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# Effective Way of Managing Fall Armyworm in Sweet Corn in South Florida

Dakshina R. Seal*[1], Rafia A. Khan[1], Catherine Sabines[1], and Shawbeta A. Seal[1]

[1]*Tropical Research and Education Center, University of Florida/IFAS, 18905 SW 280th St., Homestead, FL 33031*

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**Studies were conducted in 2016, 2017, and 2018 to determine effectiveness of various insect management programs for managing fall armyworm, *Spodoptera frugiperda* (FAW) in tomato fields in South Florida. In the first study, Spear-C alone or in combination with *Bacillus thuringiensis* provided effective control of FAW and significantly reduced FAW feeding damage. In the second study, the effectiveness of Novaluron® in controlling FAW was comparable to Radiant®. All rates of Novaluron® (6, 9, and 12 oz/acre) provided significant reduction of FAW. In the third study, both Novaluron® and Warrior® suppressed FAW. In the fourth study, Dimilin® and different formulations of diflubenzuron effectively reduced FAW as compared to the control. Fawligen®, a fungal based product, was also effective in controlling FAW. In the fifth study, Radiant®applied in a weekly rotation program with Intrepid® performed as well as Radiant® alone, indicating an effective program to control FAW and to manage the development of resistance. In the sixth study, Movento®, Sivanto®, and CX-2130 were effective in reducing FAW as compared to the control. Sivanto® and CX-2130 were the most effective insecticides in this study. The use of effective insecticides applied in a rotation program might prove effective against FAW, saving millions of dollars for the sweet corn industry in Florida. The information in this study will be useful to manage FAW using various reduced risk insecticides and reducing dependence on conventional insecticides.**

Sweet corn (*Zea mays* L.) is a common vegetable in various regions of the world. In the United States, 622,946 acres of sweet corn is produced. In Florida, 46,900 acres sweet corn is produced, which is 1/16th of the nation's total production (NASS, 2010). Sweet corn generated $160 million dollars revenue in 2015 (NASS, 2016).

In Florida, the sweet corn growing season extends from October to May. Sweet corn faces significant threats from various insect pests including fall armyworm [*Spodoptera frugiperda* (FAW)], corn earworm (*Helicoverpa zea*), corn silk fly, *Euxesta* spp., and lesser cornstalk borer (*Elasmopalpus lignosellus*). Other insect pests include wireworm, stink bugs, picnic or sap beetles, aphids, banded cucumber beetles, European corn borer, and white fringed beetles. Among all these insect pests, FAW is the most common one in the southern Florida. Its preferred scientific name is *Spodoptera frugiperda* J.E. Smith. Other scientific names mentioned in the literature include *Caradrina frugiperda*, *Laphygma frugiperda*, *Laphygma inepta*, *L. macra*, *Noctua frugiperda*, *Phalaena frugiperda*, *Prodenia autumnalis*, *P. plagiata*, *P. signifera* and *Trigonophora frugiperd* (CABI, 2018). Like scientific names, fall armyworm has various local names (CABI, 2018). In Argentian it is known as isoca military tardia; in Brazil, it is known as C\curuquere dos capinzais, curuqiere dos milharais, lagurta do cartucho do milho, and lagarra military. In Germany, it is known as Heerwurm and in Mexico as gusano cogollero del maiz.

*Corresponding author. Email: dseal3@ufl.edu

Fall armyworm belongs to the family Noctuidae, order Lepidoptera. The worm is the immature stage of the adult armyworm moth. Fall armyworm causes large-scale economic damage. The scientific name of this insect derived from frugiperda, which means "lost fruit" in Latin (Dept. of Entomology, 2017). Fall armyworm shows a long distance annual migration to extend its distribution range to avoid harsh environmental condition (Nagoshi et al., 2012). Fall armyworm cannot survive in a freezing environment. They overwinter in Texas and Florida and migrate to most of the North America during the spring and early summer causing economic damage to various crops (Barlow and Kuhar 2009). Fall armyworm is a late summer pest of sweetcorn in New Jersey and can be found in all states east of the Rocky Mountains. considered as a serious pest in the southeastern United States (Barlow and Kuhar, 2009; Capinera, 1999). In south Florida, it occurs all the time when corn plants are available. In all seasons, infestation occurs as soon as corn plants are above the ground. Infestation level may reach 70 to 100% in 2–3 weeks after planting in the absence of any control measures (Seal, D.R. unpublished data).

Fall armyworm has a multi continental distribution. It has been reported from four provinces in India (EPPO, 2018). In a short duration (2016–18), it has invaded the entire African Continent with a recent report indicating its distribution in 44 widely separated regions (IITA, 2016; FAO, 2017; EPPO, 2018). It has been reported in almost all U.S. states (EPPO, 2018). It is widespread in all regions of Central America and Caribbean (EPPO, 2018). In South America, EPPO (2018) reported FAW in 34 regions. Fall armyworm has also been reported in Germany, The Netherlands, and Slovenia.

Fall armyworm is a polyphagous pest of various plants. More than 60 plant species belonging to forage grasses, corn, alfalfa, cotton, soybean, and most vegetable crops are feeding hosts of FAW (Flanders et al. 2017).

Females prefer to lay eggs at night on the abaxial leaf surfac in clusters containing up to 400 eggs (Barlow and Kuhar, 2009; Sparks, 1979). During periods of high population density, eggs may also be laid on newly emerged ears and other growing parts of sweet corn plants. A female can lay up to 1000 eggs over her lifetime (Barlow and Kuhar, 2009). The egg mass becomes covered with a protective, felt-like layer of grey-pink scales (setae) from the female's abdomen which becomes thicker as the egg stage proceeds. Freshly laid eggs are whitish in color, dome-shaped and measure around 0.4 mm in diameter and 0.3 mm in length. They are green at the time of oviposition and turn brown as they approach hatching. Embryonic development takes place in 2–3 d at 20 to 30 °C. Newly hatched larvae are gregarious in nature and disperse toward leaf bases or whorls. The first instar is easily recognized for its large dark-colored head. There are six larval instars with the last instar measuring 3-4 cm long. Mean development time of the various instars (1–6) are 3.3, 1.7, 1.5, 1.5, 2.0 and 3.7 days, respectively at 25 °C (Pitre and Hogg, 1983). A full description of larvae is given in Crumb (1956). Levy and Habeck (1976) provided complete diagnostic features. The early instars feed on the epidermal layer in a long trail. Finally, the larvae settle in the whorl and feed on soft leaf tissues. As the larvae feed on the whorl tissue they leave masses of excreta above their body. Pupation takes place in the soil, and also in the whorl. The pupal period lasts approximately 8 d in the summer up to 30 d in the winter, and may vary with fluctuating temperature. The adult life span ranges 7–21 d.

Although eggs are laid in a mass, one to three larvae have been recorded in each whorl. Larval feeding on whorls results in a debilitated, damage plant with feeding holes on leaves. Larval feeding also causes reduced pollen, injured corn ears, and unhealthy plants. FAW-damaged corn plant tissues attract other insect pests that can also cause serious damage to corn ears (Goyal, 2010).

On maize, the initiation of spray program depends on the extent of damage. In the seedling stage, control measure should be undertaken if damage is recorded on 5% of plants, or whorl damage on 20% small plants (King and Saunders, 1985).

In the present study, six efficacy trials using reduced risk pesticides to control FAW in sweet corn were conducted. The effectiveness of growth regulators and conventional insecticides in FAW management were also determined.

## Materials and Methods

All studies were conducted in the Tropical Research and Education Center, University of Florida, Institute of Food and Agricultural Sciences (UF/IFAS) research plots in Homestead, FL. 'Bi-color' sweet corn seeds were planted with 12-in spacing within the bed and 36 in spacing in between beds. The soil type is Rockdale gravely loam, which consists of about 33% soil and 67% limestone pebbles (> 2mm) (Noble et al., 1996). Raised beds, 0.15 m high × 0.71 m wide, were formed and covered with black-white plastic mulch (0.9 mil, Canslit Inc. Victoriaville, Quebec, Canada). Beds were provided with two drip tapes (Ro Drip, USA) having emitter spaces 12 in apart and placed 6 in apart on each side parallel to the center of each bed for performing irrigation. The drip irrigation system delivered 0.4 gal/min. Plants in each study were irrigated one hour every day. The treatment plots, each 12.19 m long, were arranged in a randomized complete block design with four replications in all studies.

**Effect of reduced risk pesticides.** Various treatments used in this first study included: 1) Spear-C (bio-insecticide) at 2 pints/acre; 2) Spear-C plus Bt-K (*Bacillus thuringiensis kurstaki*, IRAC Group 11A); and 3) a nontreated control. All treatments were applied four times at weekly intervals. Treatments were evaluated by sampling 20 plants/treatment plot 48 h after each application. Presence of FAW larvae was confirmed by observing their excreta and collecting larva by using a pair of long forceps. At the time of harvesting, sweet corn foliage was rated for FAW feeding damage on a 1–6 scale, where 1 = whorl damage plus all leaves with feeding damage; 6 = absence of FAW damage.

**Effect of an Insect Growth Regulator (IGR) and Radiant®.** In the second study, two insecticides including three rates of Novaluron® (6, 9, and 12 oz/acre, novaluron, IRAC Group 15) and Radiant® (7 oz/acre; spinetoram, IRAC Group 5) were evaluated to control FAW and were compared with a nontreated control. Plot size for each treatment was 30 ft long, which was replicated four times in a randomized complete block design. Efficacy of treatment was evaluated by randomly checking 10 plants per treatment plot and confirming the presence of FAW following above procedure as discussed above.

**Effect of IGR and Warrior®.** The third study included all three rates of Novaluron® (6, 9 and 12 oz/acre, Novaluron, IRAC Group 15) and Warrior® (3.8 oz/acre, lambda-cyhalothrin, IRAC Group 3A). All materials and methods used in this study were as mentioned for the second study.

**Effect of different formulations of Diflubenzuron and Fawligen®.** In the fourth study, Dimilin® 2L (4.0 oz/acre, diflubenzuron, IRAC Group 15), Dimilin® 2L HV (4.0 oz/acre), Dimilin® 2L HAV (4.0 oz/acre), Dimilin 2L AU (4.0 oz/acre), and Fawligen® (2.8 oz/acre, occlusion bodies of *Spodoptera frugiperda* MNPV-3AP2) were compared with a nontreated control in controlling FAW. Materials and methods in preparing the study and evaluation of treatments were as discussed in the above studies.

**Effect of Intrepid®–Radiation® rotation.** Treatments evaluated in the fifth study were: 1) Radiant® (spinetoram) at 6.0 oz/acre alone; 2) Radiant® at 6 oz/acre rotated weekly with Intrepid® 2F (at 8 oz/acre, methoxyfenozide); and 3) a nontreated control. All materials and methods employed in this study and evaluation of efficacy of the treatments for controlling FAW were as in the above studies.

**Evaluation of conventional insecticides and *Bacillus thuringiensis* based insecticides.** Various treatments evaluated in the fifth study include: 1) Movento® (5.0 oz/acre, spirotetramat, IRAC Group 23); 2) Sivanto® (11 oz/acre, flupyradifurone, IRAC Group 4D; 3) CX-2102 at 1.0 ln/acre (botanical product); 4) CX-2130 at 1 lb/acre (botanical product); and 5) a nontreated control. All materials and methods to conduct this study and to evaluate the efficacy insecticides were same as the above studies.

**Statistical analysis.** Data on the abundance of FAW recorded from treated samples were transformed using square-root of $X + 0.25$ before performing an analysis of variance (ANOVA). The transformed data were analyzed by least squares ANOVA (PROC GLM, SAS Institute 2013). However, for ease of interpretation, the means of the original data are presented. The Waller-Duncan *k*-ratio *t*-test was used to separate treatment means where significant ($P < 0.05$) differences occurred (Waller & Duncan, 1969).

## Results

**Effect of reduced risk pesticides.** Fall armyworm infestations were high during the first study, about 70 to 90% plants were infested with FAW. Sperar-C alone or in combination with Bt-K significantly reduced FAW-infested plants on all sampling dates as compared to the nontreated control (Fig. 1). Spear-C alone or in combination with Bt-K significantly reduced feeding damage showing higher quality of foliage than in the nontreated control (Fig. 2).

**Effect of IGR and Radiant®.** In the second study, the treatments were evaluated four times at weekly intervals 48 h after each application (Fig. 3). Mean numbers of FAW in all Novaluron® treated plants were significantly lower than in the nontreated control on all sampling dates. Novaluron® at 9.0 oz and 12.0 oz/acre performed better than the lower rate (6.0 oz/acre) in reducing mean numbers of FAW/ treatment plot. The performance of two higher rates of Novaluron® was comparable to Radiant® in reducing FAW.

**Effect of IGR and Warrior.** In the third study, Warrior®, a pyrethroid, was compared with three rates of Novaluron® (a

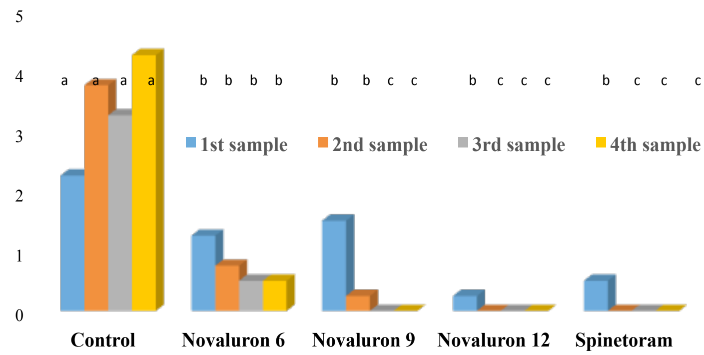


Fig. 3. Mean numbers of fall armyworm per sample of five sweet corn plants treated with Novaluron® on four sampling dates. Means with the same color in each set of bar with a same letter do not differ significantly ($P < 0.05$; Waller Duncan 1969).

growth regulator). Almost on all sampling dates, each treatment significantly reduced FAW with some minor inconsistency. On the fourth sampling date, Novaluron® at 9 and 12 oz/acre provided a similar level of control to Warrior® (Fig. 4).

**Effect of different formulations of Diflubenzuron and Fawligen®.** In the fourth study, all treated plants had fewer FAW on all sampling dates than the nontreated control (Fig. 5). Diflubenzuron HAG and Au also had a reduced mean number

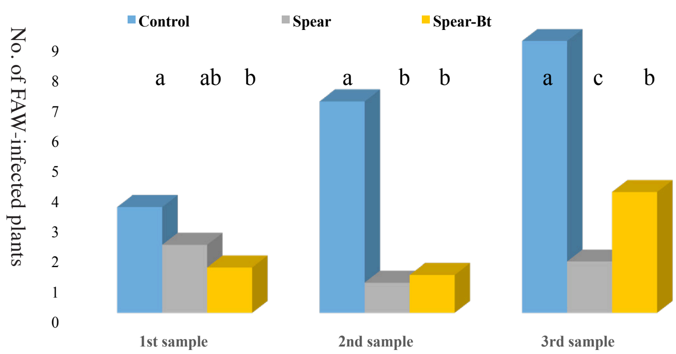


Fig. 1. Control of fall armyworm (FAW) using Spear-C®. Means with the same color in each set of bar with a same letter do not differ significantly ($P < 0.05$; Waller Duncan 1969).

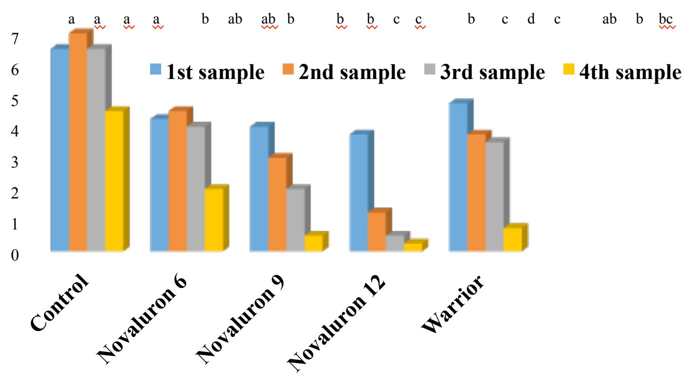


Fig. 4. Mean numbers of fall armyworm per sample of five sweet corn plants treated with Novaluron® on four sampling dates. Means with the same color in each set of bar with a same letter do not differ significantly. ($P < 0.05$; Waller Duncan 1969).

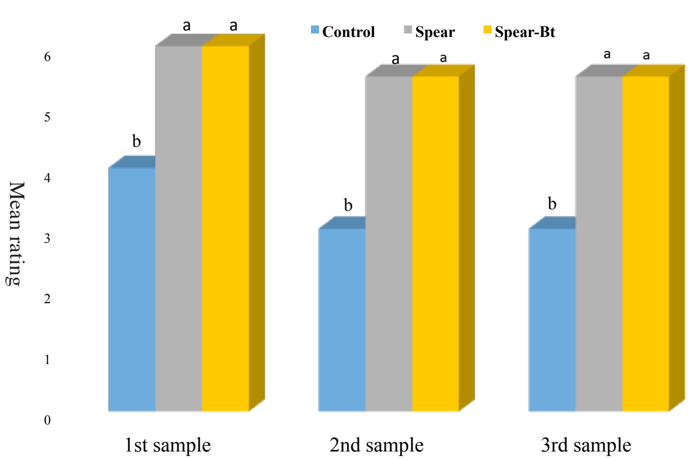


Fig. 2. Mean rating of corn foliage for fall armyworm feeding damage in three treatments. Means with the same color in each set of bar with a same letter do not differ significantly ($P < 0.05$; Waller Duncan 1969).

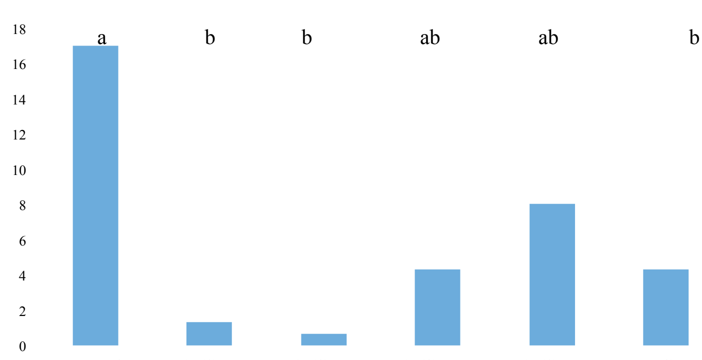


Fig. 5. Mean numbers of fall armyworm in sweet corn treated with various insect growth regulators. Means with the same color in each set of bar with a same letter do not differ significantly ($P < 0.05$; Waller Duncan 1969).

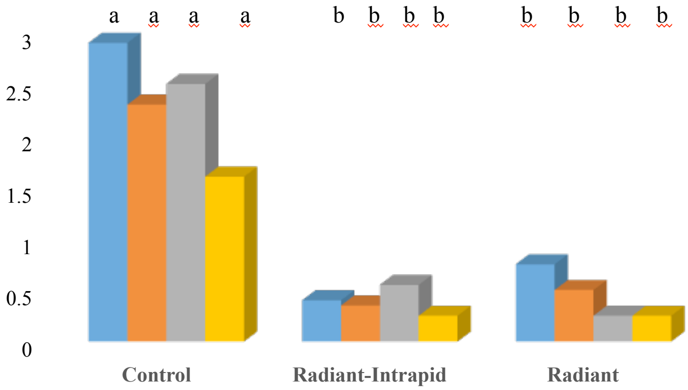


Fig. 6. Effect of a Radiant®–Intrepid® rotation on controlling fall armyworm in sweet corn. Means with the same color in each set of bar with a same letter do not differ significantly ($P < 0.05$; Waller Duncan 1969).

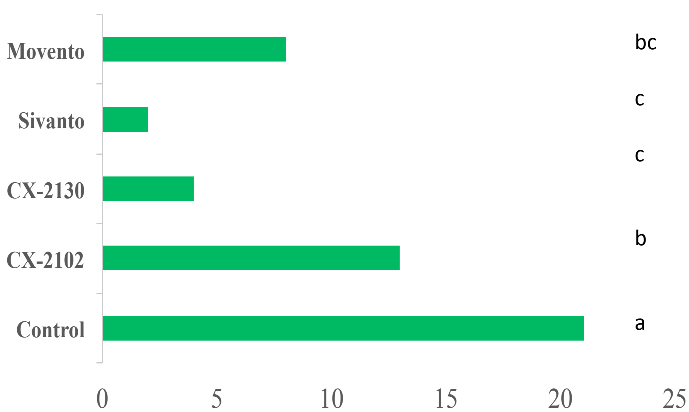


Fig. 7. Effect of Sivanto and BT based products in controlling fall armyworm. Means with the same letter do not differ significantly ($P < 0.05$; Waller Duncan 1969).

of FAW although these were not significantly different from the nontreated control. Mean number of FAW in the Fawligen® treated plants were also significantly lower than the nontreated control and did not differ from Dimilin® and Diflubenzuron HV.

**Effect of Intrepid®-Radiant® rotation.** In the fifth study, mean numbers of FAW were significantly lower in the Radiant® treated plants on all sampling dates (Fig. 6). A similar level of FAW suppression was observed when Radiant® was used in a weekly rotation program with Intrepid®. These results suggest that growers should use Radiant® in a rotation with Intrepid® to avoid development of resistance in FAW against Radiant®.

**Evaluation of conventional insecticides and *Bacillus thuringiensis* based insecticides.** In the sixth study, all insecticide treatments significantly reduced FAW larvae as compared with the nontreated control (Fig. 7). Mean number of FAW/plant was lowest on plants treated with Sivanto® followed by CX-2130 and Movento®. Mean number of FAW was numerically lower in CX-2102 than on the nontreated control.

## Discussion

Fall armyworm has achieved the status of a global pest during the last couple of years (FAO, 2017; IPPC, 2017; EPPO, 2018; Ganiger et al., 2018; ICAR-NBAIR, 2018). It has developed a long-distance migration behavior to meet its biological requirements, such as suitable development temperature, available food resource, and a habitat to complete its development cycle while avoiding adverse biological factors. In the United States, it overwinters in south Florida and south Texas where the temperature is favorable and food sources are available.

Due to its voracious feeding behavior, which often causes economic damage, growers are advised to take action by applying effective insecticides to avoid economic loss. However, the repeated use of a single effective insecticide will cause resistance to develop. The present study results provide information about the efficacy of various reduced risk insecticides, insect growth regulators, neonicotinoids, pyrethroids, *Bacillus thuringiensis* based insecticides and viral products. All these insecticides were found effective at different levels of FAW infestation and at different growth stages. Knowledge based use of these insecticides will enhance effective management of FAW.

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