a) found that minute pirate bugs did not occur in greater numbers in potato plots sprayed with artificial honeydews containing sugar than in unsprayed plots. But both bigeyed bugs and minute pirate bugs have been observed feeding at flowers and extrafloral nectaries (Yokoyama 1978, Bugg et al. 1987) and therefore might be expected to respond positively to application of sugar on at least some occasions.

We detected no numerical responses of spiders or adult damsel bugs to application of either protein supplement or sugar in our experiments. Damsel bugs also failed to respond positively to spray applications of sugar and protein supplement in alfalfa (Hagen et al. 1971) and cotton (Butler & Ritchie 1971), but were reported to respond positively to spray applications of sugar, Wheast, and honey or molasses on potatoes (Ben Saad & Bishop 1976a, see Table 1) and have been recorded feeding at flowers (Bugg et al. 1987). Spiders have not been reported upon in previous studies of artificial honeydew.

Hagen (1986) reported that a common parasitoid of aphidophagous hover flies, *Diplazon laetatorius* (Fab.) (Ichneumonidae), is attracted to the same food sprays containing protein supplements as are its hosts. With this single exception, previous researchers have not reported on the responses of parasitoids to applications of artificial honeydews. We found that the alfalfa weevil parasitoid *B. curculionis* responded positively to application of sugar solution. Thus, use of artificial honeydews may serve not only to concentrate numbers of predators that to varying degrees are aphidophagous, but also numbers of parasitoids that attack non-aphid hosts that feed in the same crops as aphids (see Evans [in press] for a review of parasitoid use of naturally occurring honeydew).

In summary, our experimental results add to those of previous researchers in illustrating that artificial honeydews can be applied to crops to aggregate large numbers of a variety of entomophagous insects, from primarily aphidophagous predators (lacewings, lady beetles, and hover flies) to more general predators (minute pirate bugs and bigeyed bugs; Salas–Aguilar & Ehler 1977, Crocker & Whitcomb 1980) to host-specific parasitoids such as *B. curculionis*. Other entomophagous insects responded positively to sucrose, but only lacewings and lady beetles responded clearly in positive fashion to protein supplement in at least one experiment. The aggregation of predators in response to application of sucrose or protein supplement, or both, was associated with immediate reduction in densities of pea aphid populations in treated plots. Longer-term suppression of aphid numbers in these plots seems likely as well, because reproduction by lacewings, and to a lesser degree lady beetles (when aphids are also present in moderate numbers), is enhanced by spray application of protein supplement (Hagen et al. 1971, Hagen 1986). The effects of a single spray application on numbers of adult predators can be long-lasting in the absence of rain (effects may persist for up to 7 d application), although the strength of these effects is influenced by local densities of aphids and associated levels of naturally occurring honeydew.

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