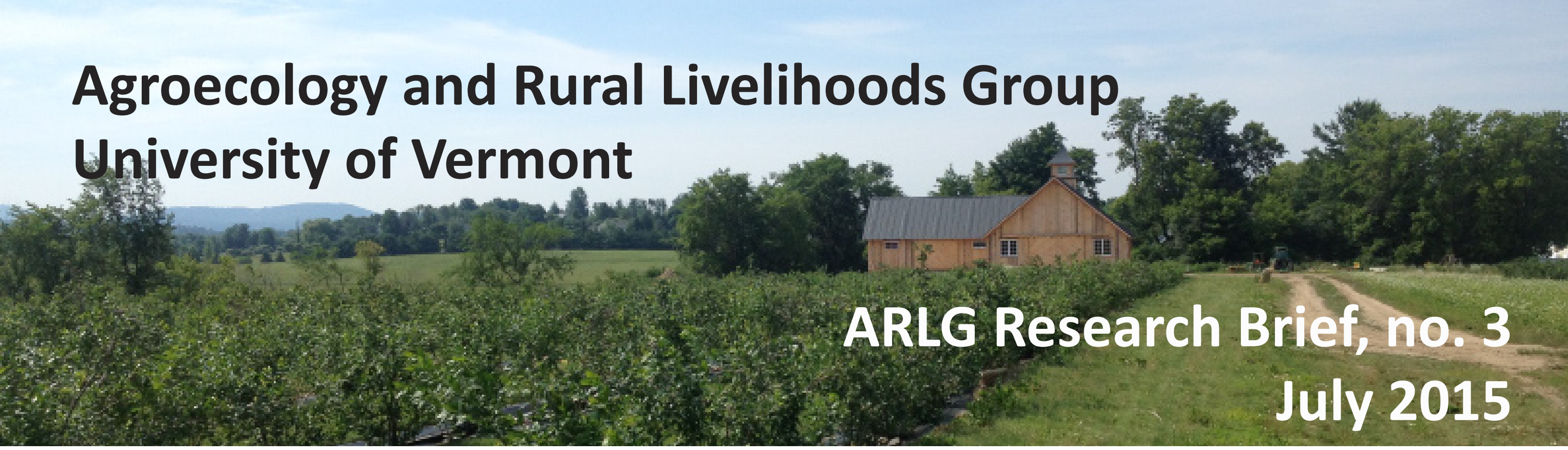


Exclusion Netting for Managing Spotted Wing Drosophila on Berry Farms in the Northeastern United States

Rachel E. Schattman, Victor Izzo and Yolanda H. Chen

Key findings

1. Spotted wing drosophila (SWD) is a relatively new invasive pest that will likely have severe economic impact on berry growers in the northeastern United States.

2. Exclusion netting can be used in combination with good sanitation practices to control SWD in commercial raspberry production.

3. Exclusion netting is effective at lowering populations of SWD in and around commercial raspberry crops.

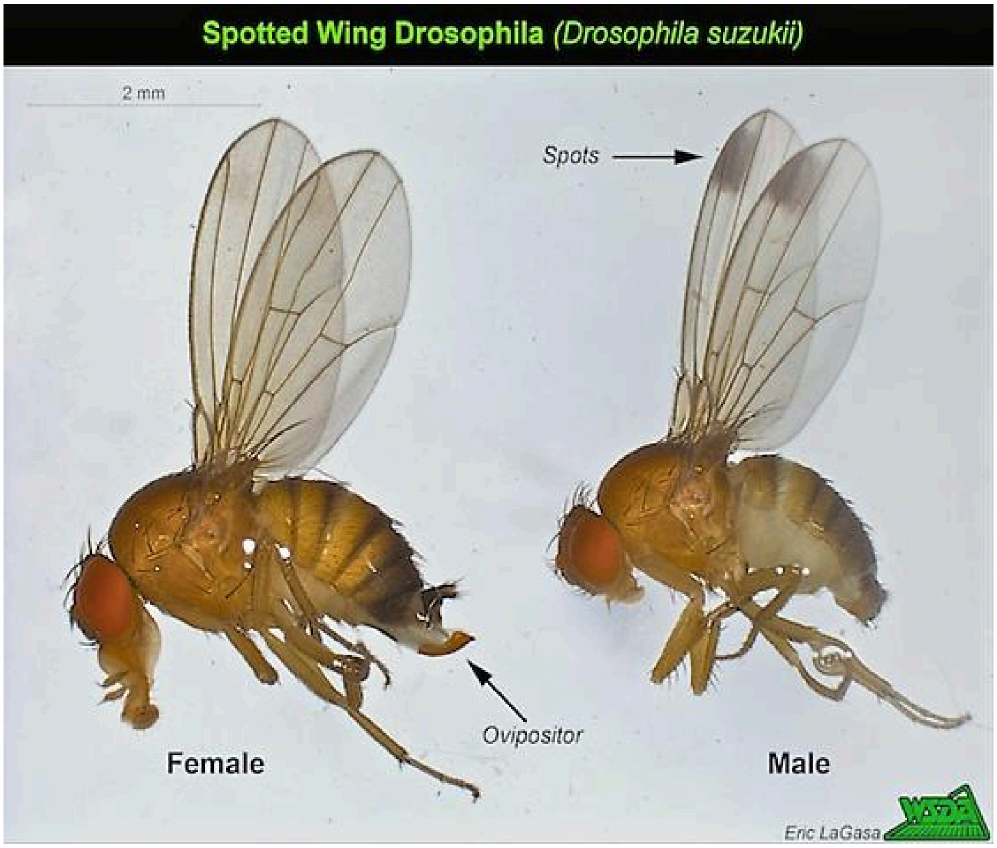
4. Our research suggests that there is an unequal sex distribution of SWD inside netted plantings, with a higher concentration of female SWD found inside the nets. This area should be further researched.

Background

Drosophila suzukii (Matsumura) (Diptera: Drosophilidae) is commonly referred to as spotted wing drosophila or SWD. First found in the continental United States in 2008, it is now present in 35 states in the U.S. in addition to many European countries (Burrack et al. 2012; Cini, Ioriatti, and Anfora 2012). It is a highly mobile pest, with a reported migration of 1400 km in one year (Calabria, Máca, Bächli, Serra, and Pascual 2012). SWD is attracted to a number of commercial crops including apples, blackberries, blueberries, cherries, grapes, peaches, pears, plums, raspberries and strawberries. Female SWD lay eggs via a serrated ovipositor, laying as many as 300 eggs over the course of their lifetime. The lifecycle of the fly is dependent upon the time of year, and can range from eight days to three weeks. Once eggs have been laid in ripening fruit, larvae will develop, making the crop unsalable.

Depending on crop and location, economic losses associated with SWD in 2009 on the west coast of the U.S. ranged from 0-80%, with an estimated loss in California in 2008 of $33M for strawberries, $56M for blueberries and $156M for raspberries and blackberries combined (Bolda, Goodhue, and Zalom 2010). The range of losses experienced by individual farms are highly variable, and accumulated industry losses are not reflective of damages experienced by each business (Dreves 2011). The pest arrived in Vermont and all other northeastern states in 2011 (Burrack et al. 2012). According to the 2012 United States Department of Agriculture (USDA) Agriculture Census, there are 475 farms in Vermont that grow berries, with a combined gross annual income of over $3M (USDA-NASS 2013). Of these farms, 330 grow tame blueberries (typically high bush, not wild), up from 213 in 2007. Additionally, 228 farms grow raspberries, up from 142 in 2007. Cornell Cooperative Extension estimates that, in New York, early/midseason blueberry growers could experience 30-50% losses if no management of SWD is undertaken, and growers of late season raspberries could experience losses of up to 80% (Cornell University 2012). It is likely that growers in Vermont face similar odds.

SWD are difficult for growers to identify in the field. A microscope is needed to distinguish these flies from many related (though less threatening) species of vinegar flies. Male SWD are identified by a black apical wing spot, as well as black combs above the first and second tarsi of their front legs. Females are distinguished by a large ovipositor with two rows of serrated teeth, which allow them to puncture fruit (Hauser 2011). Female flies lay eggs in ripening fruit. The rate of oviposition increases as fruit ripens and brix levels also increase (Lee et al. 2011).



This research focuses on non-chemical control methods with the hope that these approaches can limit the amount of chemical applications on blueberry and raspberry crops, thereby increasing farm profitability and protecting worker health and ecological biodiversity. Specifically, we look at the efficacy of exclusion netting, from both a pest management and an economic perspective. Past research shows that exclusion netting used on blueberries for controlling SWD damage is effective if the openings in netting mesh is smaller than the size of adult flies (the width of a male SWD body is 0.70 - 0.94mm, females were measured at 0.85 - 1.24mm.) According to Kawase and Uchino (2005), mesh openings that are 1.0mm or smaller prevent SWD from entering crop areas, while mesh openings of .98mm or smaller effectively eliminate SWD presence. Since the study cited was conducted in a lab, it is important to field test these findings. In addition to verifying that the findings were relevant to Vermont growers, we sought to expand our study to address differences in temperature between netted and un-netted berry plantings, and differences in male versus female presence in traps. Because the project was conducted on two working farms, our work also raises issues about the practicality and economic viability of using exclusion netting to manage SWD.

Considering the challenges faced by organic growers of soft fruit when managing SWD on their farms, our team developed the following research objectives:

Objective 1: Identify types of netting with the greatest impact on protecting soft fruit from SWD.

Objective 2: Determine the difference between temperatures inside and outside of netted crop areas.

Objective 3: Summarize costs of four management strategies (organic insecticides, conventional insecticides, netting, and sanitation) to help farmers make informed decisions about managing SWD.

This research provides information about SWD management for growers of soft fruit and berries in the northeastern U.S. Specifically, our findings about the efficacy of exclusion netting as a control method and an economic comparison between the four management strategies listed above can help producers evaluate their management options. This will be especially useful for certified organic producers, who have fewer management options than conventional producers.

Current management strategies

Exclusion netting is widely used to control bird damage in fruit and berry crops in the Northeast, but few growers in Vermont currently use netting to protect crops from SWD (Link 2014). For conventional growers, insecticides are a more common method of controlling SWD. There are several categories of pesticide controls effective against D. suzukii, including pyrethroids, carbamates, diamides, spinosyns and neonicotinoids (Isaacs 2013). According to Cornell Cooperative Extension (Loeb et al. 2013, 1), when controlling SWD with insecticides, growers must consider many factors, including pre-harvest interval; total amount of active ingredient allowed per season; minimum days between spray applications; total number of applications allowed per season; reentry interval; insecticide class; whether the insecticide is active through contact or whether it needs to be ingested by the insect; compatibility with other chemistry in the spray tank; rain fastness; length of insecticide residual; impact on beneficial insects; and cost. Good spray coverage is critical, because SWD prefers the protection of plant canopies where relative humidity is high and they are protected from the sun. Growers who rely on sprays to control SWD must invest in a high quality sprayer. There are only two classes of organically approved (listed by the Organic Materials Review Institute or OMRI) pesticides proved effective against SWD (Beers et al. 2011), with only one of these classes (spinosads) rated as effective. Spinosads are limited by both the maximum application rates and the number of applications that can be used in one season. The alternative approved organic spray family (pyrethrin) is rated as poor or ineffective (Loeb et al. 2013). The lack of effective pesticide class rotations represents a serious challenge for organically certified berry operations, since reapplication of a single class could potentially lead to developed resistance among the D. suzukii population.

Yeast bait recipe

yields 1/4 cup

1 T yeast
4 T white sugar
4 T whole wheat flour
3 tsp apple cider vinegar
1.5 C water

The traps equired approximately 1.5 to 2 inches (150 ml) of bait in the bottom of the cup. In the red cup (outside of the vial), we poured a mixture of apple cider vinegar (90%) and ethanol (10%) as a “kill liquid.” Two drops of odorless dish soap were added to the bait to break the surface tension and increase the likelihood that flies were trapped (Cowles per com.; Liburd and Iglesias 2013).

Methods

Site Selection

In 2014, we conducted trials on two berry farms in northeastern Vermont. The study sites were located in Johnson, Vermont and Charlotte, Vermont, approximately 60 miles apart. The blueberry variety at both sites was Patriot, an early fruiting variety. This work followed two seasons of preliminary trapping, which allows us to make comparisons between dates of first detection and dates at which captured SWD populations peaked (see table 1).

Treatments

At both farms, we set up netting enclosures around individual blueberry plants (sampling unit = one blueberry bush). At the first farm, we enclosed 36 bushes (see figure 1). At the second, we enclosed nine bushes for a total of 45 bushes. We installed four wooden stakes (7’) around each bush over which we draped the insect netting (Proteknet 80 or 60), gathering the netting at the base and weighting

Trap for SWD adults in the shade of raspberry leaves.

the netting with bags of rocks. The Proteknet 80 and Proteknet 60 are both high-density polyethylene nets with small holes (1x.85mm and 1.9x.95mm respectively), and high levels of light transmission. Netting that was not wide enough to cover an entire bush was sewed with white polyester thread. Stiches were sized to prevent fly entry at the seams of the fabric. We applied equal numbers of four treatments: (a) control (no netting) with only support posts, (b) support posts with a partial covering of Proteknet 80, (c) support posts with complete cover of Proteknet 80, and (d) support posts with complete cover of Proteknet 60. The netting was sourced from Dubois Agrinovation (Quebec). Sampling in the Patriot blueberries started in early July and concluded in late August 2014.

We also conducted tests in fall raspberries at the first site only. This farm had recently constructed six hoop houses, which were located in general proximity to each other. Three tunnels were enclosed in Proteknet 80 and three were not. We treated each hoop house as a sample. Sampling in the raspberries started in late August and concluded in early October 2014.

Because this project was conducted on working farms, both blueberry and raspberry plots were managed by the farmers and their crews during the course of the experiment. This means that nets were opened and closed to allow for weeding, pruning and harvesting. At several points, nets were found open either because of wind, customers at the pick-your-own operation, or crews entering and exiting the netted areas. Data from these points was discarded prior to analysis.


Netting and partial netting covers on blueberry bushes.


High tunnels with Proteknet80 around sides and end walls.

Adult trapping

Because SWD are not attracted to fruit before ripening begins (Lee et al. 2011), we set out traps for adult SWD just prior to blueberries being ripe. Our traps followed Extension guidelines (Liburd and Iglesias 2013), and were constructed from red plastic cups with clear caps, encircled with a ring of black electrical tape with small holes punched around the top (see photograph on page 3). The color scheme has been shown to be highly attractive to SWD (Cowles, pers. comm.). Inside the cups were secondary vials, covered with a small piece of window screen secured with a rubber band.

Traps were baited with a yeast and sugar mixture (Liburd and Iglesias 2013), to which whole wheat flour and apple cider vinegar had been added to increase attractiveness (Cowles, pers. comm.). This was placed in the secondary vial. Traps were monitored and the bait refreshed once per week. Samples were taken back to the lab and counted and sexed weekly. When counts exceeded 200 individuals per trap (male and female), counting was stopped for that trap. We concluded trapping after the last harvest of Patriot blueberries at our sites.

Larval abundance

We started sampling for larvae after the first date that adults were observed in red traps in blueberries (August 12, 2014) and raspberries (September 2, 2014). We collected 30 healthy, undamaged, ripe berries from each plant (randomly from different branches), and placed them in a clear plastic bag. These were taken back to the lab, where we mixed

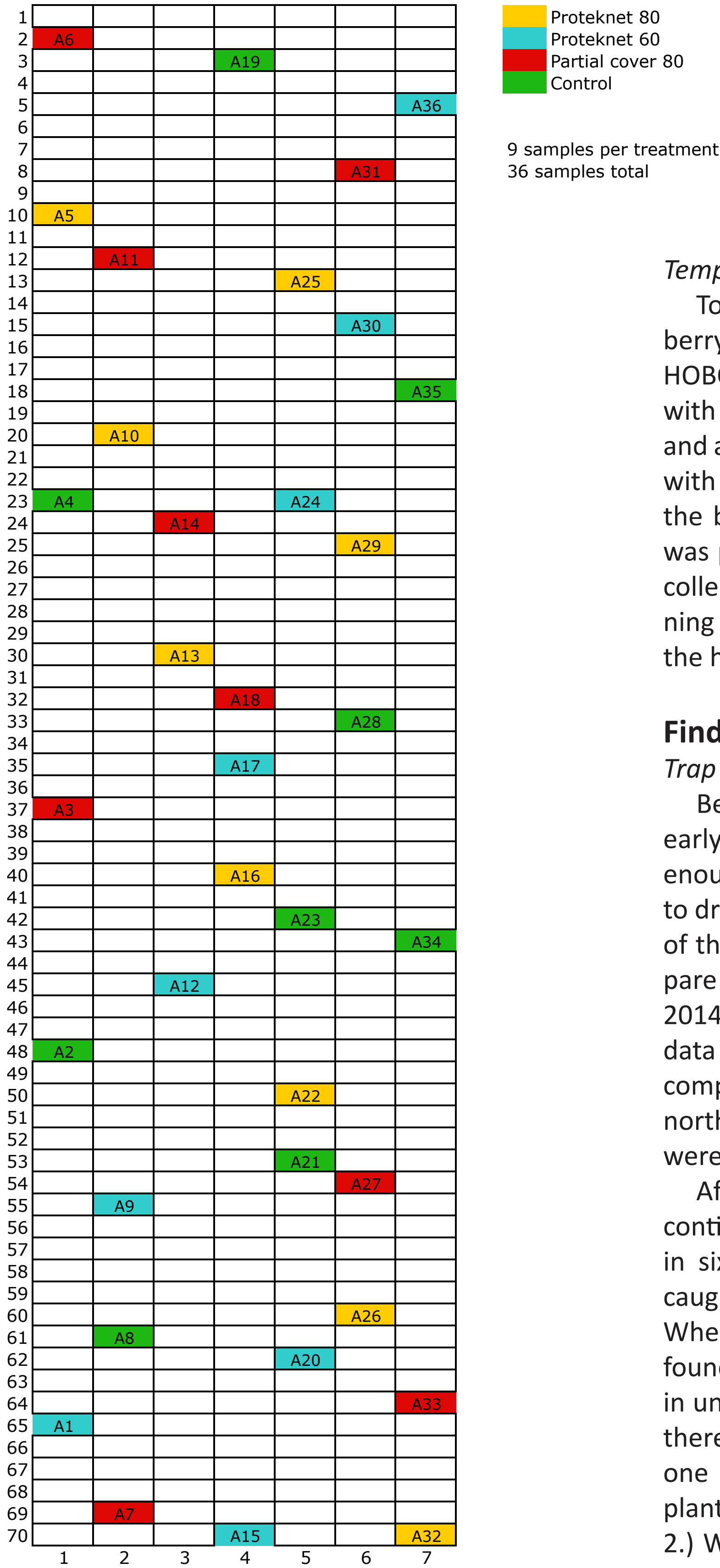


Figure 1: Experimental design at the Charlotte, VT site: 7 rows of berries, 70 bushes per row. Sampling unit = 1 bush.

a salt solution of 1/4 C salt and 4 C water, lightly crushing the berries in the bag with the salt solution. After allowing the fruit to sink to the bottom of the bag (10-15 minutes), we counted the larvae that floated to the top (Liburd and Iglesias 2013). This detection method was performed weekly until fruiting was complete.

Temperature

To find out if insect netting would impact blueberry plants in other ways, we placed three Onset HOBO dataloggers in three bushes: a bush covered with Proteknet80, a bush covered with Proteknet60, and a partial control. Each datalogger was equipped with two sensors. One sensor was placed next to the base of the bush (inside the netting) and one was placed outside of the netting. The dataloggers collected temperature data hourly from the beginning of the trial until the nets were removed after the harvesting period was over.

Findings

Trap Counts

Because the population loads were so low in the early part of the summer of 2014, we did not get enough adult SWD in traps in the Patriot blueberries to draw any valuable conclusions about the efficacy of the treatments. However, we were able to compare dates of first detection for three years (2012-2014) and dates of peak populations in traps using data from preliminary studies (see table 1). These comparisons show that both the arrival of SWD in northern Vermont and the date of peak population were later in 2014 than in 2013.

After the Patriot blueberries finished fruiting, we continued trapping for eight weeks in the summer in six raspberry plantings. When counting adults caught in the traps, we separated based on sex. When trap counts were summed across dates, we found there were significantly more SWD in traps in un-netted high tunnels (t(4)=.0187) even though there were fewer raspberries on those bushes (only one out of three high tunnels had fruit bearing plants during the period of sampling). (See figure 2.) We also found that the ratio of female to male SWD was close to equal in the un-netted traps, but that there were significantly more females in the

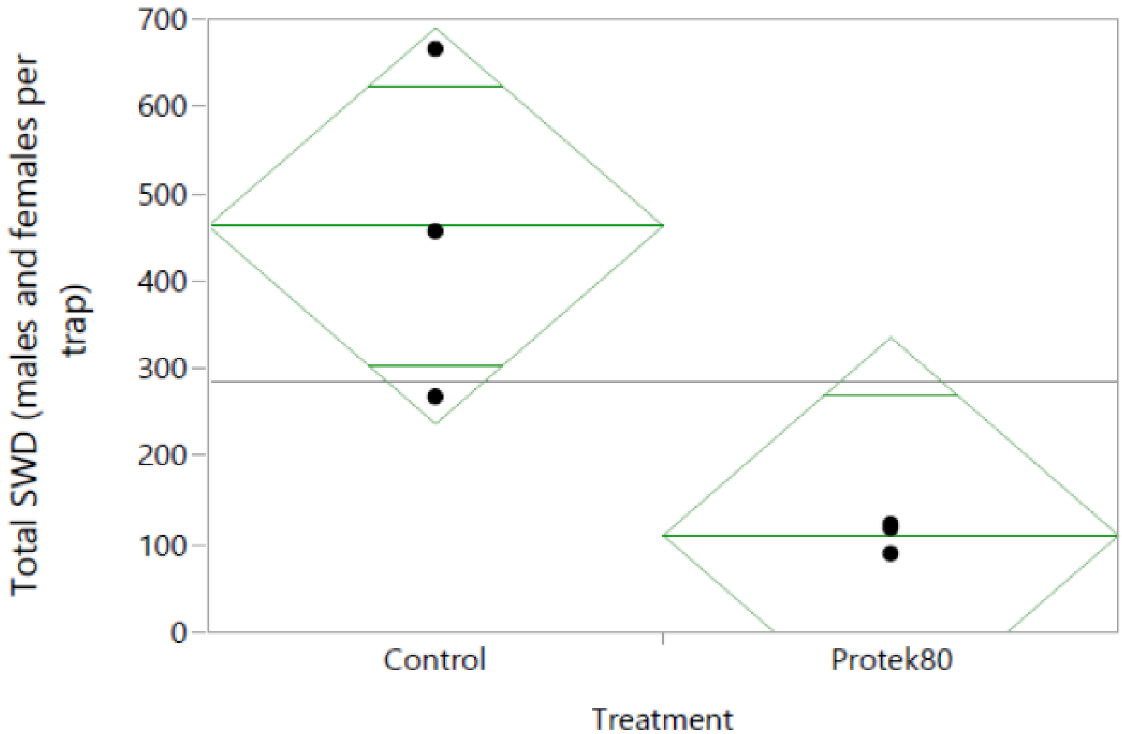


Figure 2: Combined male and female SWD population by treatment in raspberry plantings

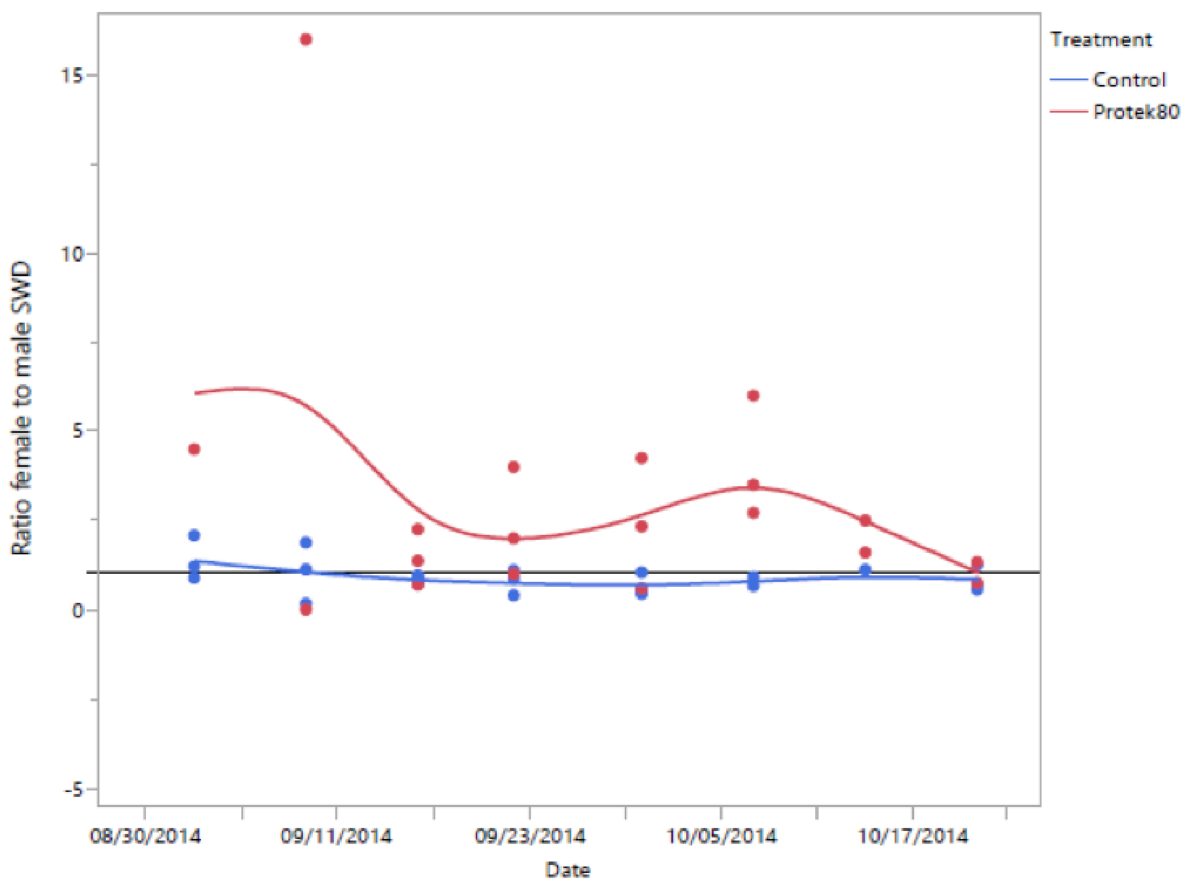


Figure 3: Ratio of female to male SWD over time in raspberry plantings

Table 1: Adult SWD presence in blueberries and raspberries in Vermont, 2012-2014

Year	Date of first detection		Date of peak population in traps	
	Northern VT site	Southern VT site	Northern VT site	Southern VT site
2012		August 1*		
2013	July 2**	June 15**	September 12**	August 18**
2014	August 4**		October 7**	

* (Grubinger and Smith 2014)

** Unpublished study, Grubinger, Schattman & Izzo

netted traps (t(4)=.0157). (See figures 3 and 4.) Figure 3 demonstrates how the ratio of male to female flies changed over the eight week trapping period.

In addition, we found that there was more variation in the number of SWD caught in traps outside of the netting structure (see figure 5). In other words, all three traps inside the netted raspberry plantings had similar numbers of adults, while traps in the control tunnels (un-netted) had a much larger spread of individuals. The traps in the netted plantings also had a fairly consistent number of individuals caught week to week, while the control (un-netted) traps fluctuated more. These findings should be further explored in a study with a larger number of samples.

Larval counts

Because of the low levels of adult SWD in traps, we did not begin sampling for larvae in the blueberries until the very end of the trial period. We found few larvae in the blueberries. As a result, we were unable to perform any useful statistical analysis to distinguish between treatments. We also sampled fruit in raspberries weekly. There were far fewer larvae in the berries collected in the houses protected with netting than in the houses without netting. however, there were confounding variables: (1) two houses without netting did not have fruiting berries during the period of sampling (one did), and (2) the grower who hosted our research was rigorous about picking clean the bushes in the netted houses, meaning the single house with berries that was not netted would be more attractive to SWD. This study should be followed up with another test in raspberries that can confirm our findings.

Temperature

To analyze the data, we conducted paired T-tests between the control temperatures and each of the treatments. There was no significant difference between the temperature next to the blueberry plants in the partial control and the control treatments (t(998)=.92), while the Proteknet 80 and Proteknet 60 both significantly changed the temperature next to the blueberry plants (t(998)=.0045 and t(998)=.0011 respectively). (See figures 6 and 7). Though these differences are significant, they likely do not influence blueberry ripening or yield: the average temperature difference between Proteknet80 covered bushes and the control bushes was 13.6˚F, while the average difference between Proteknet80 covered bushes and the control bushes was only 1.2˚F.

Discussion

Efficacy of Exclusion Netting

Our findings that Proteknet80 netting is effective at excluding SWD from berry plantings in the northeastern U.S. is supported by similar findings in a study conducted in New York (also in 2014) (Riggs 2015). In most parts of Vermont and the northeastern U.S., the rate at which SWD will survive winter temperatures is low (Coop et al. 2013), which reinforces our observations over the past three field seasons. Specifically, we observed SWD populations building in the later part of summer, after many early season berries had already passed. In 2014, blueberry varieties such as Patriot finished production prior to SWD population levels rising to the point at which they would cause economic impact on farms. It is likely that small numbers of SWD overwinter in Vermont, and populations do not reach a point of economic damage until late July or early August.

In addition to their ability to migrate annually, SWD is likely able to overwinter in protected areas (under mulch, in buildings, etc.) (Kimura 2004), so growers should evaluate the type of mulch

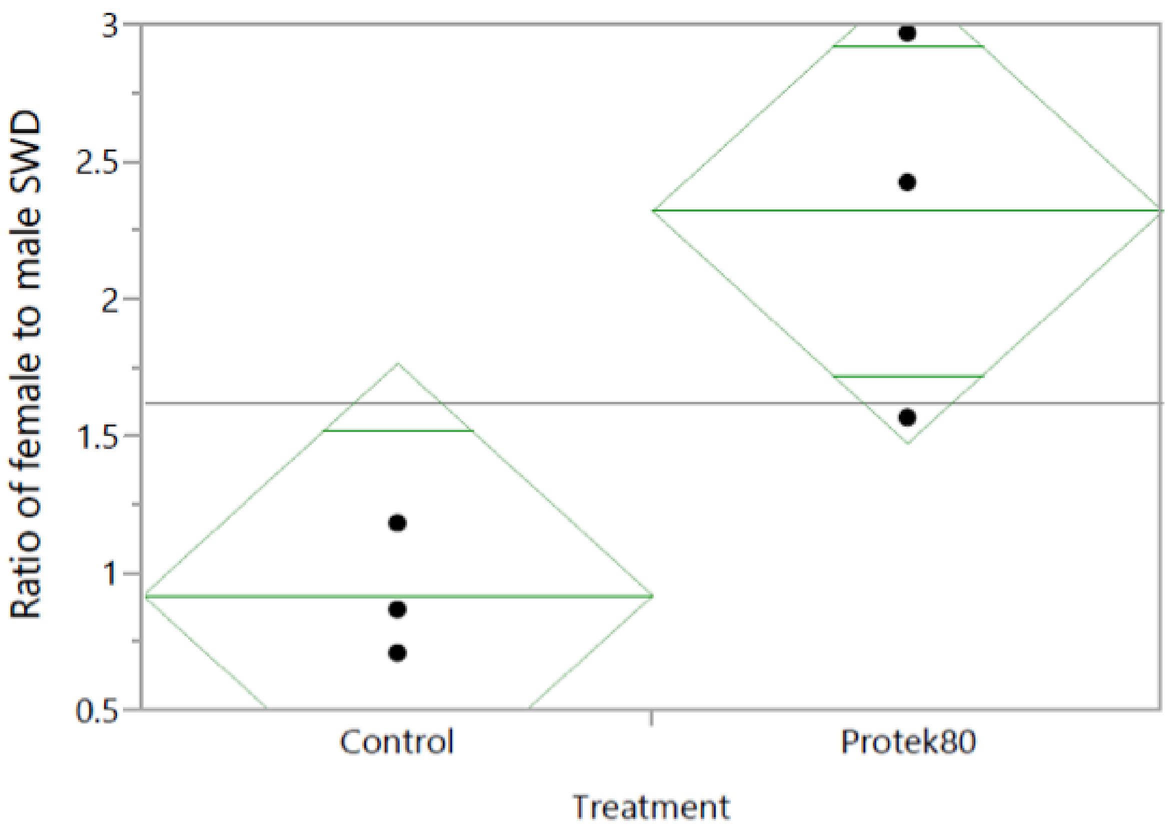


Figure 4: Ratio of female to male SWD per trap by treatment in raspberry plantings

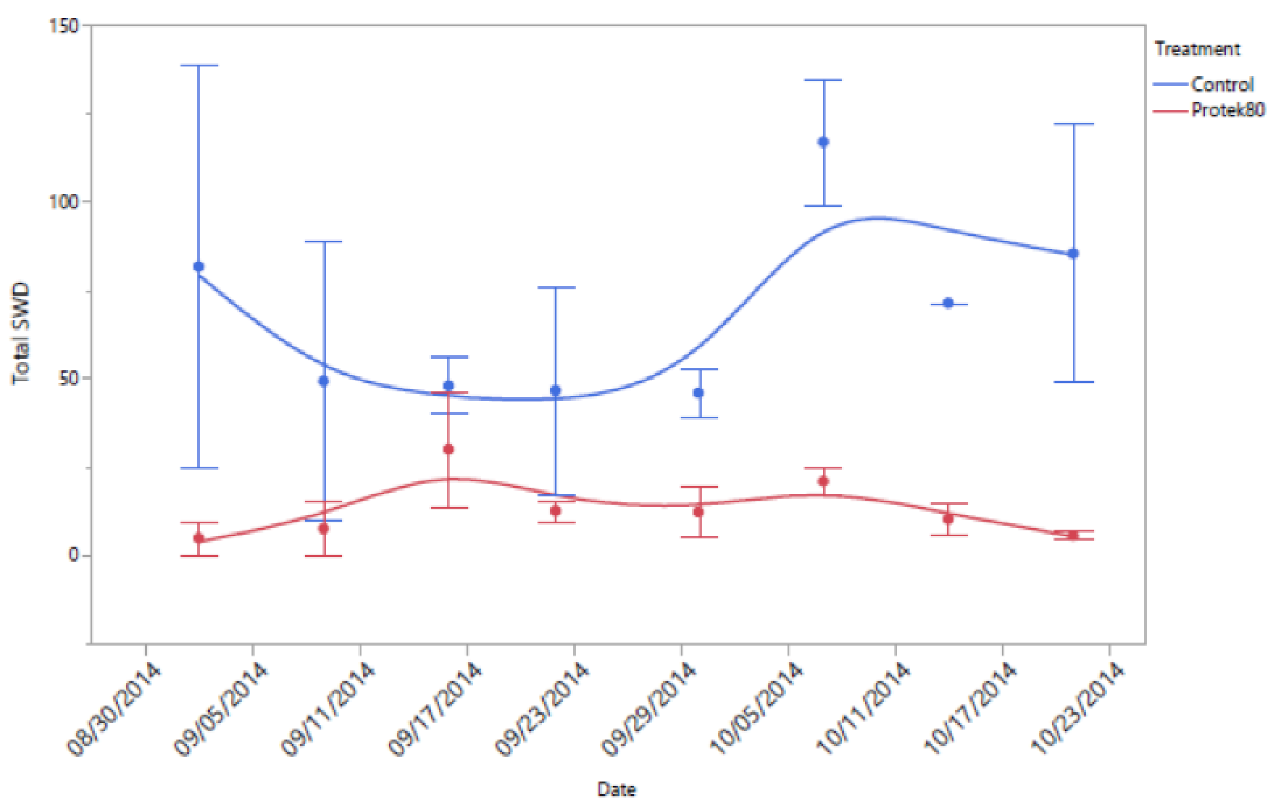


Figure 5: Variation of trap counts by treatment in raspberry plantings

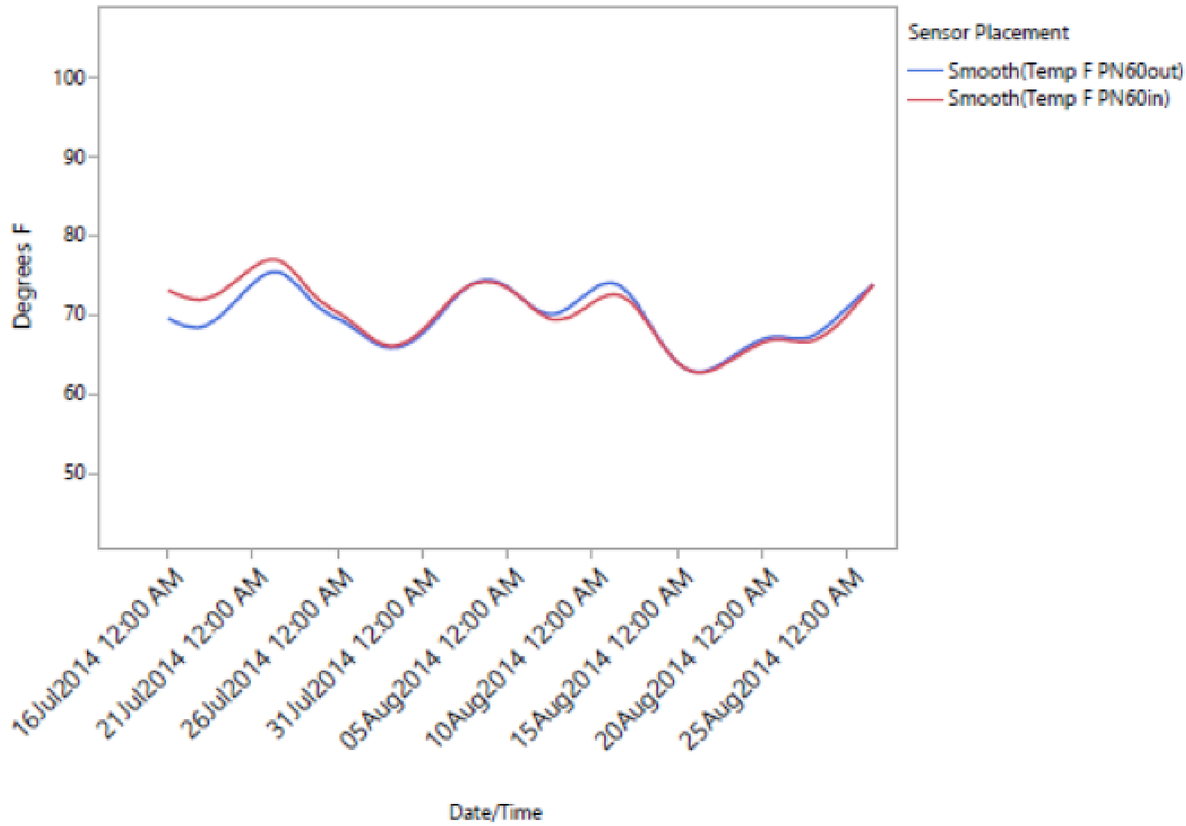


Figure 6: Temperature differences between Proteknet60 and control in blueberry plantings

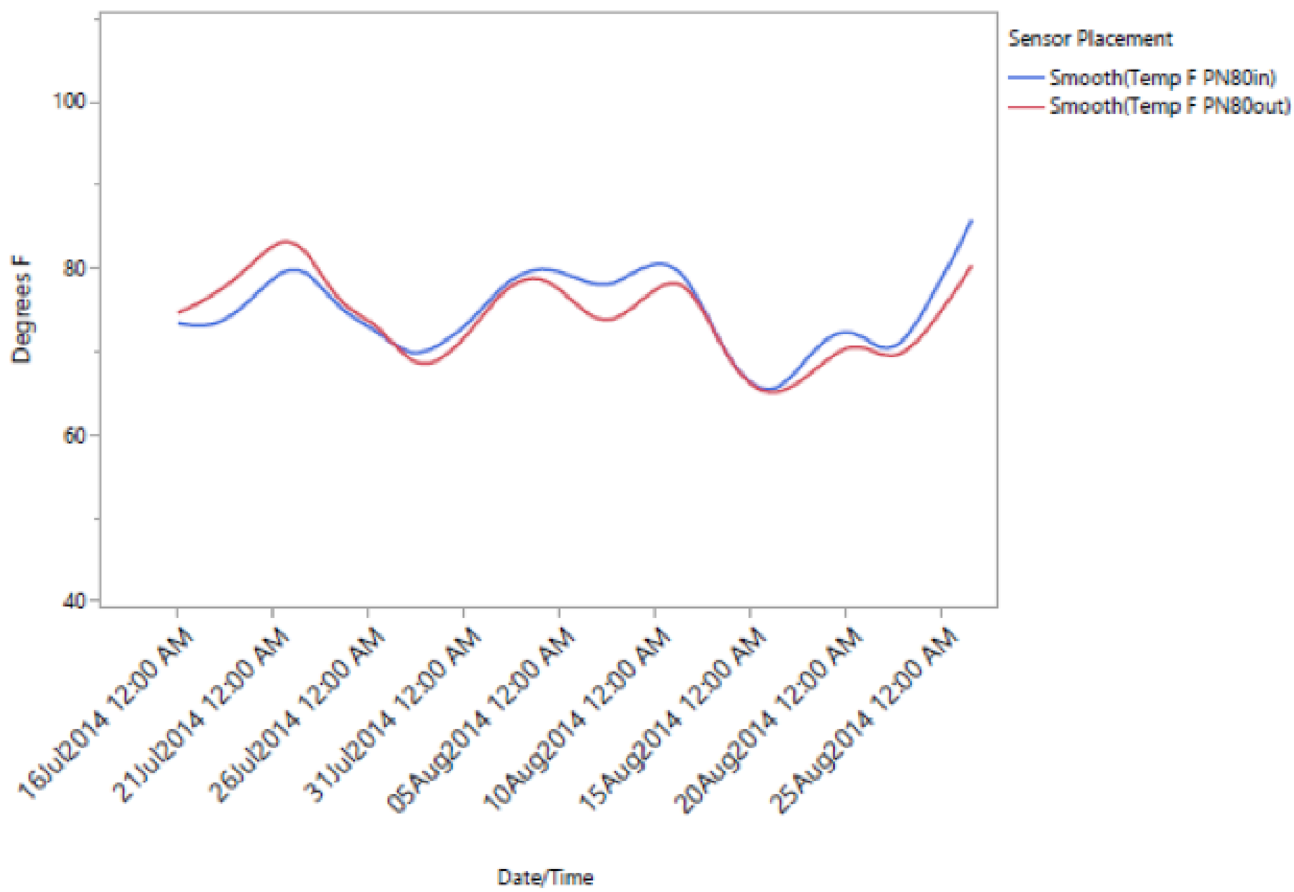


Figure 7: Temperature differences between Proteknet80 and control in blueberry plantings

they use in and around their plantings, and other areas of their farm that may provide overwintering habitat for SWD. SWD adults are able to overwinter in mild, temperate climates (Dreves, Walton, and Fisher 2009). Ideal temperatures for active SWD are between 20-25˚C (66-77˚F), with fitness decreasing above 30˚C (86˚F) (Kimura 2004; Calabria et al. 2012). Temperatures below 10˚ Celsius are expected to decrease the survivorship of overwintering populations (Dalton et al. 2011), though surviving SWD are also thought to overwinter in heated buildings and other protected areas.

Our study suggests that the date when SWD populations peak will vary year to year, likely based on the severity of the winter season and the availability of overwintering habitat on or near the farm. Based on only three years of trapping, we see that these important dates can vary by up to one month. The first signs of SWD damage and peak population will likely be seen first in the southern part of Vermont, and later in the northern region of the state. Because blueberries are not attractive to SWD prior to ripening (Lee et al. 2011), we recommended that netting not cover the planting until just before berries begin to color.

Sex Ratios in Raspberries

Our data shows that the ratio of females to males in netted raspberries was highest at the beginning of our eight week sampling period, gradually becoming a more predictable 1:1 ratio by the end of the trial. We could not find literature specific to SWD that could explain why there were more females than males inside the netted raspberry high tunnels; however these skewed sex ratios within the enclosed raspberry crop may be the result of differences in the foraging behaviors of male and female fruit flies. According to Simon et al. (2011), in their study of the common fruit fly, Drosophila melanogaster, male and female fruit flies exhibit different strategies under certain ecological settings. In a scenario of limited resources (i.e. within a continually harvested enclosure) male fruit flies will disperse farther than females, especially after mating. Female fruit flies, on the other hand, prioritize feeding over dispersal as they look to acquire resources for developing eggs. Essentially, post mating, males seek new mates while females search for resources.

While there is little information directly exploring sex ratios in SWD, Dalton et al. (2011) note that a greater ratio of female to male SWD have been observed during early season counts in the Pacific Northwest. Again, as resources are limited during the early parts of the growing season, the higher number of females in baited traps may be a result of mated females more actively seeking limited resources. Once resources are abundant and populations of SWD are large, sex ratios likely equilibrate. Interestingly, in parts of the country where it is too cold for SWD to easily overwinter (i.e. in the northeastern U.S.), ratios between male and females in early season traps were more predictably 1:1. This more equitable ratio may simply be the result of random mortality occurring during overwintering.

Netting and Abiotic Conditions

Other than its ability to exclude SWD from crop areas, netting has the potential to affect plants in other important ways: temperature and humidity. As documented, there are significant differences in the temperature inside and outside of netted areas. Whether these temperature differences impact plant development or fruit set is less obvious. There are several critical temperatures that affect blueberry development. These are mostly related to bud production, flower development and overall plant reproduction. When blueberries are in full bloom, temperatures below 32˚F can cause significant yield loss (Michigan State University 2012), but because netting would typically be put on after fruit set (but before ripening) this has little or no relevance to growers who are trying to control SWD. Research done on polyethylene covers show blueberry ripening can be accelerated by up to a month (Baptista et al. 2006), but no studies to our knowledge examine how temperature

Table 2: Up-front and amortized costs of netting systems

	Upfront cost	Amortized over 10 years	Amortized over 7 years
Blueberry trellising system (1 acre) with netting (field)	$10,675	$1,068	$1,525
Raspberry high tunnel system with netting (3 bay)	$50,000	$5,000	$7,142

Table 3: Costs for managing SWD in blueberries

	Organic spray regimen	Conventional spray regimen	Sanitation	Netting	Notes
Labor					
One time				30 hours to construct and install trellis + 8 hrs to sew netting together = 38 hrs	*Netting sewing services provided by netting resellers for approximately $1600/acre, or growers can do it themselves if they have a sewing machine.*
Yearly	1 hr/application x 6 applications = 6 hrs; Interior pruning to remove SWD habitat and better spray penetration = 5 hrs per acre.	1 hr/application x 6 applications = 6 hrs; Interior pruning to remove SWD habitat and better spray penetration = 5 hrs per acre.	Sanitation harvests require 1 additional hour for every 5 hrs of harvest (estimated)	3 hrs to install and remove netting (pre-and post-harvest).	*Extra labor in a spray regime = spraying every 5 days; extra labor in a sanitation regimen = clean harvest, fruit sorting + solarizing contaminated fruit.*
Capital Expenses					
Airblast sprayer (new)	$13,000	$13,000			*New, estimated life is 15 years, estimated use is 99 hours/year (source is Oregon State Economic Analysis and the American Society of Agricultural Engineers), operating cost per hours = $8.75*
Supplies					
Trellis supplies	$0	$0		$1,700	*Trellises based on the large box design by Hannah Lee Link, 2015. Available at http://www.uvm.edu/vtvegandberry/SWD/SWDNettingFrameFactsheet.pdf. Cost estimated based on Oregon State estimates: two wire, wooden end post, metal in-row post. Estimated life expectancy = 20 yrs.*
Netting	$0	$0		$7,315	*Proteknet 80, 13x328' x 11 rolls @$665/roll. Sewing required.*
Heavy duty ground staples (12")	$0	$0		$1,090	*$1.09 each x 1000*
Other	$0	$0	$50		*Clear plastic bags for solarizing infected fruit.*

Table 4: Pesticide control for SWD (price per maximum application allowed per acre)

Brand name, application rate per acre, (days till re-entry)(*IRAC class*)	**Organic sprays, price per acre**	**Conventional sprays, price per acre**	**Price in typical units sold**	**Efficacy**
Assail 30 SG 4.0-6.9 oz (1) (*4A)*		$53	$350/4lbs	2 out of 4↨
Asana XL, 4.8-9.6 0z (14) (*3)* ‡		$5	$67/G	4 out of 4↨
Bifenture 10DF, 5.3-16.0 oz (1) (*3*) ‡		$28	$27.61/lb	2 out of 4↨
Brigade WSB, 5.3-16.0 oz (1)(*3*) ‡		$25	$62.50/2.5lbs	Excellent†
Danitol 2.4EC, 10.6 oz (3)(*3*) ‡		$20	$221.61/G	Excellent†
Delegate WG, 3-6 oz (3)(*5*)		$72	$12.03/oz	Excellent†
Exirel, 13.5-20.5 oz (3)(*28*)		$126	$739.41/G	4 out of 4↨
Imidan 70 W, 1 1/3 lb (3)(*1B*)		$19	$71.95/5lbs	Excellent†
Lannate 90, 0.5 - 1 lb (3)(*1A*) ‡		$43	$43.06/lb	4 out of 4↨
Mustang Max, 4.0 oz (1)(*3*) ‡		$7	$209.45/G	Excellent†
Entrust, 1.25-2 oz (3)(*5*) (OMRI)	$27		$400/Qt	Good - Excellent†
Pyganic 1.4, 1-4 pints (0)(*3A*) (OMRI)	$125		$250/G	Fair - Poor†

(OMRI) Approved by the Organic Materials Review Institute

‡ Restricted use, pesticide applicator license required

† Efficacy reported for products tested in Loeb et al. (2013)

↨ Efficacy reported for products tested in Isaacs (2013)

under netting does or does not impact blueberry yield or quality.

While we did not collect temperature data in the raspberry high tunnels, it is worth noting that covering raspberries in this manner is often used to both extend the season, with elevated temperatures reported as influencing both ripening time and yield (Strik 2012; Carew et al. 2003) and to protect against rainfall on fruit (which limits shelf-life and harvesting days). Historical research finds no difference between plants covered with polyethylene covers and those without, specifically on raspberries and cane growth or node development, though both soil and air temperatures are higher under these treatments (Nonecke and Taber 1989). It should be noted that in the Nonecke and Taber's study, both the control and treatments were within the temperature range for optimal growth for raspberries (Strik 2012). More recently, however, Carew et al. (2003) have reported that temperatures up to 24˚C (75˚F) increase yields in raspberries, while temperatures above this level can diminish yield. Strik (2012) also reported that light transmission has an effect on harvest time, which is something that should be taken under consideration in light-diminishing netting systems. Light transmission of Proteknet80 is 83% (Link 2014).

Humidity was not measured in our study, but is of critical importance in raspberry high tunnel production. By netting the tunnels, airflow is reduced and control of excess humidity becomes a challenge, which can increase the conditions favorable for fungal disease. An increase in fungal disease pressure means that growers will have to utilize additional strategies for protecting their crops: removing netting as soon as harvest is concluded for the year, attentive pruning, and judicious spraying are potentially useful strategies. Some fungal diseases of which growers should be aware are Botrytis cinerea (Botrytis fruit rot and cane botrytis or grey mold wilt), Leptosphaeria coniothyrium (cane blight), and Didymella applanta (spur blight) (Heidenreich et al. 2012).

Variation in SWD in traps

Adult SWD collected in traps in the netted raspberry plantings were more variable that those in un-netted plantings (see figure 4). There are several reasons why this could be true. First, the greater fluctuation in population size within the un-netted raspberry plantings may be the result of the immigration (travel into an area) and emigration (travel out of an area) of SWD from the surrounding wild areas. Conversely, because the enclosed raspberry bushes are isolated from other populations, SWD abundance is directly correlated with food resources within the hoop house, which is a relatively fixed quantity. However, there were too few traps for any statistical significance to be established and further investigation is needed before anything conclusive can be said.

Economic Analysis

Although the cost of managing SWD will be different for every farm, we attempted to forecast the costs (beyond a business as usual scenario) of four management strategies: (a) using conventional sprays, (b) using sprays approved for use on organic farms, (c) exclusion netting, and (d) sanitation (picking clean and solarizing infected fruit). While it is difficult to compare the costs of using exclusion netting and sanitation to organic or conventional spray regimens, we attempted to detail some costs that growers can expect associated with each management strategy.

The cost of netting an acre of berry plants is significant in the year that the trellising system is installed and netting is purchased. According to McDermott (2014), netting one acre of blueberries can average around $10,000, with a lifespan of seven years (amortized cost = $1,428/year not including labor). We estimate that, including labor paid $15/hour (not including tax withholdings), a system would cost $10,675 per acre (see tables 2 and 3). Two expenses included in this projection merit special explanations: first, when considering covering large areas (not using high tunnel structures) sewing the netting can be a significant expense. Growers can sew the fabric themselves if they have a sewing machine (care should be taken to use a polyester thread which will not degrade as quickly as cotton), or some companies that sell netting will join pieces together for a fee. Sewing a piece of netting that would cover a quarter acre (328 square feet, 40 ft wide x 328 ft) could cost $400, or $1600 for four sections to cover one acre. In addition, some suppliers will supply growers with designs for entrance/exit vestibules to netting systems, which can reduce the number of flies that can reach the crop during normal maintenance and harvest activities.

Second, for growers who use netting to enclose high tunnels instead of constructing a trellising system, the cost of netting will be lower (since plastic covering the tunnels will reduce the square footage of netting required to enclose the plantings), though the cost of a tunnel will be much greater than that of trellising supplies. Heidenreich et al. (2012) estimate that a multi-bay high tunnel for raspberry production will cost around $34,000. Despite the higher cost of high tunnels covered in plastic, these structures carry several other benefits besides protection from SWD, including easier harvesting, better fruit quality, and reduced disease pressure.

The cost of building a trellised netting structure or a multi-bay high tunnel is higher than yearly pesticide use, even when amortized over seven years and with labor costs included. Table 4 shows spray rates were based upon recommendations published by the University of Massachusetts Amherst (2015). We estimate that growers who choose to spray will need to do so six times per season. Based on our summary of the cost per acre of the twelve sprays listed, we estimate that growers using organic sprays can expect to spend $456 in insecticides per acre per year (applying 6 sprays a year and rotating between IRAC classes). Conventional growers can expect to pay between $73-$538 per acre per year, if they alternate applications in different insecticide resistance action committee (IRAC) classes. For organic and conventional growers alike, a high quality boom sprayer is needed for effective application of insecticides. As shown in table 3, a $15,000 new sprayer amortized over 15 years has a yearly cost of $867.

For a summary of efficacy of different sprays, see Loeb et al. (2013) or Isaacs (2013). It should be noted that this analysis does not place any monetary value on ecological or human health costs associated with pesticide use, which some argue should be considered in any economic analysis (Wilson and Tisdell 2001). We suggest that the ecological and human costs of heavy pesticide use should be considered by growers seeking to control SWD with sprays.

Labor required for each approach varies (see table 3). While spraying may already be a part of a growers activities, both sanitation and netting requires additional hours. Sanitation involves regular and frequent harvests, taking all ripe berries off of the bushes, and separation of infected from uninfected fruit. Infected fruit are placed in clear plastic bags and left in the sun, where excessive heat destroys SWD larvae. One grower in our study estimated that sanitation practices required an extra hour of effort for every five hours of harvest. Construction of trellis systems of high tunnels is highly labor intensive in year one, but installing and removing netting on a yearly basis requires fewer hours, which vary depending on the trellising system.

It would be useful for growers to know what potential crop losses they face under each management strategy. Unfortunately, a comprehensive review has not yet been completed. Estimates from Cornell Cooperative Extension state that growers could experience 30-50% loss in mid-season blueberries and 70% loss in late-season raspberries if no action is taken to protect crops (Cornell University 2012). A grower in our study estimated that sanitation practices reduced loss in his late-season raspberries of 30%, but this is unconfirmed. Our work confirms that use of exclusion netting reduces adult populations of SWD in and around berry plantings, but did not result in a difference in marketable yield.

Conclusion and Recommendations

Because SWD is likely to have a significant economic impact on fruit and berry crops in the northeastern U.S. in coming years, growers of these crops need to manage with this pest in mind. While insecticides may be an economically viable choice for conventional growers, the external costs of this management approach should be considered (including worker and ecological health). Organic growers do not have adequate chemical control options available to them, with only one spray available with acceptable efficacy.

Berry varieties that ripen early in the season do not require extensive protection from SWD at this point. This is due to the low numbers of SWD that are likely to overwinter in a northeastern U.S. climate. Milder winters will likely increase survivorship rates, however. Growers should be prepared for fluctuations in SWD pressure on crops depending on annual variations in winter conditions. Crops that ripen in late summer, such as fall raspberries, are more at risk from SWD. Exclusion netting can be used in combination with good sanitation practices to control SWD in commercial raspberry production. This research shows that exclusion netting is effective at lowering populations of SWD in and around commercial raspberry crops, though growers must put additional effort into training staff to close netting after entering and exiting crop areas.

Our research suggests that there is an unequal sex distribution of SWD inside netted plantings, with a higher concentration of female SWD found inside the nets. While our study cannot conclude why this is the case, it is possible the SWD behave similarly to Drosophila melanogaster when there is limited food available (as is the case in a homogeneous netted crop system): in this scenario, male fruit flies will disperse and female fruit flies will stay close to their food source. This should be further researched to determine if this is indeed the case with SWD.

As growers select strategies for managing SWD on their farms, cost is a significant factor. All four management approaches we included in this study (conventional insecticides, organic insecticides, sanitation and exclusion netting) require additional labor. Exclusion netting and spraying also require significant investment in equipment. High tunnels for raspberry production are notably expensive, but have benefits that extend beyond SWD control, including disease control and season extension. Many growers who currently grow raspberries in high tunnels can add exclusion netting to these existing systems for relatively little extra investment.

By providing this information, we hope that growers can make an informed decisions about how best to address SWD in their operations.

Resources for Growers

- ♦ Vermont Vegetable and Berry Growers Association, Spotted Wing Drosophila resource webpage: http://www.uvm.edu/vtvegandberry/?Page=SWDInfo.html
- ♦ Factsheet on netting trellis designs: http://www.uvm.edu/vtvegandberry/SWD/SWDNetting-FrameFactsheet.pdf
- ♦ Michigan State University Integrated Pest Management, Spotted Wing Drosophila resource webpage: http://www.ipm.msu.edu/invasive_species/spotted_wing_drosophila
- ♦ Cornell University, Small Fruit http://www.fruit.cornell.edu/spottedwing/

Sources of netting, sewing, and vestibules (not an exhaustive list):

- ♦ Berry Protection Solutions: berryprotection@fairpoint.net 413-329-5031
- ♦ Dubois Agrinovation: http://www.duboisag.com 800-463-9999
- ♦ American Nettings and Fabric: http://www.americannettings.com 800-811-7444
- ♦ Brookdale Fruit Farm: http://www.brookdale-fruitfarm.com 603-465-2240

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References

Baptista, M.C., P.B. Oliveira, C.M. Oliveira, Instituto Superior De Agronomia, and Tapada Ajuda. 2006. "Early Ripening of Southern Highbush Blueberries under Mild Winter Conditions." In VIII International Symposium on Vaccinium Culture, 191–96. *ISHS Acta Horticulturae* 715.

Beers, E.H., R. a Van Steenwyk, P.W. Shearer, W.W. Coates, and J.A. Grant. 2011. "Developing Drosophila Suzukii Management Programs for Sweet Cherry in the Western United States." *Pest Management Science* 67 (11): 1386–95.

Bolda, M.P., R.E. Goodhue, and F.G. Zalom. 2010. Spotted Wing Drosophila: Potential Economic Impact of a Newly Established Pest. Agricultural and Resource. http://pmtp.wsu.edu/downloads/SWD-v13n3_2.pdf.

Burrack, H.J. J.P. Smith, D.G. Pfeiffer, G. Koeher, and J. Laforest. 2012. "Using Volunteer-Based Networks to Track Drosophila Suzukii (Diptera : Drosophilidae) an Invasive Pest of Fruit Crops." *Journal of Integrated Pest Management* 4 (3): 3–7.

Calabria, G., J. Máca, G. Bächli, L. Serra, and M. Pascual. 2012. "First Records of the Potential Pest Species Drosophila Suzukii (Diptera: Drosophilidae) in Europe." *Journal of Applied Entomology* 136: 139–47.

Carew, J.G., K. Mahmood, J. Darby, P. Hadley, and N.H. Battey. 2003. "The Effect of Temperature, Photosynthetic Photon Flux Density, and Photoperiod on the Vegetative Growth and Flowering of 'Autumn Bliss' Raspberry." *Journal of the American Society of Horticulture Science* 128 (3): 291–96.

Cini, A., C. Ioriatti, and G. Anfora. 2012. "A Review of the Invasion of Drosophila Suzukii in Europe and a Draft Research Agenda for Integrated Pest Management." *Bulletin of Insectology* 65 (1): 149–60.

Coop, L., V. Walton, A. Dreves, D. Dalton, P. Jepson, P. Shearer, and S. Castagnoli. 2013. "A Model Estimating Spotted Wing Drosophila Overwintering Mortality: Basis of Model." In Spotted Wing Drosophila – Overwintering Mortality.

Cornell University. 2012. "Spotted Wing Drosophila: Economic and Environmental Impact." Small Fruit. http://www.fruit.cornell.edu/spottedwing/ecoenvimp.html.

Dalton, D.T., V.M. Walton, P.W. Shearer, D.B. Walsh, J. Caprile, and R. Isaacs. 2011. "Laboratory Survival of Drosophila Suzukii under Simulated Winter Conditions of the Pacific Northwest and Seasonal Field Trapping in Five Primary Regions of Small and Stone Fruit Production in the United States." *Pest Management Science* 67: 1368–74.

Dreves, A. 2011. "IPM Program Development for an Invasive Pest : Coordination , Outreach and Evaluation." *Pest Management Science* 67: 1403–10.

Dreves, A., V. Walton, and G. Fisher. 2009. New Pest Attacking Healthy Ripening Fruit in Oregon.

Grubinger, V., and J. Smith. 2014. Insect Netting Trial for

SWD at Deer Ridge Farm, Guilford, VT.
Hauser, M.. 2011. “A Historic Account of the Invasion of Drosophila Suzukii (Matsumura) (Diptera:Drosophilidae) in the Continental United States , with Remarks on Their Identification.” *Pest Management Science* 67: 1352–57.
Heidenreich, C., M. Pritts, K. Demchak, E. Hanson, C. Weber, and M. Kelley. 2012. High Tunnel Raspberries and Blackberries. Cornell University Department of Horticulture. Ithaca, NY. http://www.fruit.cornell.edu/berry.html.
Isaacs, R.. 2013. Chemical Control Options for SWD in Blueberries, Caneberries, Strawberries, Grapes and Stone Fruits. East Lansing, MI. http://extension.missouri.edu/sare/documents/Chemical Control2013.pdf.
Kawase, S., and K. Uchino. 2005. “Effect of Mesh Size on Drosophila Suzukii Adults Passing through the Mesh.” *Annual Report of the Kanto-Tosan Plant Protection Society,* no. 52: 99–101.
Kimura, M.T. 2004. “Cold and Heat Tolerance of Drosophilid Flies with Reference to Their Latitudinal Distributions.” *Oecologia* 140 (3): 442–49.
Lee, J.C., D.J. Bruck, H. Curry, D. Edwards, D.R. Haviland, R. a Van Steenwyk, and B.M. Yorgey. 2011. “The Susceptibility of Small Fruits and Cherries to the Spotted-Wing Drosophila, Drosophila Suzukii.” *Pest Management Science* 67 (11): 1358–67.
Liburd, O.E., and L.E. Iglesias. 2013. Spotted Wing Drosophila: Pest Management Recommendations for Florida Blueberries.
Link, H.L.. 2014. “An Investigation of Insect Netting Trellis Systems to Manage Spotted Wing Drosophila for Vermont Blueberry Farms.” University of Vermont.
Loeb, G., C. Heidenreich, L. Mcdermott, P. Jentsch, D. Breth, and J. Carroll. 2013. Chemical Control of Spotted Wing Drosophila in Berry Crops.
McDermott, L. 2014. Berry Notes: Using Exclusion Netting to Control Spotted Wing Drosophila in Blueberries. Vol. 26. http://extension.umass.edu/fruitadvisor/sites/fruitadvisor/files/newsletters/berry-notes/2014MBNOct.pdf.
Michigan State University. 2012. “Michigan Blueberry Facts: Spring Critical Temperatures.” http://blueberries.msu.edu/growing_blueberries/spring_critical_temperatures.
Nonecke, G.R., and H.G. Taber. 1989. “Effects of Row Cover on Vegetative and Reproductive Growth of ‘Heritage’ Red Raspberry.” *Acta Horticulturae* 262. Ames, Iowa: 391–94.
Riggs, D.I.M. 2015. Using Exclusion Netting to Manage Spotted Wing Drosophila in Blueberries. http://www.hort.cornell.edu/grower/nybga/swd/pdfs/Management-Cultural/Using Exclusion Netting to Manage SWD in Blueberries.pdf.
Simon, J.C., W.B. Dickson, and M.H. Dickinson. 2011. “Prior Mating Experience Modulates the Dispersal of Drosophila in Males More than in Females.” *Behavior Genetics* 41 (5): 754–67.
Strik, B.C. 2012. “Flowering and Fruiting on Command in Berry Crops.” *Acta Horticulturae* 926: 197–214.
University of Massachusetts Amherst. 2015. “Table 39. Highbush Blueberry Pest Management Table.” Agriculture and Landscape Program Fruit Advisor. https://extension.umass.edu/fruitadvisor/ne-small-fruit-management-guide/table-39-highbush-blueberry-pest-management-table.
USDA-NASS. 2013. “Table 2. Market Value of Agricultural Products Sold Including Landlord’s Share and Direct Sales: 2007 and 2002 USDA.” USDA Agriculture Census - Vermont. http://www.agcensus.usda.gov/Publications/2012/Full_Report/Volume_1,_Chapter_1_State_Level/Vermont/st50_1_002_002.pdf.
Wilson, C., and C. Tisdell. 2001. “Why Farmers Continue to Use Pesticides despite Environmental, Health and Sustainability Costs.” *Ecological Economics* 39 (3): 449–62.

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