Crop Protection 98 (2017) 149–156

Contents lists available at ScienceDirect

Crop Protection

journal homepage: www.elsevier.com/locate/cropro

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

Lauren M. Diepenbrock, Jesse A. Hardin, Hannah J. Burrack*

North Carolina State University, Department of Entomology and Plant Pathology, United States

ARTICLE INFO

Article history:
Received 20 December 2016
Received in revised form
17 March 2017
Accepted 19 March 2017

Keywords:
Drosophila suzukii
Season-long treatment program
Integrated pest management
Resistance management

ABSTRACT

Drosophila suzukii is an invasive insect pest which impacts small fruit production throughout much of the world. Current management programs use regular applications of broad-spectrum insecticides which must be rotated for resistance management. This study examined the efficacy of rotational treatment programs designed to meet the needs of commercial growers in the southeastern United States, a region which experiences frequent rainfall during the growing season. In bioassays, all insecticides in our programs killed at least 50% of all female flies. Despite this good efficacy and weekly applications, infestation still occurred within fields. Our findings demonstrate the necessity of a comprehensive management strategy for blackberries, requiring additional efforts to current chemical-intensive management regimes, including cultural management practices such as pruning, harvest frequency, and post-harvest cooling.

1. Introduction

Drosophila suzukii Matsumura (Diptera: Drosophilidae), commonly referred to as spotted wing drosophila, is a polyphagous invasive pest of soft skinned and stone fruits. Originating from Asia, *D. suzukii* has now become widespread throughout Europe and the Americas (Asplen et al., 2015; Calabria et al., 2012; Cini et al., 2014, 2012; Deprá et al., 2014; Hauser, 2011; Lee et al., 2011b). Unlike many drosophilids common to North America, whose larvae feed upon overripe or rotting substrates, *D. suzukii* females prefer to lay eggs in ripe and ripening fruit (Kinjo et al., 2013; Lee et al., 2011b; Swoboda-Bhattarai and Burrack, 2016), and possess a large, heavily sclerotized ovipositor which enables their oviposition into these substrates (Atallah et al., 2014; Hauser, 2011). In North America, *D. suzukii* infestation results in hundreds of thousands of dollars in crop losses from rejected harvested fruit from host crops including blueberries, cherries, caneberries (raspberries and blackberries), grapes, and strawberries (Cini et al., 2012; Goodhue et al., 2011; Vilela and Mori, 2014), and its management adds significantly to production costs of these fruit (Diepenbrock et al., 2016a; Goodhue et al., 2011).

D. suzukii has been detected throughout the United States, with much research effort devoted towards the management of this pest. Previous management studies have been performed in raspberries and cherries on the west coast (Beers et al., 2011; Bruck et al., 2011), in blueberry in the Great Lakes region (Van Timmeren and Isaacs, 2013), and in blueberry in the southeast (Diepenbrock et al., 2016a). To date, none have explored management programs in blackberry (*Rubus spp.*), arguably the most impacted host crop in the southeastern United States (eFly Working Group, 2014). In North Carolina, blackberry producers grow either floricane-fruiting or floricane and primocane fruiting varieties of blackberry. Floricane-fruiting varieties (e.g. 'Navajo', 'Ouachita', 'Natchez') produce fruit from mid-June until the end of July, while floricane and primocane-fruiting varieties (e.g. Prime-Ark® 45) will bear fruit until the first freeze. Because blackberry is highly susceptible to *D. suzukii* infestation, growers must proactively protect their fruit once it becomes vulnerable, as they begin to ripen (Swoboda-Bhattarai and Burrack, 2016). These conservative management practices represent an increase in insecticide use of at least 90% compared to the period before *D. suzukii* detection, but significant crop losses still occur (eFly Working Group, 2014). Diamides, organophosphates, pyrethroids, and spinosyns are the most effective insecticide classes against *D. suzukii* (Bruck et al., 2011; Diepenbrock et al., 2016a). There is significant concern about potential effects on non-target organisms with increased use of these primarily broad-spectrum insecticides. There are also limitations to

* Corresponding author.
E-mail addresses: laurendiepenbrock@gmail.com (L.M. Diepenbrock), hannah_burrack@ncsu.edu (H.J. Burrack).

http://dx.doi.org/10.1016/j.cropro.2017.03.022

insecticide based management programs for *D. suzukii* that make them challenging for growers to implement, including seasonal application restrictions, long pre-harvest intervals, and potential trade barriers due to insecticide residue tolerances.

Relatively few insecticides effective against *D. suzukii* are labelled in blackberry, and creating management programs that rotate mode of action to reduce risk of resistance development while also adhering to seasonal application restrictions is challenging. Our overall goal was to evaluate season-long insecticide rotations for *D. suzukii* in blackberry crops in the southeastern U.S. We compared three management programs designed to minimize insecticide residue levels on marketable fruit, maximize efficacy and residual activity, and reduce risk to beneficial insects by using insecticides considered to be less toxic to these organisms (Roubos et al., 2014a, 2014b). To evaluate these programs, we compared the efficacy of individual treatments within rotational programs in laboratory bioassays, and monitored adult fly presence, infestation rates, and pesticide residues from field plots.

2. Experimental methods

2.1. Experimental design

Field experiments were conducted at one grower-cooperator farm during 2014 and two farms during 2015 in the piedmont region of North Carolina (NC). The 2014 experimental location consisted of Prime-Ark® −45, a floricane and primocane-fruiting variety (Clark and Perkins-veazie, 2011). In 2015 one location had a pure stand of the floricane-fruiting 'Navajo' (Moore and Clark, 1989) and the other location had a mixed planting of the floricane-fruiting varieties 'Navajo' and 'Ouachita' (Clark et al., 2005) (Table 1). None of the plantings were under covers or high tunnels. All fields were picked at regular 2–4 d intervals depending on labor availability, and damaged fruit were left to decay on the ground in row centers, standard practice in the region. Treatments were replicated within sites and randomly assigned to plots ranging from 0.16 to 0.45 ha. Treatments were applied using grower equipment, and replicated 3–4 times per site in a randomized complete block. During 2014, materials were applied every 7 d, and every 6 d during 2015. Cost for the three programs we compared ranged from $319-$447 (USD) per ha for a 6 week period (Table 2).

Treatments consisted of insecticide programs, which were designed to address marketing, harvest interval, non-target risk, and input cost concerns (Table 2). The first, "export-friendly", treatment (Export) consisted of insecticides for which major trading partners have established Maximum Residue Levels (MRL), the second treatment incorporated all three modes of action (MaxMOA) currently possible in U.S. blackberry production systems, and the third program utilized only non-organophosphate insecticides (Non-OP). Blackberries are harvested every 2–3 days, so all insecticides used had a one day post-harvest interval (PHI) to enable growers to maintain their tight picking schedules. All insecticides were applied using grower owned equipment (Table 2) and every row was sprayed on both sides by running the sprayer through every row-middle at the maximum label rate for *D. suzukii* management in North Carolina (Table 3). Our work necessitated large plots available only on commercial farms. Because blackberry is a preferred host for *D. suzukii* (Burrack et al., 2013; Diepenbrock et al., 2016b), and there are high local populations of the pest (Swoboda-Bhattaria, *Unpub. data*), we could not include an untreated control. The goal of our project was to make comparisons among treatment programs, and all of the locations we conducted experiments have high naturally occurring *D. suzukii* populations.

2.2. Data collection

2.2.1. Single product efficacy bioassays

Bioassays using field treated material were performed to assess acute toxicity, which is not feasible to measure in the field due the small size and mobility of *D. suzukii*. A single branch with at least 3 leaflets and 3 ripe berries from the exterior edge of canes were collected from the center of each plot for use in bioassays (adapted from Diepenbrock et al., 2016a; Van Timmeren and Isaacs, 2013). Bioassay samples were taken immediately after insecticide application (0 DAT) and 6–7 days after treatment (DAT). 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 30 ml plastic cup (Dart Container Corporation, Mason, MI) (Burrack et al., 2013; Diepenbrock et al., 2016a; Van Timmeren and Isaacs, 2013). Containers 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; Diepenbrock et al., 2016a) and supplemental water.

Ten reproductively mature adult *D. suzukii* (5 male, 5 female) from laboratory colonies (Burrack et al., 2013; Dalton et al., 2011; Diepenbrock et al., 2016a) were placed into each chamber. Observations were made at 24 h to assess mortality and were left in containers for an additional 48 h, 72 h in total. Mortality at 24 h (acute mortality) is presented as it is unlikely that flies would remain in continuous contact with treated plants for up to 72 h. After 72 h, flies were removed from containers and fruit were held for an additional 48 h after which they were dissected to count larvae.

2.2.2. Adult trapping

One trap was suspended approximately 1.5 m from the ground on trellis posts 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 a 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. Flies per plot per week and total fly capture for the entire season were computed.

2.2.3. Larval infestation

Ripe, marketable berries were collected from the center of each field plot prior to insecticide applications to determine infestation.

Table 1
Field site and application rate. Maximum label rates were applied every 7 days.

Year	Location	Variety	Treatment replications	Plot size (ha)	Application Equipment	Application rate (l/ha)
2014	Cleveland County, NC	Prime-Ark®-45	4	0.16–0.18	Jacto Arbus 400 Airblast	487
2015	Cleveland County, NC	Navajo	3	0.43–0.45	Durand Wayland 557 Airblast, top nozzles off	935
2015	Cleveland County, NC	Navajo and Ouachita	3	0.19–0.31	Tifone Airblast 882	692