Flight and Landing Activity of *Rhopalosiphum maidis* (Homoptera: Aphididae) in Bean Monocultures and Bean-Corn Mixtures[1]

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J. Entomol. Sci. 27(2):143-153 (April 1992)

ABSTRACT *Rhopalosiphum maidis* (Fitch) dominated the aerial aphid plankton in bean (*Phaseolus vulgaris* L.) monocultures and mixed cultures of bean with corn (*Zea mays* L.) in Illinois. It was also the most common species landing on bean plants in this study during the summer of 1987. More flight activity was recorded in the monocultures than in the mixtures. More *R. maidis* flew at the top of the bean canopy than at the level of the corn canopy. Densely planted corn rows suppressed flight activity more than did sparsely planted rows. Plots that were planted early had lower aphid catches over the same time than did plots planted 13 and 24 days later. Aphid flight activity was negatively correlated with ground cover, corn barrier height, and corn barrier density. Aphid landing activity was not affected by planting date or corn row density but was negatively and significantly correlated with ground cover. Stepwise regression analysis revealed that ground cover was more important than barrier height and barrier density in suppressing flight and landing activity of *R. maidis.*

KEY WORDS aphids, corn, dispersal, Insecta, mixed cropping, *Rhopalosiphum maidis,* soybean.

Beans, important providers of protein in the world, suffer frequent epiphytotics of aphid-borne, non-persistently transmitted viruses that can be acquired and inoculated in a matter of seconds. Because winged aphids are able to visit and probe a large number of plants within a short time, such outbreaks are often devastating (Eastop 1977). Limiting vector dispersal would significantly reduce virus spread.

The dispersal of aphids is primarily influenced by the crop habitat, which provides stimuli that entice or repel aphids to land, alters the length of time they remain on a plant, and indirectly influences their landing behavior by altering the physical environment (Irwin and Kampmeier 1989). Vegetation provides a strong visual stimulus. Alatae of most aphid species are attracted to plants that are surrounded by bare earth (A'Brook 1968) because of the enhanced contrast between vegetation and background (Kennedy et al. 1961). However, mixed cropping experiments suggest that the barrier effect of tall plants, such as parallel rows of corn interplanted with beans, may also limit

[1] Accepted for publication 5 February 1992

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aphid dispersal (Kenny and Chapman 1988, Tingey and Lamont 1988). This barrier effect presumably results from alterations in the wind flow pattern (Halbert 1979).

Very little is known about the relative importance of ground cover and barrier effects that may govern aphid flight in crop mixtures. Mixed cropping has tremendous potential in limiting aphid-borne virus epiphytotics (Heathcote 1968, Shoyinka 1976, Farrell 1976, Mukiibi 1982, Palti 1981, van Rheenen et al. 1981). Understanding how canopy structure affects aphid flight is essential in developing crop mixtures that confer optimal protection from aphid-borne virus epiphytotics. This study was designed to characterize aphid flight and landing patterns in bean monocultures and in bean-corn mixtures, and to determine how canopy structure in these habitats affects aphid flight and landing activity.

Materials and Methods

Field and plot design. Aphid flight and landing activity were studied with vertical sticky traps in a non-replicated multifactorial experiment. Treatments were not replicated to allow a plot size (25 x 25 m) large enough to minimize edge effects, such as wind turbulence, on aphid flight pattern. The factors were planting date (22 June, 5 July, and 16 July), culture type (bean monoculture, sparse corn-bean mixture, and dense corn-bean mixture) and trap height (bean and corn canopy level). Treatments were randomized within blocks. Blocks planted at different dates were randomly assigned to three contiguous sites. Crop mixtures were created by alternating two rows of bean (*Phaseolus vulgaris* L., var. Stringless Green Pod), planted at 76 cm between rows, with a row of corn (*Zea mays* L., var. Jacques Field Corn). Corn rows were therefore 154 cm apart. Corn density was manipulated by thinning corn seedlings to 60 cm between plants in the sparse mixture (11,000 plants/ha) and by maintaining an interplant distance of 20 cm in the dense mixture (33,000 plants/ha). Bean rows were thinned to 15 cm between plants, a density that corresponded to 79,000 plants per ha. Plots had a total of 34 bean rows and an additional 16 corn rows if interplanted. The research was conducted at the experimental farm of the University of Illinois at Urbana-Champaign in the summer of 1987.

Monitoring aphid flight activity at different canopy heights. Transparent cylindrical sticky traps were used to monitor aphid flight activity at bean and corn canopy levels from August 10-31. The cylinders, 15 cm long and 15 cm wide (353.4 cm^2), were made from rigid clear vinylite sheets (0.5 mm thick). Two cylinders were attached with thumbtacks to a wooden stake (3 m long and 1.9 cm thick) driven into the ground between bean rows. A thin layer of petrolatum was applied to the outer surface of each cylinder. The lower edge of the bottom cylinder was adjusted to the height of the bean canopy; the lower edge of the top cylinder was maintained at the level of the corn canopy. In bean monocultures, the higher cylinder was maintained at a height equal to that of the corn canopy level in mixed cultures of the same block. Four sets of traps were used per plot. Aphids were collected from the cylinders with a pair of forceps every other day and stored in 70% alcohol for identification and tabulation.

Monitoring aphid landing rates on bean. Landing rates of aphids at the level of the bean canopy were monitored with horizontal pan traps. Each trap consisted of a transparent plastic sandwich box (11.5 x 11.5 x 3.2 cm; 132.25 cm^2) containing a mosaic green ceramic tile with spectral reflectance similar to that of soybean leaves (Irwin and Schultz 1981). Because spectral quality of plants varies little due to the absorption properties of chlorophyll (Prokopy and Owens 1983), the tile's spectral reflectance was also assumed to be similar to that of a snapbean leaf.

The trap was filled with water to which unscented detergent (0.01 ml/liter) was added to reduce surface tension. The trap was attached with a test tube clamp to a metal rod and positioned just above the level of the bean canopy. Trapping at the level of the corn canopy was not done. Four traps were used per plot. Aphids were collected daily from 10 August to 31 August and stored in 70% alcohol for identification and tabulation.

Aphid identification. Aphids were identified in alcohol with a dissecting steroscopic microscope using taxonomic characters, such as shape and length of siphunculi and cauda, that were visible under low power (50x). Identification was aided by a reference collection of 66 unmounted aphid species in alcohol and descriptions of easily visible taxonomic key characters (Palmer 1952). Specimens that could not be identified were categorized as unknown species.

Monitoring plant growth. Height and width of corn and bean rows were assessed at 2- to 3-day intervals from August 11-28. Row heights were estimated by placing a meter stick in corn and bean rows and judging the average row height from a distance of several meters. This method compared well with exact height measurements ($r=0.9986$, $df=13$, $p < 0.01$). The mean difference (2.06 cm, SD = 4.48) did not differ significantly from zero ($t = 1.78$, $df = 14$, $p > 0.05$). Row width (the average width of plant canopies perpendicular to row direction) was estimated by placing a meter stick on the ground perpendicular to the row with the beginning of the meter stick at the left edge of the canopy. The width of the row canopy was estimated by sighting down the right edge of the row and projecting a line along that edge. The width of each row was then determined by sighting along this line to the point where it crossed the meter stick. Two rows per plot were assessed each time, and the average row height and width were used in subsequent analyses. Because some plants died after thinning, an assessment of within-row plant distance was made from 20 bean and 12 corn plants per plot.

Derivation of crop growth parameters. Three parameters of crop structure were used: ground cover, barrier height, and barrier density. The percentage ground covered with vegetation was calculated from plant canopy width, within-row plant distance, and between-row distance. To simplify calculations while not deviating much from reality, we assumed bean canopies to be square in shape; corn canopies were rectangular with the long side perpendicular to the direction of the row and 4 x as long as the short side. Barrier height was considered to be the difference in height (cm) between corn and bean canopies.

Barrier density index, an indirect, unitless measure of corn row density, was derived by dividing corn height by within-row plant distance of corn. The theoretical basis of this index is as follows. We assumed that older, taller plants had more, longer, and wider leaves than younger, shorter corn plants. Leaf counts (range 2-10 leaves per plant) and plant height measurements (range 8-174 cm) taken during the vegetative stage showed a positive linear relationship ($y = 2.29 + 0.05x$, $r^2 = 0.945$, $n = 12$, $p < 0.01$) between the number of fully expanded leaves (y) and the height (cm) of the corn canopy (x). Depending on leaf length, leaf droopiness, and interplant distance, leaves of neighboring corn plants intertwine to form a complex meshwork that impedes airflow. Stem and whorls (leaves that are not fully expanded) also contribute to the meshwork. We assumed that mesh density increased with an increasing number of leaves and decreasing interplant distance. Therefore, by dividing corn height (which is directly related to the number of leaves) by interplant distance, we obtained a crude but functional measure of barrier density.

Statistics. Trap catches were expressed as the cumulative number of aphids caught between August 10-31, averaged over the four traps (subsamples, not true replications - see Hurlbert 1984) per plot. When the analysis of variance indicated a significant main effect, the Least Significant Difference test (LSD) was used to test differences between treatment means. Because true replications did not exist and the trap level factor was nested within planting dates and culture types, the error term for the latter two factors was the interaction between them (df = 2). The error term to test for the effect of trap level was the residual, three-way interaction term (df = 4). It was assumed that the two- and three-way interactions were not significant. Interaction plots showed lines that ran reasonably parallel, strongly suggesting that this assumption was valid (Milliken and Johnson 1989).

Ground cover, barrier height, and barrier density were averaged over the six measurements taken between 11-26 August and correlated with cumulative aphid catch between 10-31 August. All analyses were run on the mainframe IBM computer of the University of Illinois using the SAS procedures PROC CORR, PROC GLM and PROC STEPWISE (SAS Institute 1985).

Results

Aphid species. *Rhopalosiphum maidis* (Fitch) made up 70.1% (1,532 specimens) of the total (1,937) sticky trap catch and 41.8% (69) of the total (165) pan trap catch. Twenty-six and 14 species were identified among aphids caught in the sticky and pan traps, respectively. The category of unknown species, consisting mostly of *Aphis* spp., amounted to 2.7% of the sticky and 16.4% of the pan trap catch. No species other than *R. maidis* was sufficiently abundant to permit meaningful statistical analysis, therefore, a group, hereafter referred to as *other species,* was created by lumping together all species other than *R. maidis.* Because different aphid species behave differently, all results concerning the category of *other species* should be interpreted with caution. *Other species* comprised 29% (405) of the total sticky and 58% (96) of the total pan trap catch. Daily catches were generally low, particularly in pan traps; no distinct temporal fluctuations in *R. maidis* and *other species* catches were noted. Some *R. maidis* colonies developed on corn during the experiment, but bean plants did not support any aphid colonies.

Effects of culture type, planting date, and trapping level on sticky trap catch. *R. maidis* (Fig. 1). Sticky trap catch (mean ± S.D.), averaged over culture types and trap levels (n = 6), was significantly higher ($LSD_{5\%} = 8.8$) in plots planted on 16 July (29.3 ± 15.7) than in those planted on 5 July (19.8

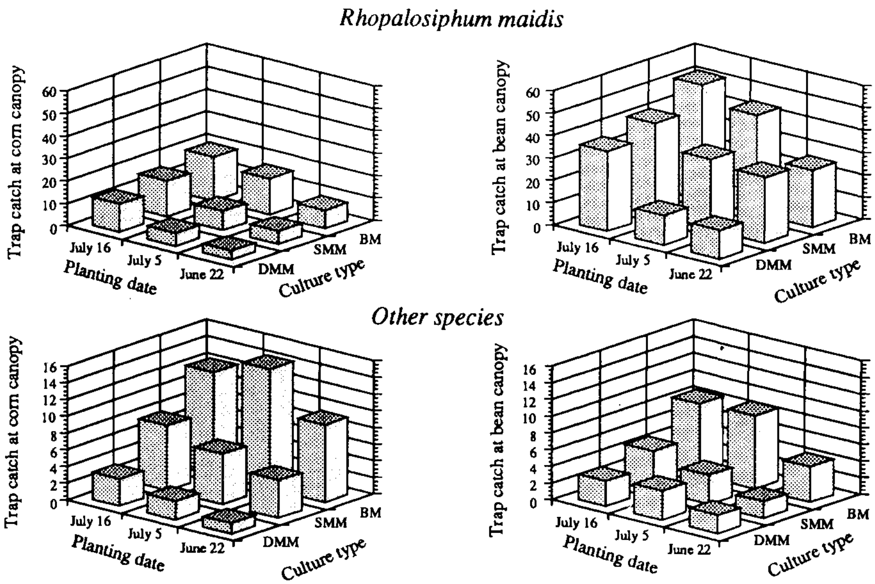

Fig. 1. Sticky trap catches (cumulative total from August 10-31, 1987, averaged per trap) of *R. maidis* and *other species* (BM = bean monoculture, DMM = dense maize bean mixture, SMM = sparse maize-bean mixture).

± 14.8) or 22 June (14.7 ± 11.5). Averaged over planting dates and trap levels (n = 6), sticky trap catch was significantly higher ($LSD_{5\%}$ = 8.8) in bean monocultures (27.4 ± 16.8) than in the dense corn mixtures (14.0 ± 11.4), but both were statistically similar to the sparse corn mixture (22.4 ± 14.4). Averaged over planting dates and culture types (n = 9), sticky trap catch was significantly higher ($LSD_{5\%}$ = 5.2) at bean (31.9 ± 13.1) than at corn canopy level (10.7 ± 5.5).

Other species (Fig. 1). Averaged over planting dates and trap levels (n = 6), sticky trap catch was significantly higher ($LSD_{5\%}$ = 2.6) in bean monocultures (9.5 ± 3.4) than in the dense (2.6 ± 0.8) or sparse (4.8 ± 2.0) corn mixtures. Averaged over planting dates and culture types (n = 9), sticky trap catch was significantly higher ($LSD_{5\%}$ = 0.8) at corn (6.8 ± 4.5) than at bean canopy level (4.5 ± 2.5). Planting date did not affect trap catch significantly (F = 4.4, $p > 0.05$).

Effects of culture type and planting date on pan trap catch. *R. maidis* pan trap catch (Fig. 2) was not significantly affected by planting date (F = 0.29, $p > 0.05$) or culture type (F = 0.60, $p > 0.05$). Likewise, other species (Fig. 2) did not respond significantly to planting date (F = 1.21, $p > 0.05$) or culture type (F = 2.68, $p > 0.05$).

Relationship between sticky trap and pan trap catch. Correlation analysis showed that pan trap catches of *R. maidis* (r = 0.78) and *other species* (r = 0.78) were significantly ($p < 0.05$, n = 9) and positively correlated with sticky trap catch at bean canopy level but not with sticky trap catch at corn canopy

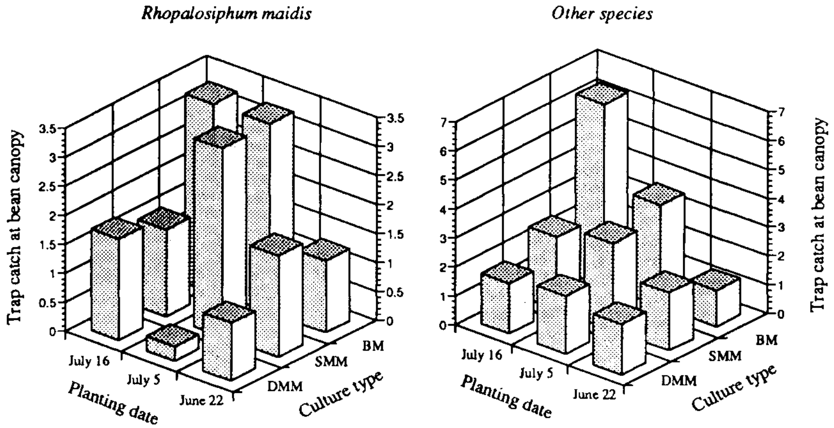

Fig. 2. Pan trap catches (cumulative total from August 10-31, 1987, averaged per trap) of *R. maidis* and *other species* (BM = bean monoculture, DMM = dense maize-bean mixture, SMM = sparse maize-bean mixture.

level ($p > 0.05$, n = 9). Expressed per unit surface area, total sticky trap catch of *R. maidis* and *other species* combined was 4 times that of the pan traps; total sticky trap catch of *R. maidis* alone was eight times that of the pan traps.

Barrier height. Bean height within blocks planted at the same time did not increase noticeably between August 11-26. The average height of bean plants in treatments planted on 22 June, 5 July, and 16 July, during the 3-week trapping period was 49, 40, and 30 cm, respectively. Corn height, in the early, medium, and late planted blocks, averaged 198, 158, and 90 cm during the trapping period and increased 7, 54, and 48 cm, respectively, between August 11-26. Corn plants in the dense mixtures were 5 to 16 cm taller than those in the sparse mixtures. Bean plants in dense mixtures with medium and late planting dates were, on average, 1 to 6 cm taller than those in sparse mixtures, which in turn were 1 cm taller than those in the bean monocultures. In the early planted plots, bean plants in the different culture types differed an average of <1 cm in height during the monitoring period. Barrier height, that is, the difference between corn and bean height, followed a trend similar to that described for corn height. Bean height never exceeded corn height during the study period.

Barrier density index. Within planting dates, dense mixtures always had the highest barrier density index. Within culture types, early planted mixtures always had a higher density index than later planted plots. Between 11-26 August, barrier density indices of early planted dense and sparse mixtures hovered around 10.6 and 3.6, respectively, and changed less than 4% during this period. Later planted plots showed a greater increase in barrier density. The sparse and dense mixtures planted on 5 July increased from 2.2 to 3.2 (mean 3.0) and from 6.2 to 8.8 (mean 8.0), respectively. The sparse and dense mixtures planted on 16 July increased from 1.0 to 2.0 (mean 1.5) and from 4.1 to 6.8 (mean 5.6), respectively. The corn barriers were generally most dense where longer, younger, fully expanded leaves crisscrossed, mostly in the upper part of the row. Gaps in the mesh of corn foliage were common in the lower half of rows.

Ground cover. Within planting dates, ground cover was always greatest in the dense mixtures, followed by the sparse mixtures and bean monocultures. Within culture types, early planted plots always had greater ground cover than did later planted plots. Ground cover increased by an overall average of 8% over the 3-week period. Mean ground cover in the bean monocultures, planted on 22 June, 5 July, and 16 July, was 69, 44, and 33%, respectively; in the dense mixtures the means were 85, 74, and 65%; in the sparse mixtures the means were 79, 58, and 45%.

Relationships between sticky trap catch and crop structure. Simple linear correlation analyses showed that sticky and pan trap catches were negatively correlated with ground cover, barrier height, and barrier density. Sticky trap catches of *R. maidis* (both levels) and *other species* at bean canopy level were best correlated with ground cover; sticky trap catches of *other species* at corn canopy level were best correlated with barrier density. Pan trap catches of *R. maidis* and *other species* were best correlated with ground cover (Table 1).

Stepwise regression confirmed that ground cover was the best single predictor for sticky trap catch of *R. maidis* at bean ($R^2 = 0.78, p < 0.01$) and corn ($R^2 = 0.91, p < 0.01$) canopy level, for sticky trap catch of *other species* at bean canopy level ($R^2 = 0.76, p < 0.01$), and for pan trap catch of *R. maidis* ($R^2 = 0.50, p < 0.05$) and *other species* ($R^2 = 0.58, p < 0.05$). Barrier density was the best single predictor for sticky trap catch of other species at corn canopy levels ($R^2 = 0.80, p < 0.01$).

Table 1. Pearson product-moment correlation coefficients (n = 9) between aphid trap catch and crop growth parameters.

Species	Trap	Canopy level	Groundcover	Barrier height	Barrier density
R. maidis	sticky	bean	-0.88**	-0.68*	-0.79*
R. maidis	sticky	maize	-0.96**	-0.79*	-0.70*
R. maidis	pan	bean	-0.71*	-0.44^{ns}	-0.63^{ns}
Other species	sticky	bean	-0.87**	-0.81**	-0.69*
Other species	sticky	maize	-0.82**	-0.86**	-0.89**
Other species	pan	bean	-0.80**	-0.45^{ns}	-0.47^{ns}

^{ns} not significant, * p < 0.05, ** p < 0.01.

Discussion

Importance of ground cover. Although aphid landing rates (as monitored with pan traps) were not significantly affected by planting date and culture type, correlation analyses suggest that landing rates were significantly and negatively related to the amount of ground cover. The apparent lack of effects due to planting date and culture type may have resulted from the inefficiency of the experimental design (no replications) and the extremely low aphid catches over the 21-day period. However, sticky trap catches were much higher and showed significant treatment effects.

Regression analyses of sticky trap and pan trap data indicated that alatae of *R. maidis* and *other species* are more attracted to habitats with an open canopy than to habitats with a closed canopy. This finding confirms earlier reports that ground cover is an important landing stimulus for certain aphid species (A' Brook 1968, Smith 1976, Halbert and Irwin 1981, Irwin and Kampmeier 1989). *R. maidis* was previously reported not to respond to ground cover (A'Brook 1968, Halbert and Irwin 1981), which may be related to low trap catches and/or the type of trap used. Our results from crop mixture experiments presented here and elsewhere (Bottenberg and Irwin 1992) and results from other experiments (Irwin unpublished data), clearly indicate that *R. maidis* is sensitive to ground cover. Kennedy et al. (1961) postulated that aphid landing behavior is primarily under the control of the optomotor response, leading alatae to land preferentially on surfaces that contrast with the background. In this study, bean monocultures always had less ground cover and therefore greater contrast between foliage and bare ground than the bean-corn mixtures.

Importance of corn rows as barriers. Except for the category of *other species* flying at corn canopy level, wind barrier effects seemed less important than ground cover in influencing aphid dispersal. This phenomenon may occur because the ground cover effect is the result of a visual stimulus with, we presume, a relatively large sphere of influence. Very little is known about wind flow dynamics in a mixed crop environment with multiple, parallel wind breaks, however, the reduction in wind velocity by parallel wind breaks (Heisler and Dewalle 1988) may well have a more limited range of influence on aphid flight than the effect ground cover.

In addition to reducing wind speed, corn rows in bean-corn mixtures also reduce light intensity at the lower bean canopy level. Although shading was not measured in this study, shading might repel aphids, as was observed with thrips in an artificial mixed crop environment (Kyamanywa and Ampofo 1988) and chrysomelid beetles in corn-bean-squash polycultures (Risch 1981). However, repellence due to shading at the bean canopy level could occur only after alatae penetrate the corn canopy.

Wind speed increases with height above crop canopy (Monteith and Unsworth 1990). Although corn is a host but bean is not, more *R. maidis* flew and were trapped at bean canopy than at corn canopy level, possibly because they preferred flying where wind speed was lowest. In addition, gaps in the corn foliage meshwork at bean canopy level would allow alatae to fly unimpeded across bean rows. Apparently, shading by corn rows did not inhibit *R. maidis* from flying at bean canopy level. *Other species,* however, flew more abundantly at corn than at bean canopy level. This finding suggests that aphids searching for hosts while flying above a crop differ in their response to vegetative stimuli and microclimatic conditions and can actively direct the altitude of their flight path. Differences in flight behavior may be species specific, but the physiological state of the aphids could also play a role. Alatae that are older may have spent more energy reserves and, as a result, may respond more readily to vegetative stimuli, thereby flying at altitudes lower than those of more recently eclosed specimens.

Relationship between flight and landing activity. The heterogeneity of the aerial aphid plankton is further exemplified by comparing sticky trap with pan trap catches. More aphid species and a greater number of aphids flew at bean canopy level than landed on bean plants. This observation indicates that only a certain proportion of the aerial aphid population landed on bean foliage, and that some species apparently never landed. Pan trap catches were correlated more with sticky trap catches at bean canopy level than at corn canopy level. This correlation suggests that aphids flying at higher altitudes were less inclined to land on bean plants than were those flying at lower altitudes. It is possible however, that some of these alatae landed on corn foliage. Because vertical sticky traps are known to give a relative measure of aerial aphid density that is strongly influenced by wind velocity (Irwin and Schultz 1981), these results should be verified with suction traps.

Conclusions and Recommendations. Despite the inefficiency of the design due to the lack of true replications, this study has revealed important relationships between aphid dispersal and crop structure. We believe that the large size of the plots (25 x 25 m) resulted in a more realistic representation of the mixed crop environment than would have been obtained with smaller plots in a replicated experiment. The experimental error was, however, fairly large. Some degree of smoothing out site-specific influences on aphid trap catch was achieved by averaging trap catch over the four traps used per plot.

Mixed cropping of bean with corn shows potential in limiting aphid flight and landing activity and consequently the spread of aphid-borne, non-persistently transmitted viruses. Sparse corn rows confer nearly equal protection as densely planted rows and minimize bean yield loss due to competition for light, moisture, and nutrients (Francis et al. 1982). The precise choice of planting distance would depend on the potential for aphid outbreaks, the presence of aphid-borne viruses, and the compatibility of the corn and bean varieties.

Acknowledgments

We thank Doyle Dazey for planting the field, Gail Kampmeier for teaching one of us (HB) to identify the numerous aphid species in Illinois, Ellen Brewer and Joan Alster for statistical advice, and Hassan Oloumi, Gail Kampmeier, and the Illinois Natural History Survey editorial staff for reviewing earlier versions of this paper. This work was carried out as part of an entomology Ph.D. dissertation by the senior author and was supported by USAID Program Support Grant #DPE-5542-G-SS-6013-00.

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