Early Spring Occurrence of *Empoasca* spp. (Hemiptera: Cicadellidae) in and Adjacent to Alfalfa Fields in Iowa[1]

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Abstract Adult *Empoasca fabae* (Harris) (Hemiptera: Cicadellidae) were monitored at three locations within four alfalfa fields (edge of field to 40 m into field) from mid-April to June and *Empoasca* spp. activity from adjacent tree and shrub species until July. Similar numbers of *Empoasca* spp. adults were collected from sticky traps placed on tree and shrub species in the four border areas. In three of the four fields examined, significantly more *E. fabae* were found at the edges of the alfalfa fields closest to the trees than at 40 m from the edge of the field during the first week of May. In subsequent samples, there was no difference in the distribution of *E. fabae* in the alfalfa fields (except Field 2, where there were more *E. fabae* near the field edge for the duration of the study). Based upon this study, *Empoasca* spp. (primarily *E. fabae*) are colonizing alfalfa fields from the field margins to the interior in early spring and may be using adjacent woody habitats (including *Gleditsia*, *Prunus*, *Ulmus*, *Tilia,* and *Quercus* spp.) as a refuge when alfalfa is unsuitable.

Key Words potato leafhopper, *Empoasca fabae*, alfalfa, alternate hosts, spring migration, *Medicago sativa*

The potato leafhopper, *Empoasca fabae* (Harris) (Hemiptera: Cicadellidae), overwinters in states along the Gulf of Mexico on evergreens (Pinaceae) and herbaceous vegetation (mostly Fabaceae), and then migrates north in spring (Medler 1957, Sidumo et al. 2005, Taylor et al. 1993, Taylor and Shields 1995). The first appearance of *E. fabae* in the midwestern United States occurs in late April or mid-May (Maredia et al. 1998, Medler 1957). Arrival of *E. fabae* in these areas coincides with low-pressure weather systems, suggesting transport is passive on warm low-level jet streams (Carlson et al. 1992). In Pennsylvania, early-spring migrant *E. fabae* populations were nearly 80% fertile females that began ovipositing upon arrival in alfalfa fields (Flinn et al. 1990).

Empoasca fabae is a key pest of alfalfa (*Medicago sativa* L.) (Fabaceae) in the midwestern United States and usually begins to arrive in Iowa in late April, but peak arrival is not until mid- to late May (Medler 1957; L.W.E., pers. obs.). Although *E. fabae* are found in alfalfa at this time, populations do not reach damaging levels in

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alfalfa fields until after the first cutting (mid-May to early June) (DeGooyer et al. 1998a, Giles et al. 1999, Steffey and Armbrust 1991). The life cycle of *E. fabae* requires approximately 350 degree days (°C) to complete development from egg to adult (Flinn et al. 1986). Consequently, the period from peak arrival in early to mid-May until harvest in late May is insufficient time for eggs laid by migrating *E. fabae* to complete development into adults in alfalfa. Because alfalfa is a disturbed habitat due to several harvests each year, *E. fabae* may be viewed as a cyclic colonizer (*sensu* Wissinger 1997). Each harvest of alfalfa creates a temporary unsuitable habitat for *E. fabae,* which then moves out of alfalfa to alternate hosts and may return once alfalfa has begun to regrow. *Empoasca fabae* feeds on over 200 host species in 100 genera and 26 families, all in the class Magnoliopsida (Hogg and Hoffman 1989, Lamp et al. 1994), thus many plant species could be used by *E. fabae* before returning to alfalfa. Sixty-two percent of these host plants belong to the family Fabaceae (Lamp et al. 1994). Recolonization of alfalfa after harvest by *E. fabae* initially occurs on the edges of the field with subsequent movement to the interior (Emmen et al. 2004, Flinn et al. 1990). In Illinois, *E. fabae* uses plant hosts in woodlands, orchards, and roadsides near alfalfa fields for feeding and reproduction in early spring (Lamp et al. 1989). Poos (1935) and Lamp et al. (1989) have suggested that *E. fabae* builds up populations on these hosts in early spring and then moves into alfalfa, but movement into alfalfa from these hosts has not been demonstrated. The objective of this study was to determine if *E. fabae* adults are colonizing Iowa alfalfa fields from adjacent nonagricultural habitat in early spring.

Materials and Methods

In 1998 and 1999, four Iowa State University alfalfa fields in Ames, IA (42°2′ N, 93°48′ W) (Ross farm [Field 1] and Applied Science Complex [ASC; Field 2]) in 1998, Beef Cattle Nutrition Management Research Center [Field 3] and ASC [Field 4] in 1999) were sampled from mid-April until late May (first alfalfa harvest). These fields were approximately 3.5 km from each other. In each of the fields, the trees and shrubs from 3 to 50 m from the edge of the field were surveyed as potential hosts of *E. fabae* (Table 1). Because several species of *Empoasca* are very similar morphologically and only distinguishable by genitalia (Chasen et al. 2014, DeLong 1931), *Empoasca* species were not determined outside of alfalfa because we used sticky cards, which can result in specimens that cannot be identified to species using genitalia. We did, however, identify *Empoasca* under a dissecting microscope using characteristics given by Fenton and Hartzell (1923). Leafhoppers in these edge plant habitats were monitored weekly by hanging one yellow sticky trap (Pherocon AM®, Adair, OK) from a branch approximately 2 m from the ground. Sticky traps were replaced weekly and the number of *Empoasca* spp. adults was counted. Tree and shrub species were monitored using sticky traps for *Empoasca* spp. activity until first alfalfa harvest in 1998 (20 May) and until the second harvest in 1999 (11 July and 18 July). To monitor the movement of *E. fabae* into alfalfa fields, sticky traps were placed within the alfalfa at the edge of the field (closest to tree/shrub line), 20 m from the edge, and 40 m from the edge. Sticky traps were placed horizontally at the top of the alfalfa canopy to maximize the number of *E. fabae* collected (DeGooyer et al. 1998b). There were four replicates at each

Table 1. List of tree species samples for *Empoasca* spp. in spring 1998 and 1999 adjacent to alfalfa fields in Ames, IA.

Tree Species	Year	Location
Acer negundo L. (Aceraceae), boxelder	1998	1, 2
Carya ovata (Mill.) K. Koch (Juglandaceae), shagbark hickory	1998	1
Celtis occidentalis L. (Ulmaceae), hackberry	1998	1
Crataegus sp. (Rosaceae), hawthorn	1999	3
Fraxinus americana L. (Oleaceae), white ash	1999	4
Gleditsia triacanthos L. (Fabaceae), honey locust	1998, 1999	1, 3
Ostrya virginiana (Miller) K. Koch (Betulaceae), ironwood (hop hornbeam)	1999	4
Prunus sp. (Rosaceae), cherry	1998, 1999	1, 3
Quercus alba L. (Fagacae), white oak	1998, 1999	2, 4
Quercus macrocarpa Michaux (Fagacae), bur oak	1998	1
Quercus rubra L. (Fagacae), red oak	1998, 1999	1, 4
Rhus glabra L. (Anacardiaceae), smooth sumac	1998	1
Rosa multiflora Thunberg (Rosaceae), multiflora rose	1999	3
Tilia americana L. (Tiliaceae), basswood	1998, 1999	2, 4
Ulmus americana L. (Ulmaceae), American elm	1998, 1999	1, 2, 3, 4
Zanthoxylum americanum Miller (Rutaceae), common prickly ash	1999	4

distance and traps in each replicate were placed 25 m apart. Sticky traps were replaced weekly and the number of *E. fabae* adults recorded. Data were analyzed using repeated measures analysis of variance; factors examined were date and location within alfalfa field (SAS Institute 1998). Weather data were collected (www.wunderground.com) to determine degree-day accumulation during the study period. To calculate degree days, a minimum developmental threshold for *E. fabae* of 8.8°C was used (Simonet and Pienkowski 1980).

Table 2. Mean ± SEM number of *Empoasca* spp. on sticky traps hung on tree and shrub species adjacent to alfalfa field in 1998 at Sites 1 and 2.

Species	Site	*n**	19 April	28 April	6 May	13 May	20 May
Acer negundo	1	1	—†	1.0	1.0	0.0	0.0
	2	1	0.0	0.0	0.0	4.0	3.0
Carya ovata	1	—‡					
	2	1	0.0	1.0	0.0	16.0	9.0
Celtis occidentalis	1	—‡					
	2	1	2.0	1.0	0.0	31.0	26.0
Gleditsia triacanthos	1	—‡					
	2	2	0.0	0.0	1.5 ± 1.5	4 ± 1.0	1 ± 1.0
Prunus sp.	1	—‡					
	2	10	0.1 ± 0.1	0.7 ± 0.6	0.4 ± 0.2	7.7 ± 2.8	2.2 ± 0.7
Quercus alba	1	1	—†	0.0	1.0	4.0	1.0
	2	—‡					
Quercus macrocarpa	1	—‡					
	2	1	0.0	1.0	2.0	32.0	6.0
Quercus rubra	1	1	—†	0.0	1.0	3.0	3.0
	2	1	0.0	2.0	0.0	4.0	8.0
Rhus glabra	1	—‡					
	2	3	0.0	0.3 ± 0.3	0.7 ± 0.3	35.3 ± 31.4	19.7 ± 5.7
Tilia americana	1	1	—†	1.3 ± 0.7	0.3 ± 0.3	4.3 ± 0.3	2.0 ± 1
	2	—‡					
Ulmus americana	1	1	—†	1.0	0.0	0.0	1.0
	2	11	0.0	0.1 ± 0.1	1.4 ± 0.7	28.3 ± 11.8	14.3 ± 5.5

* Number of sticky traps.
† No samples taken from Site 1 on 19 April.
‡ Tree not present at site.

Results

Empoasca spp. were primarily observed on sticky traps placed in field-margin trees and shrubs in Ames, IA, during the last week of April in 1998 and 1999. Leafhoppers were first found on sticky traps on *Celtis occidentalis* L. and *Prunus* sp. on 19 April 1998 and on *Gleditsia triacanthos* L. and *Quercus rubra* L. on 30 April 1999 (Tables 1, 2). However, in alfalfa fields peak numbers of adults were observed on the sticky traps during the second (1998) or third (1999) week of May (Figs. 1, 2).

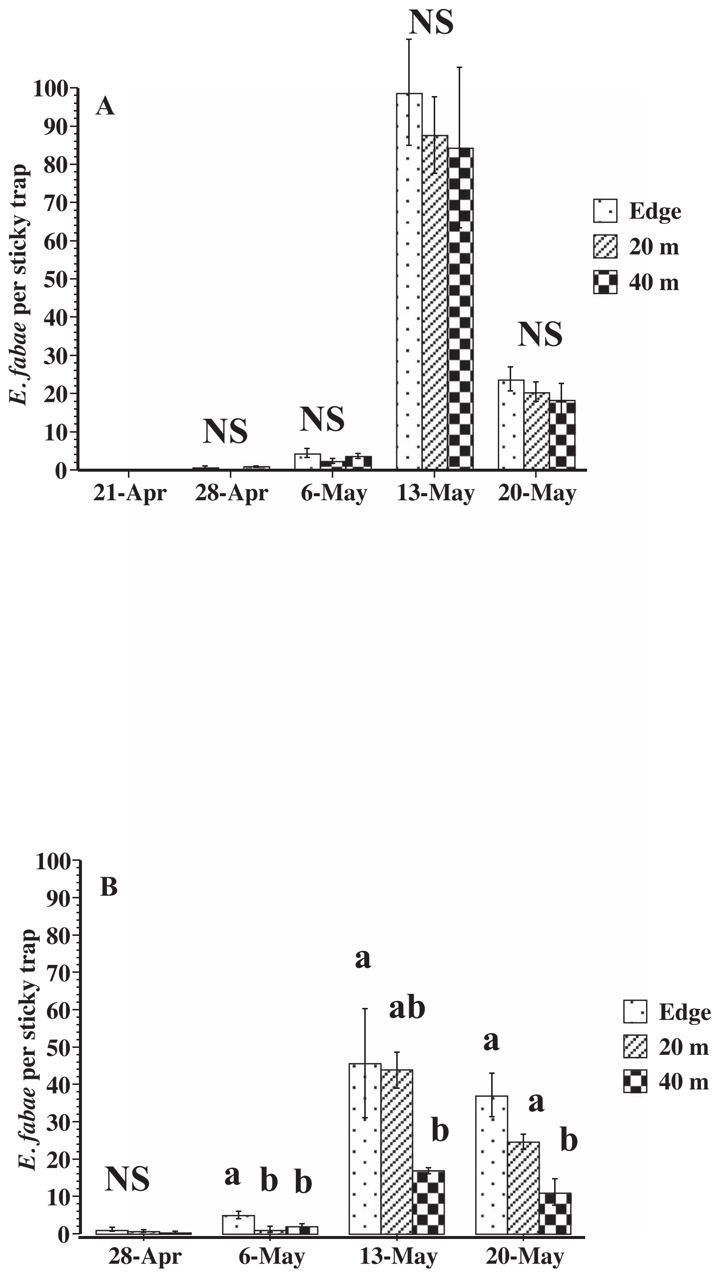

Fig. 1. Mean ± SEM number of *E. fabae* found per sticky trap at the field edge and at 20 m and 40 m within field of alfalfa in 1998 at Field 1 (A) and Field 2 (B). Different letters at each date indicate statistical significance at $P < 0.05$.

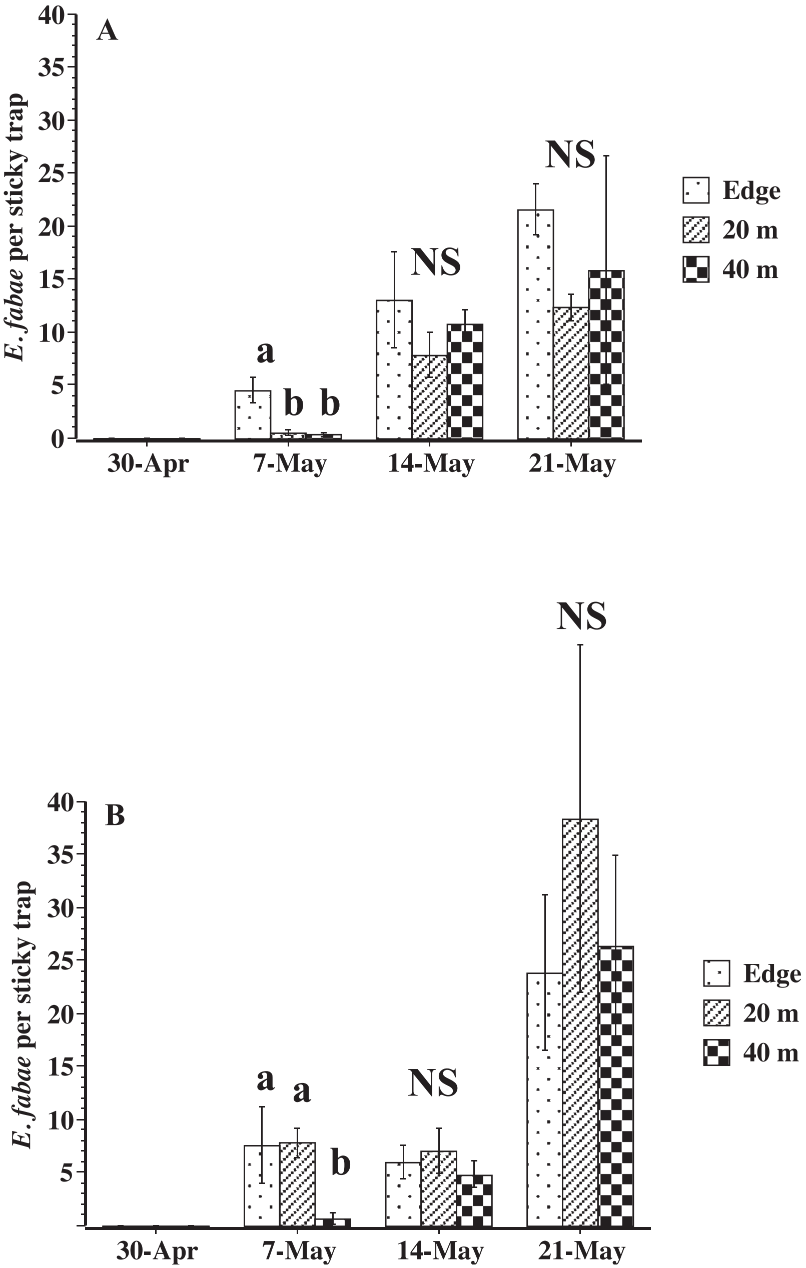

Fig. 2. Mean ± SEM number of *E. fabae* found per sticky trap at the field edge and at 20 m and 40 m within field of alfalfa in 1999 at Field 3 (A) and Field 4 (B). Different letters at each date indicate statistical significance at $P < 0.05$.

Table 3. Mean ± SEM number of *Empoasca* spp. on sticky traps hung on tree and shrub species adjacent to alfalfa field 1999 at Sites 3 and 4.

Species/Date	Site	*n**	30 April	7 May	14 May	21 May
Crataegus sp.	3	1	0.0	15.0	45.0	8.0
	4	—†				
Fraxinus americana	3	—†				
	4	1	0.0	1.0	2.0	3.0
Gleditsia triacanthos	3	5	0.4 ± 0.4	9.7 ± 3.4	79.2 ± 38.3	7.5 ± 2.3
	4	—†				
Ostrya virginiana	3	—†				
	4	1	0.0	0.0	1.0	12.0
Prunus sp.	3	1	0.0	5.0	16.0	11.0
	4	—†				
Quercus alba	3	—†				
	4	1	0.0	1.0	0.0	17.0
Quercus rubra	3	—†				
	4	2	1.0 ± 0.0	1.5 ± 0.5	5 ± 0.0	34.5 ± 11.5
Rosa multiflora	3	1	0.0	15.0	48.0	21.0
	4	—†				
Tilia americana	3	—†				
	4	2	0.0	1.5 ± 0.5	2.0 ± 1.0	10.0 ± 5.0
Ulmus americanus	3	3	0.0	5.7 ± 2.7	21.3 ± 9.4	6.7 ± 1.7
	4	2	0.0	2.5 ± 0.9	4.8 ± 2.7	10.0 ± 5.7
Zanthoxylum americanum	3	—†				
	4	1	0.0	3.0	2.0	38.0

* Number of sticky traps.
† Tree not present at site.

In 1998 at Field 1 there were similar numbers of *E. fabae* at the three locations within the alfalfa field on each sampling date ($F = 2.88$; df = 2, 9; $P = 0.08$; $F = 1.32$; df = 2, 9; $P = 0.29$; $F = 0.29$; df = 2, 9; $P = 0.75$; $F = 0.60$; df = 2, 9; $P = 0.56$) (Fig. 1A). However, there were significant differences in the distribution of *E. fabae* in the alfalfa field at Field 2 on all dates ($F = 5.56$; df = 2, 9; $P = 0.02$; $F = 3.29$; df = 2, 9; $P = 0.08$ [$t = 2.26$; df = 2, 9; $P < 0.05$]; $F = 10.33$; df = 2, 9; $P = 0.005$) except 28 April ($F = 1.40$; df = 2, 9; $P = 0.30$). The number of *E. fabae* sampled closest to the edge of Field 2 near the tree line was higher than at 40 m inside the field (Fig. 1B).

Table 3. Extended.

28 May	4 June	11 June	25 June	2 July	9 July	16 July
9.0	33.0	152.0	118.0	83.0	50.0	6.0
3.0	5.0	17.0	7.0	7.0	0.0	120.0
13.0 ± 3.8	37.8 ± 9.3	90.4 ± 29.1	108 ± 30.6	41.5 ± 11.9	32.2 ± 6.5	11.8 ± 4.1
0.0	17.0	17.0	13.0	35.0	15.0	105.0
3.0	14.0	17.0	19.0	8.0	36.0	6.0
0.0	8.0	16.0	21.0	25.0	4.0	69.0
1.5 ± 1.5	17.0 ± 5.0	53.5 ± 22.5	25 ± 8.0	19.0 ± 6.0	25.5 ± 6.5	261.5 ± 12.5
27.0	57.0	4.0	213.0	77.0	47.0	12.0
4.0 ± 1.0	5.5 ± 0.5	43.5 ± 9.5	24.5 ± 6.5	31.0 ± 0.0	15.5 ± 7.5	136.0 ± 45.0
11.3 ± 2.6	63.0 ± 21.2	56.5 ± 22	84.3 ± 17.6	38.3 ± 11.3	33.3 ± 7.3	16.7 ± 7.8
1.8 ± 0.7	16.3 ± 16.5	78.5 ± 36.4	21.7 ± 11.9	31.5 ± 17.3	15.3 ± 4.9	128.5 ± 56.3
1.0	3.0	1.5	16.0	18.0	15.0	240.0

In 1999 at Field 3, higher numbers of *E. fabae* were found at the edge than at 40 m inside the alfalfa field on 7 May ($F = 10.92$; df = 2, 9; $P = 0.004$); there were no significant differences in numbers at any of the other dates sampled (Fig. 2A). Similarly, there were significantly fewer *E. fabae* observed at 40 m compared with the edge and 20 m inside of Field 4 on 7 May ($F = 4.25$; df = 2, 9; $P = 0.046$) (Fig. 2B).

The number of *Empoasca* spp. found on the sticky traps placed in the trees and shrubs was not statistically different among tree and shrub species in either 1998 or 1999 at any of the locations ($P > 0.05$) (Tables 2, 3). The number of *Empoasca* spp. found on the sticky traps hanging from these plant species indicated that peak activity in these natural border areas occurred during the second week of May. In 1998, we sampled 10 times more *Empoasca* spp. on sticky traps hung in trees and shrubs at Site 1 than from Site 2 (Table 2). Similar numbers of *Empoasca* spp. were collected from sticky traps hung among trees and shrubs in Sites 3 and 4. In 1999, the numbers of *Empoasca* spp. collected on sticky traps in the adjacent trees and shrubs increased when the alfalfa field was harvested (Table 3).

Discussion

In this study, we sampled *Empoasca* spp. adults from vegetation bordering alfalfa fields and *E. fabae* within the alfalfa fields to determine if *E. fabae* adults colonize alfalfa by movement out of adjacent nonagricultural habitat in early spring. We assume that the adult *Empoasca* collected from sticky traps placed in alfalfa fields are *E. fabae* based on previous studies (DeGooyer et al. 1998b, Lamp et al. 1989). We did not identify the adult *Empoasca* spp. collected in the surrounding habitats to species due to the use of weekly sampling of sticky traps. During early spring, more *E. fabae* were present on sticky traps in the edges of alfalfa fields closest to the trees and shrubs in Fields 2, 3, and 4 during the first week of May (1998 and 1999). Additionally, there were more *E. fabae* collected from alfalfa near the edge of Field 2 during the second and third weeks of May (1998). These results are consistent with previous studies that examined edge colonization of *E. fabae* in alfalfa (Emmen et al. 2004, Flinn et al. 1990). Bentz and Townsend (2004) also found that potato leafhoppers tended to aggregate on habitat edges in early spring. In addition, edge colonization behavior of *E. fabae* has been demonstrated in soybean fields after an alfalfa harvest (Poston and Pedigo 1975). Given these dispersion patterns, it seems unlikely that *E. fabae* colonization of alfalfa fields in early spring happens by random deposition from their northerly migration. It appears as though *E. fabae* are moving into alfalfa from another source. Our study indicates that these leafhoppers are aggregating on the edge of alfalfa after depositing eggs in alternate hosts within adjacent woody habitats.

From first arrival of leafhoppers in Iowa until first harvest in 1998 and 1999 we determined that 233 and 148 degree days accumulated above the developmental threshold of 8.8°C, respectively. Because the life cycle of *E. fabae* requires approximately 350 degree days (°C) to complete development from the egg to adult (Flinn et al. 1986), it would not be possible for *E. fabae* to reproductively increase population numbers in the alfalfa before first harvest. Eggs laid inside alfalfa stems are removed from the field when the alfalfa is harvested. Due to low vagility of the nymphs, they would not find suitable hosts and, therefore, up to 95% of nymphs are killed when the field is harvested (Simonet and Pienkowski 1979). It appears that reproduction in alfalfa fields during early spring is, for the most part, a waste of reproductive effort because only the few eggs that were laid in late April will develop into adults. Typically, *E. fabae* may occur in damaging numbers during the second growth of alfalfa (Giles et al. 1999). Because *E. fabae* cannot complete a generation in alfalfa before the first harvest, *E. fabae* infesting second-growth alfalfa must be from other sources.

Empoasca fabae feeds and oviposits on the new growth of woody species, such as *Quercus*, *Acer*, and *Carya* (Bentz and Townsend 1999, Lamp et al. 1994, Poos

1935). Although we found leafhoppers on the sticky traps hanging on several of these woody species (Tables 2, 3), we did not confirm that the leafhoppers were laying eggs in these hosts during this time. In early May during alfalfa harvest in Illinois, Lamp et al. (1989) found more *E. fabae* in adjacent *Quercus* and *Acer* trees than in alfalfa fields. In contrast, we did not find a higher number of *Empoasca* spp. per sticky trap in the trees than in the alfalfa fields during this study. This difference may be due to the method of collection; Lamp et al. (1989) swept tree foliage to obtain *E. fabae*, whereas we used hanging sticky traps. However, the numbers of *Empoasca* spp. in our late-April and early-May samples from trees were comparable with the numbers of *E. fabae* collected on sticky traps on *Acer rubrum* L. clones in Maryland during the same time of year (Bentz and Townsend 1997). In addition, we found increased activity of *Empoasca* spp. on sticky traps in the adjacent tree and shrub species when an adjacent alfalfa field was harvested. This increased activity remained elevated for at least 2 weeks (Table 3) suggesting that *E. fabae* may be using the adjacent woodland as a refuge habitat. This is consistent with the hypothesis of Poos (1935), who collected *E. fabae* from light traps from North Carolina to New York and suggested that *E. fabae* used *Quercus* and *Carya* trees when alfalfa is unavailable.

Sources of *E. fabae* infestation of the second alfalfa growth require further investigation. It is possible that *E. fabae* may still be arriving from overwintering sites in early June as the length of the spring migration has not been determined. Although there are no distinguishable morphological characteristics between migrant versus resident *E. fabae*, molecular analyses could be used to determine the host plants of *E. fabae* and, therefore, determine status (resident versus migrant) of *E. fabae* adults in second-growth alfalfa (Taylor et al. 1993, Wassenaar and Hobson 1998). For example, Wassenaar and Hobson (1998) traced the origins of migratory *Danaus plexippus* L. (Lepidoptera: Danaidae) using the composition of stable-hydrogen and carbon isotopes found in its food source, which varies along a north–south continuum.

This study does not exclude the possibility of two distinct populations of *E. fabae*, one on woody species (i.e., trees and shrubs) and a second on herbaceous species (i.e., alfalfa and other legumes). This type of host segregation is found in pea aphids (*Acyrthosiphon pisum* [Harris]) (Hemiptera: Aphididae), where specialization occurs on alfalfa and red clover (*Trifolium pratense* L.) (Fabaceae) (Via 1991). Lamp et al. (1989) found *E. fabae* within grass, clover, and roadside weeds early in the season and suggested that these may serve as a source or sink for dispersing *E. fabae*. In Iowa, *E. fabae* may be using unharvested alfalfa or other herbaceous plants to feed and reproduce in early spring. These plants are not cut and *E. fabae* would have sufficient time to produce a new generation. Further studies examining *E. fabae* eggs deposited in these habitats in addition to woody trees adjacent to alfalfa fields in early spring may shed light on the source of *E. fabae* population buildup and subsequent infestation of second-growth alfalfa.

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