Performance of Controlled Release Dispensers for Grandlure, the Pheromone of the Boll Weevil (Coleoptera: Curculionidae)[1,2]

B. A. Leonhardt, W. A. Dickerson[3], R. L. Ridgway, and E. D. DeVilbiss

Insect Chemical Ecology Laboratory, USDA-ARS
Beltsville, MD 20705

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ABSTRACT Comparison of laboratory-measured release rates with boll weevil captures showed that dispensers containing 10 mg of grandlure with a release rate of 10 μg/hr or higher generally produced weevil captures which were at least 50% as high as those with the reference, fresh cigarette filter. Emission rates of ca. 3 μg/hr or lower and amounts of residual grandlure of ≤ 2 mg generally resulted in weevil captures below the 50% threshold. Comparisons of commercial dispenser formulations containing 10 mg of grandlure showed that a Hercon orange plastic laminate (H-OL-T) was most effective in prolonging the release of grandlure in both field and laboratory evaluations. Its emission rate was least affected by temperature changes. Scentry PVC dispensers (S-T-T, S-C-T, S-S-T, and S-YS-T) and the Consep membrane (C-M-T) lost grandlure more rapidly than did the laminate; however, differences in weevil captures were often not significant. Fermone black PVC squares (F-S-T and F-OS-T), AgriSense polymeric rods, (A-50R-T and A-35R-T) and the cigarette filter (CF-T) were less effective in extending the release of grandlure. Dispensers mounted in the capture cylinder lost grandlure more rapidly than did similar dispensers mounted in the cooler trap base. A layer of stickum on one side of flat dispensers to facilitate attachment to the trap resulted in a somewhat lower release rate of grandlure.

KEY WORDS *Anthonomus grandis*, release rates, temperature dependence, cotton, grandlure, pheromone, boll weevil.

The aggregation/attractant pheromone of the boll weevil, *Anthonomus grandis* Boheman (Coleoptera: Curculionidae), was identified by Tumlinson, et al. (1969) as a blend of four compounds. I. (+)-*cis*-2-isopropenyl-1-methylcyclobutaneethanol; II. (*Z*)-3,3-dimethyl-$\Delta^{1,\beta}$-cyclohexaneethanol; III. (*Z*)-3,3-dimethyl-$\Delta^{1,\alpha}$-cyclohexaneacetaldehyde. IV. (*E*)-3,3-dimethyl-$\Delta^{1,\alpha}$-cyclohexaneacetaldehyde. Grandlure (a mixture containing 30% of a racemic blend of I, 40% of II, and 15% of each of III and IV) has been used in traps by the U.S. Department of Agriculture in boll weevil detection and management programs (Rummel et al. 1980, Ridgeway et al. 1985) and by the Southeastern Boll Weevil Eradication Program (SBWEP, Dickerson 1986a).

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[2] This article reports the results of research only. Mention of a proprietary product or pesticide does not constitute an endorsement or a recommendation for its use by USA, nor does it imply registration under the Federal Insecticide, Fungicide, and Rodenticide Act as amended.

[3] Present address: North Carolina Department of Agriculture, Raleigh, NC.

A variety of dispensers have been used to slow evaporation of grandlure and extend the useful lifetime of the dispenser (Hardee et al. 1972, Bull et al. 1973, Coopedge et al. 1973, Johnson et al. 1976). Two types of dispensers that have been most widely used are the three-layer, plastic laminate (Hardee et al. 1975) and the plastic-wrapped cigarette filter (McKibben et al. 1980); the latter has been used as reference in many dispenser evaluations (Leonhardt et al. 1988). Commercial dispenser designs were compared in field tests but release rates and residual contents were not determined (Leggett et al. 1989).

Most pheromone dispensers for use in boll weevil field traps contain 10 mg of grandlure and are designed to remain active for two weeks.

Environmental conditions, particularly temperature, affect the useful lifetime of dispensers. Therefore, it is necessary to monitor performance of dispensers currently in use as well as evaluate the effectiveness of new formulations as they are developed.

This paper describes commercial formulations and their evaluation in laboratory and field tests. Residual grandlure contents, emission rates, and the number of boll weevils trapped were measured as a function of length of field exposure. Results were compared to those with reference dispensers.

Effect of temperature on release rates of several commercial dispensers was determined as was the effect of placement of the dispenser in the capture cylinder vs. in the base of the traps.

Materials and Methods

Five field studies (Tests 1-5, Table 1) were conducted in Midville, Georgia in 1986-1987 to compare boll weevil captures with a variety of grandlure dispensers as a function of days of exposure. Plastic molded, "Dickerson" traps (Dickerson 1986b) baited with the dispenser treatments (Table 2) were placed 1-2 m outside of cotton fields and ca. 30 m apart in 10 randomized complete blocks. Unless otherwise indicated, the dispenser was placed in the clear plastic capture cylinder on top of the trap. Insect captures were recorded for 5 or 10 replicates over 16 - 23 days as indicated in Table 1. Emission rates and residual grandlure quantities were determined on similarly aged dispensers as described below. All dispensers nominally contained 10 mg of grandlure with the exception of one membrane/reservoir treatement (C-M-T-24) which contained 24 mg. Orange plastic laminates (H-OL-T; Table 1) were the improved design with 400-μ outer poly PVC layers (Leonhardt et al. 1988) and were similar to the most effective dispenser tested by Leggett et al. (1989).

Test 1 and 2 also included a cigarette filter treatment which was replaced after each recording of weevil capture. This fresh filter was considered to be the reference treatment. Boll weevil captures were subjected to analysis of variance (ANOVA) and means were separated using Duncan's (1955) multiple range test ($P \leq 0.05$); transformed data ($\sqrt{n + 0.5}$) were used for analysis but actual means are presented for clarity.

Test 3 compared positions of the dispenser within the trap. The black, polyvinyl chloride (PVC) square dispenser (F-S-T) was placed either in the clear plastic capture cylinder (top) or in the trap base (similar to 32 oz inverted plastic cup). Temperature probes showed that the average daytime temperatures over a

Table 1. Description of five field tests conducted in Midville, GA in 1986 and 1987.

Test no.	Dates	No. of Reps.	Boll weevil captures recorded on days	Field temperatures °C Maximum	Minimum
1	May 19 - June 10, 1986	10	2, 3, 4, 7, 8, 10 11, 14, 16, 21	26-36	13-23
2	Aug. 11 - Sept. 2, 1986	5	4, 8, 16	16-36	13-24
3	May 20 - June 10, 1986	10	1, 2, 3, 6, 9, 13, 17*; 2, 4	26-36	13-23
4	July 11 - 23, 1987	5	2, 5, 9, 12, 16, 19, 23	32-38	17-23
5	Oct. 17 - Nov. 2, 1987	5	2, 4, 8, 11, 14, 18	21-28	-2-12

* Dispenser replaced following reading on day 17.

14-day period in the capture cylinder, trap base, and outside air were 42.1°, 31.2°, and 31.8°C, respectively.

Residual grandlure was measured on unaged and aged dispensers of Tests 1, 2, 4 and 5. Gas chromatographic (GC) analyses of overnight solvent extracts (1:1 hexane:acetone; generally 10-30 ml) of 1 or 2 dispensers gave amounts of each of the four grandlure components. Analyses were performed on a Model 9A gas chromatograph (Shimadzu Corp., Columbia, MD) equipped with a 30-m, 0.75 mm OD wide-bore capillary column coated with non-polar SPB-1 (2-3755, Supelco, Inc., Bellefonte, PA) held at 100°C. The retention times (min.) for the grandlure components were as follows: I, 5.02; II, 5.44; III, 5.88; and IV, 6.14 (Leonhardt et al. 1988). Peak areas were used for quantitation based on an external standard (0.100 μg/μl of grandlure in hexane). The total of the four components gave the residual grandlure contents.

The grandlure emission rates from the dispenser formulations were measured at constant temperature (28°C) under constant air flow (100 ml/min) using the oven apparatus and the procedure described by Leonhardt et al. 1988. The emitted grandlure was quantified by GC on combined hexane and ether extracts (final volume reduced to 1 ml) of the sorbent traps (Tenax® and glass beads, ST-023, Envirochem, Inc., Kemblesville, PA).

Residual quantities of grandlure and emission rates were measured on dispensers (Table 2) which had been field-aged for 0, 2, 4, 8, 14 and 21 days in Test 1 and for 0, 4, 8 and 16 days in Test 2. Residual grandlure was determined on dispensers from Tests 4 and 5 following 0, 2, 4, 8, 14 and 21 days of aging. Emission rates were not measured on dispensers from Test 4 and were determined on only unaged and 14-day aged dispensers from Test 5.

Emission rates were also measured for six dispenser formulations (CF-T, S-T-T, A-50R-T, H-OL-T, F-OS-T, and C-M-T; Table 2) at 32°, 38°, 48°, 58°, and 65° C to determine effect of temperature on release rate.

Results and Discussion

Weevil Capture vs. Release Rate: Tests 1 and 2. Quantities of grandlure recovered from unaged dispensers in Test 1 ranged from 7.2-9.6 mg in dispensers which nominally contained 10 mg of grandlure (Table 3). After 8 and 14 days of field aging, amounts ranged from 0.06 - 7.1 and < 0.06 - 3.8 mg, respectively. The orange plastic laminate (H-OL-T) ranked highest at each aging interval while the black PVC square (F-S-T) ranked lowest. Minor changes in composition of

Table 2. Description of grandlure (GL) dispensers evaluated in five tests in Midville, GA from 1986 - 1987.

Code	Description	Source*	Size (mm)	mg GL	Placed in trap†	Stickum‡	Evaluated in Test 1	2	3	4	5
CF-T	cigarette filter (polyester sleeve)	McKibben	25 l × 6 d	10	top	no	x	x			
F-S-T	black PVC square	Fermone	25 × 25 × 1.6	10	top	no	x		x		
F-S-B	black PVC square	Fermone	25 × 25 × 1.6	10	base	no			x		
F-OS-T	modified black PVC square§	Fermone	25 × 25 × 1.6	10	top	no		x			
A-5OR-T	polymeric rod (50% GL) in sleeve¶	AgriSense	8 l × 1.7 d	10	top	no	x	x		x	
A-35R-T	polymeric rod (35% GL) in sleeve¶	AgriSense	11 l × 1.7 d	10	top	no		x			
C-M-T	membrane and reservoir/foil disc	Consep	7 d/20 d	10	top	no	x				
C-M-T-24	membrane and reservoir/foil disc	Consep	7 d/20 d	24	top	no	x				
H-OL-T	orange plastic laminate G0776	Hercon	25 × 25 × 0.9	10	top	no	x			x	x
H-OL-BS	orange plastic laminate G0027-C	Hercon	25 × 25 × 0.9	10	base	yes				x	x
H-WL-T	white plastic laminate G0027-B	Hercon	25 × 25 × 0.9	10	top	no				x	x
S-T-T	black PVC tube (bullet shaped)	Scentry	28 l × 10 d	10	top	no	x	x		x	x
S-C-T	black PVC cap ("frisbee" shaped)	Scentry	19 d × 10 h	10	top	no		x			
S-S-T	black PVC square	Scentry	14 × 14 × 1.7	10	top	no				x	
S-YS-T	yellow PVC square	Scentry	15 × 15 × 1.7	10	top	no				x	x
S-YS-TS	yellow PVC square	Scentry	15 × 15 × 1.7	10	top	yes				x	x
S-YS-BS	yellow PVC square	Scentry	15 × 15 × 1.7	10	base	yes				x	x

* McKibben, G. H., USDA, Mississippi State, MS 39762; Fermone Chemicals, Inc., Glendale, AZ 85311; AgriSense, Fresno, CA 93722; Consep Membranes, Inc., Bend, OR 97708; Hercon Environmental Co., South Plainfield, NJ 07080; Scentry, Inc., Buckeye, AZ 85326.

† Placement of dispenser in the trap: top = capture cylinder; base = inside trap base.

‡ Stickum layer on one side of dispenser for attachment in trap base.

§ One side of black square covered with an orange film to reduce release rate.

¶ Glued to 25 × 25 mm plastic squares which were solid in Test 1 and grid-like with 6 mm square holes in Tests 2 and 4.

Table 3. Mean number of boll weevils captured*, residual grandlure, and emission rates for dispensers evaluated in Test 1 (May 19 - June 10, 1986).

	$\bar{x}$ weevils captured over days				Residual mg grandlure at day					Emission rate µg/hr at day				
Treatment	2	8	14	21	0	2	8	14	21	0	2	8	14	21
CF-T (fresh)†	23.9ab	50.2b	158.8a	64.7a										
CF-T (aged)	29.3a	21.3c	13.8c	2.7d	9.6	6.6	2.0	0.44	0.48	20	19	7.2	1.8	1.1
F-S-T	14.8ab	24.2c	21.9c	0.6d	7.4	2.6	0.06	0.06	0.03	12	8.2	0.7	0.5	1.7
A-50R-T	22.1ab	47.1b	62.7b	14.4c	9.2	8.2	4.8	2.0	0.23	21	20	12	2.8	1.6
C-M-T	18.3ab	62.3b	70.2b	16.4c	9.4	6.9	4.2	0.46	0.74	116	51	†	9.4	10.0
C-M-T-24	23.4ab	83.1a	112.1ab	34.4b	25	22	16	12	11	81	47	53	30	17
H-OL-T	12.2b	83.0a	104.4b	39.7b	8.4	9.4	7.1	3.8	3.2	39	34	24	17	12
S-T-T	31.8a	55.8b	76.1b	23.7bc	7.2	4.4	1.6	0.93	0.62	12	12	4.0	2.8	2.6

* Actual mean no. of weevils captured in 10 replicates for each aging period. Means followed by the same letter are not significantly different ($P \leq 0.05$; Duncan's new [1955] multiple range test). F values (ANOVA) ranged from 4.34 and 10.18. Weevil captures at 4, 7, 11, and 16 days are not presented.

† The fresh cigarette filter was replaced every 1-3 days.

‡ Sample was missing.

residual grandlure occurred during field exposure. However, the relative percents of four components remained generally constant (within ca. 10 - 20% relative) throughout the release of most of the grandlure dose. When residual grandlure was nearly depleted, the percent of components III and IV each dropped as low as 5% from their original 15%. Similar results reported by Leonhardt et al. (1988) and Hardee et al. (1974) showed that high weevil captures were maintained with 4% of III and of IV.

At all aging times longer than 7 days in Test 1, laminate (H-OL-T) gave the highest mean boll weevil captures of dispensers which initially contained 10 mg of grandlure. Captures with the 24 mg dispenser, C-M-T-24, were generally comparable to those of H-OL-T. Aged cigarette filter (CF-T) and the PVC square (F-S-T) gave lowest captures at all aging periods longer than 2 days.

The relative captures with aged dispensers (10 mg of grandlure) as compared to those with the reference, fresh cigarette filter illustrate (Figure 1) the efficacy of each dispenser type over the duration of Test 1. Although optimum insect capture is always desired, a reduced capture can be tolerated in management programs such as the SBWEP; however, reliable high attractancy must be maintained throughout the exposure period. A capture of 50% of the reference, fresh cigarette filter, is suggested (Dickerson, unpublished) as a possible threshold. Only H-OL-T had relative captures above the 50% threshold throughout the 21 days of the test. Dispensers S-T-T and C-M-T remained near the 50% level for ca. 14-16 days, A-5OR-T for ca. 11 days, and CF-T and F-S-T for ca. 8 days. The capture data essentially parallel residual grandlure contents. When the quantity of pheromone in the dispenser dropped to ca. 2 mg, weevil captures were no longer reliably high as compared to the reference, fresh CF-T. Captures with C-M-T-24 were above the 50% threshold throughout the test due to the 24 mg loading.

A comparison of laboratory measured release rates with weevil captures was made for 7 treatments and 10 aging periods in Test 1 (Table 4). Extrapolated emission rates were used for the intermediate aging intervals of 3, 7, 10, 11 and 16 days. Dispensers which had emission rates of ca. 3 μg/hr or lower, generally gave captures which were less than 50% of those obtained with the reference. This is in agreement with similar ineffective performance at $\leq$ 3 μg/hr release rate reported by Leonhardt et al. (1988). Most (36 of 38) dispensers with release rates over 10 μg/hr gave weevil captures above the 50% threshold. Release rates of 3 - 10 μg/hr showed variable performance.

Weevil activity was much lower during Test 2 than in Test 1, primarily due to frequent rainfall. The mean number of weevils captured on day 4 ranged from 0.8-3.2, on day 8 from 4.4-11.4, and on day 16 from 1.2 - 6.8. Differences in captures for the various treatments were not significant at $P \leq 0.05$. Emission rates and residual grandlure declined with increased aging time (Table 5). The orange film on one side of the PVC square (F-OS-T) failed to significantly slow the depletion of grandlure. This treatment contained the least amount (1.4 mg) of grandlure at days 8 and 16 and had the lowest release rate at day 16. It was again judged to be the least effective of the polymeric dispensers tested. Only the polymeric rod (A-50R-T) and the PVC cap (S-C-T) had release rates above 3 μg/hr at day 16. However, based on its relatively high content (2.4 mg), the PVC tube (S-T-T) would have been expected to release grandlure at a rate higher than its measured 2.4 μg/hr at day 16.

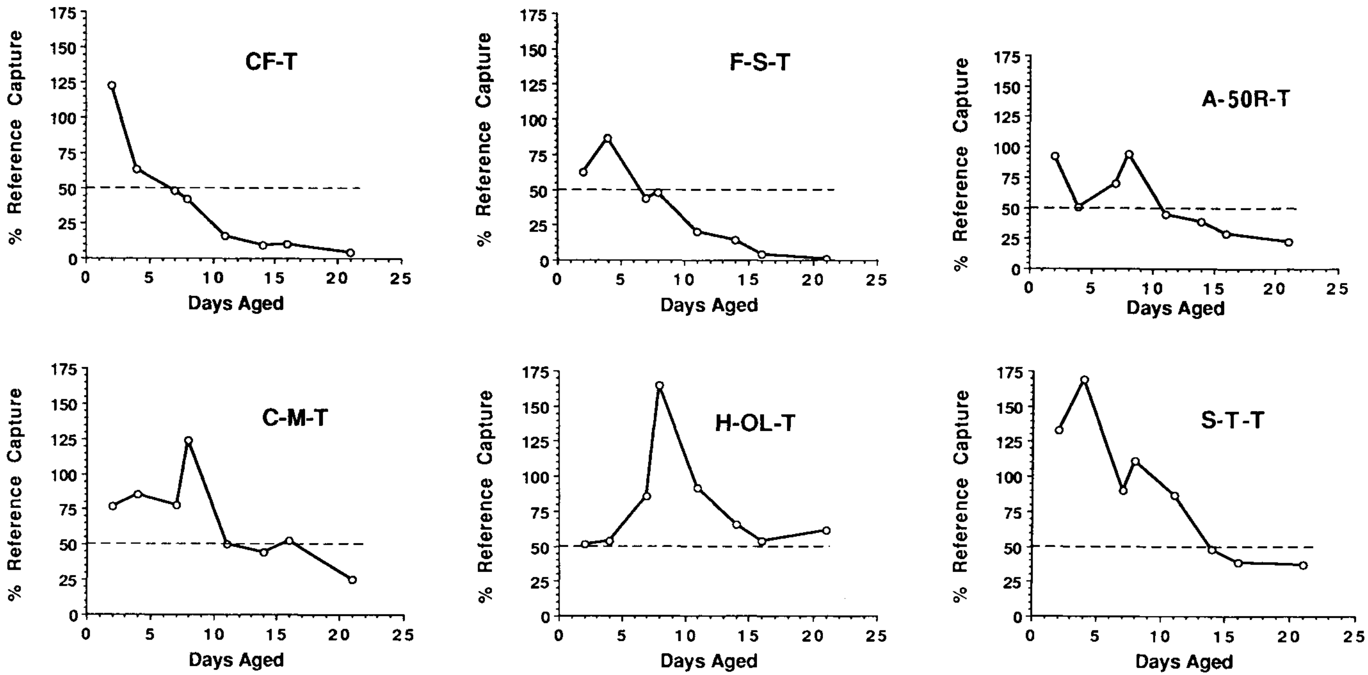

Fig. 1. Boll weevil captures relative to those with the reference, freshly treated cigarette filter for dispensers aged 0-21 days in Test 1 (cigarette filter, CF-T; Fermone PVC square, F-S-T; AgriSense polymeric rod, A-50R-T; Consep membrane, C-M-T; Hercon laminate, H-OL-T; and Scentry PVC tube, S-T-T).

Table 4. Comparison of relative boll weevil captures in Test 1 (May 19 - June 10, 1986) to grandlure release rates.*

Release rate †	Number of aged treatments with weevil capture relative to reference of	
µg/hr	< 50%	≥ 50%
<1	5	0
1-3	11	0
3-10	8	8
≥ 10	2	36

* Mean no. weevils captured with aged dispensers (all ageing periods) ÷ mean no. weevils captured with reference, fresh cigarette filter.

† Values in Table 3 were extrapolated to give emission rates at 3, 7, 10, 11 and 16 days.

Table 5. Amounts of residual grandlure and emission rates for dispensers evaluated in Test 2 (Aug. 11 -Sept. 2, 1986).

	mg Grandlure at day				emission rate (µg/hr) at day			
Treatment	0	4	8	16	0	4	8	16
F-OS-T	8.8	4.7	1.4	0.5	33	13	4.6	1.0
A-5OR-T	8.5	5.1	2.5	1.2	63	51	12.0	5.0
A-35R-T	6.7	4.8	2.4	1.2	23	19	3.3	2.0
S-T-T	8.9	5.7	3.0	2.4	13	10	5.5	2.4
S-C-T	9.7	5.9	3.2	1.9	18	17	8.2	3.7

Temperature Effect on Emission Rate. Rummel et al. (1988) showed that capture cylinders of three styles of boll weevil traps had temperatures which were 0-6°C above ambient. Since grandlure dispensers are normally mounted in the capture cylinder, traps with elevated temperatures caused more rapid depletion of grandlure from the dispensers. As a result, the number of weevils captured during the entire trapping interval was lower in these traps than in those having a lower temperature in the capture cylinder.

Test 3 compared positioning the dispenser (PVC square, F-S-T) in the capture cylinder vs. in the trap base. This dispenser, which releases grandlure rapidly, was selected to accelerate any differences due to dispenser position. Weevil captures with the dispenser mounted in the capture cylinder (average temperature ca. 10°C above ambient) declined rapidly (Figure 2) relative to those in traps baited with the dispenser placed in the trap base (at ambient temperature). When dispensers were replaced after 17 days, relative weevil captures returned to their initial levels. The emission rate and residual grandlure in the 17-day-old dispensers were <0.2 µg/hr and <0.03 mg, respectively, in F-S-T vs. 1.4 µg/hr and 0.4 mg, respectively, in F-S-B.

Laboratory emission rates measured over a range of temperatures (28 - 65°C showed that the effect of temperature on rate varied among the dispensers. The following are the release rates at 65° for six dispenser types (and the ratio of this rate to that at 28°C): 494 µg/hr (4.4) for C-M-T; 130 µg/hr (4.0) for F-OS-T; 95 µg/hr (2.3) for H-OL-T; 47 µg/hr (2.6) for A-5OR-T; 44 µg/hr (3.3) for S-T-T; and 36 µg/hr (3.6) for CF-T. Since the laminate, H-OL-T, had the lowest ratio of emission

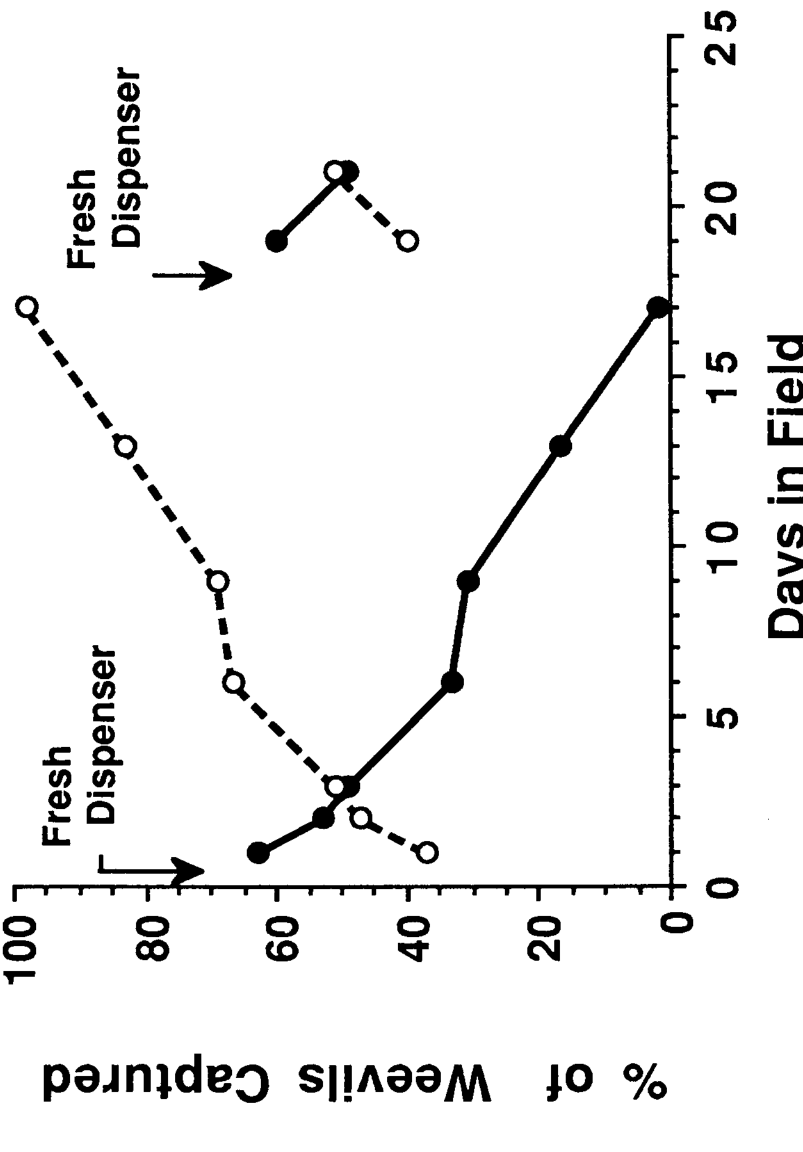

Fig. 2. Percent of the weevils captured with dispenser F-S-T in the capture cylinder (●——●) vs with dispenser F-S-B in the trap base (●------●).

rates at 65/28°C, it would be expected to be least affected by fluctuations in field temperatures. The patterns of release rate vs. temperature (28° - 65°C) were similar to those reported by Leonhardt et al. (1988). The effect of temperature is important since field temperatures vary substantially and the duration of effectiveness of dispensers would similarly vary.

1987 Tests 4 and 5. In 1987, new and modified commercial dispensers were compared. Cigarette filter dispensers were not included in these tests. Weevil captures revealed very few significant differences among treatments (Table 6). Test 4 showed only the polymeric rod (A-50R-T) to be less attractive than the other dispensers. This latter treatment was not included in Test 5. Perhaps if fresh and aged cigarette filter dispensers had been included, differences in weevil captures might have been more apparent, particularly with dispensers showing low residual grandlure at day 21. Laminate dispensers showed the highest residual grandlure contents at all aging periods and were thus the most efficient in prolonging the release of grandlure. The addition of stickum for dispenser attachment may have resulted in a slower release rate of grandlure as indicated by comparison of residual contents in S-YS-TS vs. S-YS-T at days 8 and 14 (Table 6); however, differences may not be significant. This effect is probably due to elimination of efficient release of grandlure from one surface of the dispenser when it is tightly adhered with stickum to the trap. Effect of higher temperatures in the trap capture cylinder (top) vs. the trap base was again demonstrated by comparing the residual grandlure at day 21 in S-YS-TS (0.6 mg) vs. S-YS-BS (1.4 mg). Slower grandlure release from H-OL-BS (3.1 mg remaining at day 21) as compared to that from H-OL-T (1.1 mg remaining at day 21) was probably caused by a combination of the stickum on one surface and its attachment within the cooler trap base.

Results of Tests 4 and 5 (Table 6) are similar to those of earlier tests but cooler temperatures during Test 5 caused somewhat slower release of grandlure. Laminates were most effective in prolonging grandlure release in both tests as indicated by amounts of residual grandlure. Black PVC tubes (S-T-T) and PVC squares (S-S-T and S-YS-T) again contained lower residual grandlure and had lower labortory-measured emission rates at days 14 and 21 than laminates. However, these differences did not result in significantly lower weevil captures.

In summary, field comparisons of various commercial dispenser formulations with 10 mg of grandlure showed few significant differences in mean weevil captures during the first 4 - 5 days of exposure. Comparisons of weevil captures with those of the reference cigarette filter showed that the laminate (H-OL-T) gave consistently high insect captures throughout the tests. The PVC tube (S-T-T) and the membrane (C-M-T) also gave high weevil captures through 2 weeks. The polymeric rod (A-5OR-T) was effective for 1 - 2 wk. The aged cigarette filter (CF-T) and a PVC square (F-S-T) were ineffective after 7 days. Release rates and amount of residual grandlure suggest that relative weevil captures of at least 50% are obtained if the emission rate is $\geq$ 10μg/hr. In the tested dispensers, the $\geq$ 10 μg/hr rate was generally achieved when residual grandlure was at least 2 mg. The laminate dispenser (H-OL-T) was also the most effective in prolonging the release of grandlure in the 1987 tests. Leggett et al. (1989) showed the laminate to be a highly effective dispenser. PVC dispensers without stickum (S-T-T, S-S-T, and S-YS-T) had lower residual grandlure than did the laminates in both 1987 tests but differences in weevil captures were not significant. Temperatures under which the dispensers are exposed significantly influence their effective life since grandlure

Table 6. Evaluation of commercial formulations in 1987, Test 4 and 5; mean number of boll weevils captured*, residual grandlure (mg), and emission rates (µg/hr) at 28° C.

	Test 4 (July 11 - 23, 1989)						Test 5 (Oct. 17 - Nov. 2, 1987)							
	$\bar{x}$ weevil captures over days			mg lure at day			$\bar{x}$ weevil captures over days			mg lure at day			µg/hr at day	
Treatment	0-5	6-12	13-23	8	14	21	0-8	9-14	15-18	8	14	21	0	14
A-50R-T	19.4a	2.8b	2.2b	3.6	2.5	0.7								
H-OL-T	19.8a	23.0a	9.0a	5.6	4.0	1.1	102.6a	30.5a	52.0a	8.9	8.0	6.9	66	36
H-OL-BS	36.2a	6.8ab	10.6a	6.7	5.7	3.1	96.9a	22.9a	40.3ab	8.7	8.1	7.6	46	33
H-WL-T	36.0a	10.0ab	13.0a	6.4	4.6	2.0	94.5a	23.8a	31.5b	8.1	7.5	5.8	56	35
S-T-T	40.0a	11.2ab	9.2a	2.6	1.6	0.4	79.3a	19.7a	39.9ab	3.4	3.1	2.2	27	9
S-S-T	47.6a	11.6ab	3.8ab	1.9	1.0	0.6								
S-YS-T	36.6a	16.4ab	6.6ab	3.0	1.4	0.7	81.4a	22.2a	42.1ab	4.6	4.1	3.1	90	35
S-YS-TS	38.4a	22.2ab	6.8ab	5.0	3.6	0.6	97.4a	23.9a	37.5ab	5.3	5.8	4.0	59	39
S-YS-BS	32.6a	11.4ab	9.8a	3.5	3.8	1.4	75.4a	26.5a	30.8b	†	5.9	4.8	59	32
ANOVA														
F	2.93	1.05	2.77				8.84	2.48	1.48					
P > F	0.0076	0.43	0.011				0.0001	0.0076	0.15					

* Actual mean no. of weevils captured for each aging interval. Means followed by the same letter are not significantly different ($P \leq 0.05$; Duncan's new [1955] multiple range test).

† No sample for this time period.

release rate increases with temperature. This should be taken into account when evaluating competitive dispensers.

Approximately 10 million grandlure dispensers are used annually in various programs. Technical information developed in this work provides a basis to ensure adequate performance of dispensers in the field and has led to a substantial reduction in their cost.

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References Cited

Bull, D. L., J. R. Coppedge, R. L. Ridgway, D. D. Hardee, and T. M. Graves. 1973. Formulations for controlling the release of synthetic pheromone (grandlure) of the boll weevil. 1. Analytical Studies. Environ. Entomol. 2: 829-835.

Coppedge, J. R., D. L. Bull, V. S. House, R. L. Ridgway, D. G. Bottrell, and C. B. Brown. 1973. Formulations for controlling the release of synthetic pheromone (grandlure) of the boll weevil. 2. Biological Studies. Environ. Entomol. 2: 837-843.

Dickerson, W. A. 1986a. Grandlure: Use in boll weevil control and eradication programs in the United States. Fla. Entomol. 69: 147-153.

Dickerson, W. A. 1986b. Boll Weevil Trap. U.S. Patent No. 4, 611, 425. Issued Sept. 16, 1986.

Duncan, D. B. 1955. Multiple range and multiple F tests. Biometrics. 11: 1-42.

Hardee, D. D., G. H. McKibben, R. C. Gueldner, E. B. Mitchell, J. H. Tumlinson, and W. H. Cross. 1972. Boll weevils in nature respond to grandlure, a synthetic pheromone. J. Econ. Entomol. 65: 97-100.

Hardee, D. D., G. H. McKibben, and P. M. Huddleston. 1975. Grandlure for boll weevils. Controlled release with a laminated plastic dispenser. J. Econ. Entomol. 68: 477-479.

Hardee, D. D., G. H. McKibben, D. R. Rummel, P. M. Huddleston, and J. R. Coppedge. 1974. Response of boll weevils to component ratios and doses of the pheromone, grandlure. Environ. Entomol. 3: 135-138.

Johnson, W. L., G. H. McKibben, J. V. Rodriquez, and T. B. Davich. 1976. Boll Weevil: Increased longevity of grandlure using different formulations and dispensers. J. Econ. Entomol. 69: 263-265.

McKibben, G. H., W. L. Johnson, R. Edwards, E. Kotter, J. F. Kearny, T. B. Davich, E. P. Lloyd, and M. C. Ganyard. 1980. A polyester-wrapped cigarette filter for dispensing grandlure. J. Econ. Entomol. 73: 250-251.

Leggett, J. E., G. H. McKibben, and L. Herbaugh. 1989. Evaluation of grandlure formulations and new lure dispensers for attracting boll weevils. Southwestern Entomol. 14: 97-110.

Leonhardt, B. A., W. A. Dickerson, R. L. Ridgway, and E. D. DeVilbiss. 1988. Laboratory and field evaluation of controlled release dispensers containing grandlure, the pheromone of the boll weevil (Coleoptera: Curculionidae). J. Econ. Entomol. 81: 937-943.

Ridgway, R. L., W. A. Dickerson, J. R. Brazzel, J. F. Leggett, E. P. Lloyd, and F. R. Planer. 1985. Boll weevil trap captures for treatment thresholds and population assessments. Proc. Beltwide Cotton Prod. Res. Conf. pp. 138-141.

Rummel, D. R., S. C. Carroll, and T. N. Shaver. 1988. Influence of boll weevil trap design on internal trap temperature and grandlure volatilization. Southwestern Entomol. 12: 127-138.

Rummel, D. R., J. R. White, S. C. Carroll, and G. R. Pruitt. 1980. Pheromone trap index system for predicting need for overwintered boll weevil control. J. Econ. Entomol. 73: 806-810.

Tumlinson, J. H., D. D. Hardee, R. C. Gueldner, A. C. Thompson, P. A. Hedin, and J. P. Minyard. 1969. Sex pheromones produced by male boll weevils: Isolation, identification and synthesis. Science 166: 1010-1012.