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ARTHROPOD MANAGEMENT

Quantification of Dichlorvos Released from Kill Strips Used in Boll Weevil Eradication Programs

Charles P.-C. Suh*, Jose L. Perez, Amy L. Berg, and John K. Westbrook

ABSTRACT

Two types of kill strips, Hercon Vaportape II and Plato Insecticide Strip, are used by boll weevil, *Anthonomus grandis* (Boheman), eradication programs in the United States (U.S.). Both types utilize dichlorvos as the killing agent and are typically replaced in traps on a four-week interval. However, published information on the duration of effectiveness of kill strips is not available and some programs have expressed concern over the duration of their effectiveness in traps. The weekly amounts of dichlorvos released from kill strips were quantified based on the weekly residual dichlorvos content of kill strips aged in pheromone traps up to four weeks. Three trials were conducted between May and November to cover a range of environmental conditions. On average, Hercon kill strips initially contained 61 mg of dichlorvos and released 33.0, 9.4, 5.0, and 2.0 mg of dichlorvos during the first, second, third, and fourth weeks of aging, respectively. Comparatively, Plato kill strips initially contained 93 mg of dichlorvos and released 35.6, 15.3, 9.9, and 7.3 mg of dichlorvos during the respective weeks. Although the quantity of dichlorvos needed to kill boll weevils or to deter predation of captured weevils is not known, our results suggest the effectiveness of kill strips is substantially reduced with each week of aging in traps. As such, reducing the replacement interval of kill strips may be a consideration for optimizing or at least maintaining the benefits of their use in traps.

Eradication and management programs against the boll weevil, *Anthonomus grandis* (Boheman), rely on pheromone traps to detect boll weevil populations and to indicate the need for insecticide treatments. In addition to a pheromone lure, traps are typically equipped with an insecticide-impregnated dispenser commonly referred to as a kill strip. These strips are intended to kill captured insects, thereby reducing the incidence of weevil escape and predation of captured weevils, and simplifying servicing of traps. Currently, two types of kill strips are used by eradication programs in the United States (U.S.). One is the Hercon Vaportape II (Hercon Environmental Inc., Emigsville, PA) and the other is the Plato Insecticide Strip (Plato Industries, Houston, TX). Both types of kill strips utilize dichlorvos (DDVP; 2, 2-dichlorovinyl dimethyl phosphate) as the active ingredient, but differ in dimensions, polymer formulation (proprietary), and dichlorvos concentration.

Despite the widespread use of kill strips in boll weevil eradication programs, scientific evidence demonstrating their efficacy in the field is limited. Hardee et al. (1996) reported no statistical difference in the numbers of weevils captured in traps with and without kill strips, but advocated the continued use of kill strips in eradication programs because they were relatively inexpensive and presumably simplified servicing of traps. Likewise, Armstrong and Greenberg (2008) indicated the presence of kill strips in traps did not significantly affect weevil captures or the sex ratio of captured boll weevils. Suh et al. (2003) found both kill strip types produced >90% weevil mortality in traps after 46 h of exposure, but neither type reduced the incidence of weevil escape from traps. In a follow-up study, Suh et al. (2009) reported the use of kill strips did not simplify servicing of traps as previously assumed; however, their presence in traps significantly reduced the combined incidence of trap obstructions (e.g., spider webbing) and predation of captured weevils which could impede capture or detection of weevils. Consequently, those authors suggested the use of kill strips may be justified in areas experiencing chronic problems with weevil predation and trap obstructions, or during the maintenance phase of eradication (post-eradication) when the numbers of deployed traps are greatly reduced and detection of a single boll weevil is of critical importance.

C.P.-C. Suh*, J.L. Perez, and J.K. Westbrook, USDA-ARS, Insect Control and Cotton Disease Research Unit, 2771 F & B Rd., College Station, TX 77845; A.L. Berg, Texas A&M University, Department of Entomology, College Station, TX 77845,
*Corresponding author: charles.suh@ars.usda.gov

With the exception of the Lower Rio Grande Valley production area of Texas, the boll weevil has been declared eradicated or suppressed in all cotton production areas of the U.S. (Anonymous 2014). Consequently, >90% of U.S. cotton acreage is operating under post-eradication status. Although trapping protocols differ among state programs as well as between the active and post-eradication phases, all boll weevil eradication programs in the U.S. equip traps with kill strips. Given that kill strips are marketed to be effective for one month in traps, eradication programs typically replace kill strips in traps on a four-week interval. However, published information regarding the duration of effectiveness of kill strips does not exist or is not available, and several programs have expressed concern over their duration of effectiveness. The objective of our study was to quantify and compare the weekly amounts of dichlorvos released from Hercon and Plato kill strips aged in pheromone traps up to four weeks under field conditions. This information is needed by eradication programs to determine whether the replacement interval of kill strips should be modified to ensure that the benefits associated with their use in traps are maintained.

MATERIALS AND METHODS

Packages of Hercon Vaportape II (Hercon Environmental Inc., Emigsville, PA) and Plato Insecticide Strips (Plato Industries LTD, Houston, TX), each containing 100 kill strips, were obtained directly from the respective manufacturer and stored at -20°C until needed for the experiment. According to the manufacturers' labels, the dimensions of Hercon Vaportape II strips are 2.54 cm x 1.27 cm and each contains 10% dichlorvos (wt:wt). In comparison, the Plato Insecticide strips are twice as large (~2.54 x 2.54 cm) and contain 6.98% dichlorvos (wt:wt). Neither manufacturer indicates the thickness of kill strips on their respective label, but both kill strips types have a similar thickness of ~2 mm (C. Suh, unpublished data).

Eight lines of boll weevil pheromone traps (Technical Precision, Mebane, NC), each containing 10 traps, were established next to a field at the Southern Plains Agricultural Research Center in College Station, TX. Trap lines and traps within a line were spaced ~1 m apart, and each trap was supported on conduit pipe so that the tops of traps were ~1.2 m above ground level. The first line of traps was randomly assigned a kill strip treatment (Hercon Vaportape II or Plato Insecticide Strip) and treatments were alternately assigned to the other trap lines. Thus, four lines of traps were equipped with Hercon kill strips and four lines were equipped with Plato kill strips.

Kill strip evaluations were conducted during three periods (trials) in 2014 (Trial 1, 28 May– 25 June; Trial 2, 9 Sept. – 7 Oct.; and Trial 3, 21 Oct. – 18 Nov) using a different package of kill strips for each trial. At the beginning of each evaluation period, ten kill strips of each type were randomly selected from a single package. These kill strips were used to determine the initial average dichlorvos content of the kill strips (Week 0). The remaining kill strips from the package were placed individually in traps according to their trap line assignment. One line of traps for each treatment was randomly selected after one week of aging, and the respective kill strips were removed and prepared for analysis by gas chromatography. Another set of ten kill strips of each type were removed after the second, third, and fourth weeks of aging. Thus, ten kill strips (reps) of each type (Hercon and Plato) and for each age group (0, 1, 2, 3, and 4 weeks of aging) were analyzed during each trial. A CR21XL weather station (Campbell Scientific, Logan, UT) was established next to traps to monitor ambient air temperatures during each evaluation period. The weather station was programmed to take readings every minute and record the hourly averages each day. The average daily temperature was calculated for each day based on the mean hourly temperatures from 1000 h to 0900 h the following day.

New and aged kill strips were weighed and placed individually in 60-ml amber glass jars containing a known weight (~8 g or ~10 ml) of GC-Resolv acetone. The jars were placed on a mechanical shaker for 20 hours to enhance the extraction of dichlorvos from kill strips. Because this process completely disintegrated the kill strips, the jars were removed from the shaker and particulates were allowed to settle to the bottom of the jars for two to four hours. Thereafter, an aliquot (~1 ml) from each jar was pipetted separately into1.5-ml GC vials, taking care to avoid collection of particulates. A 1-µl injection from each kill strip sample was analyzed by gas chromatography on a Shimadzu GC-2010 (Shimadzu Scientific Instruments, Columbia, MD) equipped with a flame ionization detector and a DB-5 column (60m x 0.32mm i.d. x 0.25µm thickness). Helium was used as a carrier gas with a column flow rate of 2.6 ml/min and a split ratio of 50:1. The injector temperature was set at 250°C and the detector temperature at 300°C. The initial column temperature was set at 125°C and maintained at that temperature for 14.5 min. Thereafter, the temperature was increased to 300°C at a rate of 50°C/min and maintained at that temperature for 20 min to burn off potential contaminants.

The residual content of dichlorvos in each kill strip was quantified based on the areas under the corresponding peaks using known concentrations of an external standard of dichlorvos (Dichlorvos Pestanal®, 99.1% purity; Sigma Aldrich, Milwaukee, WI) and an internal standard (λ-terpinene, 97% purity; Sigma Aldrich, Milwaukee, WI). The weekly residual values for each kill strip type were modeled separately using a non-linear regression approach with an exponential mechanistic/decay growth fit (JMP® 11.1.1, SAS Institute 2013). The models were developed solely for the purpose of visualizing the temporal patterns of dichlorvos released from kill strips. Initially, data for each trial were modeled separately; however, differences in temporal patterns of dichlorvos release among the three trials appeared to be minimal. Thus, data from all three trials were pooled to provide a more robust model, which would be applicable to the broad range of environmental conditions encountered during the study. The model formula was:

$$y = a*[1-b*Exp(-c*week)]$$

where **y**=residual dichlorvos content; **a**=asymptote; **b**=scale, and **c**=rate.

Based on the weight of kill strips and residual content of dichlorvos determined by GC analysis, the % dichlorvos content (wt:wt) of non-aged (Week 0) kill strips was calculated to estimate the initial dichlorvos content of kill strips. The amount of dichlorvos released during each week was calculated based on the average residual content of dichlorvos in kill strips from week to week. Because the initial dose of dichlorvos differed substantially between the two types of kill strips, the percentage of dichlorvos released during each week relative to the initial dichlorvos content (Week 0) of kill strips was also calculated and analyzed to standardize comparisons. The weekly amounts and relative percentages of dichlorvos released from kill strips were analyzed by mixed-model analysis of variance (PROC MIXED, SAS Institute 2012). In each analysis, the model included terms for kill strip type, week of aging, and their interaction as fixed effects with trials and trial*week serving as random effects. Denominator degrees of freedom were estimated using the Kenward-Rogers adjustment (DDFM=KR) of the MODEL statement (Littell et al. 2002), and differences among levels of main effects were separated using the ADJUST=TUKEY option of the LSMEANS statement (α=0.05). Significant interaction terms and selected differences among levels of an interaction were further examined using the SLICE option to identify differences among levels of one main effect within levels of another main effect. Actual means and standard deviations are presented in the tables to provide insight on the levels of variation among means.

RESULTS AND DISCUSSION

Kill strip evaluations were conducted over a span of seven months (May to Nov.) to cover a range of environmental conditions typically encountered during boll weevil trapping operations. With the exception of the third trial, day to day mean daily temperatures within each evaluation trial were fairly consistent (Fig. 1). The mean ± s.d. average daily temperatures during the first, second, and third trials were 27.0 ± 1.41, 25.2 ± 2.83, and 15.0 ± 7.00°C, respectively.

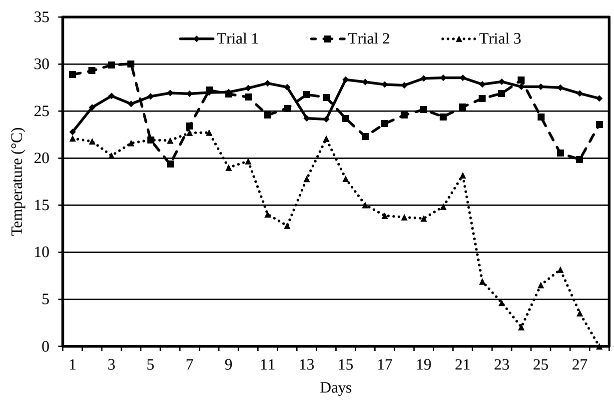

Figure 1. Profile of daily mean temperatures during each four-week kill strip evaluation trial (Trial 1, 28 May– 25 June; Trial 2, 9 Sept. – 7 Oct.; and Trial 3, 21 Oct. – 18 Nov.) in 2014, College Station, TX.

According to each manufacturer's label, the Hercon Vaportape II and Plato Insecticide kill strips contained 10 and 6.98% dichlorvos (wt:wt), respectively. Based on the initial sample of new kill strips (week 0) analyzed from each package, the mean ± s.d. % dichlorvos contents of Hercon and Plato kill strips were 10.1 ± 0.28 and 6.6 ± 0.10 % (wt:wt), respectively. Although the Plato kill strips contained a lower percentage of dichlorvos by weight, Plato kill strips were considerably larger in size than Hercon kill strips. Consequently, the Plato kill strips contained a higher initial dose of dichlorvos than Hercon kill strips. Overall, Plato kill strips averaged 93 mg of dichlorvos whereas Hercon kill strips contained 61 mg. Despite the substantial difference in the initial dichlorvos dose between the two types of kill strips, our results indicate that the dichlorvos contents of kill strips within and among packages were fairly consistent and both types of kill strips met or were near their respective labeled specifications in terms of % active ingredient.

Based on the weekly residual dichlorvos content of kill strips (Fig. 2), the Plato kill strips released more dichlorvos than Hercon kill strips (F=19.25; df=1, 8; P=0.002). On average, Plato and Hercon kill strips released 17 and 12 mg of dichlorvos per week, respectively. Although the Plato kill strips initially contained a higher dose of dichlorvos than Hercon kill strips, significant differences in the amounts of dichlorvos released between kill strip treatments were detected only during the second and fourth weeks of aging (Table 1). The amount of dichlorvos released from kill strips decreased with each week of aging (F=64.79; df=3, 6; P<0.001; Table 1), and this pattern was consistent for both types of kill strips (type*week interaction; F=0.44; df=3, 8; P=0.729). Of particular interest is the amount of dichlorvos released during the first two weeks of aging compared with the last two weeks of aging (third and fourth weeks). Based on the weekly averages over the three trials, Hercon kill strips released an average total of 42 mg of dichlorvos during the first two weeks of aging, but released only 7 mg during the last two weeks. Similarly, Plato kill strips released an average total of 51 mg of dichlorvos during the first two weeks and 17 mg during the last two weeks of aging.

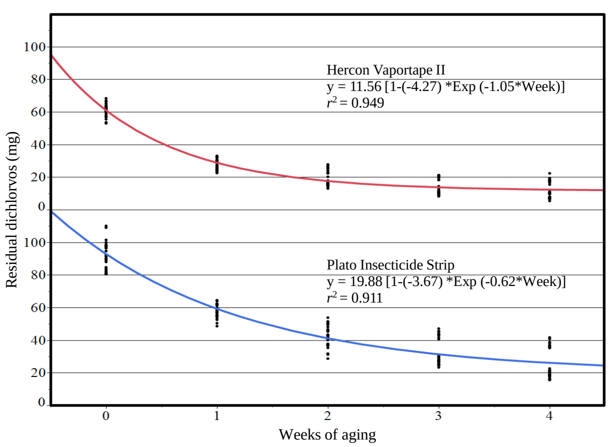

Figure 2. Predictive model of the residual dichlorvos content (mg) of Hercon Vaportape II and Plato Insecticide Strips aged in pheromone traps up to four weeks under field conditions. The formula of the model is y = a*[1-b*Exp(-c*week)] where y=residual dichlorvos content, a=asymptote, b=scale, and c=rate.

Table 1. Mean ± s. d. weekly amounts (mg) of dichlorvos released from Hercon Vaportape II and Plato Insecticide Strip kill strips aged in pheromone traps up to four weeks under field conditions in three experimental trials, College Station, TX, 2014

Kill strip type	Week of aging			
	0 to 1	1 to 2	2 to 3	3 to 4
Hercon	33.0 ± 5.30 aA	9.4 ± 3.65 aB	5.0 ± 0.74 aBC	2.0 ± 0.89 aC
Plato	35.6 ± 8.93 aA	15.3 ± 5.68 bB	9.9 ± 4.56 aBC	7.3 ± 1.16 bC

Values within a column followed by the same lower case letter and values within a row followed by the same capital letter are not significantly different (Tukey-Kramer test, α=0.05).

Although the amount of dichlorvos needed to kill captured weevils or to deter trap obstructions and predation of captured weevils has not been established, Suh et al. (2003) exposed boll weevils to new Hercon and Plato kill strips in traps and reported that over 46 hours of exposure were needed to produce ≥90% weevil mortality. Considering this finding and given the progressive reduction in the weekly amounts of dichlorvos released from both types of kill strips in our study, it is likely that the effectiveness and associated benefits of kill strips are also reduced with each week of aging in traps.

Based on the relative percentages of dichlorvos released during each week of aging, no statistical differences were detected between kill strip treatments (F=4.38; df=1, 8; P=0.070). However, significant differences were detected among weeks (F=110.42; df=3, 8; P<0.001), and the type*week interaction (F=22.44; df=3, 8; P<0.001) indicated the patterns of weekly differences varied by kill strip type (Table 2). Examination of the slice effects revealed Hercon kill strips released a greater percentage of dichlorvos than Plato kill strips during the first and fourth weeks of aging (Table 2). On average, Hercon kill strips released over 50% of its initial dichlorvos content during the first week of aging, but only 8 and 3% of the initial dichlorvos content were released during the third and fourth weeks of aging, respectively. Similarly, the relative percentage of dichlorvos released from Plato kill strips also declined numerically from week to week, but the magnitude of reduction was more gradual (Table 2; Fig. 1). These findings suggest that if Hercon and Plato kill strips were similarly dosed with dichlorvos, the Hercon kill strips likely would release more dichlorvos than Plato kill strips during the first and fourth weeks of aging, and would release as much dichlorvos as Plato kill strips during the second and third weeks of aging.

Table 2. Mean ± s. d. weekly percentages of dichlorvos released from Hercon Vaportape II and Plato Insecticide Strip (across all three experimental trials) relative to the initial dichlorvos content of kill strips, College Station, TX, 2014

Kill strip type	Week of aging			
	0 to 1	1 to 2	2 to 3	3 to 4
Hercon	53.8 ± 6.65 aA	15.2 ± 5.17 aB	8.1 ± 0.78 aBC	3.2 ± 1.67 aC
Plato	37.8 ± 6.55 bA	16.2 ± 5.21 aB	10.4 ± 3.83 aB	7.9 ± 0.69 bB

Values within a column followed by the same lower case letter and values within a row followed by the same capital letter are not significantly different (Tukey-Kramer test, α=0.05).

In summary, our results indicate both types of kill strips continued to release dichlorvos up to the fourth week of aging in traps under typical field conditions. However, the amounts released during the third and, particularly, fourth weeks of aging were considerably less than the amounts released during the first two weeks of aging. Consequently, our findings suggest the effectiveness of kill strips likely diminishes with each week of aging in traps. Given the potentially high remedial costs associated with failure of detecting incipient weevil populations, reducing the replacement interval of kill strips may be a consideration for optimizing or at least maintaining the benefits of their use in pheromone traps. Furthermore, because kill strips are relatively inexpensive and active programs already replace pheromone lures on a biweekly schedule, reducing the kill strip replacement interval to coincide with the two-week pheromone lure replacement interval should have minimal impact on trapping costs and operations.

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DISCLAIMER

Mention of trade names or commercial products in this article is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture. USDA is an equal opportunity provider and employer.

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