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Author(s): Jessica Honaker , Sarah Skrivanek , Juan Lopez , Dan Martin , Leo Lombardini , L. J. Grauke and Marvin Harris

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Blackmargined Aphid (*Monellia caryella* (Fitch); Hemiptera: Aphididae) Honeydew Production in Pecan and Implications for Managing the Pecan Aphid Complex in Texas

Jessica Honaker[1], Sarah Skrivanek[1], Juan Lopez[2], Dan Martin[3], Leo Lombardini[4], L. J. Grauke[5], and Marvin Harris[6]

Abstract. The blackmargined aphid, *Monellia caryella* (Fitch), was studied on three cultivars, 'Cheyenne', 'Kiowa', and 'Pawnee', of pecan, *Carya illinoinensis* (Wangenh.) K. Koch, in the field. Abundance of aphids and natural enemies (lacewings, ladybird beetles, and spiders) was determined twice weekly by directly inspecting foliage on each pecan variety during the summers of 2005 and 2006. Water-sensitive cards were used to measure honeydew deposited. Aphid phenologies were similar among pecan cultivars; however, Cheyenne supported more aphids than did Kiowa or Pawnee. Honeydew production was directly correlated with aphid abundance. Abundance of natural enemies increased during initial stages of aphid outbreak on all pecan cultivars, and the asymptote reached on Cheyenne exceeded the action level of 25+ aphids per leaf. Cheyenne had a lower natural enemy-to-aphid ratio than did the other cultivars, indicating that the functional response of natural enemies to increased aphid abundance was exhausted sooner on Cheyenne than on other cultivars where aphid abundance did not exceed the action level. Honeydew seems to be an attractant for natural enemies, and cost-benefit was calculated to quantify the loss of photosynthates to aphids versus the gain in natural enemies on each pecan cultivar. Cheyenne was the least efficient of the three cultivars in the utilization of this defense mechanism. The energy drain per hectare was calculated using aphid density and by measuring honeydew; data showed the energy drain on Cheyenne was 4-8 fold greater than that on Kiowa or Pawnee by using either method. Conversions of energy drain estimates to nut-equivalents indicated Cheyenne suffered economic damage that warranted treatment whereas Kiowa and Pawnee did not. These results suggested that moderately abundant blackmargined aphids efficiently attracted natural enemies with little risk of economic damage to the crop.

[1]Entomology Graduate Student, Texas A&M University, College Station, TX 77843
[2]Research Entomologist, USDA ARS APMRU, College Station, TX 77845
[3]Research Engineer, USDA ARS APMRU, College Station, TX 77845
[4]Associate Professor, Horticulture, Texas A&M University, College Station, TX 77843
[5]Research Scientist, USDA ARS Pecan Breeding & Genetics, Somerville, TX 77879
[6]Professor Emeritus, Entomology 2475, Texas A&M University, College Station, TX 77843
[6]Corresponding Author

Introduction

The blackmargined aphid, *Monellia caryella* (Fitch), yellow pecan aphid, *Monelliopsis pecanis* Bissell, and black pecan aphid, *Tinocallis caryaefoliae* (Davis), comprise the aphid complex on pecan, *Carya illinoinensis* (Wangenh.) K. Koch, foliage (Tedders 1978). They are autochthonous on pecan in North America and often are the target of insecticide application in commercial orchards (Harris 1983, Ree et al. 2006). Wood et al. (1987) reported individual energy requirements and growth efficiencies for blackmargined aphid (301 J, 5%), yellow pecan aphid (36.1 J, 18%), and black pecan aphid (44.8 J, 25%) and documented that most energy was accounted for in the excreted honeydew. They concluded based on an extrapolation of energy requirements to presumed population dynamics generated for inter-specific comparisons that blackmargined aphid was the aphid species that most limited pecan production. Examination of aphid population dynamics in the field showed blackmargined aphid had greater fecundity earlier in the growing season (Liao and Harris 1986, Mansour and Harris 1988), had a greater intrinsic rate of increase, outbreaks earlier with mixed species in closed cages and in the field where it recruits natural enemies (Li 1990, Bumroongsook and Harris 1992), and decreases following an outbreak to leave the foliage photosynthetically intact compared to the other two species of aphid (Bumroongsook and Harris 1991) that defoliate. These characteristics typify the interaction between blackmargined aphid and pecan regardless of the cultivar, but susceptibility seems to vary greatly among cultivars (Thompson and Grauke 1998, Thompson et al. 2000). Collectively, the field studies showed that within the pecan aphid complex, blackmargined aphids outbreak earlier, infest the foliage for a shorter period of time, occur in lesser numbers, recruit natural enemies, and leave the foliage intact following an epidemic compared with yellow pecan aphid or black pecan aphid. Nevertheless, blackmargined aphid is the least growth efficient and greatest individual energy consumer of pecan photosynthate within the pecan foliar aphid complex (Wood et al. 1987), and profligate excretion of honeydew is evident as shiny spots on the foliage even when <1 aphid per leaf. Is it possible that blackmargined aphid has been co-opted by the pecan to be the first aphid to outbreak and produce honeydew when natural enemy abundance begins to decrease in early summer?

Honeydew attracts such natural enemies as Coccinellidae (*Hippodamia* spp., *Hyperaspis* spp., *Harmonia* sp., and *Olla* spp.), Chrysopidae (*Chrysopa* spp., *Chrysoperla* spp., and *Micromus* spp.), and Araneae (>25 spider families, >180 species), which are among the most important predators of the pecan aphid complex (Harris and Li 1996). Spiders are ubiquitous in pecan systems and exhibit a rapid functional response to prospective prey but have a slow numerical response to greater aphid abundance (Bumroongsook et al. 1992). Lacewings and lady beetles are more rapacious feeders than spiders, although the detectable abundance of these predators is less than that of spiders when aphids are scarce (Bumroongsook et al. 1992; Liao et al. 1984, 1985). These findings suggest that: 1) honeydew from blackmargined aphid attracts natural enemies in pecan systems (Bumroongsook and Harris 1992, Harris and Li 1996), and 2) selection for this character in a pecan breeding program may discover cultivars that maximize natural enemy attraction while limiting the economic threat by aphids. The relationships among blackmargined aphid abundance, honeydew excretion, damage potential, and natural enemy abundance were examined on pecans in the field to better understand how these factors relate to pecan production.

Materials and Methods

Orchards, Cultivars, and Sampling Aphids and Natural Enemies. The pecan cultivars 'Cheyenne', 'Kiowa', and 'Pawnee' (four-tree replications) were studied in an orchard (30°44'N, 96°33'W) near Mumford, TX, in 2005. The study site was relocated in 2006 to an orchard (30°36'N, 96°33'W) near Caldwell, TX, with Cheyenne and Kiowa represented as four-tree replications, and Pawnee consisting of a two-tree replication. This unplanned change of study location was necessitated by a change of ownership of the orchard in early 2006. In both seasons, no aphicide was applied, and 10 compound leaves, each consisting of ~10 leaflets, facing each of the four cardinal directions (North, South, East, and West) were monitored 2-3 times weekly for numbers of adult and immature aphids and natural enemies on each tree of the selected cultivars. The leaves were on the sunlit periphery of the canopy, within reach of the researcher. Aphid species was determined by adult phenotype (blackmargined aphid at rest holds wings parallel to the substrate, yellow pecan aphid holds wings roof-like over the body; and black pecan aphids are distinctively black in color). The natural enemies were spiders (recorded as 'spider' regardless of whether it was an immature or an adult), lacewings (identified to Order and recorded as egg, larva, pupa, or adult), and ladybird beetles (Coccinellidae, recorded as egg, larva, pupa, or adult).

Honeydew Collection and Measurement. Honeydew deposited was measured two or three times each week when relative humidity was <80%; each tree was sampled using four 26 x 76-mm Teejet Water and Oil Sensitive Paper cards (Spraying Systems Co., Switzerland) mounted into four evenly spaced depressions cut into a 23 x 15.25-cm corrugated cardboard holder. A stable and standard placing for each holder was provided by a wooden platform (25 x 16 cm) of pine boards affixed with a double-ended screw to a 46-cm dowel (1.3-cm diameter) that affixed the platform to the tree. Each wooden platform housed one cardboard water-sensitive paper card holder. The holder fit over a 5-cm screw inserted through the bottom of the platform, and was secured by a nut to immobilize the platform. Platforms were placed directly under the canopy in sampled trees and avoided overhanging limbs or voids in the canopy so falling honeydew could be intercepted directly. Double-stick tape was used to place water-sensitive cards in the holders left for measured periods of time (~2 hours) on each sampling date during the period of interest (~3 months).

Honeydew droplets appeared as blue spots on the yellow water-sensitive cards; the color differential allowed scanned cards to be analyzed for honeydew volume by using DropletScan® software (WRK, Inc. and Devore Systems, Inc.). This provided output in gallons per acre (later converted to liters per hectare) on a per-card basis during the time the cards were exposed. The mathematical derivations of the volumetric analyses were obtained through the manufacturer's calibration of the proprietary software designed to quantify and qualify droplets of insecticide deposition from aerial application and unavailable to the researcher.

Aphid honeydew consists primarily of water and sugars (Auclair 1963). We also tested whether the sugars in a droplet of honeydew affected the way a fixed volume of fresh liquid spread on the water-sensitive cards compared to the spread that occurred when the same fixed volume was applied in a water-only droplet. Solutions of water alone and water containing 5 and 10% sucrose were prepared and sprayed onto the cards by using a spinning disc that produced droplet sizes comparable to the honeydew observed in the field. Cards were analyzed using

DropletScan; spread factors were determined for each treatment, and a regression equation was generated for use in reconciling the honeydew volume (spot) reported by DropletScan with the volume that would have occurred had only water been present (Martin, Daniel, unpublished). These analyses allowed us to convert the quantification the manufacturer obtained with DropletScan®-derived measures based on water to obtain a more exact quantification of honeydew per unit area.

Energy Drain. Estimated energy removal by blackmargined aphid during the 2006 growing season was calculated using aphid density data. The numbers of aphid adults and nymphs were plotted against sample date, and adult and nymphal aphid-days per leaf were determined for each cultivar for the 2006 season: one adult (or nymph) on one leaf for one day = one aphid-day (Southwood 1966). The total adult and nymph aphid-days per leaf for each cultivar was divided by 14.1 or 3.15 (half the adult or nymph longevity period, respectively, as reported by Tedders (1978)) to provide an absolute estimate for the number of blackmargined aphids per leaf during the season; this was converted to per-hectare data by using a multiplier of $1.5*10^6$ leaves per hectare (from Cutler (1976) and Lozano et al. (1992) who measured ~3 million leaves per hectare, which was corrected to 50% canopy coverage). The absolute estimate of aphid abundance for the 2006 growing season was analyzed using the data from Wood et al. (1987) to calculate the energy removed by aphids.

Energy removal was estimated based on measurements of honeydew volume for the 2006 season. Honeydew volume by pecan cultivar was obtained directly from the water-sensitive cards in the canopy. The honeydew reaching the cards was analyzed using DropletScan software to determine liters per hectare, and corrected for the spot size difference caused by sugar content. A correction also accounted for the filtering effect of leaves that intervened between the top of the canopy and the card surface. Leaf area index (LAI) was measured with a LiCor 2000 (LI-COR, Lincoln, NE) at noon in full sunlight to measure the density of leaves by sunlight filtering through the canopy of the sample trees. The LAI ranged from 3-5 indicating 20 to 33% of the leaves occurred in the lower canopy with their abaxial surface (and aphids) directly over the water-sensitive cards; the filtering effect that occurred with honeydew emanating from infested leaves higher in the canopy was estimated by considering three leaf layers above the lower canopy, with each layer intercepting ~50% of the honeydew produced in the next higher canopy layer. Thus, the honeydew produced in the top canopy layer would be reduced by ~50% at each of the next three lower canopy levels, so 12.5% of the total would reach the ground (=cards); similarly, 25% of the honeydew from the second and 50% from the third canopy layer would reach the ground. Because blackmargined aphids are distributed throughout the canopy (Edelson and Estes 1983), we estimated that 50% of the total honeydew produced was detected using the water-sensitive cards. Honeydew volume in liters per hectare was plotted for each cultivar by sample date and interpolated for each cultivar to determine the total volume of honeydew (in liters) produced in the 2006 growing season.

The honeydew volume in liters per hectare per year reported by DropletScan was multiplied by a factor of 0.61 per liter to account for the larger spot size observed because of an estimated sugar content of 8.2% in aphid honeydew (Auclair 1963). The corrected liters-per-hectare volume of honeydew multiplied by 0.082 derived kilograms of sugar per hectare, which was doubled to correct for the filtering effect, was used to calculate the energy in the honeydew. Auclair (1963) estimated that aphids excreted about 50% of the sugar ingested from photosynthates, so doubling the energy in honeydew provides an estimate of the total photosynthate energy removed by the blackmargined aphid. The caloric value of the photosynthates, as calculated previously using honeydew volume and aphid abundance, was converted to grams of nut tissue by using the Harris et al. (1996) value of 11.15 Kcal/g.

Statistical Analyses. Number of aphids or natural enemies per leaf were converted to numbers per hectare based on estimates of leaves per hectare (Cutler 1976, Lozano et al. 1992, Harris and Li 1996). All numerical data were analyzed using SPSS statistical software (Chicago, IL); Kruskal-Wallis test examined significance among the three cultivars, and the Mann-Whitney U test was used when comparing any two of the three cultivars.

Results

Blackmargined aphid was the dominant aphid. Yellow pecan aphid and black pecan aphid constituted <1% of the remaining aphids during the period of interest and are not addressed further in this paper.

Cultivar Ratings. *Aphid Density.* Abundance of blackmargined aphids increased in June in both years, with initiation on Cheyenne, followed by Kiowa and then Pawnee (2006 data shown, Fig. 1). Peak abundance of blackmargined aphid on the Cheyenne variety was consistently greater and sustained longer than on Kiowa, which maintained slightly fewer blackmargined aphid than did Pawnee throughout the sampling period. The distinct bimodal aphid density on Cheyenne was ascribed to brief, heavy rains that occurred from 16-21 June 2006 in the orchard. Peak bimodal aphid densities per leaf were observed in 2006 on Cheyenne (28.5 on 13 June and 20.5 on 12 July) and Kiowa (2.94 on 20 June and

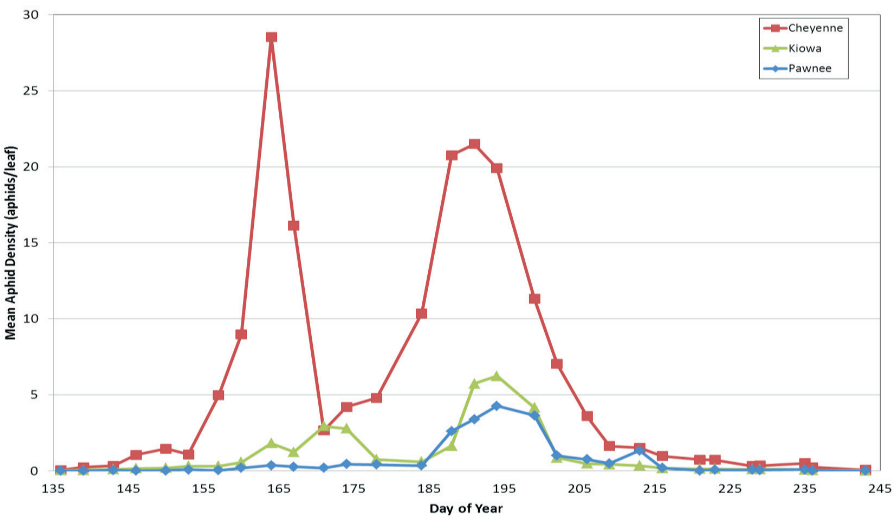

Fig. 1. Mean abundance of blackmargined aphid during the 2006 growing season on three pecan cultivars near Caldwell, TX.

6.23 on 13 July), and a unimodal peak on Pawnee (4.26 on 13 July). The recommended action level for blackmargined aphid is 25-30 per leaf, which was reached only on Cheyenne during the 2006 season.

Honeydew Collection. The volume of honeydew collected per cultivar peaked early in the growing season in 2005, with the relationship in honeydew deposition being Cheyenne > Kiowa > Pawnee (not shown). In 2006, similar patterns were found to those in 2005, with a greater volume of honeydew collected from Cheyenne than from the other two pecan varieties (Fig. 2).

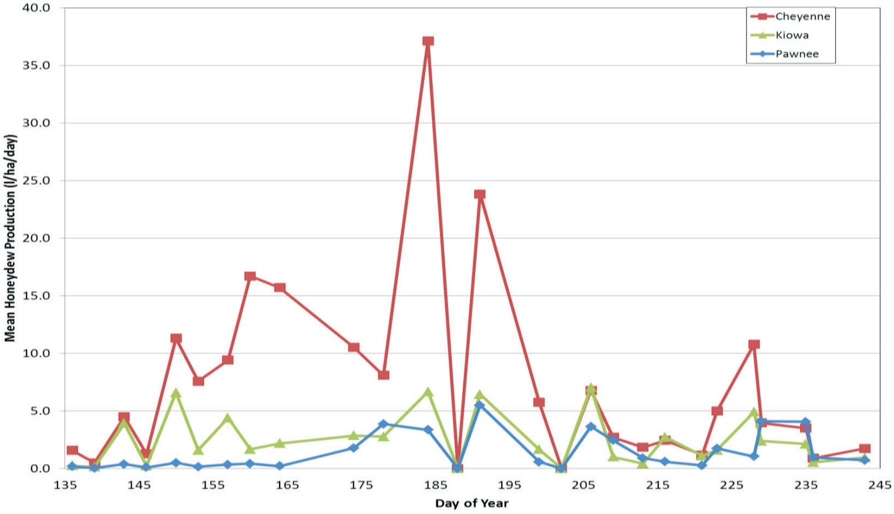

Fig. 2. Mean honeydew production of aphids during the 2006 growing season on three pecan cultivars near Caldwell, TX.

Honeydew per Aphid. Honeydew produced on a per-aphid basis did not differ significantly among the three cultivars in either year, with the exception of Cheyenne versus Pawnee in 2006 (Table 1), which was ascribed to the few aphids on Pawnee. The direct correlation between aphid abundance and honeydew volume indicated that cultivar differences in aphid abundance stem from differences in reproduction and survival rather than feeding activities.

Table 1. *P* Values of Honeydew Volume Produced per Aphid among Pecan Cultivars for the 2005 and 2006 Growing Seasons

Pecan cultivar	2005	2006
Cheyenne vs. Kiowa	0.827	0.114
Cheyenne vs. Pawnee	0.073	0.020*
Kiowa vs. Pawnee	0.168	0.443

*indicates a significant difference ($p < 0.05$) in measured parameters.

Aphid and Natural Enemy Abundance and Honeydew Collection. *Aphid Abundance and Honeydew Volume.* Significantly more aphids and honeydew were found on Cheyenne than on Kiowa or Pawnee (Table 2). Aphid abundance and honeydew did not differ significantly between Kiowa or Pawnee in either season.

Table 2. *P* Values of Mean Honeydew Production and Aphid Abundance Compared Among Pecan Cultivars during the 2005 and 2006 Growing Seasons

	2005		2006	
Pecan cultivar	Mean honeydew production (L/ha/day)	Mean aphids/ha	Mean honeydew production (L/ha/day)	Mean aphids/ha
Cheyenne vs. Kiowa	0.027*	0.001*	<0.01*	<0.01*
Cheyenne vs. Pawnee	<0.01*	<0.01*	0.001*	0.002*
Kiowa vs. Pawnee	0.069	0.082	0.403	0.069

*indicates a significant difference ($p < 0.05$) in measured parameters.

Natural Enemy Abundance. Abundance of natural enemies (lacewing eggs and larvae, ladybird beetles, and spiders) was monitored throughout the sampling period among the three pecan varieties. Relative mean spider abundance during the growing season did not significantly differ between 2005 and 2006. Mean abundances of lacewing eggs, lacewing larvae, and ladybird beetles were not significantly different in 2005 but were in 2006 (Table 3). Natural enemy abundance fluctuated with aphid abundance (Fig. 3).

Natural Enemy Abundance by Taxa. Spiders were the most abundant natural enemy, followed by lacewing (larvae) and ladybird beetles (adults and larvae) (Fig. 4). The ratio of natural enemies to aphids varied by both pecan cultivar and year.

Spiders ($p < 0.05$ for all cultivars) per aphid differed significantly among cultivars in 2005; in 2006, spiders per aphid on Cheyenne and Kiowa differed significantly, but abundance on Pawnee did not differ significantly from that on Cheyenne or Kiowa. In 2005, the number of lacewing eggs but not larvae or ladybird beetles differed significantly among pecan cultivars for all cultivar comparisons. In 2006, abundance of lacewing eggs differed significantly between

Table 3. *P* Values of Measured Parameters for Three Pecan Cultivars (‘Cheyenne’, ‘Kiowa’, and ‘Pawnee’) during the 2005 and 2006 Growing Seasons

Parameter	2005	2006
Mean aphid density	<0.01*	<0.01*
Mean honeydew volume	<0.01*	<0.01*
Mean spider density	0.382	0.477
Mean lacewing egg density	0.725	<0.01*
Mean lacewing larva density	0.406	<0.01*
Mean lady beetle density	0.524	0.003*

*indicates a significant difference in measured parameters.

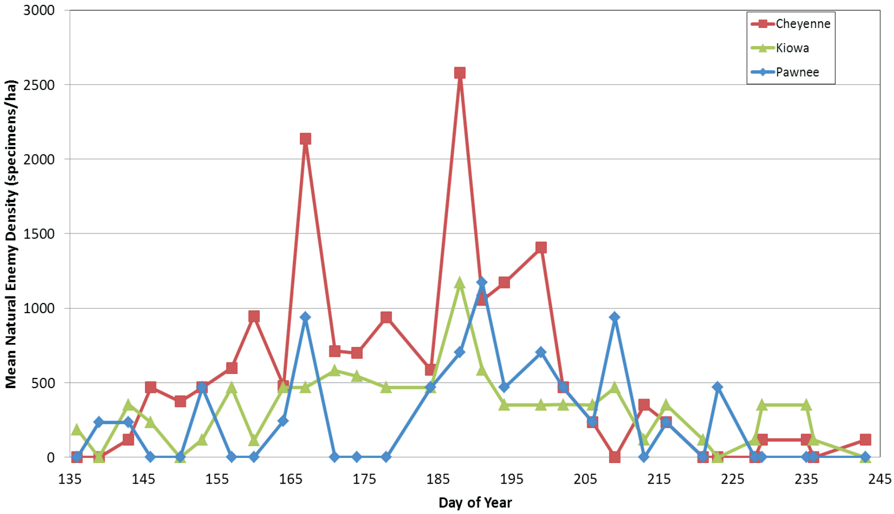

Fig. 3. Mean number of natural enemies per hectare for three pecan cultivars during the 2006 growing season.

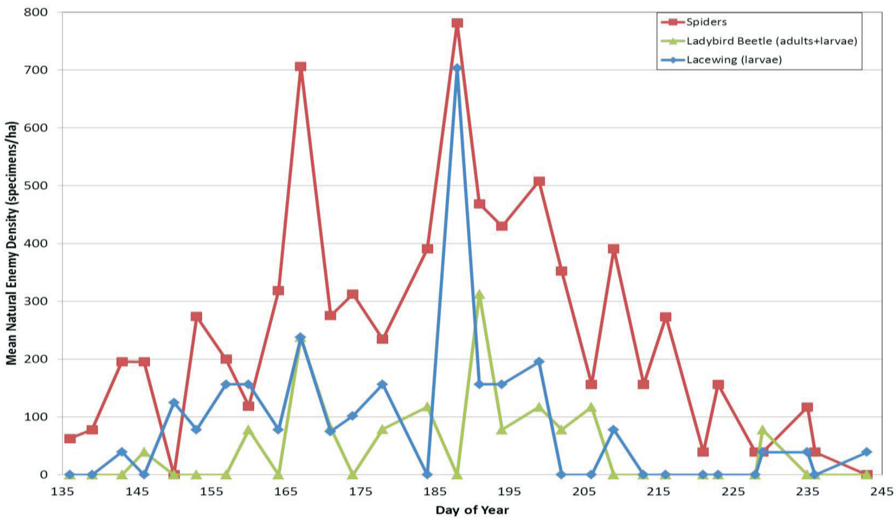

Fig. 4. Incidence of natural enemies by taxa on pecan cultivars during 2006.

Cheyenne and Kiowa, ladybird beetles differed significantly between Cheyenne and Kiowa and between Cheyenne and Pawnee, and lacewing larvae differed among all three pecan cultivars (Table 4). Overall, aphids were more abundant in 2006 than in 2005.

Table 4. *P* Values of Natural Enemy-to-aphid Ratios on Pecan Cultivars during the 2005 and 2006 Growing Seasons

Pecan cultivar	Lacewing egg	Lacewing larva	Ladybird beetle	Spider
		2005		
'Cheyenne' vs. 'Kiowa'	<0.01*	0.657	1.00	0.030*
'Cheyenne' vs. 'Pawnee'	<0.01*	0.417	0.417	<0.01*
'Kiowa vs. 'Pawnee'	0.014*	0.209	0.369	<0.01*
		2006		
'Cheyenne' vs. 'Kiowa'	0.017*	0.031*	0.022*	<0.01*
'Cheyenne' vs. 'Pawnee'	0.057	<0.01*	0.021*	0.342
'Kiowa vs. Pawnee'	0.961	0.047*	0.790	0.107

*indicates a significant difference in measured parameters

Natural Enemies by Date. Measured parameters (aphid density, honeydew volume, and natural enemy densities) by sample dates during the 2005 and 2006 growing seasons were compared to data taken on the same day grouped from all three cultivars with data from other sampling dates. In 2005, there was no significant difference in any of the parameters during the sampling period, except relative abundance of spiders, which differed significantly between 23 June and 1 August from the rest of the season. In 2006, there was no significant difference in the parameters when the cultivar data were combined by date, except spider densities from other natural enemies, which were significantly greater on six of the sampling dates between 13 June and 4 August. The greater abundance of spiders results in a faster functional response to prey, but modest voracity for aphid prey (Bumroongsook et al. 1992) limits their ability to prevent an outbreak of aphids.

The aphid-to-natural enemy ratios for the 2006 season were 201, 63, and 48 for Cheyenne, Kiowa, and Pawnee, respectively. A plot of the mean natural enemy-to-aphid ratios by sampling date showed Pawnee was greatest, followed by Kiowa, with Cheyenne having the fewest natural enemies per aphid during the season particularly during periods of aphid outbreak when rapid increases in abundance seemed to overwhelm the natural enemies (Fig. 5). The earlier onset and longer duration of the aphid outbreak on Cheyenne compared to other cultivars in 2006 (Fig.1) was characterized by a much lower natural enemy-to-aphid ratio throughout the outbreak. Bumroongsook and Harris (1991, 1992) also showed the blackmargined aphid exerts a conditioning effect on the infested foliage that progressively limits the suitability of the infested leaves to support further infestation. The aphid/natural enemy dynamics observed in 2006 are consistent with a relative conditioning effect being weakest in Cheyenne, followed by Kiowa and then Pawnee that, together with natural enemies, may explain the duration and degree of the outbreak experienced on each cultivar.

Energy Drain. The average aphid days per leaf for adult and nymph blackmargined aphid on each cultivar were calculated using the methods in Southwood (1968) and converted to absolute estimates of the number of adults and nymphs completing their development on each leaf of Cheyenne, Kiowa, or Pawnee, respectively (Table 5). Wood et al. (1987) reported the energy drain caused by each blackmargined aphid life stage, and these were used to calculate the joules per leaf removed based on the respective abundance of the aphids from each cultivar. The equivalent sugar loss was calculated by converting joules per leaf to kilograms of sugar per hectare (16,702 joules = 1 g of sugar; 1.5×10^6 = leaves per hectare).

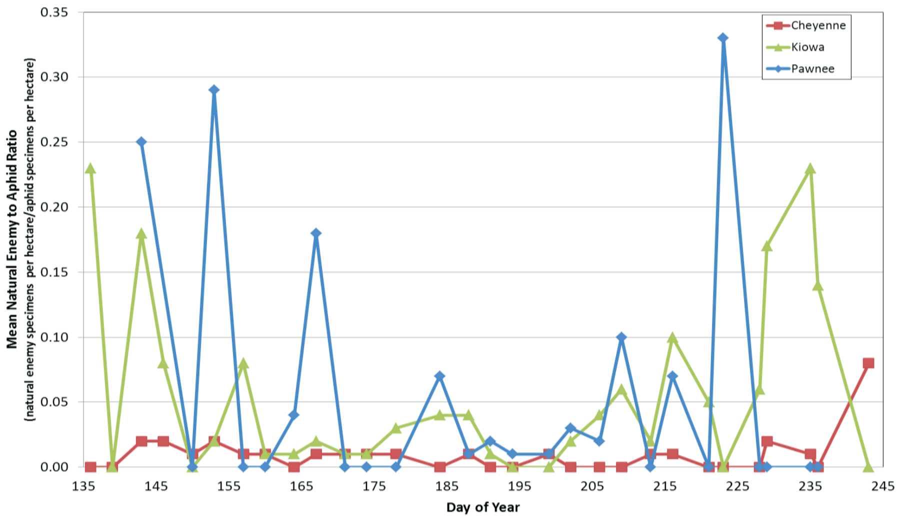

Fig. 5. Mean number of natural enemies per aphid on Cheyenne, Kiowa, and Pawnee pecans near Caldwell, TX, during 2006.

Table 5. Impact of Blackmargined Aphid, *Monellia caryella*, on Three Pecan Cultivars Measured in Two Ways Using Aphid Density and Honeydew in the 2006 Season

	Absolute estimated aphid density/leaf[1]		Energy impact estimates/ha			
			Aphid density data[2]		Honeydew data[3]	
Pecan cultivar	Adult	Nymph	Joules/leaf	Kg sugar/ha	L/ha/yr	Kg sugar/ha
Cheyenne	9.1	156	12,592	1,181	1,084	91
Kiowa	2.0	23.2	1,936	182	269	22
Pawnee	1.3	14.0	1,177	110	155	13

[1]The number of aphid days was determined for each cultivar to estimate the absolute density of aphid adults and nymphs per leaf (see Southwood 1968).
[2]Aphid/leaf data were used to calculate the energy drain caused by adults and nymphs using procedures in Wood et al. (1987), and the results were combined to estimate the overall aphid impact based on aphid density.
[3]The honeydew data collected using DropletScan were corrected for sugar content and the filtering effect of overlapping foliage using the leaf area index data (see text).

The tests of the 0, 5, and 10% sugar solutions showed equivalent volumes of sugar produced relatively consistent and larger spots on the water-sensitive cards than did water alone. Thus, DropletScan measures of honeydew were overestimating honeydew volume. Honeydew was estimated to contain 8.2% sugar and, based on the Martin tests (unpublished), a DropletScan measure of 1 liter of honeydew was actually 0.61 liter per hectare. Thus, the honeydew volume in liters per hectare per year reported by DropletScan was multiplied by a factor of 0.61 per liter. The corrected liter-per-hectare volume of honeydew multiplied by 0.082 derived kilograms of sugar per hectare, which was doubled to correct for the filtering effect, was used to estimate the amount of sugar in the honeydew (Table 5).

Comparison of the estimated sugar removal based on aphid abundance by using energy equivalents provided by Wood et al. (1987) with the direct measurements of honeydew collected by the water-sensitive cards shows aphid density always provided about a nine-fold greater estimate of sugar removal than did the honeydew data (Table 5). The honeydew measurements account only for aphid excretion and are expected to underestimate the energy removed. Auclair (1963) estimated that aphids excrete about 50% of the sugar ingested from photosynthates, so doubling the energy in honeydew can be used to estimate the total photosynthate energy removed by the blackmargined aphid. A doubling of the sugar data derived from honeydew shows the sugar removal estimates based on aphid density were then ~5-fold greater than those from honeydew. These measurements should agree in so far as they both are attempts to measure the same impact of the blackmargined aphid on these pecan cultivars.

Discussion

Blackmargined aphid abundance and honeydew production consistently varied among cultivars and were correlated. Cheyenne was very susceptible to the blackmargined aphid, and Pawnee was among the least susceptible of commercial pecan cultivars (Thompson et al. 2000), which was also found in this study. Kiowa was consistently intermediate in aphid abundance and honeydew production so the degree of susceptibility to blackmargined aphid could be determined by a relative ranking of the three cultivars when aphids were present. Honeydew measurements could be used to determine relative susceptibility to blackmargined aphid in a pecan population of unknown susceptibility during an infestation.

The population dynamics of the blackmargined aphid among the three cultivars showed the interaction with Cheyenne exceeded the 25 aphids per leaf action level on one occasion, while aphid abundance on Kiowa and Pawnee did not reach this action level during the 2006 season. The action level has been used for decades as a guide for if and when to apply an aphicide in IPM programs. However, correlating this action level with real economic loss is problematic because the blackmargined aphid is an indirect pest of the pecan fruits, which constitute the human-valued resource. Infestation by aphids removes photosynthate in mid-season that is otherwise destined to contribute to a multitude of plant products of which only a small portion is thought to be dedicated to fruit production; the actual amount of this photosynthate channeled for fruit production is unknown, and we used an estimate of 10% in this paper to evaluate the action level of 25 aphids per leaf. Harris and Chung (1998) estimated that a gram of mature fruit tissue represented 11.15 Kcal for the pecan to produce from photosynthate; thus, the sugar equivalents in kilograms per hectare (Table 5) can be converted simply to mature fruit equivalents per hectare. This calculation results in the blackmargined aphid removing 41.1, 6.3, and 3.8 kg per hectare of fruit equivalents based on energy losses using aphid density measurements for Cheyenne, Kiowa, and Pawnee, respectively, and 6.3, 1.5, and 0.9 kg per hectare using honeydew measurements (these are doubled to convert back to photosynthate). In-shell pecans in 2011 were priced at ~$6 per kilogram at the farmgate, so Cheyenne had a potential maximum estimated loss of $247 per hectare from blackmargined aphid, which may have been prevented had a standard $50 per hectare aphicide been applied when aphid abundance reached the action level; the remaining fruit loss estimates do not result in expected losses >$50 per hectare, and thus a treatment would exceed the benefit expected from it.

A decision to treat blackmargined aphid during the June/July period when abundance exceeded the action level of 25 aphids per leaf on Cheyenne seemed to be warranted if the greatest estimate of expected damage were chosen and no other costs were incurred as a result of this action during the season. The expected cost ($50 per hectare) would presumably conserve most of the expected loss of the 41.1 kg of fruit tissue to provide a maximum benefit of $197 per hectare ($247 in yield minus the $50 management cost) if only the Cheyenne were treated; if the other cultivars were also treated, then the benefits would be less because the management costs for them were not compensated by economic benefits). This estimated net benefit to Cheyenne production represents a presumed protection of 3.3% of a 1,000 kg-per-hectare average yielding crop; this is challenging to empirically demonstrate because of the small difference between a treatment and control and the intrinsic variability inherent in pecan yield tests in the field. An additional factor that should be considered is the effect that reducing the abundance of blackmargined aphid has on natural enemies. This and previous work showed natural enemy abundance increases as a blackmargined aphid outbreak commences and the natural enemies persist when aphids decrease in abundance. The increase and persistence in abundance of natural enemies associated with an aphid outbreak in the pecan canopy also provide some protection from other potential pests and can on occasion obviate the need for additional treatments later in the season. This retrospective analysis of the current data suggests that the action level of 25 aphids per leaf is useful as a decision aid and treatment of Cheyenne may have conserved sufficient yield to justify the cost of treatment; not treating less-infested cultivars also seems justified.

The correlation between aphid abundance and honeydew production combined with the direct link between honeydew and photosynthate production offers new opportunities for additional work. A pecan physiologist may find the aphid a useful intermediary to remove specific amounts of photosynthate at specific times to investigate downstream effects on other physiological processes of pecan. Measuring honeydew requires less time and effort than does directly counting aphids, and use of the former may allow a pecan breeder to more efficiently evaluate large numbers of pecan cultivars for susceptibility to blackmargined aphids.

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