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Season-long programs for control of *Drosophila suzukii* in southeastern U.S. blueberries

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ABSTRACT

Drosophila suzukii is an invasive insect pest which has major impacts on small fruit production throughout North America. Current control programs use frequent applications of broad-spectrum insecticides. To prevent resistance, modes of action must be rotated. This study examines the acute and residual efficacy of rotational treatment programs designed to meet the needs of commercial growers in the southeastern United States, a region which experiences significant precipitation throughout the growing season. All insecticide applications had greater adult acute mortality than controls, and some had residual efficacy for three or more days after treatment. Programs had no residual effects at seven days after treatment. Within programs, organophosphates (phosmet and malathion) and pyrethroids (zeta-cypermethrin and fenpropathrin) were the most effective. Some programs also resulted in less offspring production by *D. suzukii* in bioassays and reduced field infestation compared to controls. Results show that effective, season-long rotational chemical treatment programs can be designed to minimize crop damage, meet exportation requirements and manage for resistance. Understanding the effect of regional climate on the performance of individual insecticide treatments and their efficacy will be critical for widespread implementation of effective control programs for *D. suzukii*.

1. Introduction

Drosophila suzukii Matsumura (Diptera: Drosophilidae), commonly referred to as spotted wing drosophila, is a polyphagous invasive pest of soft skinned fruits. Since its initial detection in the United States, it has quickly spread throughout North America, Europe, and South America (Walsh et al., 2011; Cini et al., 2012; Vilela and Mori, 2014; Asplen et al., 2015). Native drosophilids primarily infest overripe or rotting fruit, but *D. suzukii* females possess a large, heavily sclerotized ovipositor, enabling them to oviposit in ripe and ripening fruits (Burrack et al., 2013; Goodhue et al., 2011; Hauser, 2011; Lee et al., 2011a). In North America, *D. suzukii* has resulted in over $700 million in losses in host crops including blueberries, cherries, caneberries (raspberries and blackberries), grapes and strawberries (Bolda et al., 2010; Burrack et al., 2013; Cini et al., 2012; Goodhue et al., 2011; Kinjo et al., 2013; Lee et al., 2011b; USDA NASS, 2014; Vilela and Mori, 2014; Walsh et al., 2011b). Crop damage is caused both via direct consumption of fruit by larvae as well as by puncture wounds caused by egg laying. Puncture wounds enable the entrance of secondary contaminants, including other species of fruit flies and pathogens, into berries (Walsh et al., 2011).

D. suzukii has been detected in all fruit growing areas of the United States. Previous management studies have been performed in the western states of Washington, Oregon and California (Beers et al., 2011; Bruck et al., 2011) and in the Great Lakes region (Van Timmeren and Isaacs, 2013). However, none have explored the efficacy of management programs in the southeastern United States, a distinct climate region of North America (Karl and Koss, 1984).

North Carolina and Georgia are the largest blueberry producing states in the southeastern United States, with an annual crop value of $196.6 million (USDA NASS, 2014). Blueberry producers in the southeast mostly grow both southern highbush and rabbiteye blueberries. Southern highbush (*Vaccinium corymbosum* L.) fruit ripen 3–4 weeks earlier than rabbiteye (*Vaccinium ashei* Reade), providing fresh fruit from mid-April through July (Nesmith and

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Krewer, 2012; www.georgiablueberries.org). Since the arrival of *D. suzukii*, growers have increased pesticide use by 50% or greater and still have crop losses (eFly Working Group, n.d.). The most effective insecticides for use against *D. suzukii* include organophosphates, pyrethroids and spinosyns (Bruck et al., 2011), the use of which is complicated by their potential effects on non-target organisms, seasonal application restrictions, impractically long pre-harvest intervals, and trade related concerns due to insecticide residue tolerances. Our goal was to evaluate the efficacy of chemically-based season-long control programs against *D. suzukii* in blueberry crops in the southeastern U.S. We compared management programs designed to minimize pesticide residue levels on marketable fruit, maximize efficacy and residual activity, facilitate short time from application to harvest, and reduce risk to beneficial insects by using only insecticides considered to be less toxic to these organisms (Roubos et al., 2014a, 2014b).

2. Experimental methods

2.1. Experimental design

Field experiments were conducted during 2013 and 2014 at seven sites in Georgia (GA) and North Carolina (NC). Three grower-cooperator sites were used in southeastern North Carolina. Two research farm and two grower-cooperator sites were used in southeastern Georgia. Trials included both southern highbush and rabbiteye blueberries (Table 1). Treatment programs were replicated within each site and randomly assigned to plots ranging from 0.08 to 0.4 ha. Treatments were applied weekly using grower equipment (Table 1), and replicated 3–4 times per site in a randomized complete block design.

Programs were designed to address marketing, harvest interval, non-target risk, and input cost concerns and compared to an untreated control (UTC) (Table 2). Three "Export-friendly" programs used insecticides for which major international trading partners have established Maximum Residue Levels (MRL) and included a maximum number of modes of action (Export 1, 2 and 3). Because of harvest conditions and variable labor available, growers need options with short pre-harvest intervals (PHI). Therefore the second program (Short PHI) included two materials with a 1 day PHI. The third program used insecticides considered to be "reduced risk" to non-target organisms (Roubos et al., 2014a, 2014b). All insecticide applications were made at the maximum label rate for *D. suzukii* in blueberry in North Carolina and Georgia (Table 3), and sprays were done on every individual row to provide maximum coverage.

2.2. Data collection

2.2.1. Semi-field bioassays

Because *D. suzukii* field populations are highly variable, semi-field bioassays were conducted following treatments to assess program efficacy. A single branch with at least 10 leaves and 5 ripe berries was collected from the center of each plot for use in bioassays (Van Timmeren and Isaacs, 2013). In NC, bioassay samples were collected immediately after treatment and 7 days after treatment (DAT). In GA, samples were collected 1, 3 and 7 DAT at the research farm, and 5 DAT at grower sites to accommodate harvest schedules. Samples were collected at 3 DAT in GA to determine a precise period during which insecticides remain active on treated plants. Bioassay chambers were constructed using 946 ml plastic containers (PFS Sales Co., Raleigh, NC). Branches were inserted into floral water picks (Koyal Wholesale, CA) containing 10 ml of water and placed through a hole in the bottom of the chamber. Berries were placed at the bottom of chambers in a wire mesh (0.5 cm wire mesh) boat (GA) or 30 ml plastic cup (NC- Dart container Corporation, Mason, MI) (Burrack et al., 2013; Van Timmeren and Isaacs, 2013). Chambers were ventilated through a 5 cm diameter opening in their lids, covered with white tulle mesh. Flies were provided a strip of filter paper soaked in liquid diet (1:2:3 sugar/yeast/water by weight (Burrack et al., 2013)) and supplemental water.

Ten reproductively mature adult *D. suzukii* (5 male, 5 female) from laboratory colonies (Burrack et al., 2013; Dalton et al., 2011) were placed into each chamber. Observations were made at 24, 72, and 120 h to assess mortality. In general, mortality at 24 h (acute mortality) is presented as we considered it unlikely that flies would remain in continuous contact with treated plants for up to 120 h. 72 and 120 h observations were conducted because some the insecticides compared were anticipated to be slower acting than others, and we wanted to capture potential differences in speed of induced mortality. After 120 h, any remaining flies were removed. In NC, fruit were held for additional 48 h and then dissected to count larvae.

2.2.2. Adult trapping (NC sites only)

One baited trap was suspended from a 1.2 m step-in fence post in the center of each plot and serviced weekly. Traps consisted of 946 ml plastic deli containers (PFS Sales Co., Raleigh, NC) with 12, 0.5 cm holes evenly spaced around the top of the container. Traps were baited with 150 ml each of yeast and sugar slurry, 4:2 tbsp. sugar/yeast (Domino Sugars, Iselin, NJ; Red Star dry active yeast, Milwaukee, WI) mixed in 946 ml water. Bait was replaced weekly and *D. suzukii* from each trap were counted and sexed under a stereomicroscope.

Table 1
Field site and application rates. Maximum label rates for each state were applied every 7–10 days.

Year	Location	Cultivar/Variety	Treatment replications	Application equipment	Application rate (l/ha)
2013	Bladen County, NC (grower)	Southern highbush, var. Duke	3	Airtech air cannon trailer mounted	468
2013	Sampson County, NC (grower)	Southern highbush, var. Legacy	3	Airblast Jacto Arbus 1000 trailer mounted	682
2014	Sampson County, NC (grower)	Rabbiteye, var. Tiff Blue	4	Airblast Jacto Arbus 1000 trailer mounted	664
2014	Bacon County, GA (research farm)	Southern highbush, var. Star	4	Airblast Jacto Arbus 400 (top two nozzles and the bottom nozzles were closed)	468
2014	Bacon County, GA (research farm)	Rabbiteye var. Climax, Powderblue and Brightwell	3	Airblast Jacto Arbus 400 (top two nozzles and the bottom nozzle were closed)	468
2014	Bacon County, GA (grower)	Southern highbush, var. Star, V1	3	Airblast	468
2014	Bacon County, GA (grower)	Rabbiteye, var. Brightwell, Powderblue, Premier	3	Airblast	468