Spodoptera frugiperda Pheromone Lures to Avoid Nontarget Captures of *Leucania phragmatidicola*

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ABSTRACT We confirmed that commercial three- or four-component *Spodoptera frugiperda* (J.E. Smith) pheromone lures had a high nontarget capture rate for *Leucania phragmatidicola* Guenée, which compromised monitoring efforts in the northeastern United States. We compiled taxonomic features to distinguish *L. phragmatidicola* from *S. frugiperda*, and we compared five new lures. *S. frugiperda* catch specificity was improved by removing (Z)-11-hexadecen-1-ol acetate (Z11–16:Ac), which attracted *L. phragmatidicola.* Four lures tracked late-season *S. frugiperda* immigration, but two of these lures also tracked a bivoltine *L. phragmatidicola* flight with a second generation coincident with *S. frugiperda* immigration, and one lure attracted the first, but not the second, generation of *L. phragmatidicola*. In both low- and high-moth flight conditions, two-component lures had low *L. phragmatidicola* captures (0.5–1.4%), and although lures with more pheromonal components captured more *S. frugiperda*, they also had a high percentage of capture of *L. phragmatidicola* (38–48%). We conclude that although two-component lures captured fewer *S. frugiperda*, their similar temporal pattern, along with the lower level of *L. phragmatidicola*, makes them useful for development for monitoring programs in the northeastern United States.

KEY WORDS fall armyworm, *Spodoptera frugiperda*, *Leucania phragmatidicola*, pheromone, monitoring

Spodoptera frugiperda (J.E. Smith), the fall armyworm, is a polyphagous pest that lacks a true diapause and overwinters in subtropical and tropical habitats, but it annually reinvades a northern geographic area that extends into southern Canada. Regional monitoring programs are developing to map the annual northern reinvasion migratory pest Lepidoptera (e.g., www.pestwatch.psu.edu). These monitoring programs map male moth capture from traps baited with sex pheromones. Commercial pheromone lures to attract *S. frugiperda,* however, recruit large numbers of nontarget species in the northeastern United States, dramatically compromising monitoring efforts (Adams et al. 1989, Weber and Ferro 1991). *Leucania phragmatidicola* Guenée was captured at more than twice the rate as *S. frugiperda* in Massachusetts (Weber and Ferro 1991). Other *Leucania* species have been consistently captured when trapping for noctuids, including *L. pseudargyria* Guenée in *Helicoverpa zea* (Boddie) traps in Massachusetts (Weber and Ferro 1991); *L. anteoclara* Smith in bertha armyworm, *Mamestra configurata* Walker, traps; and *L. commoides* Guenée in variegated cutworm, *Peridroma saucia* (Hübner), traps in western Canada (Byers and Struble 1987, Byers and Herle 1997).

The sex pheromone of *S. frugiperda* was studied in the southeastern United States where the species is most prevalent. Sekul and Sparks (1967) elicited male responses from (Z)-9-tetradecen-1-ol acetate (Z9–14: Ac) isolated from female abdominal tip gland extracts, but they found no field activity from this compound (Sekul and Sparks 1976). They later found field activity from (Z)-9-dodecen-1-ol acetate (Z9–12:Ac) from gland extracts (Sekul and Sparks 1976), and this activity was influenced by the dose (Mitchell et al. 1983). However, the role of the former compound was unclear. Jones and Sparks (1979) reported that field activity was synergized, but Mitchell et al. (1983) reported no affect by the addition of Z9–14:Ac to Z9–12:Ac. Tumlinson et al. (1986) noted that the volatile components identified from calling females differed from components extracted from glands in the abdominal tips of females. Tumlinson et al. (1986) identified five volatile components from calling females: (Z)-7-dodecen-1-ol acetate (Z7:12 Ac), Z9–14: Ac, (Z)-11-hexadecen-1-ol acetate (Z11–16:Ac), dodecan-1-ol acetate (12:Ac), and 11-dodecen-1-ol acetate (11–12:Ac). Two of these, Z7–12:Ac and Z9–

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Table 1. Percentage of contribution of pheromone components for five lures

Component	Lure (mg load)				
	A (2 mg)	B (2 mg)	C (2 mg)	D (2 mg)	E (0.3 mg)
(Z)-7-Dodecen-1-ol acetate (Z7–12:Ac)	0.45	0.58	3.2	3.5	
(Z)-9-Dodecen-1-ol acetate (Z9–12:Ac)	0.25				
(Z)-9-Tetradecen-1-ol acetate (Z9–14:Ac)	81.61	99.42	90.1	92.0	
(Z)-11-Hexadecen-1-ol acetate (Z11–16:Ac)	17.69		2.6		100
Dodecan-1-ol acetate (12:Ac)			1.9	2.0	
11-Dodecen-1-ol acetate (11–12:Ac)			2.2	2.5	

Lure A, the original Scentry formulation, approximates extracts of female sex pheromone glands[a,b,c)]. Lure B is a subset of lure C. Lure C represents the full composition of volatiles collected from the headspace of calling females[c], and lure B represents the critical components needed for fall armyworm field attraction from this full composition[c]. Lure D includes all the fall armyworm volatile components except for one hypothesized to be attractive to *L. phragmatidicola.* Lure E represents a component hypothesized to be attractive to *L. phragmatidicola.*

[a] Sekul Sparks (1967).

[b] Sekul and Sparks (1976).

[c] Tumlinson et al. (1986).

14:Ac, were the most critical for attraction in the field, whereas Z9–12:Ac, isolated from glands, was not needed. Mitchell et al. (1985) showed that lures blended from either two or four of the components defined by Tumlinson et al. (1986) were useful for monitoring across a wide geographic range. Commercial pheromone lures available at the time of these studies were available as three-component or four-component formulations, with unknown pheromonal components and loading rates.

Few reports exist on the pheromones of *Leucania* spp. However, Z11–16:Ac, a minor (2.6%) component of volatiles from calling *S. frugiperda* (Tumlinson et al. 1986), was recently identified as the main pheromonal component for *L. anteoclara* and *L. commoides* (Byers and Herle 1997). The major (90.1%) *S. frugiperda* component, Z9–14:Ac (Tumlinson et al. 1986), elicited electroantennagram response and field attraction by *L. phragmatidicola* (Roelofs and Comeau 1971) and is the secondary component of *L. anteoclara* and *L. commoides* pheromone blends (Byers and Herle 1997).

Visual cues and trap design also affect trap capture of *S. frugiperda.* Although Harstack traps resulted in higher captures than bucket traps at high (e.g., >100 moths per night) densities (Mitchell et al. 1985), the bucket traps captured equal rates at lower densities (Mitchell et al. 1985) and differences were inconsistent in tests among other locations (Pair et al. 1989). Currently, the bucket traps, which are the easiest trap to use in the field, are typically used for monitoring *S. frugiperda.* Although multicolor (yellow/white/green) bucket traps presents a problem when servicing traps due to captures of bees (Gross and Carpenter 1991), they captured higher numbers of *S. frugiperda* than solid forest green traps (Mitchell et al. 1989, Pair et al. 1989).

A fall armyworm lure with a low rate of nontarget captures under northeastern U.S. conditions is needed to improve data quality of regional monitoring of the annual reinvasion of this insect. The goal of this work was to determine whether available commercial lures would be adequate, and if not, then to refine lures to remove components that result in the extensive nontarget capture that can be easily confused with *S. frugiperda.* We also report taxonomic features to distinguish *L. phragmatidicola* from *S. frugiperda,* and volatile components and blends that attract *L. phragmatidicola.*

Materials and Methods

Work was conducted at the Russell E. Larson Agricultural Research Farm in Rock Springs, PA. Pheromone lures were secured to the top inside cover of a tricolor (yellow/white/green) bucket trap (Gempler's, Belleville, WI). A 10% DDVP insecticidal strip (Hercon Vaportape II, Gempler's) was placed in each bucket trap to reduce escape and to reduce damage by moving moths or carrion feeding insects. In 1999, we deployed two replicates in a completely randomized design. In 2002 and 2001, we deployed traps in a randomized complete block design with four replicates of pheromone lure treatments. In all years, each block was a 0.4-ha sweet corn field, and traps were separated by a minimum of 30 m. The four blocks were separated by an average distance of 1.5 km, with the two end blocks separated by ≈7 km. Pheromone lure treatments were replaced and rerandomized within each block each week. Moths were collected on Monday mornings, from 19 June to 18 September 2000 and from 4 June to 1 October in 2001. Captured moths were gently transferred into a labeled zip lock bag, frozen, and identified by J. Grehan to *S. frugiperda, L. phragmatidicola,* or other.

In 1999, we compared two commercial lures obtained through a commercial distributor (Great Lakes Integrated Pest Management, Vestaburg, MI): a three-component lure (Trécé, Adair, OK) and a four-component lure (Scentry, Billings, MT). Lure components and loading rates used in 1999 are unknown. Pheromone lures in 2000 and 2001 were prepared and supplied by J. White (Scentry Biologicals, Inc., Billing, MT). These lures were loaded with 2 mg of pheromonal components, and the percentage of contribution of each component is detailed in Table 1. In 2000 and 2001, work with the three-component lure was discontinued, and the four-component lure, designed

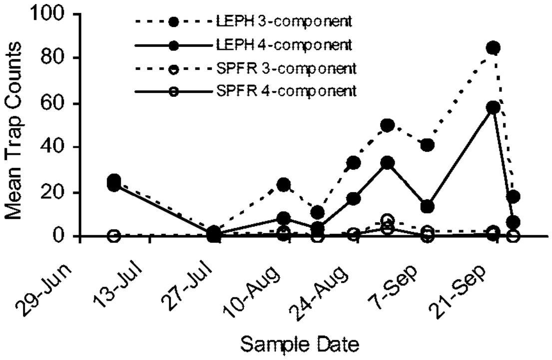

Fig. 1. Mean weekly catch of *S. frugiperda* (SPFR) and *L. phragmatidicola* (LEPH) from commercial three- and four-component lures in 1999.

to approximate the extract of *S. frugiperda* sex glands (Sekul and Sparks 1967, 1976; Tumlinson et al. 1986) was designated lure A. In 2000 and 2001, three additional lures (B–D) were tested against lure A to see whether one might maintain attractiveness for *S. frugiperda* while reducing attractiveness to *L. phragmatidicola.* Lure C represents the full composition of volatiles collected from the headspace of calling females, and lure B, which is a subset of lure C, represents the critical components needed for fall armyworm field attraction from this full composition (Tumlinson et al. 1986). Lure D includes all the fall armyworm volatile components except for Z11–16:Ac, which we hypothesized to be attractive to *L. phragmatidicola.* This experiment was repeated in 2001 with the addition of a fifth lure (E), containing only Z11–16:Ac.

To visualize the temporal dynamics, the mean ± SE trap capture of *S. frugiperda* and *L. phragmatidicola* were compared through the season for each lure, and for all lures combined. We also examined the seasonal mean captures among the lures.

We compiled characteristics that can be used to distinguish between *S. frugiperda* (Smith 1797, Todd and Poole 1980) and *L. phragmatidicola* (Corvell 1984, Forbes 1952). Voucher specimens have been archived at the Frost Entomological Museum, University Park, PA.

Results

In 1999, we observed that both a three-component and a four-component pheromone lure used to attract *S. frugiperda* males also recruited *L. phragmatidicola* in large numbers (Fig. 1). Greater than 95% of all the nontarget captures were from a single species, *L. phragmatidicola.*

We compared lures A–D in a year of relatively high (2000) and low (2001) moth activity (Fig. 2, note difference in scales). Rank patterns in mean yearly trap capture for lures A–D was consistent between years for all taxa: all moths, *S. frugiperda* only, and *L. phragmatidicola* only (Fig. 2). Lure A consistently had the greatest total moth captures, due to almost equal attractiveness to both *S. frugiperda* and *L. phragmatidicola.* All four lures showed similar temporal dynamics for the species that they captured (Figs. 2 and 3). *S. frugiperda* was only present later in the season (August–September). *L. phragmatidicola* had two flights, one concurrent with *S. frugiperda,* plus an early season presence during June.

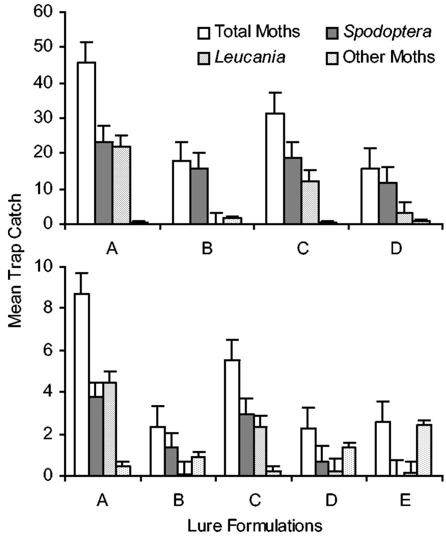

Fig. 2. Seasonal mean weekly trap catch of *S. frugiperda, L. phragmatidicola,* and other species from four lures (described in Table 1) in 2000 (top) and 2001 (bottom).

Lure B is the only one which failed to recruit any *L. phragmatidicola* during the June flight in both 2000 (Fig. 3) and 2001 (Fig. 4). Thus, though the magnitude of fall armyworm capture for lure B was only 0.33–0.5 the magnitude of lure A (note scale differences among graphs for lures A and B in Figs. 2 and 3), its ability to discriminate between fall armyworm and *L. phragmatidicola* suggests it as the most promising for future development in the northeastern United States. It is interesting to note that *L. phragmatidicola* varied in its response to lure D. It seems that the first generation was attracted to lure D, but the second generation was not, in both 2000 and 2001 (Figs. 3 and 4). Lure E was able to discriminate against fall armyworm and captured only *L. phragmatidicola* during its two periods of flight (Fig. 5), but mean capture rates were extremely low and variable.

Characteristics that can be used to distinguish *S. frugiperda* from *L. phragmatidicola* are presented in Table 2. Four characteristics are presented, in increasing order of difficulty. Supporting illustrations are available at http://www.ento.psu.edu/extension/factsheets/armyworm/idfallarmyworm.htm.

Discussion

The *S. frugiperda* population had one immigration flight late in the season in the 3 yr of this study, which is consistent with a lack of overwintering and a geographic range expansion from southern states. The *L.*

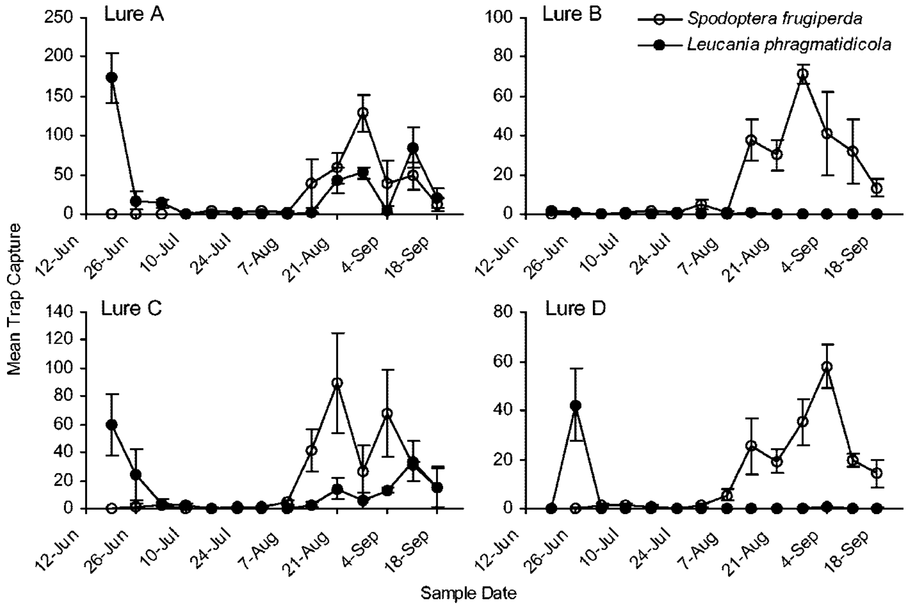

Fig. 3. Mean weekly capture of *S. frugiperda* and *L. phragmatidicola* for lures A–D (described in Table 1) in 2000. Note that the y-axis scales differ dramatically.

phragmatidicola population had two generations, the first at the initiation of the study and the second co-occurring during the immigration of *S. frugiperda.* The presence of the first generation suggests that *L. phragmatidicola* overwinters in Pennsylvania.

In Pennsylvania, both *S. frugiperda* and *L. phragmatidicola* are medium-sized brown moths that co-occur in the late season and were both trapped with commercial lures (Fig. 1) and blended lures A, C, and D, which corroborates the concern raised in Adams et al. (1989) and Weber and Ferro (1991) about monitoring *S. frugiperda* in the northeastern United States. Lure and trap evaluations from Florida and Caribbean Islands (Mitchell et al. 1985) or Texas and Georgia (Pair et al. 1989) have no mention of nontarget captures. It is possible that *L. phragmatidicola* was not recognized or that it does not occur in those locations. The difficulty in distinguishing nontargets may be greater in the northeastern United States because all *S. frugiperda* captured are migrants and their age dis-

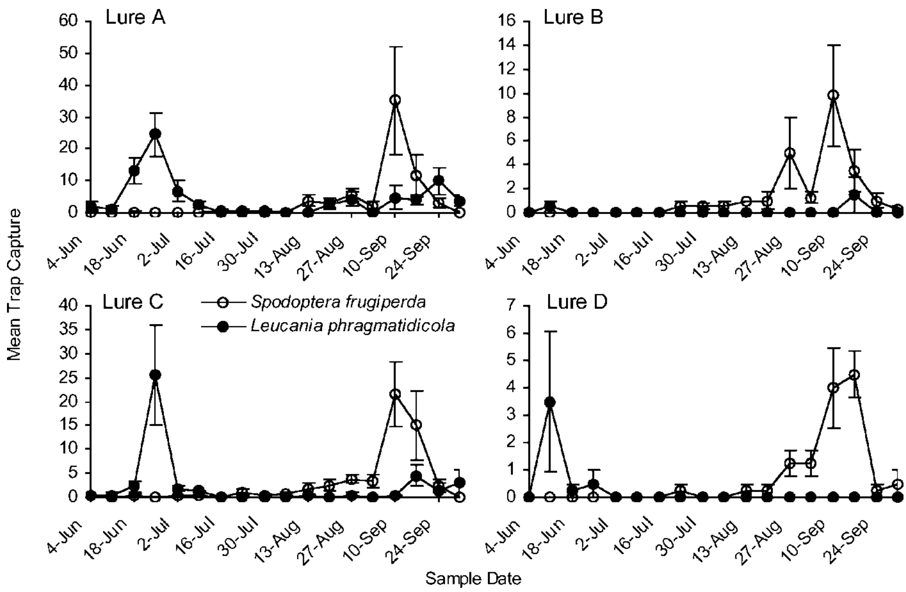

Fig. 4. Mean weekly capture of *S. frugiperda* and *L. phragmatidicola* for lures A–D (described in Table 1) in 2001. Note that the y-axis scales differ dramatically.

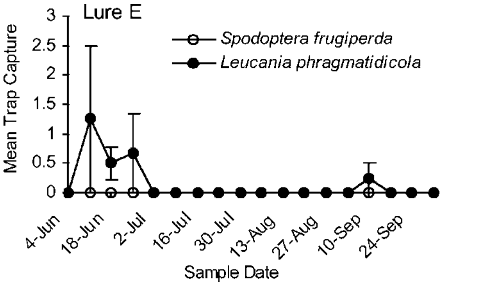

Fig. 5. Mean weekly capture of *S. frugiperda* and *L. phragmatidicola* for lure E (described in Table 1) in 2001.

tribution may be older, relative to those from southeastern United States. In monitoring programs in the northeastern United States, specimens collected weekly from traps have many wing and body scales missing, making it difficult to distinguish between the two species.

High trap captures of *L. phragmatidicola* inflate the trap counts, resulting in recommendations for sprays that are not necessary. It is important to distinguish between these species because the fall armyworm is a significant pest of sweet corn, whereas *L. phragmatidicola* feeds on grasses. The compiled characteristics to distinguish between *S. frugiperda* and *L. phragmatidicola* (Table 2) are ranked according to ease of use. However, specimens from traps are often worn, and the latter characters help distinguish among worn specimens.

Table 2. Characteristics to distinguish *S. frugiperda* (Smith 1797, Todd and Poole 1980) from *L. phragmatidicola* (Forbes 1952, Corvel 1984)

Diagnostic feature	Description
Wing characters	*S. frugiperda* forewing is mottled and the rear wing has a purple sheen in direct light. The forewing of *L. phragmatidicola* has a number of spots running parallel to the distal margin and a rough texture with wing veination clearly visible.
Color of scales adjacent to claspers	Male *S. frugiperda* have white scales on either side of the claspers at the end of the abdomen, even though the outer scales are tan. *L. phragmatidicola* has only tan scales surrounding the claspers.
Banding pattern behind the eyes	*S. frugiperda* has a single broad dark band immediately posterior to its eyes that is visible from both an anterior and dorsal view. *L. phragmatidicola* has three thin dark bands behind the eyes. This character may be obscured in damaged specimens.
Shape of male claspers	*S. frugiperda* claspers are round, similar to a bellows or paddle. *L. phragmatidicola* claspers come to a sharp point at the dorso-posterior end (top, rear) and have an invagination about two-thirds from the bottom.

Supporting photographs at http://www.ento.psu.edu/extension/factsheets/armyworm/idfallarmyworm.htm.

Although it is functionally possible for trap operators to sort *S. frugiperda* from *L. phragmatidicola*, it is unlikely that a monitoring program necessitating taxonomic sorting would maintain economic feasibility. In this study, most specimens that were classified as "other" were easily distinguished, such as grasshoppers and bees. However, in 2002 (data not shown), we observed a distinct flight of *Cucullia intermedia* Speyer (Noctuidae: Cuculliinae) by using lure B from traps that were part of a monitoring program in Pennsylvania. Densities were low, and the moths were easily distinguished by color, size, and shape from both *S. frugiperda* and *L. phragmatidicola.*

The response of *L phagmatidicola* varied among the lures. Lure E, loaded with 0.3 mg of Z11–16:Ac, discriminated against fall armyworm and captured *L. phragmatidicola* during its two flight periods (Fig. 5). This chemical was also the major component of an optimized pheromone blend for *L. anteoclara* and *L. commoides* (Byers and Herle 1997). Thus, Z11–16:Ac may be at least partly responsible for *L. phragmatidicola* contamination in the other lures. However, the mean capture rates were extremely low, and the data come from a single field season. Byers and Herle (1997) showed a dose response in the blended *Leucania* lures up to a loading rage of 2 mg, and our Lure E only used 0.3 mg. Further work with higher loading rates or blends with other pheromonal components are warranted relative to determining *L. phragmatidicola* pheromone. It is interesting to note that *L. phragmatidicola* varied in its response to lure D. It seems that the first generation was attracted to lure D, but the second generation was not in both 2000 (Fig. 3) and 2001 (Fig. 4). We have no explanation for this, but might speculate that two seasonal populations may respond to different chemistries. Also, there may be sibling species in what is now being called *L. phragmatidicola.*

Lure B is the only one that failed to recruit any *L. phragmatidicola* during the June flight. Thus, although the magnitude of fall armyworm capture for lure B is only 0.5–0.33 the magnitude of lure A, its ability to discriminate between fall armyworm and *L. phragmatidicola* suggest it as the most promising for future development, including work to consider the relationship of trap catch and field infestation rates.

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