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Use of Early Ripening Cultivars to Avoid Infestation and Mass Trapping to Manage *Drosophila suzukii* (Diptera: Drosophilidae) in *Vaccinium corymbosum* (Ericales: Ericaceae)

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ABSTRACT Use of early ripening highbush blueberry cultivars to avoid infestation and mass trapping were evaluated for managing spotted wing drosophila, *Drosophila suzukii* (Matsumura). Fourteen highbush blueberry cultivars were sampled for spotted wing drosophila infestation. Most 'Earliblue', 'Bluetta', and 'Collins' fruit were harvested before spotted wing drosophila oviposition commenced, and so escaped injury. Most fruit from 'Bluejay', 'Blueray', and 'Bluehaven' were also harvested before the first week of August, after which spotted wing drosophila activity led to high levels of blueberry infestation. In a separate experiment, damage to cultivars was related to the week in which fruit were harvested, with greater damage to fruit observed as the season progressed. Attractant traps placed within blueberry bushes increased nearby berry infestation by 5%, irrespective of cultivar and harvest date. The significant linear reduction in infestation with increasing distance from the attractant trap suggests that traps are influencing fly behavior to at least 5.5 m. Insecticides applied to the exterior of traps, compared with untreated traps, revealed that only 10–30% of flies visiting traps enter the traps and drown. Low trap efficiency may jeopardize surrounding fruits by increasing local spotted wing drosophila activity. To protect crops, traps for mass trapping should be placed in a perimeter outside fruit fields and insecticides need to be applied to the surface of traps or on nearby fruit to function as an attract-and-kill strategy.

KEY WORDS *Drosophila suzukii*, *Vaccinium corymbosum*, mass trapping, cultivar avoidance

The spotted wing drosophila, *Drosophila suzukii* (Matsumura), is a fruit fly native to Southeast Asia that damages blueberries, raspberries, blackberries, strawberries, peaches, grapes, and cherries (Bolda et al. 2010, Landolt et al. 2012). It was first found in California in 2008 and has since spread throughout the United States (Goodhue et al. 2011). Female flies cause damage by puncturing ripening fruit with their serrated ovipositor to lay eggs just inside the skin (Walsh et al. 2011). Once the egg hatches, larvae feed, grow, and pupate, often within the fruit. Infested fruit start to rot and may become unsalable within a few days. Damage caused by spotted wing drosophila can lead to economic losses of up to 100%, as an entire crop can be rejected upon inspection if spotted wing drosophila larvae are found in berries (Kinjo et al. 2013). In 2011, it was estimated that a yield loss of 20% in the United States could result in a revenue loss of US$33.4 million for strawberries, US$56.7 million for blueberries, US$156.6 million for caneberries, and US$174.8 million for cherries for California, Oregon, and Washington combined (Lee et al. 2011).

Monitoring spotted wing drosophila populations is important to prevent damage to fruit. *D. suzukii* is closely related to *Drosophila melanogaster* Meigen, for which a good understanding exists of the chemical ecology of host volatiles (Baker et al. 2003, Zhu et al. 2003, Becher et al. 2010, Stökl et al. 2010). Yeast volatiles mediate host finding and feeding in *D. melanogaster*, and odors from *Saccharomyces cerevisiae* are sufficient on their own for fruit fly attraction (Becher et al. 2012). Fruit-infesting Drosophilids appear to have a well-conserved (or perhaps convergent) response to blends of volatiles that provide a gestalt of fruits infected with yeasts and other microorganisms (Stökl et al. 2010). Like other Drosophilids, spotted wing drosophila is closely associated with yeasts (Hamby et al. 2012). Attractants used for monitoring spotted wing drosophila usually involve odorants derived from yeast fermentation and fruit materials, such as combinations of wine and vinegar, or of components identified from their antennally active head space volatiles (Landolt et al. 2012). Inexpensive and effective homemade attractants have included combinations of molasses, sugar, vinegar, wine, alcohol, yeast, banana pulp, and fermenting whole wheat

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dough (Kanzawa 1939, Wu et al. 2007, Landolt et al. 2012, Maier 2012).

Besides being used for monitoring purposes, attractant traps could also be deployed for mass trapping. Kanzawa (1939) reported that one attractant trap placed per tree was adequate to protect cherries from economic damage by spotted wing drosophila. However, cherries are an early season crop, relative to seasonal activity of spotted wing drosophila. In Connecticut, resumption of spotted wing drosophila adult activity appears to coincide with ripening of sweet cherries (≈15–19 June in 2012 and 2013, M.E.C. Concklin, Univ. CT, personal communication), before populations have grown to large numbers. Later ripening crops could be more difficult to protect via mass trapping, as there may be larger populations of flies, for which mass trapping may not be sufficiently effective (Lanier 1990).

Highbush blueberries, *Vaccinium corymbosum* L., provide an excellent model to study the interactions between ripening phenology and mass trapping for protecting fruit from spotted wing drosophila. As a mid-season fruit crop, populations of spotted wing drosophila generally are present at the time that blueberry fruits start to ripen. When several varieties with different maturity dates are present in a field, there is an opportunity for spotted wing drosophila populations to increase through successive generations in this crop. Understanding the relationship between ripening time and spotted wing drosophila infestation may help fruit growers minimize damage. Furthermore, evaluation of mass trapping and avoidance through early cultivar ripening may lead to reduced dependence on conventional insecticides to manage this pest in blueberries. This work studies the following questions: 1) Does the maturity date of particular blueberries varieties influence the risk of injury from spotted wing drosophila? 2) Does maturity date influence how well the fruit can be protected by mass trapping? and 3) Are fruits located close to traps jeopardized by flies attracted to their vicinity?

Materials and Methods

Avoidance Through Early Ripening. The experimental field was at the research farm of the University of Rhode Island, Kingston, RI, and consisted of an unsprayed field of 20 cultivars planted between 1979 and 2009 in randomized groups of five plants per plot, up to five replicate groups per cultivar, and a plant spacing of 1.5 by 2.4 m. The planting was surrounded on the north and west sides, and 50 m to the east, by extensive woods, containing wild alternate hosts for spotted wing drosophila including *Rubus* and *Lonicera* spp., and American pokeweed, *Phytolacca americana* L. The nearest tree of an unsprayed crabapple planting (146 trees) is located 61 m to the northeast and the first tree of two rows of 34 sprayed apple trees is located 70 m to the southeast. There were two rows of raspberries and three rows of strawberries (5-m rows) 30 m to the east of the blueberries. Of the 20 cultivars, 14 were sufficiently well-replicated and mature

enough to collect fruit from to determine the percent infestation. Starting 17 June 2013, 10 berries from each of five bushes (50 from each of three replicates) were taken weekly from each of these cultivars to determine whether the ripening phenology influences infestation by spotted wing drosophila. Berries were placed in tissue culture plates (Celltreat Scientific Products, Shirley, MA) in a dark incubator at 30°C for 10 d and checked for emerged pupae or flies to determine the percent of infested berries.

Mass Trapping. The influence of mass trapping on spotted wing drosophila infestation of blueberries was studied at a cooperating grower's farm in Middletown, RI. The experimental area consisted of a rectangular area within an unsprayed field. There were four cultivars, each planted with two rows of 18 plants spaced 2.7 m apart, and an additional cultivar ('Darrow') with 18 plants in a single row. Bushes were planted 1.8 m apart within the row. Cultivars were planted so that the earliest ripening varieties were at one end, and the ripening peak for each cultivar progressed across the field. The experimental area was in close proximity to several potential sources for spotted wing drosophila adults, including early ripening blueberries to the east, additional blueberries to the north, and woods containing potential wild hosts to the south and west—all <20 m from the experimental plot edge. Furthermore, there were extensive plantings of raspberries within 50 m to the west (Fig. 1).

Our ability to randomize treatments was limited by both the need to look at mass effects for placement of attractant traps, and by the physical layout of the field. The field was first divided into three replicate strips of 54 plants each (12 plants of each cultivar, with the exception of Darrow, which only had 6 plants), with strips orthogonal to the cultivar and walkways. The strips were then divided into two halves, three plants wide, into which placement of attractant traps or not was randomized (Fig. 1).

Red cups (530 ml; Fig. 2; Dart, Mason, MI) were used as traps and the bait described below were selected based on extensive field and laboratory testing (R.S.C. unpublished data). Strips of black electrical tape were placed around the top exterior edge of each cup. Four rows of 10 3.2-mm-diameter (one-eighth inch) holes were then punched into the black electric tape and around one-half of the cups to allow entrance of spotted wing drosophila to the bait-drowning solution (Fig. 2). Holes were only made around one-half of each cup to allow bait and flies to be poured into containers for removal from the site. The bait for one trap consisted of 110 ml of water, 4.5 ml of apple cider vinegar (Great Value, Bentonville, AR), 2.6 g of dry active yeast (Red Star, Lesaffre Yeast, Milwaukee, WI), and 38 g of whole wheat flour (Gold Medal, General Mills, Minneapolis, MN). Each red cup was filled with 150 ml of the bait mixture and changed weekly. Traps were placed within blueberry plants with plant stakes (Panacea Products, Columbus, OH) with the top of the trap 34 cm above ground level and spaced 1.8 m apart.
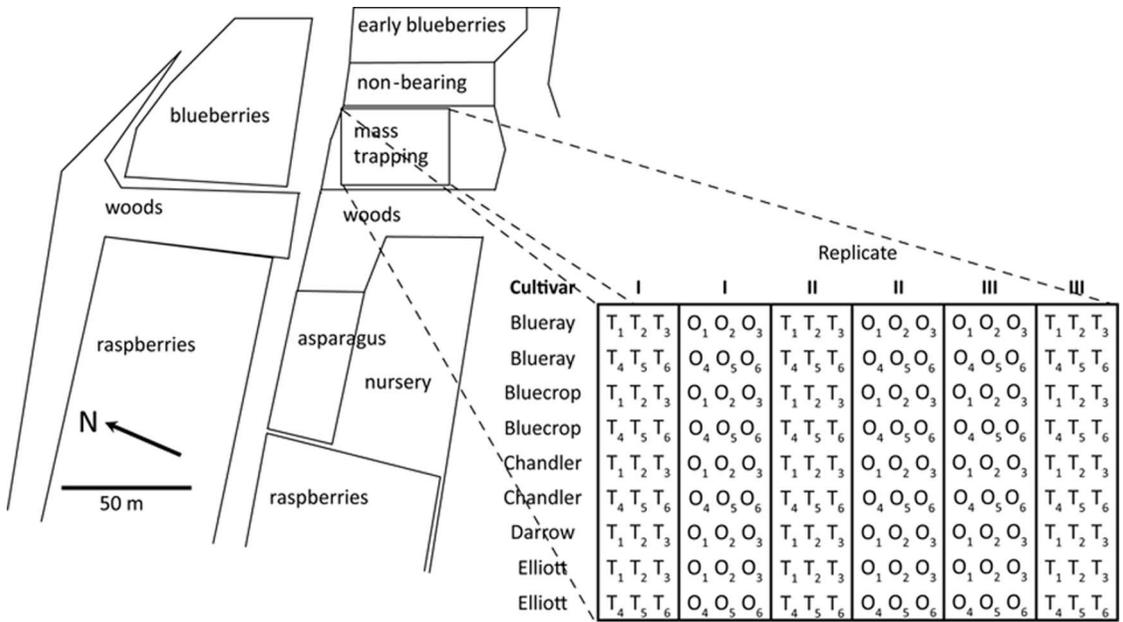
Fig. 1. Field layout for the mass-trapping experiment. T, trap; O, no trap. Subscripts indicate sample designation for each plant within the replicate and cultivar. The distance between plants within the row was 1.8 m, and the distance between rows was 2.7 m.

Ten ripe berries were collected during the first week (3 July); then 12 ripe berries were collected weekly from each bush with ripe fruit (up to 432

Fig. 2. Cup trap used for mass-trapping spotted wing drosophila. Traps had 40 holes of 3.2 mm punched into only one side of the cup.

berries for each cultivar per week) and placed in 12-well tissue culture plates. Plates were placed in a dark incubator at 30°C for 10 days and checked for emerged pupae or flies to determine the percent of infested berries.

Trap Efficiency Test. To measure the ratio of flies drowning in the trap, relative to those visiting the trap surface, two experiments were conducted at the Connecticut Agricultural Experiment Station Research Farm at the Valley Laboratory, Windsor, CT.

In experiment 1, red cup traps (as described above, but suspended with a wire hanger from tree branches) were fitted with screen over a 7.5- by 2.5-cm opening. For each pair of traps in a two-choice field trial, one trap had screen consisting of fiberglass wall repair tape (Ace Hardware, Oak Brook, IL) over the opening. The mesh had square openings of 2.5 mm, sufficiently large to allow spotted wing drosophila adults to enter. For the other trap of the pair, the opening was covered with a nylon screen with a mesh too small for spotted wing drosophila adults to enter. A 1-cm-wide stripe of black tape held the top and bottom edges of the screen tightly to the cup surface. The fermenting whole-wheat attractant bait was added to all traps (75 ml per trap), and traps were deployed on 3 October 2013, as a six-replicate paired choice experimental design. Because fruits had mostly been harvested at the research farm, traps were set in a habitat where flies were expected to be in transit between vineyards and woods. Two pairs of replicates were placed within a plum orchard, and four replicates placed around the perimeter of a plot forested with eastern hemlocks. Traps were hung so that the entry holes were at a height of 55 cm, and the pair of traps was set ≈7 m

Table 1. Mean (±SE) percent blueberries infested by spotted wing drosophila from different highbush blueberry cultivars

Cultivar	Date berries were harvested					
	25 July	1 Aug.	8 Aug.	15 Aug.	22 Aug.	29 Aug.
Earliblue	43.3 ± 5.9a	–	–	–	–	–
Bluetta	23.3 ± 3.5ab	77.3 ± 7.7a	–	–	–	–
Collins	16.0 ± 11.1ab	76.7 ± 8.4a	–	–	–	–
Bluejay	13.3 ± 6.6ab	82.0 ± 8.1a	79.3 ± 7.1a	–	–	–
Bluehaven	2.7 ± 1.8b	72.7 ± 8.8a	84.7 ± 2.4a	–	–	–
Blueray	2.7 ± 1.8b	58.0 ± 11.1a	71.3 ± 7.5ab	–	–	–
Chandler	–	–	87.3 ± 5.7a	–	–	–
Bluecrop	–	–	84.0 ± 3.7a	84.7 ± 4.8a	–	–
Northland	–	–	81.3 ± 3.7a	62.0 ± 3.5ab	–	–
Darrow	–	–	70.0 ± 5.8ab	50.0 ± 10.1ab	–	–
Jersey	–	–	88.0 ± 3.1a	56.7 ± 4.4ab	38.7 ± 4.4a	–
Bluegold	–	–	45.3 ± 13.8b	47.3 ± 15.0b	21.3 ± 4.7a	64.7 ± 2.4a
Herbert	–	–	–	−78.7 ± 0.7ab	46.0 ± 10.5a	–
Lateblue	–	–	–	–	46.0 ± 4.2a	36.0 ± 6.9b

Fruit from Earliblue, Bluetta, and Collins harvested 17 June to 18 July were free from infestation.

[a] Means in the same column followed by the same letter are not significantly different Tukey's HSD test ($P = 0.05$). For 25 July: $F = 5.85$; df = 5, 10; $P < 0.01$; 1 August: $F = 0.89$; df = 4, 8; $P = 0.5$; 8 August: $F = 4.21$; df = 8, 16; $P < 0.01$; 15 August: $F = 4.40$; df = 5, 10; $P = 0.02$; 22 August: $F = 3.63$; df = 3, 6; $P = 0.08$; 29 August: $F = 27.6$; df = 1, 2; $P = 0.03$.

apart. The exterior of each trap with exclusion screen was sprayed with 50 ml of a mixture containing 60 mg of bendiocarb (Turcam 76W, AgrEvo, Wilmington, DE) and 7 mg of bifenthrin (Talstar F, FMC, Philadelphia, PA). One bucket (20 liter; 28 cm in diameter by 37 cm) was placed on the ground directly under each trap to capture spotted wing drosophila knocked down and killed after exposure to the insecticides. A bucket under each noninsecticide-treated cup trap was placed there to properly control for visual appearance of the traps. Traps were left in place for 5 d, whereupon the flies from the traps and buckets were counted. The counts of flies collected from the bucket (for the insecticide-treated cup) were compared with flies drowned in the cup traps (which had no flies captured in their buckets).

In experiment 2, the same cup trap design was deployed as was used in the blueberry studies (red cup and black electrical tape with 40 holes), but traps were suspended from hangers as in experiment 1. Both insecticide-treated and untreated traps permitted entry of flies. Traps were set on 9 October 2013 and the samples evaluated on 16 October 2013. Otherwise, the experiment was conducted exactly as described for experiment 1. The combined counts of flies captured from the bucket and drowned in the insecticide-treated group were compared with the counts of flies drowned in the cup traps (there were none found in the buckets for the noninsecticide-treated group).

Statistical Analysis. Percent fruit infestation data from the early ripening avoidance study were analyzed as a three replicate randomized complete block design analysis of variance (ANOVA) with Statistix 9 (Analytical Software 2008), with cultivar as the treatment variable. Separate analyses were conducted for each week because there were varying groups of cultivars with ripe fruit on any given week. Percent infestation data did not require transformation. When there were statistical differences among cultivars, their means were separated by Tukey's honestly significant difference (HSD) test ($P = 0.05$).

For the mass-trapping experiment, there was a tremendous amount of detailed information available to analyze the influence of ripening season and proximity to attractant traps on infestation of fruit because the proportion of infested fruit was determined for each of the 162 bushes within the experimental area, for each week in which there were ripe fruit available. However, these data are unbalanced, as there were varying numbers of plants in each variety, varying numbers of weeks in which each cultivar produced ripe fruit, and four possible distances of bushes from the nearest attractant trap. Two different analyses were conducted. In the first, the data were subjected to multiple linear regression (Analytical Software 2008), in which the influences of harvest date and presence or absence of an attractant trap within the bush were evaluated to determine whether they were related to the percentage of infested fruit.

Because specific sample weeks had either early or late season ripening fruit (but not both simultaneously) available to sample, cultivars could not be directly compared via factorial analysis until data were averaged over sampling dates. Data were first averaged over sample dates for all bushes of a cultivar in a replicate at the same distance to an attractant trap. These averages were then subjected to factorial ANOVA (five cultivars × four distances; Analytical Software 2008) to investigate the influence of cultivar and distance from traps on infestation levels found in fruit.

Counts of spotted wing drosophila from the trap efficiency studies required $\log(x + 1)$ transformation to establish homogeneity of variance to conduct a paired t-test (Analytical Software 2008). Nontransformed means are reported.

Results

Avoidance Through Early Ripening. The percent infestation of the 14 cultivars is shown in Table 1. Early ripening cultivars, 'Earliblue', 'Bluetta', and 'Collins',
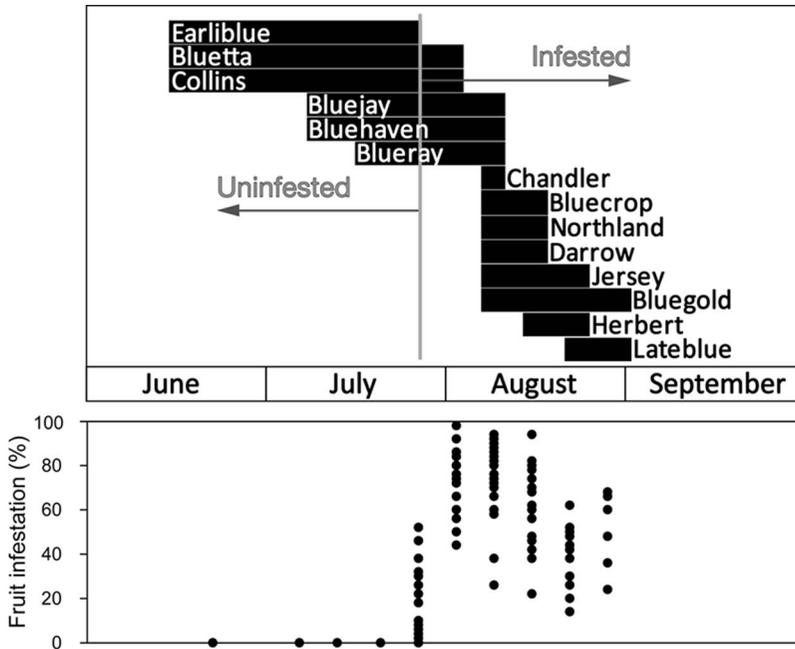
Fig. 3. Timeline of blueberry harvest and spotted wing drosophila infestation. The bottom panel presents the percentage infestation observed from samples collected from 14 cultivars, aligned with the timeline.

can be harvested before spotted wing drosophila are active and infest berries (Fig. 3). By the time infestation was first observed (the last week of July) most of the fruit from these three cultivars had been harvested. Fruit remaining on these varieties and harvested after 25 July were overripe and should have been harvested earlier. Much of the crop from 'Bluejay', 'Blueray', and 'Bluehaven' also ripen and were harvested before spotted wing drosophila began infesting berries. Other noteworthy observations are that some varieties initially had low-percentage infestation just as the fruit were starting to ripen (such as Bluehaven and Blueray on 25 July); 'Bluegold' had significantly less damage than some other varieties on 8 and 15 August, and the latest ripening variety, 'Lateblue', had less damage than Bluegold on 29 August (Table 1).

The timeline for harvest of these cultivars is shown in Fig. 3, along with a summary scatterplot of the percent fruit infestation for all samples taken over the harvest period. The scatterplot illustrates the explosive nature of spotted wing drosophila population dynamics, with an extremely rapid increase in fruit infestation during the last week in July.

Mass Trapping. The regression model was highly significant ($F = 245.6$; df = 2, 519; $P = 0.0009$; adjusted $R^2 = 0.484$). Both the week of harvest and the presence of attractant traps on fruit infestation were significant, with partial correlation coefficients of 9.94 and 2.35 ($t = 21.95$ and 3.05, $P < 0.0001$ and $P = 0.0024$, respectively). As the season progressed, the degree of infestation of fruit increased, and bushes with traps had greater fruit injury (Fig. 4).

The factorial ANOVA (Fig. 5) revealed that there were highly significant main effects for cultivar ($F = 117.6$; df = 4, 33; $P < 0.0001$), and distance to the nearest trap ($F = 4.63$; df = 3, 33; $P < 0.01$), with an insignificant interaction ($F = 0.99$; df = 12, 33; $P = 0.48$). The percent damage for cultivars ($\pm$SE) increased as the season progressed (Fig. 4), with three statistically nonoverlapping groups: Blueray with 3.6% (1.0), 'Bluecrop' and 'Chandler' with 9.7 (1.6) and 13.3% (1.6), and Darrow and 'Elliott' with 36.1 (1.9) and 35.4% (1.6) damage, respectively (Tukey's HSD test, $P < 0.05$). Bushes without traps had 18.2 (1.1) and with traps had 23.3% (1.1) damage. The ordering of overall damage is consistent with the regression analysis, as damage tended to increase over time both within variety and as the season progressed (Fig. 4).

The effect of distance from an attractant trap on fruit infestation was quite consistent, with a nearly uniform 5% increase in fruit infestation when a trap was present, relative to neighboring bushes without a trap (Fig. 5). There were significant linear and quadratic effects associated with distance from traps ($t = -2.54$, $P = 0.016$ and $t = 2.24$, $P = 0.032$, respectively). Examination of the data (Fig. 5) revealed that the quadratic effect may mostly be due to an increase in infestation between two and three bushes distant from a trap, uniquely observed for Bluecrop.

There was significantly less ($t = 8.58$; df = 5; $P < 0.001$) fruit damage among berries from the mass trapping plot in Middletown compared with those from the same cultivars harvested 1 d later in Kingston (Table 2).
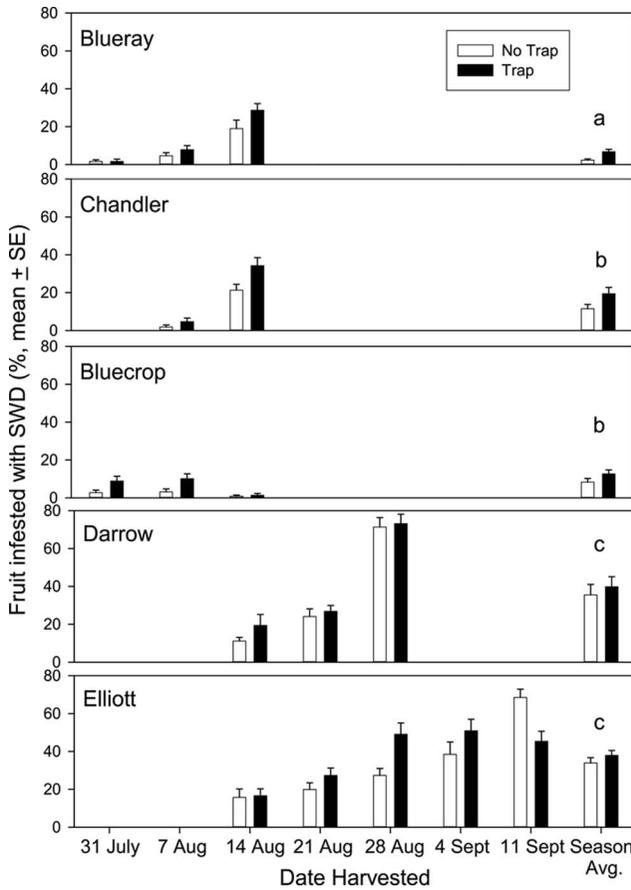
Fig. 4. Weekly estimates of mean (+SE) percent infested berries for each of five highbush blueberry cultivars from bushes with and without attractant traps. Seasonal average percent damage means with the same letter do not significantly differ (Tukey's HSD test, $P < 0.05$). Bushes without traps had 18.2% (1.1) and with traps had 23.3% (1.1) damage.

Trap Efficiency Test. There were significantly more flies ($t = 4.83$; df $= 5$; $P = 0.0047$) found killed within the bucket below the insecticide-treated trap

Fig. 5. Mean ($\pm$SE) percent infested berries within the bush with a trap (0 distance) or at a distance of 1, 2, or 3 bushes away from the trap (1.8, 3.7, and 5.5 m). There were significant linear and quadratic effects for infestation found with linear contrasts ($P < 0.05$). See the results section for statistical details.

than were captured by drowning in experiment 1 (Fig. 6). In experiment 2, the combined number of flies drowning and in the bucket was significantly greater ($t = 2.98$; df $= 5$; $P = 0.03$) for the insecticide-treated traps than for the untreated traps (Fig. 6).
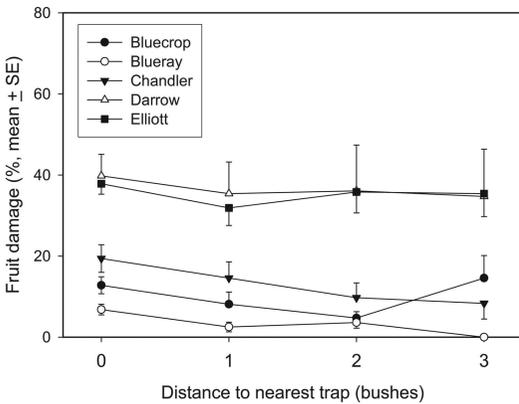
Discussion

We can recommend that growers plant early ripening cultivars such as Earliblue, Bluetta, and Collins to avoid spotted wing drosophila infestation. Other cultivars that nearly ripened before spotted wing dro-

Table 2. Comparison of mean percentage fruit infestation by spotted wing drosophila for cultivars planted at two farms, one with mass trapping (Middletown) and the other without (Kingston)

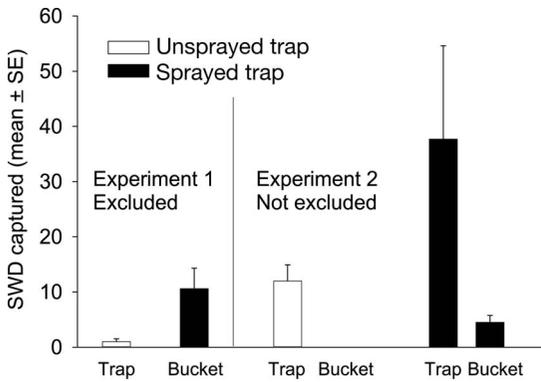| Cultivar	Date	Farm location	
		Middletown	Kingston
Blueray	31 July–1 Aug.	5.8	58.0
	7–8 Aug.	6.7	71.3
Chandler	7–8 Aug.	3.2	87.3
Bluecrop	7–8 Aug.	6.3	84.0
	14–15 Aug.	23.8	84.7
Darrow	14–15 Aug.	15.3	50.0

Fig. 6. Comparison of trap catches of spotted wing drosophila flies (mean ± SE) for experiments where cup traps were either sprayed with an insecticide or not. Flies were captured in the cup traps or in 20-liter buckets placed underneath the cup trap. In experiment 1, flies were excluded from entering the insecticide-treated cup with fine screen, whereas in experiment 2, flies could enter either trap. Total trap catches were significantly different between the two paired comparisons in each experiment (paired *t*-test, df = 5; $P < 0.05$).

sophila activity escalated were Bluejay, Blueray, and Bluehaven. If the berries from these bushes were picked immediately after ripening, berries would not be infested. Other early ripening blueberry cultivars to consider for the northeast are 'Duke', 'Patriot', 'Spartan', 'Reka', and 'Hannah's Choice' (Galletta and Himelrick 1990, Barney 1999). Bluegold showed statistically significant lower infestation for the weeks of 8 August and 15. However, for the week of 29 August, the infestation was significantly higher than that seen for Lateblue. Bluegold plants in the trial planting were immature and smaller with fewer berries than other cultivars and may have avoided infestation until the fruit became overripe during the week of 29 August.

Mass trapping does not appear to have been an effective management technique against spotted wing drosophila in blueberries using the most effective trap design and bait developed for the 2013 field season. These traps are clearly competitive with nearby ripe fruit, as evidenced by the extremely high trap catches when placing these traps among fruiting blueberries and raspberry plants (R.S.C., unpublished data). However, there always is a question of whether attractant traps will cause more harm than good when placed close to acceptable host material. Attractant traps could bring pests into an area, and they may engage in feeding or egg laying before encountering the trap, a pattern often observed when deploying attractants to influence pest behavior (Gordon and Potter 1985, 1986). In the mass-trapping experiment, the distribution of infested fruit suggests that there was significantly greater spotted wing drosophila activity immediately surrounding the traps. The decline in percentage of damaged fruit from the trap to a distance of 5.5 m (distance between three bushes) suggests that the trap influenced fly behavior to at least a distance of 5.5 m, perhaps by shifting local activity closer to the trap.

The trap efficiency studies provide additional insight into the phenomenon of greater fruit damage close to traps. In the first study, only about one-tenth of the flies visiting traps entered the traps and subsequently drowned, based on the ratio of flies visiting and killed by an insecticide-treated trap, compared with drowning in its paired trap. In the second experiment, ≈30% of the flies visiting the noninsecticide-treated traps drowned compared with the insecticide-treated trap. The two experiments provide an interesting comparison and allow dissection of the fly behavior. In experiment 2, flies apparently were already intoxicated through exposure to insecticides when they entered, and so subsequently drowned within the trap, elevating the counts compared with paired noninsecticide-treated traps. Therefore, for untreated traps, many flies visit the exterior surface of the trap, enter into the trap, and later leave. In experiment 1, flies could not enter the trap, and remained on the outside long enough to be knocked down and collected in the bucket.

Traps placed within fruit fields provide some measure of spotted wing drosophila activity. But the number of flies not trapped is more important for mass-trapping efforts, as these are the flies that will continue to put fruit at risk. The trap efficiency studies were designed to provide some insight to the paradoxical problem of measuring the number of flies that visit a trap but are not captured; we now know that only 10–30% of spotted wing drosophila visiting this particular design of baited trap enter and are captured by drowning. This low-capture efficiency is worrisome—flies that leave the surface of a trap are free to visit and lay eggs in surrounding fruits. This helps to explain the pattern of increased damage of fruit immediately surrounding our traps.

The trap efficiency estimate provides a handle for the question of how many visits are required to reach a known degree of insect population reduction. With a probability of capture of 0.2, the number of flies remaining after n visits is $(1-0.2)^n$, requiring an average of 13.4 visits to achieve a 95% reduction in the population. Clearly, greater trap efficiencies will be required to make mass trapping of spotted wing drosophila practical. The success of the insecticide combination in knocking down and killing flies for the trap efficiency experiments suggests that insecticides applied to the outside of the trap, and possibly surrounding fruit and foliage, could increase the "trap" efficiency greatly, in which the virtual trap (the combination of those captured by drowning and those that die elsewhere) then changes the use of the trap to an attract-and-kill device. In fact, a trap that does not capture any flies may be convenient if it also reduces trap maintenance. The concept of using fast-acting contact insecticides to dissect the performance characteristics of traps designed for spotted wing drosophila should be useful for measuring the capture efficiency for other combinations of trap designs and odor attractants.

Other behavioral phenomena may contribute to enhanced risk to fruit near traps. Insects following odor cues may be programmed to stop when they encounter suitable host materials within the odor plume, as has been seen with Japanese beetles (Gordon and Potter 1985, 1986). Placing attractant traps in a perimeter barrier, rather than within the crop, may be one approach to minimize the risk to nearby fruit.

Odor cues usually have optimal concentrations. Lower concentrations do not elicit as strong a response or probability of response and the active space can be expected to not reach as far downwind. Above the optimal concentration, upwind response may be arrested before arrival at the odor source because of sensory adaptation (Baker et al. 1988). Therefore, odor release rate will be critically important for optimizing the distance from which insects will respond, relative to the proportion that will reach the trap. Combining an insecticide-treated zone to coincide with the area within which responding insects are arrested could permit lures with higher-than-optimal release rates (relative to a dosage resulting in trap contact by the insect) to act efficiently in an attract-and-kill paradigm.

Mass-trapping experiments are difficult to evaluate because the traps may reduce the spotted wing drosophila population within an entire field, which would influence damage within both the trapped and nontrapped plots. For cultivars in common between the two research sites and with comparable sample dates, there was an average of 72.6% damage without mass trapping and 10.1% damage with mass trapping (Table 2). This is an evaluation similar to that by Kanzawa (1939), who compared damage levels from fields in separate growing areas. It is impossible to ascribe the difference in infestation entirely to the mass-trapping efforts because there were many other uncontrolled differences between these field sites. Confounded factors that could have contributed to lower fruit infestation in Middletown included fewer berries as a result of *Botrytis* infections at the time of bloom, and ripe berry removal by customers and birds; temperature moderation from being located close to the ocean, and extensive raspberry plantings 50 m and further from the test area (Fig. 1), which could have diverted flies away from the blueberries. However, the magnitude and consistently lower infestations of fruit in the presence of mass trapping suggests that these efforts may have provided some degree of whole-field protection. Our suggestive data will require large cage studies or spatially segregated whole-field replicated tests to validate the benefits of mass trapping. Additional tests should use improved trapping methods to enhance fly removal from fields.

Evidence that our traps may have influenced spotted wing drosophila behavior at a distance of ≈5.5 m should encourage further efforts to make practical use of mass trapping, especially by deploying traps in combination with effective insecticides applied to either the trap surface, or to the trap and surrounding vegetation and fruit. Use of more potent attractants with traps could improve mass-trapping efforts, but only if the traps are designed to better capture flies, or if integrated with insecticides used within the zone where flies might be arrested (Baker et al. 1988, Huang et al. 2013). Use of attractant traps in a perimeter barrier may also minimize the risk of fruit infestation by shifting the spotted wing drosophila activity away from the fruit planting.

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