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Profile

Biology and Management of the Threecornered Alfalfa Hopper (Hemiptera: Membracidae) in Alfalfa, Soybean, and Peanut

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Abstract

The threecornered alfalfa hopper, *Spissistilus festinus* (Say) (Hemiptera: Membracidae), was first described in 1831. Since its discovery, it has been observed feeding on > 20 plant species across seven plant families; preferred hosts include species in the family Fabaceae. *Spissistilus festinus* has been identified as a serious economic pest of alfalfa, *Medicago sativa* L.; soybean, *Glycine max* L; and recently peanut, *Arachis hypogaea* L. Damage by *S. festinus* results from feeding and girdle formation on the plant stems; stem girdles inhibit the transportation of photosynthate through the phloem. Photosynthates accumulate above girdles, and the insects feed preferentially at these locations. Girdles can also reduce the structural stability of stems, resulting in significant stand loss in extreme circumstances. The timing of chemical applications for management of *S. festinus* is critical for successfully reducing insect populations, but information regarding *S. festinus*' economic impact in modern alfalfa, soybean, and peanut production systems is scarce. The following is a review of the biology, life history, distribution, pest status, and management of *S. festinus* on alfalfa, soybean, and peanut.

Key words: threecornered alfalfa hopper, *Spissistilus festinus*, soybean, peanut, alfalfa

Biology

Description and Behavior

The *Spissitilus festinus* (Say) adult is light green and 6–7 mm long, with an elongated pronotum that extends to the tip of the abdomen (Wildermuth 1915). *Spissistilus festinus* receives its common name from its pronotum; when observed from the front (Fig. 1A), it possesses three corners, one at each "shoulder" and one at the apex of the pronotum. Adult males (Fig. 2A) are readily distinguishable from females (Fig. 2B) by a red tint on the dorsal surface of the male's pronotum, marginally smaller male body size, and lack of an ovipositor (Fig. 1B; Wildermuth 1915).

Eggs (Fig. 3A) range in size from 0.9 to 1.3 mm long. They are white in color and oblong in shape, with one end larger than the other. The larger end of the egg is covered in papillae, which are thought to secure the egg within the plant tissue (Wildermuth 1915). Eggs are inserted under the epidermis in a slit created by the ovipositor (Fig. 4). Oviposition behavior has been shown to vary depending on the host species and the maturity of that species. For example, in soybean, *Glycine max* L., oviposition occurs near the base of the main stem early in the season (Wildermuth 1915), and occurs in softer tissues such as terminals and nodes as the season progresses (Mitchell and Newsom 1984a, Rice and Drees 1985). The number of eggs laid in each slit varies by plant species. In soybean, approximately six eggs are laid per slit, but in alfalfa, *Medicago sativa* L., 1–2 eggs were found per slit (Wildermuth 1915, Jordan 1952). Meisch and Randolph (1965) reported that oviposition slits damage tissue and can be harmful to plants when oviposition is heavy.

Spissistilus festinus undergoes hemimetabolous development. It progresses through four to six instars depending on nutrition and weather conditions; five total instars is most commonly reported (Wildermuth 1915, Moore and Mueller 1976, Deitz and Wallace 2012). The first and second instars (Fig. 2B and C) are 1.6 mm and 2.1 mm in length, respectively; they are pale green or straw colored, with a series of dorsal spine-like protrusions. At each successive nymphal stage, the spines grow and develop divergent lateral spurs that occur along the length of each spine. Wing pads and pronounced development of the pronotum appear in the third nymphal stage; third instars (Fig. 2D) are darker yellow-brown color with green markings, and are ~2.9 mm in length. Fourth and fifth instars (Fig. 2E and F) are similar in appearance and grow progressively greener with pronounced wing pads, dorsal spikes, and pronotum.

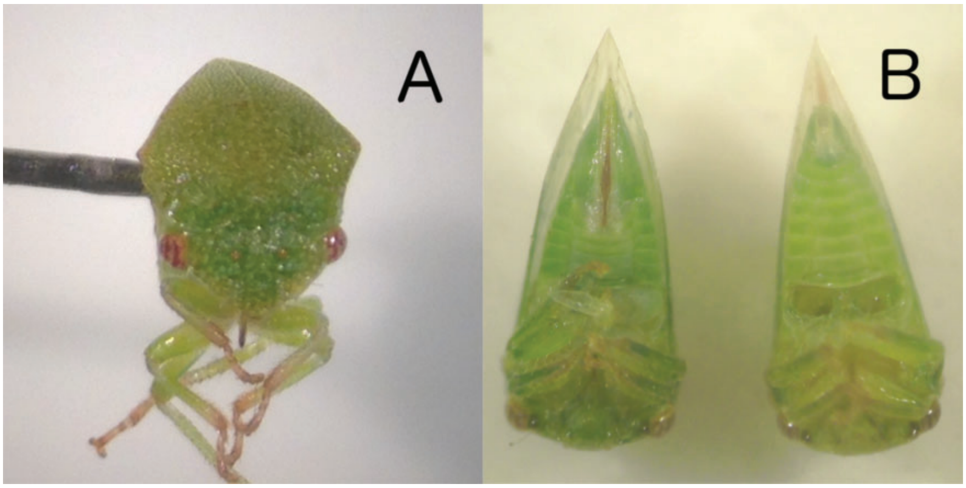

Fig. 1. (**A**) Frontal perspective of adult *S. festinus*, exhibiting the three corners at the "shoulders" and dorsally. (**B**) Ventral perspective showing female (left) and male (right) *S. festinus*.

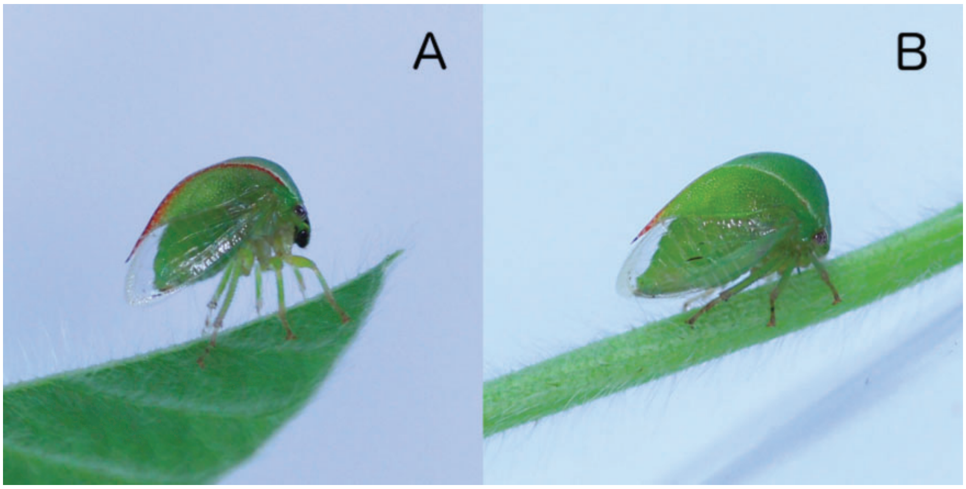

Fig. 2. Side by side perspective of adult *S. festinus* displaying sexual dimorphism. Males (**A**) possess a red coloration that runs along the dorsal edges of the pronounced pronotum. Females (**B**) possess a slight red tinge posteriorly on the pronotum, as well as an elongated abdomen.

Third through fifth instars are more mobile than the first and second instars (Wildermuth 1915). When disturbed, nymphs will sometimes produce a globule from the abdomen as a defense mechanism and quickly move to the opposite side of the stem (Wildermuth 1915). Adults will also attempt to conceal themselves in a similar manner, though they commonly fly away when disturbed (Wildermuth 1915). Adults generally fly within 33 cm above the soil or just above the plant canopy (Johnson and Mueller 1989, 1990).

Life History

Spissistilus festinus can have multiple generations per year depending on weather conditions and availability of host plants (Wildermuth 1915, Mitchell and Newsom 1984b). Adults overwinter in a state of reproductive diapause (Newsom et al. 1983, Mitchell and Newsom 1984b), though reproduction has been reported to continue during mild winters (Wildermuth 1915). A nascent adult female reaches sexual maturity in 7–14 d; she will mate and lay eggs soon after (Jordan 1952, Meisch 1964, Meisch and Randolph 1965). Males reportedly die soon after copulation, but females live for an average of 38.6 d postcopulation (Mitchell and Newsom 1984b). Wildermuth (1915) reported that populations generally consist of more males than females. However, Mitchell and Newsom (1984b) and Newsom et al. (1983) documented that sex ratios vary throughout the season; the proportion of males to females was equal at overwintering habitats. The first migration skews the ratio toward females, suggesting that only the females migrate from overwintering sites. Ratios equalize after the first spring generation (Mitchell and Newsom 1984b, Newsom et al. 1983). An egg-laying female can be found with an average of 21–30 eggs in her ovaries at any one time, and can produce up to 220 eggs over her lifetime (Mitchell and Newsom 1984b).

The embryo's development lasts from 6 to 27 d, with an average of 16.5 d from oviposition to eclosion (Meisch and Randolph 1965). The first three instars are completed in 3–5 d each, depending on temperature, humidity, and nutrition. The fourth and fifth instars last 4–8 d each (Wildermuth 1915, Jordan 1952, Meisch and Randolph 1965, Spurgeon and Mack 1990). Total nymphal development time has been shown to vary with temperature. Wildermuth (1915) observed that nymphal development required 69 and 32 d when mean temperatures were 16 °C and 30 °C, respectively. Other reports estimate development time to be 18–24 d at temperatures of 32 °C and 26.6 °C and 75–80% relative humidity (Jordan 1952, Meisch 1964, Meisch and Randolph 1965, Spurgeon and Mack 1990).

Fig. 3. Life stages of the *S. festinus*. (**A**) Egg (**B**–**F**) Instars 1–5.

Fig. 4. Eggs of *S. festinus* in the base of a soybean, *G. max*, stem.

Distribution and Host Range

Wildermuth (1915) reported that *S. festinus* had been observed from Ottawa, Canada, to Mexico; this distribution was refined by Caldwell 1949. His description of the different species of *Spissistilus* using the genitalia revealed that the original reported distribution was based on misidentified *Spissistilus* species. The upper limits of the distribution are closer to the Midwest United States as opposed to Canada. In the United States, *S. festinus* is prevalent in the Southeast and Midsouth, where the abundance of preferred host plants such as soybean and peanut, *Arachis hypogaea* L., provides suitable habitat for breeding and development (Moellenbeck et al. 1993, Deitz and Wallace 2012).

The host range of *S. festinus* consists of many plant species in a number of families. The insect was first identified as a potential pest of tomato in personal communications between Oemler and the University of Georgia in 1888 (Oemler 1888). Cockerell (1899) first reported *S. festinus* as a pest on alfalfa 11 yr later. The known host range of *S. festinus* includes alfalfa; cowpeas, *Vigna unguiculata* (L.); clover, *Trifolium* spp; various trees; shrubs; grasses; herbs; sugarcane, *Saccharum officinarum* L.; potato, *Solanum tuberosum* L.; cotton, *Gossypium hirsutum* L.; and field pea, *Pisum sativum* L. (Wildermuth 1915, Van Zwaluwenburg 1926, Swezey 1937). Plant species in the Fabaceae have been shown to be better reproductive and developmental hosts, and the insect is considered an economic pest of alfalfa, soybean (Caviness and Miner 1962, Tugwell et al. 1972, Mitchell and Newsom 1984a, Sparks and Newsom 1984, Sparks and Boethel 1987a, Johnson et al. 1988), and peanut (King et al. 1961, Todd et al. 1979, Andersen et al. 2002, Rahman et al. 2007). In Louisiana, overwintering adults have been observed on pine, *Pinus* spp.; in spring, adults were found on vetch, *Vicia* spp. and clover, before moving onto newly emerged soybean (Newsom et al. 1983).

Economic Importance

Direct and Indirect Injury

Spissistilus festinus is a phloem feeder with piercing–sucking mouthparts and two distinct feeding behaviors. The first behavior involves sporadic probing and consumption of phloem sap (Andersen et al. 2002). The other behavior involves the formation of a continuous series of lateral punctures around the circumference of a stem (Wildermuth 1915). Commonly referred to as a girdle (Fig. 5), the aforementioned ring of punctures often results in a gall-like growth (Fig. 5A) in the area surrounding the feeding site (Wildermuth 1915). Smith (1933) found that after the insect feeds, insoluble salivary sheaths are left in the plant tissue. Mitchell and Newsom (1984a) discovered that it is these sheaths that disorganize and disrupt the vascular bundles of the phloem, as well as induce cellular hyperplasia (Johnson et al. 1988). Multiple studies across different plant species have shown that the third through fifth instars (as well as adults) are capable of creating stem girdles (Meisch and Randolph 1965, Moore and Mueller 1976, Mitchell and Newsom 1984a, Andersen et al. 2002).

Girdling interrupts the flow of nutrients in the phloem and causes an accumulation of photosynthates in the area above the girdle (Osborn 1911, Wildermuth 1915, Mitchell and Newsom 1984a, Andersen et al. 2002). Andersen et al. (2002) reported that many of the amino acids that increase in concentration above the stem girdle are likely the result of plant responses to feeding and are not essential to insect development. Nevertheless, concentrations of amino acids required for *S. festinus* development are also elevated by the girdling process (Andersen et al. 2002). On peanut and other host plants, nymphs gather within 5 mm above the girdle, and feed for up to 7 d (Moellenbeck and Quisenberry 1991, Andersen et al. 2002). New girdles are formed above existing girdles, and nymphs will relocate to continue feeding (Moellenbeck and Quisenberry 1991, Andersen et al. 2002). In alfalfa and soybean, heavy girdling reduces the forage quality owing to lowered levels of carbohydrates and amino acids, as well as increased levels of detergent fibers (Wilson and Quisenberry 1987, Moellenbeck and Quisenberry 1991).

Nutrient loss is not the only consequence of girdling. Girdles on the main stem of soybean seedlings can impact the structural stability of the plant, leaving the girdled stem susceptible to lodging from wind and mechanical disturbance (Sparks and Boethel 1987a). In peanut, which has a more prostrate growth habit and multiple branches, stand loss owing to lodging is not a serious concern. Sparks and Newsom (1984) speculated that high levels of late-season petiole feeding could lead to leaf death and reduce both effective leaf area and yield in soybean.

Spissistilus festinus damage has been linked to an increase in the likelihood of disease complexes in soybean. Herzog et al. (1975) observed increased incidence of blight caused by *Sclerotium rolfsii* (Sacc.) infection in girdled versus nongirdled stems. Although *S. festinus* did not actively transmit the pathogen, the presence of girdles close to the soil where *S. rolfsii* occurred significantly increases frequency of infection. *Sclerotium rolfsii* is one of the most damaging peanut pathogens. It can cause up to 12% yield loss in Georgia, where losses and accompanying treatment costs associated with *S. rolfsii* are estimated to be US$41 million annually (Woodward 2010, 2011, 2012, 2013). No work has been published on the interaction of *S. festinus* infestation and *S. rolfsii* incidence in peanut, but it should be noted that *S. rolfsii* incidence in soybean increases with mechanical damage. Therefore, *S. festinus* infestation on peanut could increase the occurrence of infection (Herzog et al. 1975, Russin et al. 1986). A study of soybean with symptoms of stem canker, *Diaporthe phaseolorum* (Cke. and Ell.), found that girdle presence resulted in larger cankers and reduced yields (Russin et al. 1986). Russin et al. (1987) found that girdles on soybean did not increase infection rate of pod or stem blight, *Phomopsis sojae* and *Colletotrichum truncatum* (Schw.), but did increase symptom severity of both diseases and reduced yields.

Alfalfa

Spissitilus festinus was first described as a pest of alfalfa in 1899 (Cockerell 1899). Alfalfa is a perennial forage and hay crop that can be harvested multiple times a year, but *S. festinus* feeding girdles can cause significant loss in quality of the new growth (Wilson and Quisenberry 1987). Entire fields can require reseeding when heavy infestations result in high stem girdle counts owing to the persistent nature of the girdles (Graham and Ellisor 1938).

Spissistilus festinus has multiple and overlapping generations annually on alfalfa, with two population peaks occurring late June to early July and late August through September in Louisiana (Farlow et al. 1981, Moellenbeck et al. 1993). The latter peak is often much greater than the former, and as a result, the amount of damage to the new growth can be considerable (Wilson and Quisenberry 1987). Nymphs in a greenhouse study did not have any measurable effect on "Florida 77" alfalfa at one and three nymphs per plant (Wilson and Quisenberry 1987). However, when the densities increased to six nymphs per plant, protein content decreased, fiber density increased, and root carbohydrate levels decreased (Moellenbeck and Quisenberry 1991). Although overall dry weight was not affected, the quality of harvested hay was reduced. It is possible that the regrowth capability of the plants was affected owing to reduced root carbohydrate concentrations (Moellenbeck and Quisenberry 1991).

Currently, *S. festinus* is not considered a major pest of alfalfa. The insect is either not mentioned (Undersander et al. 2011, Whitworth et al. 2015) or is described as a minor, occasional pest (Summers et al. 2007) in the most recently published alfalfa pest management handbooks. Recent pest management handbooks for Tennessee, Georgia, and Alabama suggest that insecticides may be needed if adults or nymphs are present on 10% of seedlings and young plants (up to 10–12 inches tall) or if 10% of lateral stems are being killed from damage (Flanders and Everest 2014, Buntin 2016, Stewart and McClure 2016). For older plants, an economic threshold of two adults or nymphs per sweep with a 0.38-m sweep net has been published (Stewart and McClure 2016). In Tennessee, however, a study showed that a 25% reduction in stand count did not cause any economic impact in alfalfa (Bates et al. 2005).

Soybean

Spissistilus festinus has long been considered a pest of soybean. It was first detected on soybean in the early 1900s, but significant damage was not reported until 1957 (Caviness and Miner 1962). It was initially thought that yield loss resulted from early-season girdling of the main stem (V1–V5 growth stages). The damage to the main stem caused large swathes of soybean plants to lodge. However, Caviness and Miner (1962) found evidence that lodging had minimal effects on yield. Artificially reduced stands had the highest loss in yield (up to 15%) when stand loss occurred after bloom, and less yield loss (up to 7%) when damage occurred 2 wk prior to bloom. It should be noted that lodging simulations in this study were evenly distributed throughout the plots, allowing maximum compensation from adjacent plants. In studies simulating the effect of early-season *S. festinus* girdling of main stems, Cook et al. (2014) found that yield of indeterminate Maturity Group IV soybean was significantly reduced by stand loss occurring from R1 to R5. Yield response was inconsistent across reproductive growth stages in this study, and it is unknown what levels of insect girdling would result in the rates of stand loss tested. Bailey (1975) reported a yield reduction of >14 bushels per acre when *S. festinus* adults were caged at densities of four adult insects per plant

Fig. 5. Girdles on peanut, *A. hypogaea*. (**A**) Stem girdle resulting in gall formation as well as adventitious root growth. (**B**) *Spissitilus festinus* nymph forming a girdle on a peanut leaf petiole.

compared with one adult per five plants on 1.5–2-inch tall soybean seedlings.

The number of generations of *S. festinus* occurring annually in soybean varies. Mueller (1980) found three overlapping generations, whereas Mitchell and Newsom (1984b) found only two. These differences suggest that the number of generations occurring annually fluctuates and is likely affected by local environmental conditions. When observing the effects of individual generations on the host, Sparks and Newsom (1984) found that early-season damage (when there is the highest danger of lodging from girdles on the main stem) did not significantly impact yield. However, Bailey (1975) found significant reduction in yield at a rate of one hopper per plant when plants were 1.5–2.0 inches tall, indicating that it is possible that damage occurring in the early season has the capability to impact yield. No difference in yield between individual girdled and nongirdled plants was observed, indicating that lodging is a cause of yield reduction when girdling rates are high. Nevertheless, Caviness and Miner (1962) artificially removed plants from the stand and demonstrated that soybeans have incredible compensatory power. Mueller and Jones (1983) showed that yield was reduced only when 70% or more of plants had a main stem girdle. The lack of yield response at lower feeding levels was attributed to compensation and high seeding rates (12 seed per 0.33 m row). In one study, late season damage during the second in-field generation of *S. festinus* resulted in significant reductions in yield (Sparks and Boethel 1987a). This result was most likely related to *S. festinus* feeding on the succulent petioles, peduncles, and pedicels after the soybean's R1 stage (Mitchell and Newsom 1984a). Though nutrient flow on a girdled petiole resumes after 10 d (Spurgeon and Mueller 1993), the damage may be enough to decrease the number of seedpods produced or the number of seed per pod, thereby reducing yield (Sparks and Newsom 1984).

The first economic threshold for *S. festinus* was established by Sparks and Newsom (1984), who determined that one adult per sweep at soybean pod set until leaf yellowing is enough to cause economic damage and should be treated. This threshold was based on the hypothesis that late season damage consisting of mostly petiole girdling is the cause of significant yield loss. Sparks and Newsom (1984) also hypothesized that when the threshold for adults is met, the nymphs have already done a substantial amount of damage. Sparks and Boethel (1987a) found that yield reductions occurred at 60% of the aforementioned threshold, and introduced the hypothesis that pod or peduncle feeding contributes more to yield loss than petiole girdling.

A relatively recent shift from traditional timings of soybean planting (late May and early June) to early-season planting (mid-April) occurred in the midsouthern United States primarily as an effort to avoid periods of drought (Heatherly 1998). This early soybean production system (ESPS) incorporates earlier maturing varieties and can result in greater yield, and can result in less late-season damage resulting from caterpillar feeding compared with the traditional production system (Heatherly 1998). Early-planted soybean production may affect many of the previously established economic thresholds for pests of soybean, including *S. festinus*. In ESPS, *S. festinus* populations are higher early in the season, and late season infestations are largely avoided (Bauer et al. 2000, McPherson et al. 2001). Pulakkatu-Thodi (2010) and Ramsey (2015) were unable to observe any impact on yield in reproductive, early-planted soybeans, as a result of adult numbers at 3× the established threshold of one adult per sweep. Infestations occurring prior to or after pod fill appear to have little or no consistent effect on yield. It should be noted that only adults were included in both of these studies, and as such, the full impact of *S. festinus* in contemporary early-planted season soybean production systems is as of yet undetermined. There are no recently published or validated thresholds for *S. festinus* on early-planted soybean.

Peanut

Spissistilus festinus has been observed feeding on peanut for the past half-century, though there have been no intensive investigations of its economic impact (King et al. 1961, Todd et al. 1979). In Georgia and surrounding states, growers now see *S. festinus* in great abundance in peanut fields, and there are concerns about possible yield loss associated with feeding. Though there have been estimates of the economic impact of *S. festinus* in peanut ranging from US$1.5 million in yield loss (Brown et al. 1997) to no impact other than treatment costs (Adams 2008), no science-based economic injury level has been determined.

Two nymphal *S. festinus* population peaks are observed in peanut annually in the Southeast. The first generation of nymphs appears in late June to early August after an initial appearance of

Table 1. Insecticides registered for management of *S. festinus* in Alfalfa (Georgia Pest Management Handbook–2016 Commercial Edition)

Insecticide AI Common names	Insecticide Type	IRAC	Amount/acre	Lbs AI/acre	**REI/PHI[a]**
Alpha-cypermethrin	Pyrethroid	3A			
Fastac 0.83			2.2–3.8 fl oz	0.012–0.025	12 h/3 d
Beta-cyfluthrin	Pyrethroid	3A			
Baythroid XL 1.0EC			1.6–2.8 fl oz	0.0125–0.022	12 h/7 d
Carbaryl	Carbamate	1A			
Sevin 80S			1.25 lb	1.0	12 h/48 d
Sevin XLR Plus, 4F			1.0 qt	1.0	
Cyfluthrin	Pyrethroid	3A			
Tombstone 2.0			1.6–2.8 fl oz	0.025–0.044	12 h/7 d
Gamma-cyhalothrin	Pyrethroid	3A			
Declare 1.25			1.02–154 fl oz	0.01–0.015	12 h/
Proaxis 0.5			2.56–3.84 fl oz	0.01–0.015	7 d
Lambda-cyhalothrin	Pyrethroid	3A			
Karate Zeon 2.08			1.28–1.92 fl oz	0.02–0.03	12 h/
Silencer 1			2.56–3.84 fl oz	0.02–0.03	7 d
Zeta-cypermethrin Mustang MAX,	Pyrethroid	3A			12 h/
Respect 0.8EC			2.24–4.0 fl oz	0.014–0.025	3 d

[a] Re-entry interval/plant harvest interval.

adults, and the second generation develops during late August into early September (Rahman et al. 2007). The majority of girdling occurs 3 wk after the initial appearance of nymphs in June (Rahman et al. 2007); this coincides with the approximate development time from eclosion to fourth instar (Meisch 1964, Meisch and Randolph 1965, Spurgeon and Mack 1990). The fourth instar is thought to be responsible for most of the girdling in peanut (Moore and Mueller 1976, Johnson and Mueller 1988).

Although *S. festinus* is capable of girdling peanut, no published reports correlate peanut damage with yield loss. Andersen et al. (2002) reported reduced biomass, nitrogen content, and carbon content in girdled peanut stems in northern Florida, but this effect was not consistent over years of the study. *Spissistilus festinus* damage, characterized by number of girdles, was shown to vary by cultivar, with runner-type Georgia Green and Virginia-types AT VC2, GA-HI-O/L, Virugard, Wilson, and Phillips being particularly susceptible. Nevertheless, no measurable effect on yield was detected from girdling alone, with damage rates up to six girdles per plant (Rahman et al. 2007).

The economic injury level for *S. festinus* in peanut is unknown, and there are no experimentally validated economic thresholds. However, at least one set of anecdotal thresholds has been reported, where one adult per 6 feet of row at 75 d prior to digging or one adult or nymph per 3 feet of row 25–75 d prior to digging warrants treatment (Brown 2006). Preliminary studies conducted recently at the University of Georgia suggest that these thresholds overestimate the economic impact of *S. festinus* and trigger insecticide applications at population levels that are not yield limiting. It is important to know at what point *S. festinus* damage impacts peanut yield. Growers in the Southeastern United States currently treat *S. festinus* as a pest and manage populations with insecticides. The broad-spectrum insecticides used to target *S. festinus* can flare secondary pests, negatively impact natural enemies and pollinators, and reduce net profits when applied unnecessarily (Ware 1980, Adams 2008).

Monitoring

Sampling Methods

In soybean (Sparks and Boethel 1987a) and peanut (Rahman et al. 2007), *S. festinus* females are randomly distributed throughout the field; therefore, plant injury can be assessed within 10 m of field borders to adequately estimate whole field injury levels according to Rahman et al (2007). Whole plant observations provide an accurate assessment of nymph populations (Spurgeon and Mueller 1991), but this method is impractical for IPM because of the time required for each sample. Beat sheet sampling is less time consuming than whole plant observations, but it is not ideal for detecting the younger, smaller nymphs in soybean, as their small mass reduces the chance of dislodging from the plant (Spurgeon and Mueller 1991). The beat net (Sparks and Boethel 1987b) and vertical beat sheet (Drees and Rice 1985) are alternatives to the beat sheet for sampling nymphs. The former involves utilizing a standard 33-cm sweep net held at a 45-degree angle to the plant base; the plant is then beat into the net at 10 different locations in the field. The latter method involves a similar technique, where a beat sheet is held parallel to the plants, with a trough at the bottom to collect the nymphs that are shaken or beaten off the plant. Sparks and Boethel (1987b) utilized these methods to good effect for sampling *S. festinus* nymphs, finding that the beat net was the most efficient and effective.

Adult populations can be assessed effectively with a sweep net in soybean (Kogan and Herzog 1980) and peanut (Rahman et al. 2007). Adults can also be monitored in soybean with yellow sticky traps (Johnson and Mueller 1988) placed 33 cm above the ground or at just above canopy level (Johnson and Mueller 1989); however, trap counts were not as accurate as sweep samples for predicting actual field populations (Johnson and Mueller 1988, Johnson and Mueller 1990).

Sampling Timing

Critical sampling periods differ from crop to crop and may even vary within a crop depending on production practices as with soybean planting date. Feeding in alfalfa was most injurious during the second population peak (Wilson and Quisenberry 1987). Managing *S. festinus* in alfalfa requires monitoring plant stands for stem death resulting from girdles, as well as monitoring for sudden increases in populations of *S. festinus* adults.

Though the economic impact of *S. festinus* in modern U.S. soybean production systems is not clear, research suggests the crop may be vulnerable to damage at distinct development periods. Prior to

Table 2. Insecticides registered for management of *S. festinus* in Soybean (2016 Insecticide Recommendations for Arkansas [Studebaker])

Insecticide AI Common names	Insecticide Type	IRAC	Amount/acre	Lbs AI/acre	REI/PHI[a]
Beta-cyfluthrin	Pyrethroid	3A			
Baythroid XL 1.0EC			1.6–2.8 fl oz	0.013–0.022	12 h/45 d
Clothianidin	Neo-nicotinoid	4A			
Belay 2.13 EC			3–6 fl oz	0.05–0.1	12 h/21 d
Cyfluthrin	Pyrethroid	3A			
Tombstone 2 EC			1.6–2.8 fl oz	0.025–0.044	12 h/45 d
Esfenvalerate	Carbamate	1A			
Asana XL 0.66 EC			5.8–9.6 fl oz	0.03–0.05	12 h/21 d
Gamma-cyhalothrin 1.25	Pyrethroid	3A			
Prolex/Declare CS			0.77–1.28 fl oz	0.0075–0.013	12 h/30 d
Lambda-cyhalothrin	Pyrethroid	3A			
Karate Zeon 2.08 CS			0.96–1.6 fl oz	0.015–0.025	12 h/30 d
Lambda-cyhalothrin +chlorantranilipole	Pyrethroid	3A			
	Diamide	28			
Beseige 1.252			5.0–8.0 fl oz	0.049–0.08	12 h/30 d
Zeta-cypermethrin	Pyrethroid	3A			
Mustang Maxx			2.8–4.0 fl oz	0.0175–0.25	12 h/21 d
Zeta-cypermethrin + bifenthrin	Pyrethroid	3A			
Hero 1.24 EC	Pyrethroid	3A			
			4.0–10.3 fl oz	0.04–0.1	12 h/21 d

[a] Re-entry interval/plant harvest interval.

Table 3. Insecticides registered for management of *S. festinus* in peanut (Georgia Pest Management Handbook–2016 Commercial Edition)

Insecticide AI Common names	Insecticide Type	IRAC	Amount/acre	Lbs AI/acre	REI/PHI[a]
Carbaryl	Carbamate	1A			
Sevin 80S			1.25 lb	1.0	12 h/48 d
Sevin XLR Plus, 4F			1.0 qt	1.0	
Bifenthrin	Pyrethroid	3A			
Brigade 2EC			2.1–6.4 fl oz	0.33–0.1	12 h/14 d
Beta-cyfluthrin	Pyrethroid	3A			
Baythroid XL 1.0EC			1.6–2.8 fl oz	0.0125–0.022	12 h/7 d
Lambda-cyhalothrin	Pyrethroid	3A			
Karate Zeon 2.08			1.28–1.92 fl oz	0.02–0.03	12 h/7 d
Silencer 1			2.56–3.84 fl oz	0.02–0.03	

[a] Re-Entry Interval/Plant Harvest Interval.

the shift to early-season planting, the critical sampling and treatment period to prevent early-season damage resulting from main stem girdles in soybean was when the plants were around the V3 stage (Spurgeon and Mueller 1992). Averting late-season damage in soybean required sampling for *S. festinus* populations before V12 growth stage (Fehr et al. 1971, Spurgeon and Mueller 1992). Sparks and Newsom's 1984 treatment threshold in soybean was based on the observation that economic losses could occur from pod set to leaf yellowing. Additional research is needed to quantify the economic impact of *S. festinus* on soybean and to determine optimal monitoring time(s).

Rahman et al. (2007) recommend monitoring peanut for nymph and girdle presence in the first 2–3 wk of July. Damage increased in the third week of July, after consistent weekly increases in nymph numbers, indicating that early July is the optimal time for scouting nymphs (Rahman et al. 2007). An increase in adult *S. festinus* abundance was observed a few weeks before damage levels rose in peanut. This is likely a result of the earliest nascent adults from the first generation appearing when the majority of nymphs are still forming girdles. Using these adults as a direct, numerical indicator of injury may result in an appropriate diagnosis, but only after the damage has been done (Rahman et al. 2007). Because the correlation between the number of adults and nymphs in the field at any given time is unknown, using adults as a predictor of damage could over or under estimate the impact of *S. festinus*.

Management

Insecticides are the most effective tool to quickly reduce *S. festinus* populations in the crops discussed here. Pyrethroid and organophosphate insecticides are commonly recommended, though published efficacy of individual products in these classes varies. There are no recent, experimentally validated economic thresholds for *S. festinus* in any crop. Because most of the damage caused by threecornered alfalfa hopper is attributed to feeding by the third, fourth, and fifth instars (Andersen et al. 2002), management strategies should focus on reducing population levels of this life stage. In some crops, it may be possible to prevent infestations of immature stages by targeting immigrating adults with insecticides. This strategy can fail if adult movement into a crop occurs over a long period of time and residual insecticide efficacy is short. Applying insecticides only when the nymphs are present on a susceptible crop stage is an ideal strategy, but accurately assessing nymph populations is difficult. Regardless of the life stage targeted by insecticides, coverage of the crop canopy will affect control.

Alfalfa

In alfalfa, cultural practices that reduce the impact of *S. festinus* include increasing seeding rate to mitigate stand loss and removing weedy borders around fields to eliminate overwintering sites (Bates et al. 2005). Insecticides listed in the 2015 Georgia Pest Management Handbook for management of *S. festinus* in alfalfa when adults or nymphs are found on 10% of alfalfa seedlings, or losses exceed 10% of lateral stems are provided in Table 1 (Buntin 2016).

Soybean

Spissistilus festinus is still regarded as a soybean pest, though recent studies suggest its pest status may have diminished in the early-soybean production system (Pulakkatu-Thodi 2010, Ramsey 2015). Current soybean thresholds may not be valid for early-soybean production systems, and the lack of consistency found in state management guides is indicative of the lack of consensus regarding the insect's pest status. The thresholds published in the 2016 Insecticide Recommendations for Arkansas (Studebaker 2016) recommend treatment when "50% of the plants are girdled, or if fewer than 4–6 ungirdled plants per row foot remain in conventional rows, 30 [inches] to 38 [inches], and hopper nymphs are still present" for plants still under 10". Insecticides recommended by the University of Arkansas in 2016 for management of *S. festinus* in soybeans are given in Table 2. These recommendations and those published by Mississippi State University include neonicotinoid seed treatments which can provide control of *S. festinus* for 3–4 wk (Catchot 2016). A recently published survey of U.S. soybean producers showed that 51% used insecticide (neonicotinoid) seed treatments (Hurley and Mitchell 2017). Only 1.4% of survey respondents indicated that they actively managed *S. festinus*, but no Southeastern soybean growers were included in the study. Louisiana State University recommends treatment when three or more nymphs or one or more adults are present beginning at pod set, and no neonicotinoids are included in published recommendations (Davis 2017).

Peanut

The impact of *S. festinus* feeding on peanut is poorly understood. Clemson Cooperative Extension suggests treating peanut with insecticide at 45–60 d after planting to reduce damage caused by *S. festinus* (Chapin 2015). Though the University of Georgia Cooperative Extension Service has not published validated thresholds or recommendations for optimum treatment timing, growers in Georgia commonly target *S. festinus* populations with pyrethroid insecticides. Mississippi State University recommends treatment when fresh damage and two insects per six-row feet are present (Catchot 2016). The insecticides listed in the Georgia Pest Management Handbook for management of *S. festinus* in peanut are given in Table 3 (Abney 2016).

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