POTENTIAL OF FIELD CORN AS A BARRIER CROP AND EGGPLANT AS A TRAP CROP FOR MANAGEMENT OF *BEMISIA ARGENTIFOLII* (HOMOPTERA: ALEYRODIDAE) ON COMMON BEAN IN NORTH FLORIDA

HUGH ADAM SMITH AND ROBERT MCSORLEY
Department of Entomology and Nematology
University of Florida
Gainesville, FL, 32611

ABSTRACT

Trap crops and barrier crops are among the cultural control methods promoted for management of *Bemisia argentifolii* Bellows & Perring, particularly for small farmers in the tropics. In 1996 eggplant, *Solanum melongena* L., was tested as a trap crop, and in 1996 and 1997 corn, *Zea mays* L., was tested as a barrier crop for management of *B. argentifolii* on bean, *Phaseolus vulgaris* L. In 1996 treatments were compared by sampling immature *B. argentifolii* on bean leaves. Neither egg nor nymphal densities were reduced by eggplant or corn treatments in 1996. In the 1997 corn barrier trial plot size was increased and the orientation of barrier row to wind direction was evaluated. A dust-and-release procedure was used to measure entry of greenhouse-reared adult *B. argentifolii* into experimental plots. Counts from yellow sticky traps in 1997 indicated that migration by adult whiteflies into plots was determined primarily by air currents and was only marginally influenced by the presence of a corn barrier. The results indicate that barrier crops and certain trap crops may have limited value for whitefly management.

Key Words: Intercropping, polyculture, vector management, wind dispersal, pest management

RESUMEN

El uso de cultivos trampa y cultivos de barrera se está promoviendo como medida de control de la mosquita blanca (*Bemissia argentifolii* Bellows & Perring), principalmente entre pequeños agricultores de los trópicos. En 1996 se probó el cultivo de berenjena (*Solanum melongena* L.) como planta trampa y en 1996 y 1997 se utilizó maíz (*Zea mays* L.) como cultivo barrera para el control de *B. argentifolii* en un campo de frijol, *Phaseolus vulgaris* L. En 1996 se colectaron muestras de *B. argentifolii* en fase inmadura de hojas de frijol para comparar el efecto de los tratamientos. En 1996 no se logró reducir la densidad de huevecillos o ninfas en el frijol al emplear berenjena o maíz. En 1997 se aumentó el tamaño de la parcela experimental de maíz y se evaluó el efecto de la orientación del surco barrera en relación a la dirección del viento. La cantidad de adultos de *B. argentifolii* que entraron a los lotes experimentales se cuantificó mediante un procedimiento de espolvoreo y liberación (dust-and-release). En 1997 se encontró que la migración de adultos de mosquita blanca hacia los lotes experimentales fue determinada principalmente por corrientes de aire y que la presencia de maíz barrera tuvo muy poco efecto en controlar su entrada. Los resultados indican que los cultivos barrera y trampa fueron poco efectivos en el control de la mosquita blanca.

Bemisia argentifolii Bellows & Perring, also known as the B strain of *B. tabaci* (Gennadius), causes significant economic damage to agronomic and horticultural crops throughout warm regions of the world (Brown et al. 1995). *Bemisia argentifolii* is a phloem-feeder which vectors numerous geminiviruses and inflicts a variety of plant disorders as well as mechanical damage (Byrne et al. 1990, Hiebert et al. 1996, Shapiro 1996). It has demonstrated resistance to most classes of pesticides (Denholm et al. 1996), forcing growers and researchers to evaluate alternative methods of control. Attempts to manage whiteflies by cultural means have included the use of trap crops (Al-Musa 1982, Ellsworth et al. 1994, McAuslane et al. 1995, Schuster et al. 1996) and barrier crops (Sharma & Varma 1984, Fargette & Fauquet 1988, Rataul et al. 1989, Morales et al. 1993).

Trap crops are preferred host plants which are used to draw an herbivore away from a less-preferred main crop (Vandermeer 1989). *Bemisia argentifolii* has been observed to oviposit heavily on eggplant, *Solanum melongena* L. (Tsai & Wang 1996), leading researchers to suggest eggplant as a promising trap crop (Faust 1992).

Whiteflies are weak fliers, relying on air currents for both short and long distance migration (Byrne & Bellows 1991, Byrne et al. 1996). Several tall-growing non-host plants, primarily in the family Gramineae, have been tested as barrier crops or intercrops to reduce whitefly colonization and virus transmission among main crops. Results have been mixed. Morales et al. (1993) reported that a sorghum, *Sorghum bicolor* (L.) Moench, barrier reduced *B. tabaci* densities and transmission of virus, on tomatoes, *Lycopersicon esculentum* Mill. A pearl millet, *Pennisetum typhoides* (Burm. f.) Stapf & Hubbard, barrier reduced whitefly virus transmission on cowpea, *Vigna unguiculata* (L.) Walp. (Sharma & Varma 1984) and on soybean, *Glycine max* (L.) Merrill (Rataul et al. 1989). Gold et al. (1990) found reduced densities of *Aleurotrachelis socialis* Bondar and *Trialeurodes variabilis* (Quaintance) on cassava, *Manihot esculenta* Crantz, intercropped with maize, *Zea mays* L., and cowpea, but attributed this in part to reduced host quality due to intercrop competition. Fargette & Fauquet (1988), whose study included the effect of wind direction, found densities of *B. tabaci* and virus incidence were sometimes higher on cassava intercropped with maize than on monocropped cassava.

These studies have been carried out primarily in the tropics, where safe, inexpensive cultural control measures are a priority for low resource farmers. Extension material from Central America promotes the use of crop barriers as a component of whitefly management programs (Salguero 1993). The present study was undertaken in 1996 to test the usefulness of eggplant as a trap crop and field corn as a barrier crop for management of *B. argentifolii* on common bean, *Phaseolus vulgaris* L. It was continued in 1997 focusing only on the barrier crop treatment and including the effects of wind direction and barrier row orientation.

MATERIALS AND METHODS

Research Design and Plot Management, 1996

The experiment was carried out at the University of Florida Green Acres Agronomy Research Farm, northwest of Gainesville, FL (29°40'N, 82°30'W). Four treatments were compared: 1) bean planted in monoculture, 2) bean intercropped with eggplant, 3) bean intercropped with field corn, and 4) bean monoculture treated with imidacloprid (Provado 1.6F, Bayer, Kansas City, MO), a systemic insecticide. The imidacloprid treatment was included for yield comparison only. It was not sampled for whiteflies.

'Espada' bean (Harris Seed, Rochester, NY) was used in the monoculture and intercrop treatments. 'Black Beauty' eggplant (Ferry-Morse Seed, Fulton, KY) was tested as a trap crop in one intercrop treatment. The subtropical field corn hybrid Howard II-IST (Gallaher et al. 1998) was tested as a barrier crop in the other intercrop treatment. Plant spacing within the row was 10 cm for bean, 15 cm for corn, and 46 cm for eggplant. Each plot contained 14 rows which were 6.1 m in length with 0.9 m between rows. Intercropped plots were planted in a 2:4:2:4:2 pattern, with corn or eggplant in the outermost and central 2 rows, surrounding 2 four-row patches of bean. Each treatment was replicated 5 times and arranged in a randomized complete block design.

Corn was planted on 26 July and fertilized with 0.68 kg 15-0-14 (N-P_2O_5-K_2O) per row. Corn received 0.3 kg 15-0-14 per row on 9 August. Heavy *Spodoptera frugiperda* (J. E. Smith) damage threatened the barrier crop treatment in August. Corn was treated with 1.74 liter/ha methomyl (Lannate, DuPont Corp., Wilmington, DE) on 9 August and 29 August. Eggplant was transplanted on 22 August when 3 wks old. Eggplant received 0.23 kg per row 15-0-14 fertilizer 27 August, and 0.8 kg on 27 September and 10 October. Beans were planted on 15 September and fertilized with 0.37 kg 15-0-14 per row on 23 September and 12 October.

The experimental area was treated with 0.19 liter/ha paraquat (Gramoxone, Zeneca) on 26 July. Subsequent weed control was mechanical or by hand. The imidacloprid-treated beans received 52.6 g/ha ai imidacloprid (Provado 1.6 F, Bayer) on 4 October and 12 October. This is the rate recommended on the label for most vegetables (Bayer, Kansas City, MO). Provado 1.6F was applied with a backpack sprayer. Imidacloprid is not registered for use on beans but was included so that yield from intercropping treatments could be compared with yield from chemically-protected beans.

Sampling

Whole plant examinations were made of 1 or 2 bean plants per plot each week from 22 September through 11 November except for 29 September. Only the underside of the leaf was examined. The area of each leaf was recorded using a LI-COR portable leaf area meter (model LI-3000A, LI-COR, Lincoln, NE). Bean treatment comparisons were made on the basis of whole plant counts. Leaf counts from upper, middle, and lower plant strata were used for comparison with eggplant on 21 October and 4 November. On 29 September bean and eggplant comparisons were based on the average of counts taken from one 3.35 cm^2 disc from a leaf in the upper and lower strata of two plants per plot (McAuslane et al. 1995).

Whole plant examinations were made of 1 to 3 eggplants per block each week from 25 August through 8 October. After that time, plants became too large for whole plant examinations. Whole leaf counts from upper, middle, and lower strata were made of eggplant on 21 October and 4 November.

Leaves were examined using a stereoscope and fiber-optic light. Total number of *B. argentifolii* eggs, nymphs, parasitized nymphs, and red-eyed nymphs (also called 'pupae') was recorded for each leaf. Leaves with nymphs showing symptoms of parasitism were placed in unwaxed cylindrical 0.95 liter cardboard cartons (Fonda Group, Union, NJ) to allow parasitoids to emerge.

The height of five corn plants per row was measured on 4 October to assess the barrier effect. Beans were harvested from two 1.8-m sections from each plot on 22 November and fresh weight was recorded.

Research Design and Plot Management, 1997

In 1997 the corn barrier treatment was repeated on a larger scale. Three treatments were compared to evaluate the influence of the barrier crop and the effect of barrier row orientation to wind direction on adult whitefly movement. Prevailing winds in August in the area tend to be from the east. The treatments were 1) bean planted in monoculture (bean alone), 2) alternating rows of bean and corn planted north to south (barrier), and 3) alternating rows of bean and corn planted east to west (open).

Treatments were arranged in a randomized complete block strip split plot design. Each treatment was replicated four times. The four blocks were arranged in pairs on either side of a 12 m-wide path running north to south. Treatment plots were 15.25 m × 30.5 m, with the shorter side parallel to the central path. This design was used to allow for a release of whitefly adults from points spaced evenly along the central path.

Corn was planted on 25 March. It was fertilized with 67 kg/ha 15-0-14 (N-P_2O_5-K_2O) on 1 April, 26 April, and 14 May. Bean was planted on 1 July and fertilized with 33 kg/ha 15-0-14 (N-P_2O_5-K_2O) at planting, 10 July, and 20 July. Overhead irrigation was used to supplement rainfall. Plots were weeded mechanically and by hand.

Mass-rearing of *B. argentifolii*

About 30 senescing broccoli, *Brassica olerecea* L., plants infested with *B. argentifolii* were removed from an organic farm near Gainesville between 1-6 June. They were potted and placed with 36 flowering hibiscus, *Hibiscus rosa-sinensis* L., plants in a greenhouse at the Department of Entomology and Nematology at the University of Florida. Hibiscus plants were watered regularly and fertilized with Purcell's Sta-Green® plant food (18-6-12 N-P_2O_5-K_2O, Purcell Industries, Sylacauga, AL). By early August, the hibiscus plants were heavily infested with whiteflies.

Trap Preparation

Yellow sticky traps have been used in many instances to monitor and sample whitefly adults (Ekbom & Xu 1990). In the evening of 7 August 180 plastic yellow 710-ml cups (Solo Cup Company, Urbana, IL) were coated with an aerosol adhesive (product 95010, Tanglefoot Company, Grand Rapids, MI) for use as whitefly traps. The traps were arranged in 5 rows within each plot at 1.5, 7.6, 14, 20, and 26 m from the edge of the plot bordering the central path. Three traps were placed in each row. One trap was placed 3.8 m in from either side of the plot, and one was placed 7.6 m within the plot, at the center of the row.

Dust-and-release Procedure

Byrne et al. (1996) developed a method of dusting whitefly adults with a fluorescent pigment in the field and trapping them at a distance as a means to monitor movement. We modified this method to distinguish the released whitefly adults from the trapped field population.

Before dawn on 8 August the infested hibiscus plants were enclosed in 113.5 liter plastic leaf litter bags. The nozzle of a technical duster (product 1964, Lesco, Cleveland, OH) was forced through the plastic and approximately 8.5-14 g orange fluorescent AX-14-N pigment (Fire Orange, Day-Glo Color, Cleveland, OH) was puffed from the duster into the bag onto the infested plants. The hibiscus plants were transported to the experimental area enclosed in plastic bags and arranged in 6 clusters of 6 plants along the central path and between pairs of treatment plots. The plastic bags were removed between 7:30 and 7:50 AM to allow a unified release of dyed whitefly adults. The traps were removed and replaced at dusk. The second set of traps was removed at dusk on 9 August. After removal, traps were kept refrigerated until examined.

On 10 August, the hibiscus plants were returned to the greenhouse. Traps were placed in the plots from 8:00 AM to 5:00 PM on 14 August to determine that whitefly adults from the first release were no longer measurably present in the area. On 24 August the dust-and-release procedure was repeated. Traps were set out from 8:00 AM to 8:00 PM on 24 August, and replaced with traps that were recovered at dusk on 25 August. Hibiscus plants were removed after the second set of traps had been retrieved.

Traps were examined using a Spectroline 365 nm black light (model B-14N, Spectronics, Westbury, NY). The number of fluorescing whitefly adults on each trap was recorded. The height of 15 corn plants per plot was measured on 27 August to evaluate the barrier effect.

Statistical Analysis

In 1996, densities of *B. argentifolii* eggs, nymphs, parasitized nymphs, and red-eyed nymphs were compared among bean treatments using analysis of variance (PROC GLM, SAS Institute 1996). Densities of whitefly immatures on bean and eggplant in the trap crop test were compared using the same test, as was bean yield. For the 1997 study, the effect of treatment, block, and trap position on trap count was analyzed using analysis of variance. Orthogonal contrasts were then used to compare trap counts in the same treatment east and west (upwind and downwind) of the release point, and to compare trap counts among treatments in blocks west of the release point. Wind direction data collected at the site were provided by Dr. E. B. Whitty, Agronomy Department, University of Florida, Gainesville, FL.

Results and Discussion

Whitefly Densities, 1996

Densities of eggs were highest on bean when sampling began and declined over subsequent weeks (Table 1). Nymphal densities were highest during weeks 3 and 4. Observations of parasitized nymphs and red-eyed nymphs were low throughout, although parasitism increased slightly over time.

TABLE 1. MEAN (±SD) NUMBER OF IMMATURE *BEMISIA ARGENTIFOLII*/CM² FOLIAGE ON BEAN, 1996.

Date	Treatment	Egg	Nymph	Para. nymph[1]	REN[2]
22 Sept.	Bean alone	0.79 ± 0.58	0	0	0
	Bean w/ corn	1.04 ± 0.73	0	0	0
	Bean w/ eggplant	1.27 ± 0.68	0	0	0
8 Oct.	Bean alone	0.62 ± 0.40	0.64 ± 0.29	0	0
	Bean w/ corn	0.93 ± 0.26	0.86 ± 0.33	0.002 ± 0.004	0
	Bean w/ eggplant	1.00 ± 0.58	1.31 ± 0.87	0.006 ± 0.01	0.004 ± 0.008
14 Oct.	Bean alone	0.40 ± 0.30	0.79 ± 0.30	0.010 ± 0.008	0.010 ± 0.02
	Bean w/ corn	0.67 ± 0.49	1.10 ± 0.65	0.010 ± 0.004	0.002 ± 0.004
	Bean w/ eggplant	0.60 ± 0.27	0.80 ± 0.25	0.004 ± 0.005	0
21 Oct.	Bean alone	0.36 ± 0.20	0.48 ± 0.30	0.006 ± 0.005	0.006 ± 0.005
	Bean w/ corn	0.39 ± 0.10	0.80 ± 0.51	0.016 ± 0.015	0.008 ± 0.013
	Bean w/ eggplant	0.44 ± 0.15	0.61 ± 0.33	0.006 ± 0.008	0.004 ± 0.005
28 Oct.	Bean alone	0.41 ± 0.34	0.46 ± 0.23	0.004 ± 0.005	0.012 ± 0.011
	Bean w/ corn	0.43 ± 0.16	0.58 ± 0.22	0.020 ± 0.015	0.018 ± 0.016
	Bean w/ eggplant	0.46 ± 0.14	0.67 ± 0.26	0.010 ± 0.007	0.016 ± 0.011
4 Nov.	Bean alone	0.54 ± 0.58	0.51 ± 0.26	0.010 ± 0.01	0.010 ± 0.010
	Bean w/ corn	0.22 ± 0.18	0.44 ± 0.15	0.016 ± 0.015	0.016 ± 0.013
	Bean w/ eggplant	0.34 ± 0.32	0.41 ± 0.22	0.036 ± 0.027	0.014 ± 0.008
11 Nov.	Bean alone	0.26 ± 0.06	0.45 ± 0.35	0.046 ± 0.049	0.006 ± 0.008
	Bean w/ corn	0.06 ± 0.04	0.31 ± 0.20	0.052 ± 0.043	0.008 ± 0.008
	Bean w/ eggplant	0.11 ± 0.16	0.33 ± 0.24	0.024 ± 0.018	0.002 ± 0.004

[1]Parasitized nymphs.
[2]Red-eyed nymphs.

There were no differences ($p > 0.10$) in egg density among treatments during the first six weeks of sampling. Egg densities on bean alone were higher ($p < 0.05$) than on bean intercropped with corn or eggplant during weeks 7 and 8. No differences ($p > 0.10$) in nymphal densities occurred among treatments. Densities of red-eyed nymphs were higher ($p < 0.05$) on bean alone than on the corn and eggplant treatments during week 4. During week 7, parasitism was more than twice as high in the eggplant treatment as in the other two treatments.

Whitefly adults were observed on eggplant the day following transplanting on 22 August. Egg densities on eggplant foliage ranged from $0.66 \pm 0.46/cm^2$ on 25 August to $3.53 \pm 0.72/cm^2$ on 16 September, and declined over the following weeks. Nymphal densities on eggplant foliage were 1.31 ± 1.60/cm2 on 1 September and peaked at 2.39 ± 0.33 on 16 September, declining on subsequent sampling dates. When bean plants were emerging, eggplants were quite large; they had an average of 7.0 ± 1.3 branches, a mean height of 17.33 ± 0.28 cm, and mean leaf area of 485 ± 156 cm^2 ($n = 5$).

Bean vs. Eggplant

On all sampling dates after the first week, egg densities were higher ($p < 0.05$) on bean than on eggplant (Table 2). During the week that nymphs were first observed on bean, densities were lower ($p < 0.05$) on bean than on eggplant. During subsequent sampling dates, nymphal densities were either higher ($p < 0.05$) on bean or not statistically different. Observations of parasitized and red-eyed nymphs were either higher on eggplant than on bean or not statistically different on the two hosts.

Parasitoid Species

All parasitoids reared from bean and eggplant were hymenopterans from the family Aphelinidae. Thirty-nine parasitoid individuals were recovered from bean leaves. Thirty-two of these were *Encarsia nigricephala* Dozier (82%), 4 were *Eretmocerus* sp. (10.3%), and 3 were *Encarsia pergandiella* Howard (7.7%). Among the 121 parasitoid individuals reared from eggplant leaves, 51 were *E. pergandiella* (42.1%), 48 were *E. nigricephala* (39.7%), 13 were *Eretmocerus* sp. (10.7%), 6 were *E. transvena* (Timberlake) (5%), and 3 were *Encarsia* sp. (2.5%). The greater parasitism and variety of parasitoid species on eggplant may be due to the greater number of weeks that eggplant was in the field.

Bean Yield

There was an average of 37.30 ± 5.88 bean plants per 3.6 m of row in all treatments. Bean yield per 3.6 m of row was not different among the three treatments and the imidacloprid-treated bean plants (imidacloprid: 0.95 kg ± 0.71; bean: 0.87 kg ± 0.58; corn: 0.47 kg ± 0.28; eggplant: 1.14 kg ± 0.77).

Eggplant as a Trap Crop

Eggplant did not reduce oviposition on adjacent bean early in the season, and so did not function as a trap crop. Oviposition was not consistently higher on eggplant than on bean as reported elsewhere (Tsai & Wang 1996). Eggplant leaves may have been less suitable for oviposition because they were several weeks older than the bean leaves. A concurrent test of squash, *Cucurbita pepo* L., as a trap crop for whiteflies also produced negative results (Smith 2000).

It is possible that host-finding mechanisms used by whitefly adults prevent them from being drawn away from one host plant by the presence of another. *Bemisia tabaci*

TABLE 2. IMMATURE *BEMISIA ARGENTIFOLII* (MEAN ± SD/CM^2 FOLIAGE) ON BEAN AND EGGPLANT, 1996.

	Egg		Nymph		Parasitized nymph		Red-eyed nymph	
Date	Bean	Eggplant	Bean	Eggplant	Bean	Eggplant	Bean	Eggplant
22 Sept.	1.66 ± 1.67	2.74 ± 1.72	0	1.84 ± 1.72*	0	0	0	0
29 Sept.	5.52 ± 3.44	1.68 ± 1.72*[1]	0.88 ± 0.62	2.13 ± 1.78*	0	0	0	0.031 ± 0.104
8 Oct.	0.65 ± 0.31	0.24 ± 0.41*	1.59 ± 0.83	0.29 ± 0.19*	0.005 ± 0.016	0.035 ± 0.037*	0.005 ± 0.016	0.012 ± 0.015
21 Oct.	0.64 ± 0.54	0.23 ± 0.22*	0.45 ± 0.35	0.49 ± 0.65	0.009 ± 0.014	0.025 ± 0.038	0.003 ± 0.009	0.046 ± 0.078
4 Nov.	0.26 ± 0.26	0.02 ± 0.03*	0.28 ± 0.19	0.11 ± 0.10*	0.024 ± 0.043	0.069 ± 0.067	0.006 ± 0.012	0.048 ± 0.043*

[1]*Indicates that numbers on bean and eggplant are significantly different on a given date according to analysis of variance at $\alpha = 0.05$.

apparently does not respond to host-specific visual or olfactory cues (Mound 1962). Elucidation of the precibarial and cibarial chemosensilla of *B. tabaci* by Hunter et al. (1996) indicates that *B. tabaci* may be able to evaluate plant sap before ingesting it. It has been demonstrated that *Trialeurodes vaporariorum* (Westwood) relies on gustatory information to accept or reject a host (van Lenteren & Noldus 1990), and this may also be true for *B. argentifolii*. In addition, whitefly adults tend to leave some host plant species more quickly than others (Costa et al. 1991, Verschoor-van der Poel 1978). The observed differences in host-specific oviposition density by *B. argentifolii* may be due in part to length of tenure on the plant rather than to some preference expressed in the host-finding stage (Bernays 1999).

Many trap crop studies have not resulted in consistent reductions of whitefly densities on the main crop (Ellsworth et al. 1994, McAuslane et al. 1995, Perring et al. 1995, Puri et al. 1996, Schuster et al. 1996). However, Al-Musa (1982) and Schuster et al. (1996) reported a reduction in virus incidence on tomato using cucumber, *Cucumis sativus* L., and squash, respectively, as trap crops. Power (1990) suggests that crop combinations which cause virus vectors to probe for briefer periods may reduce the incidence of persistent viruses such as geminiviruses. Bernays (1999) demonstrated that *B. tabaci* tends to move more often and spend less time on certain plants when they were grown in combination than when they were grown in pure stands. The crop combinations and densities employed by Al-Musa (1982) and Schuster et al. (1996) may have led to reduced probing by the vector, and so reduced incidence of virus.

Corn as a Barrier Crop

The corn did not grow well in 1996 due to insufficient fertilizer. It attained a mean height of 1.18 m ± 0.34 ($n = 150$) and a density of 27 ± 7 plants per 6.1m row ($n = 30$). We re-evaluated the barrier effect in 1997 with larger, properly fertilized plots. Eggplant did not appear to be a promising trap crop, and so was not included in the field experiment the following year.

Release of Adult Whiteflies, 1997

Average corn height was 2.45 ± 1.97 m when whitefly releases were made. The effect of treatment on trap count was not significant ($p > 0.10$) on any of the four collection dates. Wind direction was from the east or northeast during the 4 days that collections were made (Table 3). Trap counts in plots to the west of the release point were significantly higher than trap counts in plots to the east of the release point for each treatment on each collection date (Table 3). When treatments were compared on the basis of downwind plots only, counts were lower ($p < 0.05$) in the barrier treatment than the monocropped bean treatment on 9 August and 25 August. Trap counts were lower in the downwind barrier plots than in the downwind 'open' plots on 24 August ($p < 0.05$) and 25 August ($p < 0.1$) (Table 3).

Wind direction appeared to be the primary factor determining where whitefly adults were trapped. This is consistent with observations that whitefly adults move passively with wind currents as 'aerial plankton' (Byrne & Bellows 1991). Among downwind plots, the barrier treatment tended to have the lowest counts, indicating that the arrangement of corn rows perpendicular to the prevailing wind direction did have some effect on the movement of adults within the plot. However the overall trap counts in this study were low. The contribution made by corn barriers to reducing whiteflies may depend on the density of the whitefly population. Crop barriers such as corn may be more effective when used with other control measures. Short of employ-

TABLE 3. WHITEFLY ADULTS (MEAN ± SD) PER TRAP UNDER 3 CROPPING SYSTEMS, AUGUST 1997.

		Bean alone		Corn: barrier to wind		Corn: open to wind	
Date	Row[1]	Downwind	Upwind	Downwind	Upwind	Downwind	Upwind
Release 1[2]							
8 Aug.	1	1.67 ± 2.25	0.33 ± 0.52	2.33 ± 1.03	0.33 ± 0.52	2.33 ± 1.21	0.50 ± 0.84
	2	1.33 ± 1.97	0	1.00 ± 0.63	0	0.33 ± 0.52	0.17 ± 0.41
	3	0.67 ± 0.52	0	1.33 ± 1.51	0	0.17 ± 0.41	0.17 ± 0.41
	4	0.50 ± 0.55	0.33 ±	0.33 ± 0.52	0	0.67 ± 0.82	0
	5	0.33 ± 0.52	0	0.17 ± 0.41	0.16 ± 0.41	0.67 ± 1.03	0
	$\bar{x}$[1]	0.90 ± 1.40	0.13 ± 0.35*[3]	1.03 ± 1.16	0.10 ± 0.31*	0.83 ± 1.12	0.17 ± 0.46*
9 Aug.	1	2.00 ± 1.79	0.17 ± 0.41	1.17 ± 0.75	0	1.83 ± 1.47	0.33 ± 0.52
	2	1.67 ± 0.82	0.33 ± 0.52	1.00 ± 0.89	0.17 ± 0.41	1.17 ± 1.17	0
	3	1.50 ± 1.22	0	0.83 ± 0.98	0	0.67 ± 1.21	0
	4	0.50 ± 0.55	0	0.50 ± 0.84	0	1.00 ± 0.89	0
	5	0.50 ± 0.84	0.17 ± 0.41	0.67 ± 0.82	0	0.50 ± 0.84	0
	$\bar{x}$[1]	1.23 ± 1.22a[4]	0.13 ± 0.35*	0.83 ± 0.83b	0.03 ± 0.18*	1.03 ± 1.16ab	0.07 ± 0.25*
Release 2[2]							
24 Aug.	1	3.00 ± 2.00	0.33 ± 0.52	2.83 ± 3.25	0	3.50 ± 2.17	0.17 ± 0.41
	2	1.67 ± 1.21	0.17 ± 0.41	1.50 ± 1.05	0.17 ± 0.41	2.50 ± 1.05	0.17 ± 0.41
	3	0.83 ± 0.75	0.17 ± 0.41	0.50 ± 0.84	0	1.83 ± 1.33	0
	4	0.50 ± 0.55	0.17 ± 0.41	0.17 ± 0.41	0	1.17 ± 0.41	0

[1]Row refers to trap location (1 = nearest, 5 - farthest from release point; see text). ($\bar{x}$ = mean across all 5 row locations.)
[2]Wind direction on release dates: 8 Aug.: 75°; 9 Aug.: 97°; 24 Aug.: 61°; 25 Aug.: 55°.
[3]*Indicates mean trap counts in the same treatment upwind and downwind of the release point are significantly different at $p < 0.05$ according to F-test for contrasts.
[4]Different letters indicate that mean trap counts among treatments downwind of release point are significantly different at $p < 0.05$ according to F-test for contrasts.

TABLE 3. (CONTINUED)WHITEFLY ADULTS (MEAN ± SD) PER TRAP UNDER 3 CROPPING SYSTEMS, AUGUST 1997.

		Bean alone		Corn: barrier to wind		Corn: open to wind	
Date	Row[1]	Downwind	Upwind	Downwind	Upwind	Downwind	Upwind
	5	0.33 ± 0.52	0.17 ± 0.41	0	0	1.33 ± 1.21	0
	$\bar{x}$[1]	1.27 ± 1.46b	0.20 ± 0.41*	1.00 ± 1.82b	0.03 ± 0.18*	2.10 ± 1.52a	0.07 ± 0.25*
25 Aug.	1	3.33 ± 1.97	0.17 ± 0.41	0.33 ± 0.52	0	1.17 ± 1.17	0
	2	1.00 ± 1.10	0	1.00 ± 1.10	0	1.00 ± 0.89	0
	3	1.17 ± 0.98	0	0.17 ± 0.41	0	0.50 ± 0.55	0
	4	0.67 ± 0.82	0	0.33 ± 0.82	0	0.83 ± 1.17	0
	5	0.33 ± 0.52	0	0.17 ± 0.41	0	1.00 ± 0.89	0
	$\bar{x}$[1]	1.30 ± 1.53a	0.03 ± 0.18*	0.40 ± 0.72b	0	0.90 ± 0.92	0*

[1]Row refers to trap location (1 = nearest, 5 - farthest from release point; see text). ($\bar{x}$ = mean across all 5 row locations.)
[2]Wind direction on release dates: 8 Aug.: 75°; 9 Aug.: 97°; 24 Aug.: 61°; 25 Aug.: 55°.
[3]*Indicates mean trap counts in the same treatment upwind and downwind of the release point are significantly different at $p < 0.05$ according to F-test for contrasts.
[4]Different letters indicate that mean trap counts among treatments downwind of release point are significantly different at $p < 0.05$ according to F-test for contrasts.

ing manufactured barriers such as floating row covers or fine mesh screens, whitefly adults probably cannot be excluded from a cropped area (Norman et al. 1993).

Trap position had a significant effect on trap count (ANOVA, d.f. = 4; 8 August, $F = 4.67$, $p < 0.05$; 9 August, $F = 4.65$, $p < 0.05$; 24 August, $F = 2.99$, $p < 0.1$; 25 August, $F = 2.86$, $p < 0.1$). The number of whiteflies caught decreased as trap distance from the release point increased. The interaction of treatment and trap position interaction was not significant, suggesting that this decline was not different among treatments.

Data derived from attractive traps may be ambiguous. A gravid or hungry whitefly adult which is surrounded by non-hosts, such as corn, may be more sensitive to a distant patch of bright yellow than an adult in similar condition surrounded by acceptable hosts, such as bean. It is conceivable that the whitefly adults in the corn treatments spent more time searching and so were drawn from a greater area than the whitefly adults trapped in the monocropped bean treatments. It is possible that fewer whitefly adults entered the corn treatments than the monocropped bean, but that a higher proportion of those entering the corn treatments were trapped. However, these considerations do not alter the overall impression that where air currents can enter, whitefly adults can follow.

ACKNOWLEDGMENTS

The authors would like to thank to R. Wilcox, without whom this research would not have been possible. We are grateful to D. C. Beitrusten, D. W. Dickson, R. N. Gallaher, and C. W. Scherer for field assistance, and to J. L. Stimac for sampling advice. G. A. Evans kindly identified whitefly parasitoids, and J. M. Harrison gave invaluable statistical guidance. We thank E. B. Whitty for wind direction data. Thanks to R. N. Gallaher and H. J. McAuslane for improving earlier versions of this manuscript. This research was made possible by support from the Ruth Freeman and Anselm Fisher Foundation. Florida Agricultural Experiment Station Journal Series No. R-06937. No endorsements or registrations are implied herein.

REFERENCES CITED

AL-MUSA, A. 1982. Incidence, economic importance, and control of tomato yellow leaf curl in Jordan. Plant Dis. 66: 561-563.

BERNAYS, E. A. 1999. When host choice is a problem for a generalist herbivore: experiments with the whitefly, *Bemisia tabaci*. Ecolog. Entomol. 24: 260-267.

BROWN, J. K., D. R. FROHLICH, AND R. C. ROSELL. 1995. The sweetpotato or silverleaf whiteflies: biotypes of *Bemisia tabaci* or a species complex? Ann. Rev. Entomol. 40: 511-534.

BYRNE, D. N., T. S. BELLOWS, JR., AND M. P. PARRELLA. 1990. Whiteflies in agricultural systems, pp. 227-261 *in* D. Gerling (ed.), Whiteflies: their bionomics, pest status and management. Intercept Ltd. Andover, Hants, U.K. 348 pp.

BYRNE, D. N., AND T. S. BELLOWS, JR. 1991. Whitefly biology. Ann. Rev. Entomol. 36: 431-57.

BYRNE, D. N., R. J. RATHMAN, T. V. ORUM, AND J. C. PALUMBO. 1996. Localized migration and dispersal by the sweet potato whitefly, *Bemisia tabaci*. Oecologia 105: 320-328.

COSTA, H. S., J. K. BROWN, AND D. N. BYRNE. 1991. Host plant selection by the whitefly, *Bemisia tabaci*, under greenhouse conditions. J. Appl. Ent. 112: 146-152.

DENHOLM, I., F. J. BYRNE, M. CAHILL, AND A. L. DEVONSHIRE. 1996. Progress with documenting and combating insecticide resistance in *Bemisia*, pp. 507-603 *in* D. Gerling and R. T. Mayer (eds.), *Bemisia* 1995: taxonomy, biology, damage, control, and management. Intercept Ltd. Andover. Hants, U.K. 702 pp.

EKBOM, B. S., AND R. XU. 1990. Sampling and spatial patterns of whiteflies, pp. 107-121 *in* D. Gerling (ed.), Whiteflies: their bionomics, pest status and management. Intercept Ltd. Andover, Hants, U.K. 348 pp.

ELLSWORTH, P., D. MEADE, D. BYRNE, J. CHERNICKY, E. DRAEGER, AND R. GIBSON. 1994. Progress on the use of trap crops for whitefly suppression, p. 160 *in* T. J. Henneberry, N. C. Toscano, R. M. Faust, and J. R. Coppedge, (eds.), Silverleaf whitefly: 1994 supplement to the five-year national research and action plan. ARS-125, United States Department of Agriculture, Washington, D.C.

FARGETTE, D., AND C. FAUQUET. 1988. A preliminary study on the influence of intercropping maize and cassava on the spread of African cassava mosaic virus by whiteflies. Aspects Appl. Biol. 17: 195-202.

FAUST, R. M. 1992. Conference report and five-year national research and action plan for development of management and control methodology for the sweetpotato whitefly, p. 58. ARS-107, United States Department of Agriculture, Washington, D.C.

GALLAHER, R. N., R. MCSORLEY, R. L. STANLEY, AND D. L. WRIGHT. 1998. Howard II-IST and Howard IIST subtropical corn hybrids. Agronomy research report AY-98-02. Agronomy Department, Institute of Food and Agricultural Sciences, University of Florida.

GOLD, C. S., M. A. ALTIERI, AND A. C. BELLOTTI. 1990. Direct and residual effects of short duration intercrops on the cassava whiteflies *Aleurotrachelus socialis* and *Trialeurodes variabilis* in Colombia. Agric. Ecosystems Environ. 32: 57-68.

HIEBERT, E., A. M. ABOUZID, AND J. E. POLSTON. 1996. Whitefly-transmitted geminiviruses, pp. 277-288 *in* D. Gerling and R. T. Mayer (eds.), *Bemisia* 1995: taxonomy, biology, damage, control, and management. Intercept Ltd. Andover, Hants, U.K. 703 pp.

HUNTER, W. B., E. HIEBERT, S. E. WEBB, J. E. POLSTON, AND J. H. TSAI. 1996. Precibarial and cibarial chemosensilla in the whitefly, *Bemisia tabaci* (Gennadius) (Homoptera: Aleyrodidae). Internat. J. Insect Morphol. Embryol. 25: 295-304.

MCAUSLANE, H. J., F. A. JOHNSON, D. L. COLVIN, AND B. SOJACK. 1995. Influence of foliar pubescence on abundance and parasitism of *Bemisia argentifolii* on soybean and peanut. Environ. Entomol. 24: 1135-1143.

MORALES, J. R., D. E. DARDÓN, AND V. E. SALGUERO. 1993. Parcela MIP de validación y transferencia en tomate, p. 130 *in* Manejo integrado de plagas en tomate; fase 1: 1991-1992. Ministerio de Agricultura, Ganaderia y Alimentacion, Guatemala City, Guatemala.

MOUND, L. A. 1962. Studies on the olfaction and colour sensitivity of *Bemisia tabaci*. Entomol. Experiment. Appl. 5: 99-104.

NORMAN, J. R. JR., D. G. RILEY, P. A. STANSLY, P. C. ELLSWORTH, AND N. C. TOSCANO. 1993. Management of silverleaf whitefly: a comprehensive manual on the biology, economic impact and control tactics. United States Department of Agriculture, Washington, D.C.

PERRING, T. M., K. S. MAYBERRY, AND E. T. NATWICK. 1995. Silverleaf whitefly management in cauliflower using a trap crop, p. 151 *in* T. J. Henneberry, N.C. Toscano, R. M. Faust, and J. R. Coppedge (eds.), Silverleaf whitefly: 1995 (USDA), Supplement to the five-year national research and action plan. ARS 1995-2.

POWER, A. G. 1990. Cropping systems, insect movement, and the spread of insect-transmitted diseases in crops, pp. 47-69 *in* S. R. Gliessman (ed.), Agroecology: researching the ecological basis for sustainable agriculture, vol. 78. Springer-Verlag, New York.

PURI, S. N., B. B. BHOSLE, P. S. BORIKAR, M. K. FARTADE, R. N. KOLHAL, M. ILYAS, B. R. KAWTHEKAR, G. D. BUTLER, AND T. J. HENNEBERY. 1996. Wild brinjal *Solanum khasianum* Clarke as a potential trap crop management tool for *Bemisia* in cotton, pp. 237-240 *in* D. Gerling and R. T. Mayer (eds.), *Bemisia* 1995: taxonomy, biology, damage, control and management. Intercept, Ltd. Andover, Hants, U.K. 703 pp.

RATAUL, H. S., C. K. GILL, AND S. BRAR. 1989. Use of barrier crop and some cultural measures in the management of yellow mosaic virus on soybean. J. Res. Punjab Ag. Univ. 26: 227-230.

SALGUERO, V. E. 1993. Manejo de mosca blanca y acolochamiento en tomate. Ministerio de Agricultura Ganaderia y Alimentacion, Guatemala City, Guatemala.

SAS INSTITUTE INC. 1996. SAS/STAT® Software: changes and enhancements through release 6.11, SAS Institute. Cary, NC.

SCHUSTER, D. J., P. A. STANSLY, D. E. DEAN, AND J. E. POLSTON. 1996. Potential of companion plantings for managing silverleaf whitefly and tomato mottle geminivirus on tomato, pp. 168 *in* T. J. Henneberry, N.C. Toscano, R. M. Faust, and J. R. Coppedge (eds.), Silverleaf whitefly: 1996 supplement to the five-year national research and action plan. ARS 1996-01, United States Department of Agriculture. Washington, D.C.

SHAPIRO, J. P. 1996. Insect-plant interactions and expression of disorders induced by the silverleaf whitefly, *Bemisia argentifolii*, pp. 167-177 *in* D. Gerling and R. T. Mayer (eds.), *Bemisia* 1995: taxonomy, biology, damage, control, and management. Intercept Ltd. Andover, Hants, U.K.

SHARMA, S. R., AND A. VARMA. 1984. Effect of cultural practises on virus infection in cowpea. Zeitschrift für Acker- und Pflanzenbau 153: 23-31.

SMITH, H. A., R. L. Koening, H. J. McAuslane, and R. McSorley. 2000. Effect of silver reflective mulch and a summer squash (*Cucurbita pepo* L.) trap crop on densitites of immature *Bemisia argentifolii* (Homoptera: Aleyrodidae) on organic bean (*Phaseolus vulgaris* L.) Journal of Economic Entomology 93: (in press).

TSAI, J. H., AND K. WANG. 1996. Development and reproduction of *Bemisia argentifolii* on five host plants. Environ. Entomol. 25: 810-816.

VANDERMEER, J. 1989. The Ecology of Intercropping. Cambridge University Press. Cambridge, UK.

VAN LENTEREN, J. C. AND L. P. J. J. NOLDUS. 1990. Whitefly-plant relationships: behavioral and ecological aspects, pp. 47-87 *in* D. Gerling (ed.), Whiteflies: their bionomics, pest status and management. Intercept Ltd. Andover, Hants, U.K. 348 pp.

VERSCHOOR-VAN DER POEL, P. J. G. 1978. Host-plant selection by the greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood) (Homoptera: Aleyrodidae) (in Dutch). M.Sc. Thesis, University of Leiden, 39 pp.