Evaluation of Emergence Traps for Monitoring Blueberry Gall Midge (Diptera: Cecidomyiidae) Adults and Within Field Distribution of Midge Infestation

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ABSTRACT The blueberry gall midge, *Dasineura oxycoccana* (Johnson) (Diptera: Cecidomyiidae), is a key pest of rabbiteye blueberry, *Vaccinium virgatum* Aiton, in the southeastern United States, but it has not been studied extensively and little is known about its ecology and management. Studies were conducted to develop an improved method for monitoring *D. oxycoccana* adults and to determine the within-field distribution of infestation. Four emergence traps were evaluated in an organic rabbiteye blueberry planting for their effectiveness in capturing *D. oxycoccana* adults early in the season. These traps included a jar trap, wheat blossom midge trap, petri dish trap, and bucket trap. The petri dish and bucket traps captured the highest numbers of adults in 2007 and 2008, respectively. Both traps had a clear plastic panel coated with adhesive. Adult midges emerging from the soil beneath the traps were caught in the adhesive as they flew up toward the light. Emergence traps are useful for detecting the presence of adults early in the season before larval infestation is apparent in the flower buds. To determine the pattern of midge infestation, flower buds were collected weekly from January to March in 2006 from rabbiteye blueberry plants located in a plot at the southwest border of an existing blueberry planting. There were no differences found in the number of larvae collected from various distances within blueberry rows. However, when flower buds were collected from an isolated rabbiteye plot in 2007 and 2008, *D. oxycoccana* infestation was not uniform. In both years, the southern border row had a significantly higher number of midge larvae per bud compared with the other rows.

KEY WORDS *Dasineura oxycoccana*, rabbiteye, blueberries, emergence trap, distribution

Blueberry gall midge, *Dasineura oxycoccana* (Johnson) (Diptera: Cecidomyiidae), is a key pest of rabbiteye blueberry, *Vaccinium virgatum* Aiton, in the southeastern United States (Dernisky et al. 2005). *D. oxycoccana* larvae feed in developing flower and leaf buds. In susceptible cultivars, >80–90% of flower buds can be destroyed, reducing potential fruit yield (Lyrene and Payne 1992, Sampson et al. 2002, Sarzynski and Liburd 2003). Production of rabbiteye blueberries in Florida has been jeopardized due to heavy infestations (Sampson et al. 2002). Development of an effective integrated pest management (IPM) program for *D. oxycoccana* will require practical monitoring techniques and knowledge of its distribution.

Monitoring is an important component of any successful pest management program. Effective monitoring of midge populations should detect adult emergence and population fluctuations. *D. oxycoccana* adults are difficult to detect due to their small size (2–3 mm). Sticky traps have been used in some plantings to catch adult midges but have proven ineffective (Sarzynski and Liburd 2003). Furthermore, key morphological features can be damaged or obscured by the trap's sticky surface, making subsequent identification difficult (Sarzynski and Liburd 2003).

Sarzynski and Liburd (2003) investigated methods for detecting *D. oxycoccana* and found an emergence technique and bud dissections were useful for monitoring populations in the field. The emergence technique involved removing flower buds from blueberry bushes, holding them in a growth chamber for 10–14 d, and counting larvae or adults as they emerge. With this technique, however, there is a time lag between oviposition and mature larvae emerging from buds. Larvae begin emerging from buds within hours of being collected, but buds need to be held for a minimum of 10 d to obtain accurate counts of population density (unpublished data). Although bud dissection is a good technique for detecting eggs (Sarzynski and Liburd 2003), it is time-consuming, requires visual aid, and is not practical for growers (Finn 2003).

Traps have been designed to catch adults of some cecidomyiid species as they emerge from the soil. Specialized traps have been developed for the midge *Dasineura mali* Kieffer (Smith and Chapman 1996); balsam gall midge, *Paradiplosis tumifex* Gagné (Akar and Osgood 1987); wheat midge, *Sitodiplosis mosellana* (Géhin) (NDSU n.d.); and *Prodiplosis longifila*

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Gagné (Peña and Duncan 1992), but these traps have not been used for monitoring *D. oxycoccana.* An effective emergence trap that can detect adults in the field at an earlier stage would give growers more time to implement a management program before midge populations reach damaging levels.

Information on pest distribution is important for assessing the risk of plant injury when developing management programs for a particular pest. Insecticides, as well as other agricultural inputs, are traditionally applied uniformly to entire fields with little consideration for within-field variations (Weisz et al. 1996). Site-specific IPM requires inputs to be adjusted to match within-field pest population densities. This involves implementing management strategies (such as insecticide use) only in those areas where the pest population has reached the economic threshold. This not only has the potential to reduce the cost and ecological impact of excess insecticide applications but also promotes resistance management by preserving refugia for susceptible individuals (Weisz et al. 1996). Increasing the number of refugia also promotes natural enemy conservation (Weisz et al. 1996). A better understanding of *D. oxycoccana* distribution within blueberry plantings would allow the potential for the development of site-specific IPM programs.

Our objectives were to evaluate emergence traps for monitoring *D. oxycoccana* adults in a rabbiteye blueberry planting, and secondly, to investigate the distribution patterns of *D. oxycoccana* populations to explore the potential for site-specific management. Trap effectiveness was determined by the number of adults caught and time of catch (early versus later in the season). We also determined whether trap catch can be used to predict outbreaks of larvae infesting blueberry flower buds, and investigated whether *D. oxycoccana* infestation was greater at field border rows compared with interior rows.

Materials and Methods

Study Site. The study was conducted at an organic blueberry farm in Gainesville, FL. The farm consisted entirely of rabbiteye blueberry plants of primarily three varieties ('Aliceblue', 'Beckyblue', and 'Climax'). Bushes were planted 1.5 m apart within rows, and row centers were 3.7 m apart. All blueberry bushes in the study were at least 1.5 m in height. At the time of the study, no pruning or weed control had been practiced for several years. No fungicides or insecticides were applied during the years in which experiments were conducted.

Experiment to Evaluate Emergence Traps for Monitoring Adults. Four experiments were conducted to evaluate the various trap designs, two in 2007 and two in 2008. Two plots (designated A and B), each 0.15 ha, were established in two separate 1-ha plantings. Three different trap designs were evaluated in each experiment, described separately for each experiment. Each year experiments were conducted in both plots using the same treatments and experimental design. Experimental design was randomized complete block with four replications (blocked by variety) and three treatments (trap types) for each plot. We evaluated a total of six traps for plots A and B, each trap replicated four times. Trap designs were modifications based on descriptions from Smith and Chapman (1996), who constructed traps from 10-liter plastic buckets. They developed two designs that used either adhesive-coated petri dish tops or inverted plastic funnels with 60-ml specimen containers mounted on the tops of the buckets to retain insects (Smith and Chapman 1996).

In all experiments, traps were placed on the soil surface ≈0.3 m from the crown of a blueberry bush. Traps were spaced ≈15 m apart within each replication. Soil was piled over the edges of the traps to prevent midges from escaping. Trap tops were removed each week and replaced with fresh adhesive or a clean glass jar. The trap tops were brought to the Small Fruit and Vegetable IPM Laboratory at the University of Florida in Gainesville, FL, where adult midges were counted, removed, and placed in vials with 70% ethyl alcohol. Adults caught on Tangle-Trap (The Tanglefoot Company, Grand Rapids, MI) were soaked in Histo-clear (National Diagnostics, Atlanta, GA) to remove the adhesive before transferring to alcohol.

To compare bud infestation with trap captures, 25 flower buds were collected each week from the two blueberry plants adjacent to each trap position. All flower buds collected were in either development stage 2 (bud beginning to swell, scales separated, flowers completely enclosed) or stage 3 (bud scales separated and apices of flowers visible) according to Spiers (1978). Buds were placed in 9-cm-diameter petri dishes with moistened filter paper, sealed with Parafilm (Pechiney Plastic Packaging, Menasha, WI), and placed in a growth chamber (model I-35 LL, Percival, Perry, IA) for 2 wk at 30 ± 2°C (day) and 20 ± 2°C (night), with a photoperiod of 14:10 (L:D) h for larval emergence (Sarzynski and Liburd 2003).

2007. The three trap designs evaluated were: 1) glass jar trap; 2) petri dish trap; and 3) wheat blossom midge trap (Fig. 1). All traps were constructed from 3-liter plastic food containers. The exterior of the traps were painted white (Krylon Interior-Exterior, 1502 Flat White, Krylon Products Group, Cleveland, OH). The only light entering the traps came from the top to exploit the positive phototactic behavior of *D. oxycoccana.* The glass jar trap consisted of an inverted plastic funnel and a 473-ml (1-pint) glass jar for collecting midges. The top of the petri dish trap was a 14-cm-diameter petri dish, the underside of which was coated with Tangle-Trap (The Tanglefoot Company). Alternatively, the wheat blossom midge trap had a translucent plastic lid with a 7.6-cm screen covered opening in the lid and two 5.1-cm-diameter openings in the sides (NDSU n.d.). The underside of the lid was coated with vegetable oil spray. All traps received fresh adhesive or a new jar each week. Captured midges were sexed, and sex ratios were calculated. Traps were deployed in the field for 12 wk from 17 January to 11 April (beginning of flower bud swell to early bloom). Larvae were collected from flower buds

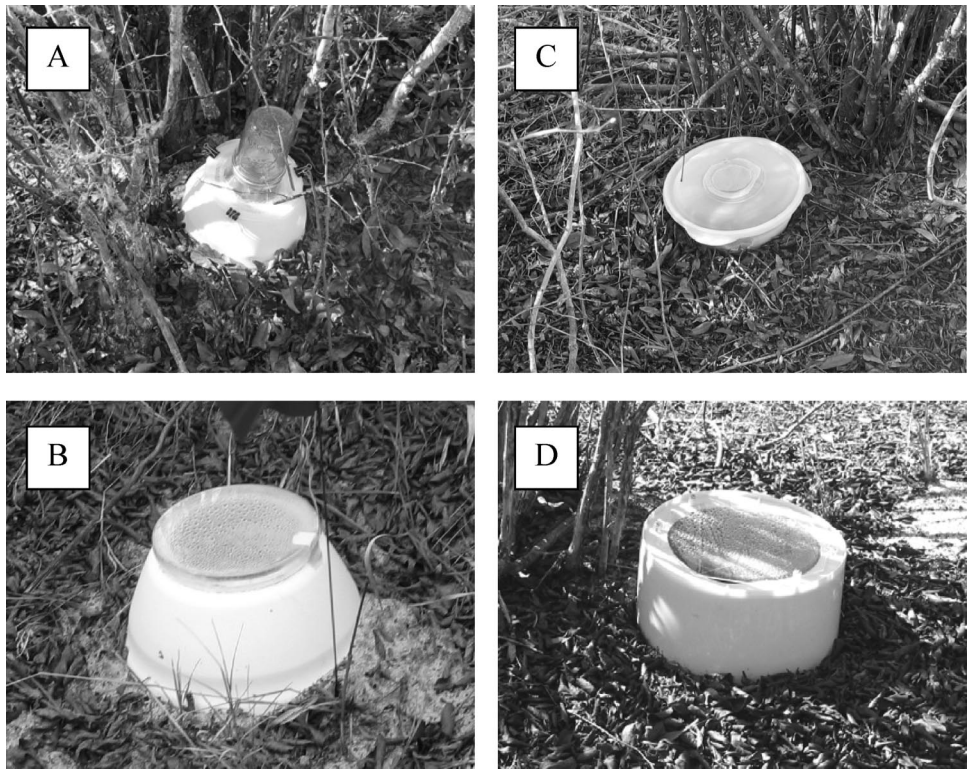

Fig. 1. Emergence traps evaluated in 2007 and 2008. (A) Glass jar trap. (B) Petri dish trap. (C) Wheat midge trap. (D) Bucket trap.

for six weeks from 24 January to 28 February (beginning of flower bud swell to bud scale abscission).

2008. These experiments were conducted in the same two plots used in 2007. The three trap designs evaluated were: 1) petri dish trap; 2) modified petri dish trap; and 3) bucket trap (Fig. 1). Both the glass jar and wheat blossom midge traps from 2007 were excluded in 2008 because captures of *D. oxycoccana* were very low in these traps in 2007 (both locations). The petri dish trap was the same as the one used in 2007. The modified petri dish trap was similar to the one used in 2007 except the interior was painted black (Krylon Interior-Exterior 1613 Semi-Flat Black, Krylon Products Group) to determine whether darkening the trap interior would increase trap captures due to an increased response to light coming from the top of the trap. The bucket trap, a new trap design, was constructed from the bottom of a white 18.9-liter (5-gallon) bucket. The interior was painted black, and a 19.4-cm-diameter hole was cut in the bottom and covered with a 21.3-cm-diameter acrylic sheet (3 mm in thickness) coated on the underside with Tangle-Trap. Experimental design was the same as in 2007. Traps were rotated and moved to a new location within the same replication each week to avoid bias and prevent trapping out all of the midges beneath each trap position. Traps were deployed in the field for 16 wk from 9 January to 30 April (beginning of flower bud swell to full bloom). Larvae were collected from flower buds for 12 wk from 9 January to 26 March (beginning of bud swell to early pink).

Experiment to Investigate Distribution Patterns of *D. oxycoccana* Infestation. Blueberry gall midge infestation was determined by counting the number of larvae and adults that emerged from blueberry flower buds. Flower bud samples were taken from the field in resealable plastic bags and processed in the Small Fruit and Vegetable IPM Laboratory at the University of Florida in Gainesville, FL.

2006: Investigation of Distribution Patterns Within Blueberry Plantings. The study was conducted in a 0.6-ha plot that was at the southwest corner of the organic blueberry farm mentioned before. The plot was bordered to the west and south by a city park consisting of diversified flora. To the north was an uncultivated 0.5-ha field with mixed vegetation but no blueberries. The research plot was 11.5 m from the northern boundary of the field and 7 m from the southern boundary. The plot contained the following three varieties of rabbiteye blueberries: 'Climax', 'Aliceblue' and 'Beckyblue'. Rows were planted in pairs according to variety and alternated Climax, Beckyblue, and Aliceblue from north to south. Each row contained ≈100 blueberry bushes. Samples were collected from bushes 1–5, 20–25, and 46–50. These correspond to distances from the western border of 0–5, 25–30, and 60–65 m, respectively. For each distance, the bud collection area consisted of ten plants (five

from two adjacent rows). Twenty-five flower buds were collected randomly from all 10 plants once a week from 10 February to 10 March from each collection area. Buds were processed as previously described by allowing larvae to exit the buds (for larval/adult collection). All samples were taken from the Climax blueberries. There were four replications each consisting of different rows of Climax blueberries and separated by four rows of the other varieties.

2007: Investigation of Distribution Patterns in Isolated Plots With Potential Edge Effects. This experiment was conducted in a 0.13-ha plot consisting of nine rows of rabbiteye blueberry plants located on the north side of the farm. Bush height and spacing were similar to the within field plot used in 2006 (1.5 m in height and 1.5-m spacing between plants within rows). This plot was used because it was isolated by uncultivated fields and access roads from other blueberry plantings on the farm; therefore, it was expected that edge effects would be easier to observe. The closest blueberry planting was 80–90 m to the southeast. A drainage ditch ran parallel to the plot, 6.7 m from the southern border row. Beyond the ditch was a service road and tree line. Samples were taken from three rows: the southern border row, northern border row, and center row. Sampled rows were separated by three unused rows (14.6 m). Each week from 18 January to 8 March, five bushes were selected in each of the three sampled rows and 25 flower buds were collected from each bush. Individual bushes were treated as replications. Flower bud samples were taken from bushes all along the north and south border rows. In the center row, sampling was restricted to plants in an 18-m section near the center of the row to avoid edge effects in the east–west direction.

2008. The second year of the study to investigate *D. oxycoccana* distribution patterns in isolated plots was conducted at the same site used in 2007. The sampling protocol was the same as in 2007, except that 15 flower buds were collected per plant rather than 25, and bud samples were taken twice per week (as opposed to once per week in 2007) to determine whether any rapid changes in *D. oxycoccana* populations occurred in isolated plots. Sampling began on 9 January and concluded on 10 March. The increased frequency of sampling required that fewer buds be taken per sample to have sufficient buds to last until bloom. Bud samples were collected consistently (twice per week) during mid-January, but sampling had to be suspended from 23 January to 10 March due to a shortage of flower buds.

Statistical Analysis. The number of adults captured per week was compared across trap types using repeated measures analysis of variance (ANOVA) (PROC MIXED, SAS Institute 2003). Variables in the model included trap type, sample date, and their interaction. Data were transformed by $\log_{10}(x + 1)$ to satisfy model assumptions. Differences among means were determined using the least-squares mean (LS Means) separation test ($P < 0.05$). Differences between the number of males and females captured for each trap type were analyzed using *t*-tests ($\alpha = 0.05$). For each trap type, the zero frequency of trap catch was calculated. Zero frequency is the percentage of traps that caught zero adults over a 1-wk sample period. Standard (Pearson) correlation analyses were conducted to determine how well trap catch correlated with bud infestation (PROC CORR, SAS Institute 2003). The objective was to determine the potential of these traps for predicting midge infestation so trap catch from a given sample week was compared with buds collected 1 wk later.

D. oxycoccana infestation levels at field borders and centers were compared by analyzing the differences in the numbers of larvae per flower bud at different field locations. The data were analyzed using repeated measures ANOVA (PROC MIXED). Variables in the model included location, sample date, and their interaction. Data were $(x + 1)^{-1/2}$ transformed to satisfy model assumptions. Differences among means were estimated using the LS Means procedure ($P < 0.05$). In cases where significant interaction effects were observed, differences in infestation were tested by sample date using a two-way ANOVA (PROC GLM, SAS Institute 2003). Differences among means for each week were estimated using least significant differences (LSDs) ($P < 0.05$). Untransformed means and standard errors are reported in tables and figures.

Results

Emergence Trap Evaluation. *2007.* The petri dish trap caught significantly more midge adults than the other trap designs at both plots (Table 1). The percentage of traps with zero catches was lowest for the petri dish trap and highest for the wheat blossom midge trap (Table 1). The sex ratio of captured adult midges was not significantly different from 1:1 for any of the trap types (Table 1). Petri dish traps captured the most adults in the first week of sampling (Fig. 2). Peak trap catch occurred on 21 March for the glass jar and petri dish traps. The number of *D. oxycoccana* adults caught in the wheat blossom midge trap was too low to define a peak. Interaction effects for plot A traps by sample date were not significant ($F = 1.28$; df = 22, 103; $P = 0.202$). Interaction effects for plot B traps by sample date were significant for two out of the 12 wk ($F = 2.34$; df = 22, 69; $P = 0.004$). On 14 and 28 March, the petri dish traps trapped significantly more adults than the other two trap types. At the beginning of the sample period, from 24 January to 7 March, the number of midge adults captured per trap was low and there were no significant differences among trap types.

Correlation between trap catch and bud infestation were compared over a 6-wk period (24 January to 28 February). The wheat midge traps in plot B were the only traps in which the number of *D. oxycoccana* adults was correlated with bud infestation ($r = -0.597$, $P = 0.005$). Over the 6-wk period, bud infestation increased, but trap catch showed an overall decline in the petri dish and wheat midge traps (Fig. 2).

2008. The number of adult midges caught in the bucket trap was significantly higher than the other

Table 1. Mean ± SEM number of *D. oxycoccana* adults caught per emergence trap, sex ratio, and frequency of traps with zero captures per week in 2007 and 2008

Yr	Trap type	Mean no. *D. oxycoccana* adults trapped per week		Sex ratio (F:M)		Zero frequency (%)	
		Plot A	Plot B	Plot A	Plot B	Plot A	Plot B
2007	Petri dish	1.48 ± 0.35a	4.02 ± 1.16a	1:1.0	1:1.1	56.3	52.1
	Glass jar	0.83 ± 0.43b	1.00 ± 0.36b	1:1.2	1:1.7	78.5	54.2
	Wheat midge	0.30 ± 0.15b	0.48 ± 0.16b	1:0.9	1:0.6	86.8	74.3
2008	Bucket trap	2.44 ± 0.35a	1.95 ± 0.48a	1:3.8*	1:2.4*	35.9	55.8
	Original petri	1.30 ± 0.28b	0.92 ± 0.22a	1:1.9	1:1.0	54.7	57.8
	Modified petri	0.89 ± 0.19b	0.80 ± 0.15a	1:1.4	1:1.3	62.5	57.8

Means in columns followed by the same letter are not significantly different (2007 plot A: $F = 7.70$; df = 2, 103; $P < 0.001$; plot B: $F = 14.0$; df = 2, 70; $P < 0.001$; 2008 plot A: $F = 13.8$; df = 2, 95; $P < 0.001$; plot B: $F = 2.26$; df = 2, 96; $P = 0.110$). Zero frequency refers to the percentage of traps that did not catch any *D. oxycoccana* adults over a 1-wk sampling period. Sex ratios marked with an asterisk are significantly different from 1:1 ($P < 0.05$; *t*-test).

trap designs in plot A, but no difference due to trap type was observed in plot B (Table 1). The percentage of traps with zero catches was lowest for the bucket traps in plot A (Table 1). In plot B, all three trap types had similar percentages of zero catches. The original and modified petri dish traps tended to capture more males than females, but overall sex ratios were not significantly different from 1:1 (Table 1). The bucket trap, however, caught significantly more males than females. Interaction effects for trap type by sample date were not significantly different ($F = 1.49$; df = 30, 94; $P = 0.075$ and $F = 1.22$; df = 30, 95; $P = 0.236$ for plots A and B, respectively).

All traps caught adults in the first week of sampling, but the modified petri dish trap peaked at least 1 wk before the other trap types (Fig. 3). In plot A, modified petri dish trap catch peaked on 5 and 26 March, bucket trap catch peaked on 12 March, and original petri dish trap catch peaked on 12 March and 2 April. In plot B, modified petri dish trap catch peaked on 27 February and 2 April, bucket trap catch peaked on 12 March, and original petri dish catch peaked on 5 March.

Correlation between trap catch and bud infestation was compared over a 12-wk period (16 January to 26 March) (Fig. 3). Trap catch for all three trap types in both plots was positively correlated with bud infestation. The bucket trap had the highest correlation coefficients (plot A, $r = 0.791$; plot B, $r = 0.683$) followed by the original petri dish trap (plot A, $r = 0.599$; plot B, $r = 0.646$) and the modified petri dish trap (plot A, $r = 0.501$; plot B, $r = 0.415$).

Distribution of Infestation. *2006.* Investigation of Distribution Patterns Within Blueberry Plantings.

Interaction effects between distance and sample date were not significant ($F = 0.43$; df = 8, 30; $P = 0.894$). *D. oxycoccana* infestation increased from 17 February to its highest numbers on 10 March when sampling was concluded because flower buds became scarce. The number of *D. oxycoccana* larvae per flower bud in the 60–65-m plots was not statistically different from the number of larvae in the edge plot 0–5 m from the field border ($P = 0.109$). The mean number of *D. oxycoccana* larvae (±SEM) per flower bud was 1.44 (0.22), 1.29 (0.16), and 1.91 (0.31) at 0–5, 25–30, and 60–65 m, respectively. The effect of distance from the field border on *D. oxycoccana* infestation was not significant ($F = 2.46$; df = 2, 30; $P = 0.103$).

2007: Investigation of Distribution Patterns in Isolated Plots With Potential Edge Effects. There was a significant interaction between sample date and row ($F = 3.47$; df = 14, 64; $P < 0.001$). At the beginning of the sample period, from 18 January to 8 February, midge infestation in the southern rows were significantly different from center and northern rows (Fig. 4). From 15 February to 1 March, infestations in the southern border rows remained different from northern rows but were not significantly different from center rows. Peak in *D. oxycoccana* larval density occurred during the week of 15 February. The overall mean number of *D. oxycoccana* larvae per bud (±SEM) was highest in the south border row (2.14 ± 0.15) followed by the center row (1.43 ± 0.17) and the north border row (0.55 ± 0.05). *D. oxycoccana* infestation was significantly different in each of the rows sampled ($F = 98.3$; df = 2, 64; $P < 0.001$) (Fig. 4).

2008. Results were similar to those obtained in 2007. There was a significant interaction between sample date and row ($F = 2.33$; df = 12, 79; $P = 0.013$) (Fig. 4). The southern row had the highest level of infestation through most of the season, but in the final two weeks of sampling, there was no significant different between the center and the southern row. The highest number of larvae was collected on 10 March. As in 2007, the overall mean number of *D. oxycoccana* larvae per bud (±SEM) was highest in the south border row (1.17 ± 0.21) followed by the center row (0.91 ± 0.15) and the north border row (0.38 ± 0.06). Infestation of *D. oxycoccana* over the entire sampling period was significantly different in each of the rows sampled ($F = 32.7$; df = 2, 79; $P < 0.001$) (Fig. 4).

Discussion

In 2007, the petri dish trap caught more *D. oxycoccana* adults than the other trap designs. Smith and Chapman (1996) also found that their petri dish trap caught significantly more *D. mali* adults than the jar trap. In our study, it seems that trap effectiveness may be due to the type of trapping surface as well as the amount of light that enters the trap. The top of the

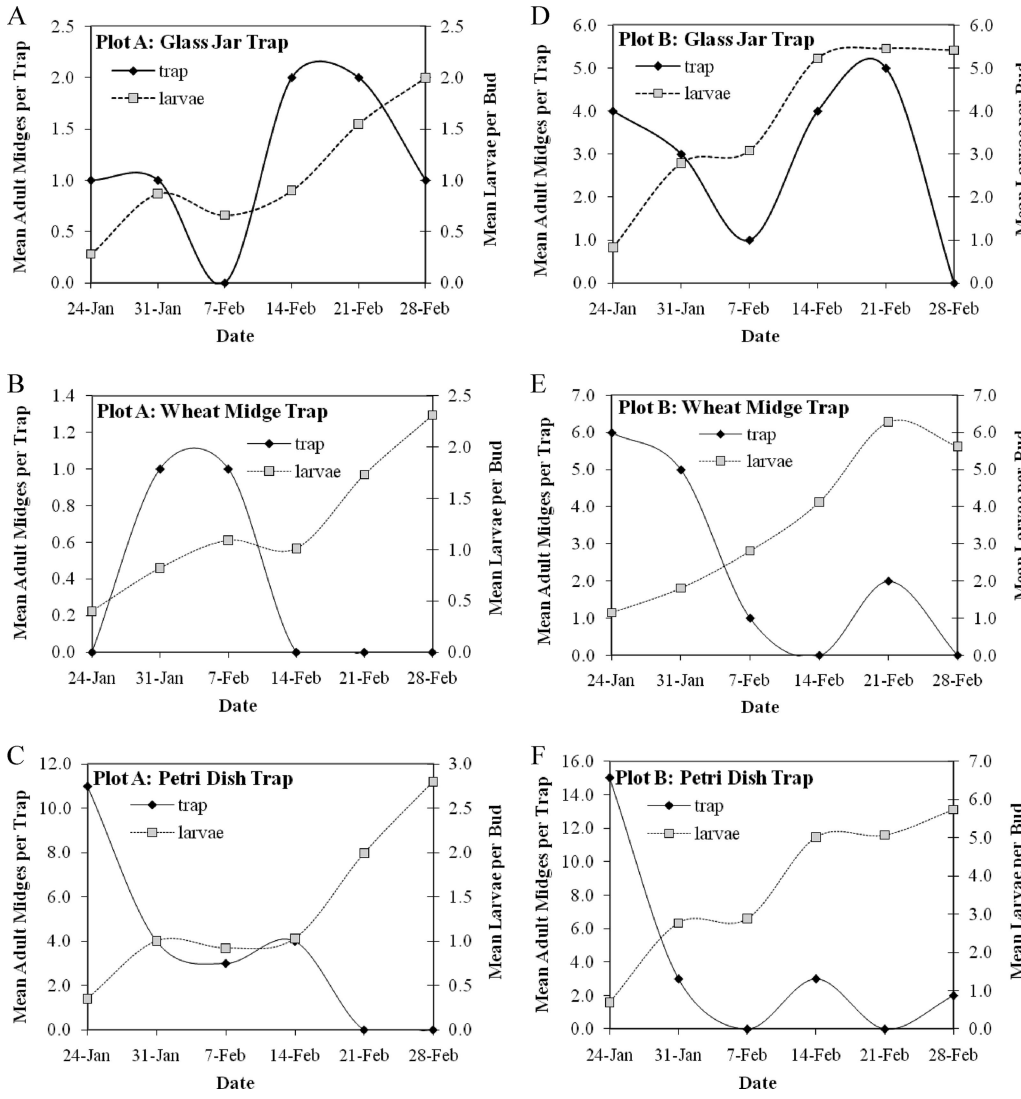

Fig. 2. Mean number of *D. oxycoccana* adults per emergence trap and mean number of larvae per blueberry flower bud collected at an organic blueberry farm in Gainesville, FL, in 2007. (A–C) Plot A traps. (D–F) Plot B traps.

petri dish trap was transparent, whereas the top of the wheat blossom midge trap was translucent. The transparent top allows more light through and may have provided a stronger positive phototactic cue. This was the justification for darkening the interior of the modified petri dish trap in 2008. A high percentage of the wheat blossom midge traps did not catch any midges (86.8% in plot A, 74.3% in plot B) in 2007, so this trap was eliminated from subsequent studies. The glass jar trap used in 2007 was not as effective as the petri dish trap possibly because of the greater distance midges had to travel to reach the collecting jar. In addition, midges could possibly escape the jar by crawling back through the funnel. It is also possible that the funnel opening could be blocked by spiders or predatory insects (Smith and Chapman 1996). As a result, this treatment also was eliminated from subsequent studies. Wheat blossom midge traps have been used effectively to estimate wheat midge distribution and abundance in wheat, *Triticum aestivum* L., fields, but in that case Tangle-Trap was used as the adhesive rather than vegetable oil (Lamb et al. 1999). Vegetable oil was used in accordance with the instructions for constructing the trap (NDSU n.d.). The instructions also recommended that the trap be used to help time scouting activities rather than as a substitute for field scouting (NDSU n.d.).

Modifying the petri dish trap in 2008 did not significantly affect the number of adults trapped. The response to light coming through the transparent top was not enhanced by darkening the trap interior. Peak trap catch in the modified trap did, however, occur 1 wk earlier than in the other two trap types. It is possible that the temperature inside the modified trap,

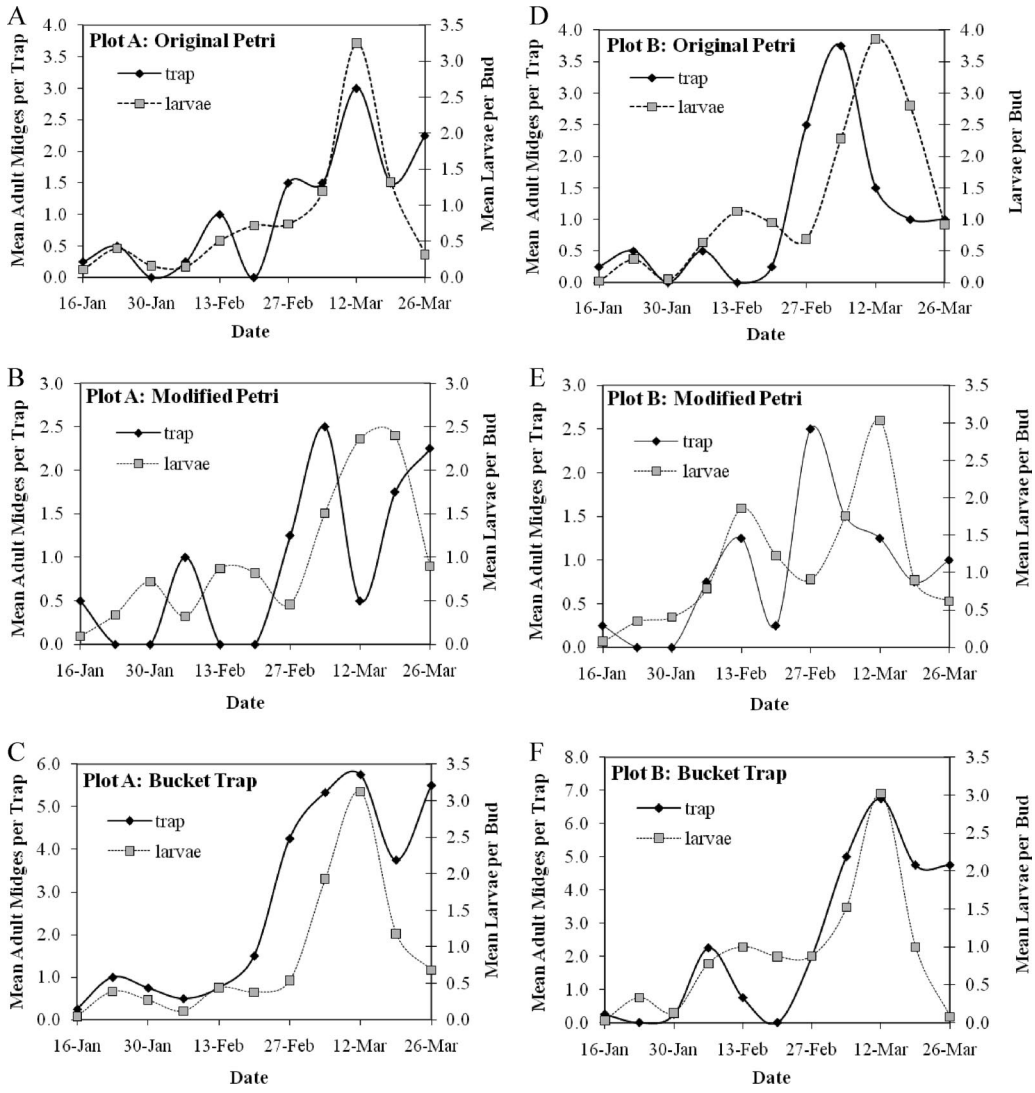

Fig. 3. Mean number of *D. oxycoccana* adults per emergence trap and mean number of larvae per blueberry flower bud collected at an organic blueberry farm in Gainesville, FL, in 2008. (A–C) Plot A traps. (D–F) Plot B traps.

which was painted black, was higher than inside the original petri dish trap, which had a white interior. The bucket trap, however, also had a black interior, but peak trap catch lagged behind the modified trap. The larger volume of the bucket trap would take longer to warm and could explain the difference. Southwood and Siddorn (1965) observed that the larger the volume of air enclosed by an emergence trap, the less the temperature of the soil will rise during the day.

It is unclear why there were differences in sex ratios in the bucket traps and not the other traps, but this could be the result of differences in soil temperatures beneath the traps. In Cecidomyiidae, males commonly emerge before females (Gagné 1994). This seems to be the result of males having a lower threshold temperature for emergence than females (Summers 1975). Summers (1975) observed that most sorghum midge, *Contarinia sorghicola* (Coquillett), males emerged at temperatures below the optimum threshold for females (Summers 1975). If soil temperatures beneath the bucket traps were lower than beneath the other traps, the number of *D. oxycoccana* females emerging could have been reduced resulting in male-biased sex ratios in the bucket traps.

The higher trap catch in the bucket trap may be due to the greater soil area covered and larger trapping surface. The soil area covered was 14% greater, and the trapping area was 78% larger than that of both petri dish traps. The increase in trap catch, however, was not proportional to the increase in area covered. In plot A, the bucket trap caught 86 and 170% more adults than the original and modified petri dish traps, respectively, and in plot B caught 108 and 141% more adults than the original and modified petri dish traps,

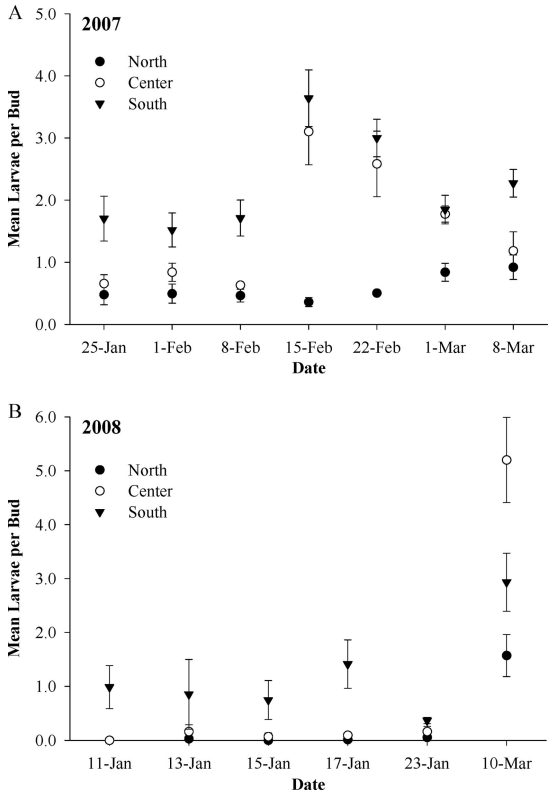

Fig. 4. Mean number of *D. oxycoccana* adults per flower bud (±SEM) from three rows of blueberries at different distances from the field border in 2007 (A) and 2008 (B).

respectively. The amount of light entering the top of the bucket trap may explain trap efficacy. The acrylic panel of the bucket trap seemed to allow more light through than the petri dish, which became more translucent after repeated applications of Tangle-Trap even though tops were cleaned.

In plot A, the bucket trap caught significantly more *D. oxycoccana* adults than the other trap types, but in plot B it was not significantly different. The findings could reflect a difference in trap performance, however, the proportion of adults trapped in bucket traps compared with the other trap types was the same for A and B. In both plots, the bucket trap caught approximately twice as many adults as the original petri dish trap and 2.5 times as many as the modified petri dish trap. Nonsignificant differences in plot B seem to be the result of high variance in the data, increasing the probability of a type II error.

When the 2007 data for trap captures were presented graphically we did not find any pattern of increased trap captures preceding increased larval infestation (Fig. 2). Correlation analysis showed that, with the exception of the wheat midge trap, trap catch and bud infestation was not correlated. The lack of fit between trap captures and larval infestation in 2007 was probably the result of leaving the traps in the same place throughout the season. The only midge adults that could be captured at each trap location were those present in the soil beneath the traps at the beginning of the experiment. As the season progressed, the number of midges decreased. This explains the negative correlation ($r = -0.597$) between trap capture in the wheat midge trap and bud infestation. In 2008, traps were moved to new locations a few meters away each week so the number of adults was not affected by how long the traps were left in a particular place. In the 2008 experiments, trap catch and bud infestation were positively correlated.

Emergence trap catch could be used to predict peaks in larval infestation. During 2008, in most cases, the peak in trap catch came one week before the peak in larval density (Fig. 3) and the number of adults trapped was correlated with the number of larvae in buds collected the following week. Gall midge eggs hatch within a few days of oviposition (Lyrene and Payne 1995), so it is possible that larvae collected from flower buds in a given week hatched from eggs deposited by females flying the previous week. Smith and Chapman (1996) found that the number of *D. mali* adults captured in traps followed a similar trend to the incidence of apple (*Malus* spp.) shoot infestation. The correlation between the number of adults captured and percentage of shoot infestation was not significant, however (Smith and Chapman 1996). The number of traps used in our study (eight of each trap type), although adequate for comparing trap efficacy, may be too few to make accurate predictions of larval infestation. Further evaluation of these trap designs would be needed to make better predictions. Yet, these traps may have some use in early season detection or detection of major peaks in *D. oxycoccana* population levels.

Although the edge effect is well documented for several species of Cecidomyiidae (Kolesik 2000), it was not observed in the 2006 experiment. The field in which the 2006 experiment was conducted was part of an existing blueberry planting. Fields were only separated by alleyways that were 8–10 m in width. Perhaps dispersing midges are moving between and within fields with well-established populations. Lamb et al. (1999) found that *S. mosellana* infestation did not differ within Manitoba, Canada, wheat fields at distances of 1, 50, or 100 m from the edge. They did observe, however, that proximity of wheat fields accounted for 75% of the variation in *S. mosellana* infestation among fields (Lamb et al. 1999).

The field used in 2007 and 2008 was an isolated plot (not adjacent to other blueberry fields), and *D. oxycoccana* infestations varied significantly by position in the field. There was a clear trend of increasing density of larvae per flower bud from south to north. The weekly collection data from 2007 show that not only do mean densities differ with sample location but also dynamics differ with location as well. Larval density remained fairly constant in the northern border row over the entire sampling period (Fig. 4). In the center and southern border rows, however, the number of larvae increased at mid-season. Higher numbers of *D. oxycoccana* larvae in the southern border row may be

the result of midges moving into this plot from other parts of the farm. To the north and west there was open ground, and to the east there was mostly woods. The nearest blueberries were ≈90 m to the south and southeast of this field. Gall midges are generally weak fliers but can disperse considerable distances with the aid of wind (Gagné 1994). The Douglas-fir cone gall midge, *Contarinia oregonensis* Foote, for example, is capable of dispersing over distances of at least 85 m (Schowalter 1984). Female *Contarinia lentis* Aczél midges have been trapped in lentil, *Lens culinaris* Medikus, fields >2 km from their emergence site (Kolesik 1993). It is possible that *D. oxycoccana* originated from the blueberry field to the south of the plot and moved north into the plot causing the population to increase in the southern border row followed by the center row. The sample period was not long enough to see whether this trend would continue into the northern border row.

Sample collection was halted prematurely in 2008 due to lack of flower buds in the center and south rows. Plants had not been pruned for a few years so there was little new growth and consequently few flower buds. The pattern of total infestation by area was the same as 2007, but due to intermittent sampling, the seasonal pattern could not be determined.

Most studies of gall midge distribution in which the edge effect has been observed were conducted either in temperate regions where midges overwinter, with annual host plants, or both (Kolesik 2000, Hodgson et al. 2004). In these cases, crops are replanted each season and infested primarily by midges dispersing from locations outside the fields. Blueberries, however, are perennial, and it is likely that *D. oxycoccana* remains in blueberry plantings throughout the year. Blueberry gall midge larvae feed in flower buds from bud break until bloom then move to leaf buds (Sampson et al. 2006). During the period when blueberry leaf and flower buds are not available, *D. oxycoccana* either overwinters or switches to an alternate host plant such as a wild *Vaccinium* species (Sampson et al. 2002). If midges were already present in the center of the field, an edge effect would not be observed if and when adults dispersed from nearby fields or alternate hosts.

An edge effect on infestation does not necessarily mean that site-specific pest management is possible. Other factors must also be considered. Hodgson et al. (2004) observed that most sunflower midge damage was concentrated in sunflower field edges, yet argued that site-specific management was not feasible. Adult sunflower midges have a prolonged emergence and infest and disperse through sunflower fields over a relatively long period of time (Hodgson et al. 2004). Management using insecticides would require multiple applications, especially if the products used have a short residual time. In Florida, *D. oxycoccana* adults also emerge and disperse over a long period (Sarzynski and Liburd 2003). At this point, it does not seem that site-specific pest management is possible to manage *D. oxycoccana* in old blueberry plantings with well established infestations. With a better understanding of *D. oxycoccana* flight behavior and dispersal combined with careful monitoring, site-specific pest management may be useful in preventing the establishment of *D. oxycoccana* in new blueberry plantings.

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