Concentration and management of *Bemisia tabaci* in cantaloupe as a trap crop for cotton

S.J. Castle*

USDA-ARS Western Cotton Lab, 4135 E. Broadway Road, Phoenix, AZ 85040, USA

Received 21 January 2005; received in revised form 10 August 2005; accepted 12 August 2005

Abstract

A greater settling and retention of *Bemisia tabaci* adults on cantaloupes over cotton was the basis for examining the potential of cantaloupes to serve as a trap crop and reduce infestations of *B. tabaci* in cotton. The preference of adults for leaves of cantaloupe compared to cotton in caged cylindrical arenas in the greenhouse was greater than 67% on average. However, when adults had access to whole plants rather than individual leaves in uncaged bench-top experiments, the preference for cantaloupe was greater than 90%. In field trials conducted in central Arizona over two seasons, much higher numbers of *B. tabaci* adults infested cantaloupes compared to cotton with egg and small nymph densities more than 10-fold greater on 9 of 12 sampling dates in 1998. The difference between trap crop-protected cotton and unprotected cotton was relatively small, although lower densities consistently occurred in protected cotton through the season. An improved field design in 1999 that provided greater separation between protected and unprotected cotton and completely surrounded the protected cotton with the trap crop yielded larger differences in *B. tabaci* densities that favored the protected cotton. Although densities in the protected cotton were reduced relative to unprotected cotton, the managed trap crop was unable to prevent economic thresholds from being exceeded in the protected cotton.

Keywords: Polyphagy; B-biotype *Bemisia tabaci*; Host preference; Pest management

1. Introduction

Trap cropping involves the manipulation of crop stands in time and space with the objective of concentrating a pest species within the trap crop rather than the main crop (Hokkanen, 1991). This can be achieved by using a trap crop that is the same species or cultivar as the main crop, but which is grown asynchronously to the main crop in order to concentrate either early or late pest invaders (e.g. Hoy et al., 2000; Moore and Watson, 1990; Scholte, 2000). Alternatively, a trap crop that is contemporaneously grown with the main crop will probably involve a different plant species that is more attractive to the target pest than the main crop (e.g. Rousse et al., 2003; Charleston and Kfir, 2000; Jackson and Sisson, 1998). In the latter case, sufficient knowledge of the feeding ecology of the target pest is helpful in selecting candidate plant species that will produce a significant differential in settling and retention rates between the trap and main crops. Providing that the biological requirements associated with host plant preferences are met, more practical concerns such as seasonal and agronomic compatibility between both crops must also be addressed as well as determining what control measures will suppress pest numbers in the trap crop.

As a widely polyphagous feeder, *Bemisia tabaci* (Gennadius) utilizes various crop, ornamental, and wild hosts in the southwestern USA, often culminating in excessive infestations in late summer/early fall that require intensive control actions. During the 1990s, progressive population build-ups on a sequence of crops including cantaloupes in the spring, cotton and alfalfa in the summer, and lettuce, broccoli, and cantaloupes in the fall resulted in unprecedented outbreaks, crop damage and economic losses (Gonzalez et al., 1992). Prior to 1990, cotton was the principal crop directly impacted and colonized by the A biotype of *B. tabaci*, whereas fall-planted cucurbits and lettuce crops were mainly impacted indirectly by viral...
diseases vectored by *B. tabaci* (Duffus et al., 1986; Brown and Nelson, 1986). However, with the advent of the B biotype (also known as *B. argentifolii* Bellows and Perring), infestations of broccoli and other cole crops during fall and winter months became common (Perring et al., 1991), and colonization of spring cantaloupes in the Imperial Valley, California, turned severe by 1991. The situation further deteriorated that year, resulting in estimated total crop losses of $111 million in the Imperial Valley alone (Gonzalez et al., 1992), but nationwide an estimated half billion dollars were lost due to severe attacks on crops by the B biotype from California to Florida (Perring et al., 1993). Losses of this magnitude became a watershed event for developing new strategies to address the burgeoning threat represented by the B biotype of *B. tabaci*.

Effective management of a polyphagous pest such as *B. tabaci* in diverse, year-round agricultural systems is often a challenge because of high crop production leading to intensified pest pressure. Its ability to colonize many different host plants that overlap through time broadens the resource base, prolongs generational expansion of populations, and improves the probability of host finding for dispersing pests. However, broad feeding habits also present certain management opportunities such as trap cropping that might not apply to more specific feeders. Polyphagous whiteflies such as *B. tabaci* are amenable to trap crop management for a number of reasons. Foremost is that *B. tabaci*, like all polyphages, exhibits distinct preferences for particular hosts (Schoonhoven et al., 1998). One of the principal lessons from the destructive events of the early 1990s was recognition of the high affinity of the B biotype to cucurbit crops in general, but especially muskmelons (*Cucumis melo*) such as cantaloupe and honeydew. The behavioral preference for cantaloupes shown by the B biotype (Chu et al., 1995) combined with increased oviposition (Veenstra and Byrne, 1998) no doubt contributed to the severe losses in fall cantaloupe yields (http://imperialcounty.net/ag/) beginning in 1991 relative to yields observed prior to the advent of the B biotype in the Imperial Valley. Anatomical differences in the organization of vascular bundles in cantaloupe leaves may contribute to better host quality compared to other crop plants (Cohen et al., 1996).

Cotton has a long history of attack by *B. tabaci* with well-documented accounts of severe infestations occurring as early as the 1920s in India (Husain and Trehan, 1933) and later with outbreaks developing in Turkey (Sengonca, 1975), Israel (Gerling et al., 1980) and Sudan (Dittrich et al., 1985). Damaging infestations on cotton also occurred in North America, especially in the southwestern USA by the A-biotype during the 1980s (Johnson et al., 1982; Watson et al., 1992), but then became more severe during the 1990s after the B-biotype became established. Intensive insecticide use against *B. tabaci* has often been cited as a principal factor in its elevated pest status (Byrne et al., 1990), especially in heavily treated cotton (Eveleens, 1983; Dittrich et al., 1985). There is much need for alternative management approaches for *B. tabaci* in cotton given its history of resistance to insecticides (Dittrich et al., 1985, 1990; Prabhaker et al., 1985, 1992; Cahill et al., 1995).

The trap crop approach to management of *B. tabaci* in cotton proposes to concentrate this pest in cantaloupes planted as a perimeter crop around cotton. The use of cantaloupe is advantageous in that cultivation (http://ceimperial.ucdavis.edu/Vegetable%5FCrops/3073.pdf) and pest management practices (Palumbo et al., 1994, 1995) are well determined. It has been cultivated in the American southwest for many decades and therefore can be readily adapted as a perimeter trap crop for cotton using existing farm equipment and implements. However, trap-crop management can only be successful if adequate control methods exist for suppressing the target pest once it has been concentrated within the trap crop. A multi-voltine pest like *B. tabaci* with a generation time < 3 weeks (in summer) is capable of rapidly increasing within the trap crop and spilling into the main crop in the absence of effective controls. An arsenal of diverse insecticides now exist for combating whiteflies while contained in the trap crop, thereby reducing the overall area exposed to insecticides while conserving beneficial arthropods in the main crop (Naranjo, 2001). Various systemic insecticides can provide long-term control in the cantaloupe trap crop (Palumbo et al., 2000, 2001), IGRs can more selectively target *B. tabaci* immatures (Ellsworth and Martinez-Carillo, 2001), while a selection of conventional insecticides can be applied to knockdown adult whiteflies if necessary (Castle et al., 2002).

Although there have been many anecdotal observations on greater densities of *B. tabaci* occurring of cantaloupe compared to cotton, relatively few studies (e.g. Chu et al., 1995) have attempted to quantify the magnitude of the differences in settling on the two crops. One objective of the present study, therefore, was to quantify settling responses on cantaloupe and cotton plants in a series of greenhouse experiments and ultimately to compare with field results. The other objective was to explore the feasibility of using cantaloupes to concentrate dispersing *B. tabaci* adults in the field and manage within the cantaloupe trap crop as a protective measure for the cotton main crop.

2. Materials and methods

2.1. Greenhouse experiments

Two different approaches were used to measure settling and retention of *B. tabaci* adults on cotton or cantaloupe plants in choice experiments. Each one involved 5 sequential observations made at 12 h intervals following release of adult whiteflies into large caged cylindrical arenas or small greenhouses. All observations were made from outside the arena or by using mirrors held underneath leaves so as not to disturb settled adults. Experimental leaves were collected after the final observation to estimate
egg density per leaf. The *B. tabaci* adults used in these studies came from an established greenhouse (2.7 × 3.7 m) culture that contained a mixture of cantaloupe, cotton, and broccoli on open bench-tops.

### 2.1.1. Cylindrical arena trials

Caged cylindrical arenas were constructed of 0.16 cm thick acetate sheeting and formed by overlapping the ends of each sheet and securing with rivets. Each cylinder was 61 cm high with 28 cm diameter and stood freely on a plywood base. The top end was covered with fine-meshed nylon organdy glued securely to the cylinder rim to prevent adult whiteflies released within the arena from escaping. Individual leaves of cotton and cantaloupe plants were projected into the cylinder space via 12 × 1.6 cm cutouts in the cylinder wall. The attached potted plants remained outside of the cylinders and were supported on adjustable stands so that a selected leaf could project cleanly into the cylinder space without being twisted or having undue stress placed on the plant or experimental leaf. The cylinders had either 3 or 4 equidistant cutouts at a height of 48 cm and foam rubber baffles that fit securely within the cutout space and around the petioles of the projecting leaves. Approximately 120 *B. tabaci* adults collected from cotton plants could be released from their holding containers into each arena by reaching through a circular cutout fitted with a sleeve. Collection and release of adults were made in the morning with the first count 12 h post-release made in the evening after sunset. A flashlight was used to illuminate the abaxial surface of each projected leaf during the evening counts; morning counts made in daylight were facilitated by using an umbrella to shade each cylinder arena to prevent glare and trans-illumination through the projected leaves.

Two cylinder arena trials were conducted using 3- and 4-slotted cylinders simultaneously, 6 replicates of each type. In the 4-slotted arenas, 2 cantaloupe leaves and 2 cotton leaves were arranged alternately by plant type and projected into each arena. To simulate field conditions where a trap crop occurs in a restricted planting relative to the main crop, a single cantaloupe leaf was projected along with 2 cotton leaves in the 3-slotted arenas to determine if responses of *B. tabaci* adults varied according to resource availability. Mature, fully expanded cotton and cantaloupe leaves that were similar in leaf area were selected from plants for projection into cylinder arenas. Experimental plants were grown in a clean greenhouse free of *B. tabaci* so as not to confound egg counts made on leaves following adult observations.

### 2.1.2. Bench-top trials

Two small greenhouses (2.7 × 3.7 m) were used in each of 2 trials that featured the same number and arrangement of cantaloupe and cotton plants on bench-tops in each greenhouse, but differed in the source of *B. tabaci* adults that were released. A randomized complete block design was used with 4 cantaloupe and 4 cotton plants randomly arranged within each of 4 blocks (replicates) aligned on the bench-top on one side of each greenhouse. The young plants (5–8 fully expanded leaves) were grown in individual 15 cm pots and equipped with automatic watering tubes to minimize any disturbance to plants and adult whiteflies following their release. The cantaloupe plants were prostrate on the bench-tops and the cotton plants erect, both arranged ahead of the release of whiteflies so that each leaf would be accessible for counts. The setup of plants and release of whiteflies from either cantaloupe or cotton plants proceeded on the same schedule to minimize variability in plant or environmental factors within each trial. Approximately 1300 *B. tabaci* adults were collected for each trial from cantaloupe source plants for release in one of the greenhouses. In the second greenhouse, approximately the same number of adults was collected off of cotton source plants for release in the first trial, but only ca. 800 for the second trial. Whiteflies were released from their holding containers on the opposite side of the greenhouse from where the plants were arranged. Evaporative coolers were shut off just prior to their release to minimize air currents as the adult whiteflies flew across the greenhouse to settle upon their choice of plants. After the last observation, leaves from each plant were collected and placed individually into labeled bags for egg counts.

### 2.2. Trap-crop experiment

Field trials were conducted during 1998 and 1999 at the University of Arizona Maricopa Agricultural Center (MAC) in south-central Arizona. Both trials involved a simple comparison of *B. tabaci* infestations between 2 treatments: either cotton protected with a cantaloupe trap crop, or cotton unprotected by a trap crop. No insecticides were applied to the cotton main crop in either treatment. In 1998, comparisons between the 2 treatments were made within a single field. Dimensions of plots were configured to provide good separation using wide, fallow alleys in an attempt to better define treatment effects. However, the potential still seemed high for *B. tabaci* adults to be drawn to cantaloupe borders of protected plots from unprotected cotton plots. Therefore, the 1999 trial was conducted in 4 different fields relatively isolated from one another on the university farm.

Standard agronomic practices (http://ag.arizona.edu/crops/cotton/cotton.html) for central Arizona cotton were followed both years. Infestations of *B. tabaci* were evaluated on protected and unprotected cotton cultivar DPL-5415 (Delta and Pine Land Co.) planted in mid-April each year. Planting of the faster growing cantaloupe (cv. Topmark) trap crop was delayed until later in the spring to time vine development to the onslaught of dispersing whiteflies.

### 2.2.1. Field trial 1998

The experimental design used in 1998 consisted of 4 replicate blocks with 2 treatments each, cantaloupe-protected
soil-drench application of imidacloprid (Admire®) at 0.39 kg A.I. ha⁻¹ was tank-mixed with endosulfan (Thiodan®) at 1.12 kg A.I. ha⁻¹ and water at the rate of 1871 ha⁻¹ to suppress further development of nymphs, principally with the IGR buprofezin, but also with the knockdown power of endosulfan to prevent adult dispersal out of the cantaloupe trap crop at the time of spraying. All spray applications to the cantaloupe trap crop were made with a backpack sprayer at 207 kPa through a single Teejet 6002 flat-fan nozzle. A final treatment with endosulfan (1.12 kg A.I. ha⁻¹) was made a few weeks later just prior to the disking of the first planting of cantaloupes. Any action carried out in the cantaloupe trap crop, spraying or disking, had to be accompanied by a knockdown treatment to prevent dispersal into the main cotton crop. The first planting of cantaloupes was disked at a time that B. tabaci infestations were increasing to the point of becoming a source of whiteflies rather than a sink, leaving only the second planting of cantaloupes as protection from immigrating whiteflies.

2.2.4. Insect sampling and counts

Evaluations of whitefly infestations in the cantaloupe-protected and unprotected cotton were made on a weekly basis beginning the first week of July and continuing through the third week of September each year. In 1998, 12 cotton plants in every third row were randomly selected and sampled at the 5th main stem node by taking a 2.5 cm² leaf punch from the basal portion of the second sector (Naranjo and Flint, 1994). This brought the total number of plants sampled per plot each week to 96, or 384 per treatment. Leaf disks from each sample row were collected into a zip-lock bag and stored on ice in the field, then in a refrigerator once returned to the laboratory. The number of eggs, small (1st and 2nd instars) and large (3rd and 4th instars) nymphs and pupal exuviae were counted on the abaxial side of each leaf disk. A similar protocol was observed for weekly samples of cantaloupe leaves, except that only 12 leaves were sampled from each cantaloupe strip on either side of protected cotton plots for a total of 96 cantaloupe leaves each week. The first leaf punches (2.5 cm²) were collected at the 3rd node back from the terminals when cantaloupe plants were in the 4–6 true leaf stage. As the plants developed, sampled leaves were collected from leaf nodes located progressively back from the terminals (up to the 8th node) to allow for a fuller evaluation of the various life stages of B. tabaci in the cantaloupe trap crop.

A similar sampling protocol was observed in 1999, but with greater attention paid to within-plot distributions of B. tabaci. This was achieved by subdividing each cotton plot into 5 longitudinal strata of 4 rows each. Leaf disk samples were collected from 24 randomly selected plants located in the inner 2 rows of each stratum for a total of 120 cotton plants per plot each week. Cantaloupe leaves were also sampled weekly from all 4 sides surrounding the protected cotton plots. Twelve leaves per side of each protected plot were sampled for a total of 48 leaves per field each week.
2.3. Data analyses

Counts of *B. tabaci* adults and eggs on cotton and cantaloupe leaves in the greenhouse experiments were log-transformed (log10\(n+1\)) to normalize variance prior to analysis of variance. A repeated measures analysis of variance was conducted independently on the cylinder cage data and the bench-top data. A sphericity test (JMP version 5, SAS Institute, Cary, NC, USA) was performed on both data sets to determine if a univariate or multivariate model should be used. In both cases, a highly significant \(\chi^2\) statistic demonstrated the need for the multivariate model (MANOVA). The test effects for the cylinder arena experiment included whether 1 cantaloupe+2 cotton leaves or 2 cantaloupe+2 cotton leaves were presented (treatment), trial number, replication (cylinder number), plant source, and a treatment x experiment term. The test effects for the greenhouse bench-top trials were slightly different with whitefly source plant, trial number, block, plant source, and leaf position. Statistical analyses of the number of eggs oviposited on either cantaloupe or cotton in both experiments was performed using a nested ANOVA with leaf node nested within host plant type.

Field data from the trap crop trials were also log-transformed prior to ANOVA. Separate analyses for each year’s results were performed due to the substantial differences in field layout and design from 1 year to the next. Weekly counts of the various stages of *B. tabaci* were evaluated independently rather than as repeated measures based on collection of samples from different plants each week, but more importantly because the influence of daily immigration into treatment plots was considered to be a much larger influence than autocorrelative factors within plots. A two-way ANOVA was used to evaluate weekly counts of *B. tabaci* eggs and nymphs in cantaloupe-protected vs. unprotected cotton with replicate as the blocking factor. A nested ANOVA was used in the 1999 trial to account for the stratified subdivisions within each plot by nesting the variable strata within treatment (cantaloupe-protected or unprotected).

3. Results

3.1. Greenhouse experiments

During the first cylinder arena trial, *B. tabaci* adults showed little difference in their responses to cantaloupe or cotton leaves at the 12 h interval (Fig. 1). However, adult numbers began to diverge at 24 h in each treatment, i.e. 1 cantaloupe+2 cotton leaves (1+2) or 2 cantaloupe+2 cotton (2+2) leaves. This trend continued through to the final evaluation at 60 h with a mean (±SEM) count of 72.8±6.5 adults on cantaloupe leaves and 27.1±2.6 on the cotton leaves in the 1 cantaloupe+2 cotton arenas. In the 2+2 arenas, the difference in mean numbers between cantaloupe (49.6±3.9) and cotton (11.0±1.3) leaves was 4.4-fold at the final evaluation (Fig. 1). The mean count of *B. tabaci* adults on cantaloupe leaves over all 5 evaluations in the 1+2 arenas was 54.2, or 62% of counted adults, compared to a mean of 32.7, or 38%, on cotton leaves (\(F_{4,13} = 6.86, P = 0.003\)). Mean counts through all evaluation intervals in the 2+2 arenas was 38.7, or 67% on cantaloupe leaves and 19.0, or 33% on cotton leaves (\(F_{4,19} = 32.97, P<0.0001\)).

The mean numbers and relative differences between hosts in the second cylinder arena trial were similar to the first, but the profile over the course of the experiment was...
quite different as *B. tabaci* adults preferentially settled on cantaloupe vs. cotton leaves at the 12 h observation (Fig. 1). A mean number of 56.9 (67%) adults across all 5 observations settled on cantaloupe leaves compared to 28.5 (33%) on cotton leaves in the 1+2 arenas ($F_{4,13} = 3.61, P = 0.034$). As with the first trial, the difference between cantaloupe and cotton leaves was greater in the 2+2 arenas with a mean of 43.7 (71%) adults settled on cantaloupe leaves compared to 17.7 (29%) on cotton leaves ($F_{4,19} = 9.74, P = 0.0002$). These differences in adult settling rates observed in both the 1+2 and 2+2 arenas translated into proportional differences in egg deposition on cantaloupe and cotton that resembled the adult densities (Fig. 2). Host plant effect proved to be a highly significant factor in the number of *B. tabaci* eggs on cantaloupe vs. cotton leaves in both the 1+2 arenas ($F_{1,27} = 40.0, P < 0.0001$) and the 2+2 arenas ($F_{1,38} = 24.4, P < 0.0001$) in the combined analysis from both trials.

Relative differences between mean numbers of *B. tabaci* adults and eggs on cantaloupe vs. cotton plants in the bench-top experiment were more pronounced than those observed in the cylinder arena experiment (Fig. 3). In trial 1 with cantaloupe as the source plant of *B. tabaci* adults released into the greenhouse, a mean of 274 adults per plant (96.5%) across all 5 evaluation intervals was recorded on cantaloupe plants compared to 10 adults per plant (ARTICLE IN PRESS

---

**Fig. 2.** The number of eggs (mean ± SEM) laid on each leaf in the cage-cylinder arena experiment as determined following completion of adult counts.

**Fig. 3.** Differences in settling rates (mean ± SEM) on cotton or cantaloupe plants by *B. tabaci* adults released into small greenhouses and monitored over 2½ days. Two trials were conducted in 2 separate greenhouses in which *B. tabaci* adults either from cotton source plants or cantaloupe source plants were released.
(3.5%) on cotton (Fig. 3). The results in the cotton source plant-greenhouse were nearly identical with a mean number of 234 (93%) per cantaloupe plant and 18 (7%) per cotton plant. The second trial produced very similar results with a mean number of adults per cantaloupe plant of 209 (93.7%) compared to 14 (6.3%) on cotton in the cantaloupe source plant-greenhouse, and 161 (90.2%) per cantaloupe plant and 17 (9.8%) per cotton plant in the cotton source plant-greenhouse (Fig. 3). These differences were highly significant ($F_{4,608} = 5.9, P = 0.0001$) for host plant effect in terms of mean numbers of $B. tabaci$ adults settled on either cantaloupe or cotton plants. The source plant from which the released $B. tabaci$ adults originated, however, was not a significant effect ($F_{4,608} = 0.8, P = 0.51$), nor was replicate ($F_{12,1609} = 1.31, P = 0.21$).

3.2. Trap-crop experiment

Following a cool spring in 1998, whitefly populations began to build rapidly in late July (Fig. 4). Whitefly egg densities peaked in cotton on 10 August and then declined continuously all the way to mid-September at which point a late season increase occurred. A similar pattern was observed for densities of whitefly small nymphs except that they peaked one week earlier than egg densities (Fig. 4). Significantly higher densities of eggs and small nymphs ($P<0.05$) were recorded on unprotected cotton on 6 consecutive dates (27 July–31 August) and 3 consecutive dates (3, 10, 17 August), respectively. The decline in whitefly densities observed in the present study (Fig. 4), even without any insecticide applications applied to cotton, was similar in pattern to a general phenomenon of declining whitefly populations observed at MAC within treated and untreated fields alike.

Egg and small nymph densities on cantaloupes were more than 10-fold greater than on cotton 9 of the 12 sampling dates (Fig. 5). A similar magnitude of difference between the two crops was observed for large nymphs and exuviae up to the time that buprofezin was applied, after which the difference declined. The high numbers of immature stages on the trap crop suggest that insecticide controls were inadequate in terms of suppressing $B. tabaci$ numbers.

During the 1999 trial, whitefly densities in the cantaloupe-protected plots of DP-5415 were consistently lower than the unprotected DP-5415 plots (Fig. 6). On 7 consecutive dates between 2 August and 13 September,
the density of eggs in the cantaloupe-protected plots was significantly lower than that in the unprotected plots (Fig. 6). Similarly during this same time span, the density of small and large whitefly nymphs was significantly lower in the cantaloupe-protected plots on 6 of 7 dates (Fig. 6) with 2–3-fold density differences occurring between treatments. However, despite the consistently lower densities in the cantaloupe-protected cotton, nymphal densities eventually exceeded currently practiced action thresholds for treatments with IGRs (Ellsworth et al., 1996). Differences in B. tabaci egg densities between the cantaloupe trap crop and the cotton main crop in 1999 were not as marked as the previous year due to better control attained with the imidacloprid treatment to the cantaloupe trap crop.

Distributions of B. tabaci eggs and nymphs within the cotton plots varied considerably depending on whether the cotton was surrounded by the cantaloupe trap crop or not. A cross-sectional profile across the protected vs. unprotected cotton plots on, for example, 16, 23 and 30 August revealed a trend toward higher egg densities (Fig. 7) in the interiors of the cantaloupe-protected cotton plots and lower densities on the edges near the cantaloupes, in particular the eastern edge (i.e. row 2). In contrast, egg densities were much higher in the unprotected cotton and without any notable trend in densities from one edge of the plots to the other. Differences in egg densities between edge and interior rows of plots were identified by dividing the row with the highest density by the row with the lowest density. The ratios for the cantaloupe-protected plots ranged from 2.5 to 6.0 for the 3 dates in August, with the lowest density in all cases occurring at the eastern edge in row 2. For the unprotected cotton, the ratios for these 3 dates ranged between 1.1 and 1.4, indicating relatively small differences in densities across the unprotected plots (Fig. 7). Similar profiles were observed on subsequent dates for B. tabaci eggs and small nymphs.

4. Discussion

The widely recognized preference for cantaloupes by B. tabaci biotype B adults was confirmed in both greenhouse experiments as well as in field experiments that used cantaloupes as a trap crop to protect the cotton main crop. However, the magnitude of response to cantaloupes relative to cotton varied considerably according to the experimental configuration in the greenhouse experiments. After 2.5 days within the cylinder arenas, B. tabaci adults had segregated to a ratio of more than 3:1 (on average for both 1+2 and 2+2 arenas) in favor of the cantaloupe leaves and oviposited preferentially on cantaloupe at nearly the same ratio. The preference ratio increased to >9:1 in the greenhouse bench-top experiment in which whole cotton and cantaloupe plants in randomized complete blocks were presented to dispersing adults within the confines of a small greenhouse. The lesser response to cantaloupes in the cylinder arena experiment may have been due partly to a limited choice of leaves projecting into the arenas and to a confined dispersal space. Nevertheless, distinctive upward orientation towards the leaves projecting into the cylinder space from the release points at the bottom of each cylinder was observed for the majority of adults released into cylinder arenas during all trials. Similarly, in the bench-top experiments, adult whiteflies released from the bench-top opposite the experimental arrangement of cantaloupe and cotton plants also appeared to orient directly to the plants upon release, moving across the greenhouse (1.5–2.5 m) rather than dispersing in all directions within the greenhouse. However, some attrition in adult numbers over the 2.5-day period was observed on both cantaloupe and cotton plants, thus suggesting some loss of experimental subjects possibly due to escapes from the greenhouses. Nevertheless, the ratio of eggs oviposited on cantaloupe relative to cotton was even greater than the adult ratio observed with >16- and 11-fold higher egg densities on cantaloupe plants in trials 1 and 2, respectively.

The architecture of available plant material was much more complex in the bench-top experiment with a minimum of 5 leaves per plant on both plant species that assumed their natural orientations, i.e. cotton plants erect and cantaloupe plants prostrate. The response to cantaloupes was more immediate as adult densities were highest at the first observation interval in contrast to the gradual increase observed on cantaloupe in the cylinder arena trials. Although tests were not performed in the current study, it may be interesting to determine what influence, if any, that plant orientation has on B. tabaci adult
orientation and settling behavior by manipulating whole-plant orientation experimentally.

Similar to the magnitude observed in the bench-top experiment, differences in \textit{B. tabaci} egg and small nymph densities between cantaloupe and cotton plants in the 1998 field trial were >10-fold on 9 of 11 sample dates, despite the fact that the cantaloupes were treated with imidacloprid and buprofezin. More effective insecticide applications made in the 1999 trial better controlled the \textit{B. tabaci} immature stages in the cantaloupe trap crop, but the

Fig. 7. Comparison of 1999 egg densities (mean±SEM) on trap crop-protected vs. unprotected cotton leaves collected from rows across respective plots. In all replicate blocks, row 2 represented the eastern edge and row 19 the western edge of each plot with rows 10 and 11 in the center. Ratios presented in each panel were obtained by dividing the row with the highest mean count by the row with the lowest mean count within each treatment plot and for each date.
differential in egg densities between the two host crops was still nearly 10-fold in favor of cantaloupes. The similarity in density ratios between cantaloupe and cotton in the bench-top experiment and the field trials suggest that the bench-top approach using whole plants provided a better estimation of settling behavior in the field than did the cylinder arena experiment. Experimental procedures that use individual leaves, as in the caged-cylinder trials, rather than whole plants may be more prone to incorrect estimates of the settling response by *B. tabaci* or other insect herbivores.

Experimental evaluation of the potential benefits of trap crops in reducing densities of *B. tabaci* or other pests is problematical due to non-independent treatment effects. Greater isolation between trap-crop protected and non-protected principle crops is required to minimize the influence of one treatment upon another. Thus, greater differences observed between the trap crop-protected cotton and unprotected cotton in 1999 were attributable to the better layout of replicate fields granting greater separation between treatments. The full perimeter of cantaloupes surrounding the protected cotton plot may have also contributed to the greater differential between protected and unprotected cotton observed in 1999. The differences in spatial distributions of eggs in the protected vs. unprotected cotton plots indicates that an unknown proportion of dispersing *B. tabaci* adults preferentially settled on the cantaloupe trap crop for feeding and oviposition. However, a portion of the adults, perhaps represented by the higher densities in the centers of the protected cotton plots, immigrated past the cantaloupes into the cotton. The differential between the outside and inside rows of the protected cotton plots compared to the unprotected cotton plots suggests that a behavioral difference in settling occurred in the field as in the greenhouse trials, but that a persistent flow of dispersing adults eventually accumulated in the protected cotton plots nonetheless.

Although the cantaloupe-protected cotton had consistently lower densities of whiteflies throughout the July September period compared to the unprotected cotton, the densities in the cantaloupe-protected cotton still exceeded the IPM guidelines that govern when treatment with the IGRs Applaud® and Knack® should commence against whiteflies in cotton (Ellsworth and Martinez-Carillo, 2001; Ellsworth et al., 1997). If the IPM guidelines had been strictly adhered to in this study, then the cantaloupe trap crop would have been effective only in delaying the timing of the first spray treatment by about 2 weeks. Considering the awkwardness involved with the additional agronomic and pest management inputs required for growing a trap crop peripheral to the cotton main crop, the cantaloupe trap crop approach including insecticide applications to the trap crop would probably have limited appeal. Moreover, a peripheral trap crop planting consumes a substantial amount of land that pragmatically is justifiable only by monetary returns that cover the lost cotton production.


Further reading