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Evaluating the Pest Status of Threecornered Alfalfa Hopper in Mississippi Agricultural Crops

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By

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Field experiments were conducted to determine the impact of threecornered alfalfa hopper, *Spissistilus festinus*, (Say), in reproductive growth stage soybeans. High densities of threecornered alfalfa hoppers were examined in field cages to understand feeding on soybean. No significant yield losses were observed from threecornered alfalfa hopper feeding during reproductive growth stages. Sweep net efficiency studies were conducted in order to convert the densities used in field cages to a sweep net threshold.

Field experiments were also conducted to determine the impact of threecornered alfalfa hopper injury to seedling cotton. Threecornered alfalfa hopper injury to seedling cotton plants impacts individual plant yield, but further research is needed to understand the ability for undamaged cotton plants to compensate for neighboring damaged plants.

DEDICATION

I would like to dedicate this research to my parents, Michael and Elizabeth Ramsey. Without your constant love, encouragement and support this would not have been possible. I also dedicate this research to my loving wife, Mallory. Thank you for being so patient and supportive throughout my graduate career. I am often reminded of how lucky I am to have such a wonderful person in my life. Lastly, I dedicate this research to the memory of my late grandfather, John Tyler Santmyer Jr. The impact he had on my life is truly invaluable.

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CHAPTER I

REVIEW OF LITERATURE

Origin of Soybean

Southeast Asia is the origin of soybean [*Glycine max* (L.) Merr.] and it was first domesticated by Chinese farmers around 1100 BC. The soybean was first introduced to the United States in the 1700's when Samuel Bowen, a colonist in the British colony of Georgia, planted soybean seed from China (Hymowitz and Shurtleff 2005). Soybean production began to increase in the United States in the late 1800's due to increased plantings for livestock forage. Soybean production in the United States increased significantly during the 1940's. China, the leading soybean producer in the world at the time, was forced to cease production due to World War II and an internal revolution. Soybean demand was very high once the United States entered the war due to the need for oils, lubricants, and plastics (North Carolina Soybean Producers Association 2014). As a result of increased prosperity in the United States following the end of World War II, livestock production increased to meet consumer demand, and soybean meal was the ideal choice of protein for livestock because of its affordability. The discovery of synthetic vitamin B12 was the primary reason soybean meal was the main source of supplemental protein in poultry and swine (Smith 1994). Tens of millions of tons of soybean meal were incorporated into the diets of chickens, turkeys, cattle and hogs each year. Soybean meal became the preferred protein option for livestock and poultry producers throughout the world and is the primary oil seed meal of the feed industry (Smith 1994). Scientific advancements in the 1990's led to the improvement of the soybean. New technology allowed farmers to spray soybeans with broad spectrum herbicides to control weeds without killing the plant. This advancement in technology allowed for new production practices around the world and has permitted U.S. farmers to be one of the top suppliers to the world when the global demand for food is reaching levels never seen before (North Carolina Soybean Production Association 2014).

Soybean production in Mississippi has changed considerably in the past few years. In the past, the primary production system involved planting maturity groups VI and VII. Today the majority of the acreage in Mississippi is planted in maturity groups IV and V (MSUCares 2011). This shift to earlier-maturing varieties allowed for soybeans to be planted in mid-April and permitted harvest by the end of August. This approach helped minimize the impact of drought conditions that often occurred in July and August and reduced pest pressure from many late season insect pests (Baur et al. 2000). Under the early season soybean production system, the two most important management decisions are variety selection and planting date (MSUCares 2011). Soybean has recently replaced cotton as the top row crop in Mississippi when it comes to production value. Soybean is number three behind poultry and forestry in terms of all agricultural commodities in Mississippi (MSUCares 2011). The total soybean production area for Mississippi in 2014 was 910,931 hectares averaging 3,497 kg/ha (NASS 2014).

Biology of Soybean

Soybean is an annual legume that is considered a short day plant, but due to its sensitivity to photoperiod there are extensive genetic differences in soybean germplasm. The soybean is a short day plant with most cultivars flowering during long nights compared to short nights (Borthwick and Parker 1938). When growing genotypes out of their primary area of adaptation, it is critical to remember sensitivity to day length. A tropical latitude genotype grown in a region of higher latitude may not mature before frost occurs (Fehr 1980). Soybean cultivars are classified in to thirteen maturity groups. Maturity group 000 is the earliest cultivar and requires short nights for development and maturity group X needs long nights for development. Fehr et al. (1971) developed descriptions for stage of development for soybean. Once soybean seed are planted, emergence or VE, occurs in approximately 5 to 10 days. During emergence, cotyledons fully unroll and unifoliate leaves develop which is referred as cotyledon stage or VC. After the unifoliate leaves develop, all subsequent leaves are trifoliate. The remaining stages of vegetative growth are identified by the number of trifoliate leaves to the n^{th} node, V^n (Fehr et al. 1971). There are eight reproductive growth stages of soybean, described as R1 to R8 (Fehr et al. 1971). R1, or beginning bloom, is identified when one open flower can be seen at any node on the soybean plant. The soybean plant reaches R2 when there is open flowers at one of the two uppermost nodes. The initiation of one 0.95 cm (3/16") pod in one of the uppermost four nodes is termed R3 or beginning pod. Pod development continues in the uppermost four nodes and when one pod reaches 1.9 cm (3/4") in length it is designated at R4. This is the end of pod formation and the beginning of seed fill (Pedersen 2004). R5 is identified when a 0.3 cm (1/8") seed is seen in a pod at one of the four uppermost nodes. Seed continue to grow from R5 and fill the inside of pods. R6 is defined as full seed and a green seed fills the pod cavity in one of the four upper most nodes (Pedersen 2004). After pod fill, the soybean plants start to reach physiological maturity. When one mature pod can be seen anywhere on the plant it is termed R7. Soybeans have reached R8 growth stage when 95% of all pods on the plant have reached a mature color and have reached full physiological maturity (Pedersen 2004). Soybean plants are ready for harvest once R8 growth stage has been reached.

Maturity groups are designated to zones where cultivars are best adapted, however this does not indicate that only cultivars of a single maturity group can be grown in that designated zone (Heatherly and Elmore 2004). Soybean cultivars are also categorized as determinate or indeterminate based on the way they flower. Determinate varieties flower simultaneously at all flowering nodes, but stop vegetative growth soon after flowering starts. Indeterminate types begin flowering at the lowest node, which is the oldest and continue flowering up the plant as new nodes are developed (Hodges and French 1985). Many growers in Mississippi plant indeterminate soybean varieties compared to determinate varieties. Indeterminate varieties are generally early maturing compared to the later maturing determinate varieties.

Insect Pests of Soybeans in Mississippi

In Mississippi, there is a complex of pests in soybean that can have an effect on yield. The stink bug (Hemiptera: Pentatomidae) complex is one of the most damaging pests of soybean. Primary stink bug species include southern green stink bug, *Nezara viridula* (L.), green stink bug *Chinavia hilaris* (Say), brown stink bug, *Euschistus servus* (Say), redshouldered stink bug, *Thyanta* spp., and redbanded stink bug, *Piezodorus* *guildinii* (Westwood). Foliage feeding insect pests such as bean leaf beetle, *Cerotoma trifurcata* (Foster), soybean looper, *Chrysodeixis includens* (Walker), green cloverworm, *Hypena scabra* (Fabricius), velvetbean caterpillar, *Anticarsia gemmatalis*, (Hubner), beet armyworm, *Spodoptera exigua* (Hubner), and fall armyworm, *Spodoptera frugiperda* (J.E. Smith) can reduce yield when levels of defoliation are high. Threecornered alfalfa hopper, *Spissistilus festinus,* (Say) feeds on stems and leaf petioles, and they can be damaging pest during the seedling stage. Corn earworm, *Helicoverpa zea* (Boddie), feeds directly on the fruit, making it an economically important pest of soybeans in Mississippi, and in recent years, the most expensive pest of soybeans in Mississippi (Musser et al 2013).

The use of an early soybean production system (ESPS) has allowed soybean producers to avoid late season foliage feeding insects. However, use of ESPS has increased feeding by stink bugs and threecornered alfalfa hopper due to plants emerging early and pods being available earlier in the growing season (Heatherly 1999).

Origin of Cotton

Cotton (*Gossypium hirsutum* (L.), *Gossypium barbadense* (L.), *Gossypium arboreum* (L.), and *Gossypium herbaceum* (L.)), is the number one fiber used worldwide and is a very significant cash crop in the United States. It was first planted in the United States in Florida in 1556 (National Cotton Council). The seed and fiber are the most useful parts of the cotton plant. Cotton fiber is used for clothing, paper products, and plastics. Oil from cotton seed is primarily used in cooking oils and livestock feed. (National Cottonseed Products Association 2002). The production of cotton in the United States is worth $5.3 billion annually in supplies and services. Annual business revenue from cotton exceeds $120 billion in the U.S. economy, making it one of the more valuable crops (National Cotton Council). In 2014, cotton production in the United States totaled 3,461,852 metric tons (NASS 2015).

Cotton is a major row crop in Mississippi following behind soybean and corn in acreage. In Mississippi cotton acreage has recently decreased due to high production costs and high value in competing commodity markets (MSUCares 2011). In 2014, Mississippi producers planted 169,967 hectares of cotton (NASS 2014). Many changes have occurred over the years in cotton production in Mississippi. The boll weevil *Anthonomus grandis* (Boheman), historically the number one pest in cotton, was successfully eradicated and is no longer a pest in Mississippi. The development of transgenic varieties expressing traits such as Roundup Ready, Bollgard I and II, WideStrike, and Liberty Link have become very popular and are planted on the majority of cotton acres in Mississippi (MSUCares 2011). Major insect pests in cotton have also changed. In the past, boll weevil, tobacco budworm, *Heliothis virescens* (Fabricius) and cotton bollworm, *Heliocoverpa zea* (Boddie) were the major insect pests in cotton. Due to new technologies and the successful eradication of the boll weevil, the tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois) is currently the number one insect pest in Mississippi cotton production (MSUCares 2011).

Biology of Cotton

Of the four cotton species cultivated around the world, *G. hirsutum* accounts for over 90 percent of the annual cotton production worldwide (Chaudhry and Guitchounts 2003). Cotton is grown as an annual crop, but it is a perennial plant by nature. When compared to other crops, cotton can be adapted to many different types of environments and during periods of stress, cotton's vegetative and fruiting balance will adjust, helping maintain the possibility of good yield if ample growing season remains (National Cotton Council 2007). The development of cotton involves a number of stages and is divided into five main grow stages: germination and emergence, seedling establishment, leaf area and canopy development, flowering and boll development, and maturation (Oosterhuis 1990). Cotton has a predictable growth rate based on growing degree day (DD) model of unit accumulation. The model is based on the accumulation of heat units for a given day. The formula for calculating DD_{60}'s is the average of the maximum and minimum daily temperatures minus 60 degrees Fahrenheit, the lowest temperature that cotton will grow. Using heating unit accumulations, cotton growth rate can be determined (Jenkins et al. 1990) (Table 1.1). If conditions are suitable, seedlings will emerge in 4 to 14 days after planting (Ritchie et al., 2008). Approximately one week after seedlings emerge, the first true leaf will develop above the cotyledons. At approximately 40 days after planting, the first flower bud (pinhead square) is visible on nodes 5 to 7. The next stage of bud development is referred as match head square or "one third grown". The period of flower bud development prior to bloom is termed squaring (Ritchie et al., 2008). The cotton is said to be flowering once it begins to bloom. On average, cotton plants flower or bloom for six weeks. The first day a flower opens it is white in color. A few hours after opening, wind pollination occurs. The second day after opening, the white flower will turn pink and will be red by day three. Usually five to seven days after the white flower has appeared it will dry up and fall from the plant revealing, a developing boll. In some instances a flower will stay attached to the boll. This is termed a bloom tag (Ritchie et al., 2008). The stages of cotton development during the flowering period are identified using nodes above white flower. This is used to measure the number of nodes between the first position white flower and the top of the plant (Ritchie et al., 2008). At first bloom, plants will have nine to ten nodes above the white flower under optimum growing conditions. As the plants put more energy into boll development, fewer new nodes are produced and flowering nears the meristem of the plant. When only 4-5 nodes are above the white flower, new node development is reduced and this is called cutout. From planting to full maturation takes approximately 140 days (2600 heat units) (Jenkins et al., 1990).

Table 1.1 Description of cotton growth stages and heat unit accumulations for the average days after planting to reach each physiological growth stage.

Growth Stage	Heat Units (DD_{60})	Days After Planting
Emergence	50	5
First Square	550	38
First Flower	950	59
Open Boll	2150	116
Harvest	2600	140

(Samples 2014)

Insect Pests of Cotton

Numerous insect pests infest cotton annually in Mississippi. During the seedling and early development stages, thrips and twospotted spider mite *Tetranychus urticae* (Koch) are the most prevalent. Tobacco thrips, *Frankliniella fusca* (Hinds), is the most common thrips species found on cotton seedlings in the mid-South (Cook et al. 2003).

Other species found in Mississippi cotton fields include western flower thrips, *Frankliniella occidentalis* (Pergande) eastern flower thrips, *Frankliniella tritici* (Fitch), soybean thrips, *Neohydatothrips variabilis* (Beach), and onion thrips, *Thrips tabaci* (Lindeman) (Cook et al. 2003). Threecornered alfalfa hopper is a sporadic pest of cotton seedlings. Damage is primarily seen along field edges, though at times damage can be widespread across fields (Catchot 2012). As the growing season progresses and reproductive development begins, the insect complex becomes more complex. This includes tarnished plant bug, corn earworm, tobacco budworm, stink bugs (Hemiptera: Pentatomidae), fall armyworm, *Spodoptera frugiperda* (J.E. Smith), and beet armyworm, *Spodoptera exigua* (Hubner). The tarnished plant bug is the number one pest of cotton in Mississippi (MSUCares 2011). Economic costs for this pest are high due to the large number insecticide applications required to prevent the tarnished plant bug from exceeding economic thresholds.

Biology of Threecornered Alfalfa Hopper

Threecornered alfalfa hopper belongs to the order Hemiptera, previously Homoptera and the family Membracidae. Thomas Say, in 1831, first described the threecornered alfalfa hopper as *Membracis festina*. The genus was later referred to as *Stictocephala* by Stal and cited in literature as *Stictocephala festina* (Wildermuth 1915). Revisions were made to the tribe by Caldwell in 1949 and the tribe was changed to *Ceresini*. Caldwell (1949) established the new genus *Spissistilus* due to his revision of the tribe *Ceresini* and moved the species *festina* in to the new genus *Spissistilus*. He changed the species name from *festina* to *festinus,* thus establishing *Spissistilus festinus* (Say) as the scientific name to describe threecornered alfalfa hopper (Davis 1969).

The threecornered alfalfa hopper is a common insect of the southeastern United States and can be found as far north as Canada and as far west as California (Wildermuth 1915), though numbers of the insect are relatively low outside of the southeastern United States. The name "threecornered alfalfa hopper" was coined by famers who observed large infestations in alfalfa. The threecornered alfalfa hopper prefers to feed on leguminous plants, but they can be found on variety of host plants such as alfalfa, *Medicago sativa* (L.), cowpeas, *Vigna unguiculata* (L.), bermudagrass, *Cynodon dactylon* (L.), johnsongrass, *Sorghum halepense* (L.), wheat, *Triticum aestivum* (L.) barley, *Hordeum vulgare* (L.), oats, *Avena sativa* (L.), sweet clover, *Melilotus officinalis* (L.), red clover, *Trifolium pretense* (L.), bur clovers, *Medicago polymorpha* (L.), soybean, sunflower, *Helianthus annus* (L.) cocklebur, *Xanthium pensylvancium* (L.), and vetch, *Vicia sativa* (L.) (Wildermuth 1915). Adult threecornered alfalfa hopper are a yellowish green color, with a triangular shaped appearance when viewed from above or from the side. They are approximately 6 mm in length. Adult males have a red line along the dorsum of the prothoracic shield, which distinguishes them from adult females (Wildermuth 1915). Males are also slightly smaller than females. The eggs are white, banana shaped, 1 mm in length and have a smooth surface. The eggs are inserted deep into the stems or just below the epidermis (Wildermuth 1915). The nymphs have a triangular shaped appearance. The prothoracic shield is absent and the body is covered with tiny hairs and spines (Davis 1969).

Rice and Drees (1985) observed four oviposition trends in preblooming soybeans. During the prebloom stage, any part of the plant could be used for oviposition. Nodes and terminals are the ideal oviposition sites rather than hypocotyl, internodes, and petioles; internodes were rarely used for oviposition, and as the plant becomes more advanced in its vegetative stages, more eggs are oviposited in upper nodes than the lower nodes. With the majority of eggs laid on terminals, this suggests that females used those sites for oviposition because it aids in oviposition and chances of a successful hatch are greater. The absence of oviposition sites at lower nodes during vegetative stages was explained by two physiological changes to the soybean plant. Lower leaves and petioles sometimes drop off, while the main stem has increased toughness and woodiness, which can prevent oviposition at these sites on the plant.

The life cycle of the threecornered alfalfa hopper starts as an egg, progresses through five nymphal instars and to adult. The duration of the life cycle is dependent on temperature, photoperiod and food availability (Davis 1969). In Mississippi, the complete life cycle of the threecornered alfalfa hopper on soybeans is 36 to 38 days. Moore and Mueller (1975) observed that a mean temperature of 26 º C was ideal for a 1^{st} instar nymph to emerge as an adult in soybeans, though not a required temperature for development. First instar nymphs start out colorless and turn a light green in later instars. The size of each nymphal instar ranges from 1.7 mm for the first instar to 6.7 mm for the fifth instar (Wildermuth 1915; Jordan 1952, Davis 1969). Different instars are identified by key spines that can be seen on the surface of the body and development of wing pads (Wildermuth 1915; Davis 1969).

Threecornered Alfalfa Hopper Injury to Soybeans

The threecornered alfalfa hopper is a pest that is found regularly in soybeans in the southern United States (Mueller and Jones 1983). There are two methods of feeding for adults and nymphs. One is a single puncture of the stem and the second is a continuous puncture around the stem, which creates a girdle (Wildermuth 1915). On young soybean, the threecornered alfalfa hopper feeds on the main stem, just above the soil line, causing a girdle to appear. Girdling from threecornered alfalfa hoppers interferes with the flow of nutrients through the phloem. This interference allows nutrients to concentrate just above the girdle, which is consumed by the threecornered alfalfa hopper feeding in the phloem tissue (Mitchell and Newsom 1984b). This injury to the plant can lead to breakage and lodging and potentially death. Packard (1951) were the first to mention the threecornered alfalfa hopper causing specific injury to soybeans. Though several reports in the past had previously referred to beans, it was unclear if the authors were referring to soybean. The threecornered alfalfa hopper was first reported in soybeans with high infestation numbers in the upper Red River Valley area of Louisiana by Jordan (1952). Yield losses from threecornered alfalfa hopper is dependent on soybean stand and environmental conditions. Losing a few plants from girdling has shown no reduction in yield in many cases (Mueller and Dumas 1975). The ability of soybean to compensate for reduced plant densities is the main reason for no reduction in yield. During early growth stages, healthy soybean plants compensate for damaged plants because of their ability to branch out and take up space. Previous research has shown that soybean can tolerate a 45% stand reduction during vegetative growth stages and not experience any significant losses in yield (Caviness and Miner 1962). Yield reduction was reported by Caviness and Miner (1962) when simulated damage was performed to a soybean stand from the bloom stage to two weeks after bloom. Tugwell and Miner (1967) found severe girdling in small, confined areas with a reduction in plant population, but no reduction in yield. Adults and nymphs feed on the plant by placing the sharp proboscis into the plant, extracting the juices. Threecornered alfalfa hopper can move directly into soybeans once they break diapause due to the early soybean production system established in the Mid-South. This is their first generation in soybeans. Feeding on these early seedling and vegetative plants is different depending on the insect growth stage. First and second instar nymphs do not cause much harm to the plant since they feed by single random punctures (Moore and Mueller 1976). Adults migrating into soybeans and late instars feed by continuously puncturing the circumference of the stem, forming a girdle. There is some controversy over which life stage is responsible for the most damage. Jordan (1952) saw little girdling from adults when they were caged on soybean plants and stated nymphs were responsible for the majority of girdling, but only made that statement because of the caged environment, saying it was highly unlikely in field conditions. In a greenhouse study, later instar nymphs were found to be the most injurious to soybean plants. Fourth instar nymphs cause the most injury and a single insect is capable of girdling the stem of a plant in 24 hours (Moore and Mueller 1976). They also found in their studies, that third and fifth nymphal instars cause minor injury to the main stem from girdling and no girdling to the main stem from adults was seen at all. Moore and Mueller (1976) observed threecornered alfalfa hopper adults feeding at main stem girdles in the field. According to Rice and Drees (1985) threecornered alfalfa hopper adults girdle main stems soon after emergence of plants. In a field study, they observed 100 percent girdling of main stems within 15 days after emergence of soybean plants. This girdling could only be associated with adults migrating into the field, because nymphs do not girdle the main stem of the plant until the third instar or later. Nymphs could not contribute to girdling of the main stem during the first 14 days of plant emergence because it requires 7 days for eggs to hatch and another 7 days for nymphs to reach the third instar. Girdles formed from feeding on the lower portion of the main stem can lead to lodging, breakage, and plant mortality. Yield losses can occur from the death of individual plants and the reduction of the number and weight of beans produced (Mueller and Dumas 1975). Feeding on the lower main stem of the plant typically occurs until plants are 20 to 25 cm tall (Bailey et al. 1970, Davis 1969). Soybean planted later in the growing season are likely to be infested with threecornered alfalfa hopper due to high numbers in the environment (Tugwell et al 1972). Sparks and Newsom (1984) saw reductions in yield in late season soybeans when adult populations ranged from 143 to 476.5 per 100 sweeps in R5 growth stage soybean. The trial was repeated a year later and they saw similar yield results with fewer adults. As the plant grows, threecornered alfalfa hopper move up into the canopy to feed on petioles. They discontinue feeding on the main stem due to the thickness and woodiness of the stem (Bailey et al. 1970, Mitchell and Newsom 1984b).

Threecornered Alfalfa Hopper Recent Emergence in Cotton

Recently, the importance of threecornered alfalfa hopper has increased in seedling cotton. This establishment is seen primarily in the Hills region of Mississippi and occasionally in areas were the Hills neighbor the Delta region. Mississippi is split geographically into two primary agricultural regions, the Hills and Delta. The Hills consist of small cultivated fields, with a low percentage of the land area devoted to row crop agriculture. The Delta, in contrast, is made up of large cultivated fields with a large percentage of the land area dedicated to row crop agriculture (NASS 2007). Typically damage from threecornered alfalfa hopper is concentrated along field edges and not across entire cotton fields (Catchot 2012). There is no previous research on threecornered alfalfa hopper damage in cotton. Threecornered alfalfa hopper cause injury to cotton when the plant is in the seedling stage. Cotton seedlings that have been injured by threecornered alfalfa hopper will have a stunted appearance, leaf veins will turn red, and leaves will have a red or orange color. Threecornered alfalfa hopper will usually girdle the main stem of cotton seedlings just below the cotyledons (Catchot 2012). In many cases threecornered alfalfa hopper injury to cotton seedlings results in lodging or plant death. Compared to soybean plants that have been injured by the threecornered alfalfa hopper, which can recover from the injury and go on to produce normal yields (Catchot 2012).

Threecornered Alfalfa Hopper Management

The current threshold for threecornered alfalfa hopper in soybeans is two hoppers per sweep or 50 per 25 sweeps when plants are greater than 25 centimeters tall. This was changed in the Mississippi Insect Control Guide for Agronomic Crops in 2011 from one threecornered alfalfa hopper per sweep based on previous research by a graduate student at Mississippi State University (Pulakkatu-thodi 2010). The threshold of one threecornered alfalfa hopper/sweep was established by researchers at Louisiana State University and University of Arkansas (Sparks and Newsom 1984, Mueller and Jones 1983). Plants less than 25 centimeters tall should be treated before plant stand is reduced below recommended plant population. The main control of threecornered alfalfa hopper in the mid-South and southeast is the use of insecticides. Current insecticide classes recommended for control of threecornered alfalfa hopper in Mississippi soybean are organophosphates and pyrethroids (Catchot et al. 2014). Recommended organophosphates are acephate and dimethoate. Recommended pyrethroids include beta-cyfluthrin, bifenthrin, esfenvalerate, gamma-cyhalothrin, lambda-cyhalothrin, and zeta cypermethrin. Insecticides should be applied only when densities exceed threshold because pyrethroids and organophosphates can reduce beneficial insect densities, potentially resulting in corn earworm and other insect outbreaks (Catchot 2014).

In cotton, no economic threshold for threecornered alfalfa hopper has been established. However, treatment is recommended when threecornered alfalfa hopper infestations threaten to reduced plant stand below desired plant population. Girdling from threecornered alfalfa hoppers usually ends when cotton is at 6 to 8 nodes. Catchot (2012) recommended treating for threecornered alfalfa hopper when cotton is at 5 nodes or less and you can visually see one threecornered alfalfa hopper per 0.6 to 0.9 row meters or 10 threecornered alfalfa hopper per 25 sweeps. However, these thresholds are not based on any research. Options for control of threecornered alfalfa hopper in cotton are similar to control options in soybean. Pyrethroids and organophosphates work well, but pyrethroids have the potential to flare spider mites in cotton, so applications should only be made when plant stand is at risk (Catchot 2012).

Population Dynamics

Threecornered alfalfa hopper activity throughout the different seasons of the year is based on climatic conditions (Davis 1969). According to Jordan (1952), adults remain active during mild winters and go into reproductive diapause during cold periods. Adults can be found overwintering under wood and trash debris as well us under pine trees. On warmer winter days, adults will feed on pine needles (Davis 1969, Newsom et al. 1983). In spring, threecornered alfalfa hopper will break diapause and move to a leguminous host such as clover or vetch and start reproduction (Newsom et al. 1983). Threecornered alfalfa hoppers can have 3 to 4 generations per year (Mitchell and Newsom 1984a, Jordan 1952, Wildermuth 1915). In soybean, threecornered alfalfa hopper has at a minimum of two generations per year (Heatherly 1999). Historically when soybeans were planted after cotton, the first generation usually occurred on some host other than soybeans. Due to early season soybean production, the threecornered alfalfa hopper is starting to break reproductive diapause and move directly into early planted soybeans instead of moving into other leguminous hosts. This is resulting in high populations of threecornered alfalfa hoppers in vegetative soybeans, which is a critical period of growth for the soybean plant (Pullakatu-Thodi 2010). To address gaps in our knowledge of threecornered alfalfa hopper impact on cotton seedlings and reproductive stage soybean, research was conducted to refine current management thresholds for threecornered alfalfa hopper. Specifically, the current threecornered alfalfa hopper threshold in reproductive-stage soybean was evaluated at very high densities, sweep net efficiency in reproductive-stage soybean was estimated so that threecornered alfalfa hopper thresholds could be generated for sweep net sampling, and the impact of threecornered alfalfa hopper on cotton seedlings was evaluated.

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CHAPTER II

REFINING THRESHOLD AND ESTIMATING SWEEP NET SAMPLING EFFICIENCY FOR THREECORNERED ALFALFA HOPPER ADULTS IN SOYBEANS

Abstract

Field experiments were conducted in 2012, 2013 and 2014 at the R. R. Foil Plant Science Research Center in Starkville, MS and the Delta Research and Extension Center in Stoneville, MS to determine the efficiency of a sweep net for threecornered alfalfa hopper sampling and to determine the impact of feeding by high densities of threecornered alfalfa hoppers in soybean. Sweep net efficiency studies were conducted in order to convert the densities used in the cages to a sweep net threshold. No significant yield losses were observed from threecornered alfalfa hopper feeding during reproductive growth stages. Densities tested were approximately three times the current threshold and exceeded the densities observed in Mississippi, so there does not appear to be a practical threshold for adult threecornered alfalfa hopper during reproductive soybean growth.

Introduction

Compared to later planting dates, planting soybeans in April and May in the Mid-South results in greater yield and profit potential, and aids in the avoidance of late season insect pests (Heatherly 1999). Planting maturity groups IV and V soybean during April and May in the Mid-South is recommended compared to planting determinate cultivars in maturity groups V, VI, and VII during June that often suffer losses in yield from drought throughout late summer (Heatherly 1999). Farmers across the Mid-South have moved toward this early season soybean production system when weather permits, and away from the traditional planting dates in May and June unless delays occur due to weather conditions or in fields planted following wheat. This new approach has benefited growers with higher yields and reduces the occurrence of late season pest pressure. However, early season soybean production practices has resulted in higher populations of threecornered alfalfa hoppers, *Spissistilus festinus* (Say) (Hemiptera: Membracidae) and stink bugs (Hemiptera: Pentatomidae) in soybean (Bauer et al. 2000, McPherson et al. 2001).

Threecornered alfalfa hopper is commonly found in soybean in Mississippi. Threecornered alfalfa hopper causes girdles to form on soybean plants due to puncturing the plant in a ring around the stem while feeding (Wildermuth 1915). Stem girdling partially blocks the flow of nutrients down the phloem of the plant, causing the accumulation of nutrients above the girdle, and providing the threecornered alfalfa hopper a more concentrated food source (Hicks et al. 1984). Lodging, or plant breakage, can occur due to girdling of the main stem by early season feeding from the threecornered alfalfa hopper (Bailey et al. 1970). Mueller and Dumas (1975) examined the impact of threecornered alfalfa hopper feeding during vegetative growth. Yield losses occurred from the death of individual plants or the reduction of the number and weight of beans produced.

Mitchell and Newsom (1984) explained that once soybean reach reproductive growth stages, threecornered alfalfa hoppers move away from the main stem and girdle leaf petioles, lateral branches, and peduncles. The effect on yield from threecornered alfalfa hopper injury recorded during reproductive stage soybean has varied among researchers. Davis (1969) found that petioles and branches girdled from threecornered alfalfa hopper did not have any serious effect on the plant. Sparks and Boethel (1987) stated that it was known that threecornered alfalfa hopper decreased soybean yield in reproductive soybeans, but were unsure of the actual cause. They hypothesized that possible reductions in yield came from girdling of petioles and feeding on pods. They conducted field experiments in reproductive stage soybean in 1983 and 1984 looking at the impact of adults and nymphs on soybean yield. The amount of yield loss in experiments performed in 1983 was double that observed in 1984. The authors suggested that other factors were involved in yield loss other than petiole girdling, such as feeding on the peduncle and pod. Sparks and Newsom (1984) suggested that yield reductions were possible due to threecornered alfalfa hopper feeding on pedicels and pods without girdling the plant. Pulakkatu-thodi (2010) observed no impact on yield at any reproductive growth stage from threecornered alfalfa hopper girdling in the field. He saw that throughout reproductive growth stages, girdled areas were concentrated on leaf petioles in the upper half of the plant. The main concentration of girdles was 8 to 17 nodes from the base of the soybean plant. The number of main stem girdles under high infestations of threecornered alfalfa hoppers was low, suggesting that main stems are not suitable for threecornered alfalfa hopper feeding during soybean reproductive growth.

He concluded that threecornered alfalfa hopper adults did not have an impact on yield during reproductive growth at densities up to 3 threecornered alfalfa hoppers per plant.

This study was conducted to determine if there is any impact of threecornered alfalfa hopper feeding in reproductive soybeans at densities exceeding those found in field situations. Research in the past established a treatment threshold for threecornered alfalfa hoppers in reproductive soybeans in Louisiana of one insect per sweep (Sparks and Newsom 1984). However, published data to support this threshold is minimal. We hypothesize that leaf injury to the soybean plant from high densities of adult threecornered alfalfa hopper will have an impact on yield during reproductive growth stages. To test this hypothesis, we looked at yield and injury from threecornered alfalfa hopper at a single high density in field cages compared to uninfested field cages during various reproductive stages of soybeans.

Materials and Methods

Feeding Impacts

Experiments were performed at the R. R. Foil Plant Science Research Center in Starkville, MS and the Delta Research and Extension Center in Stoneville, MS during 2012, 2013 and 2014. Planting date and variety for all three years and locations are shown in Table 2.1. Soybean was planted on 96 cm rows with plant density of 26 plants per row meter as recommended by Mississippi State University (Catchot et al. 2015). 1.8 m x 1.8 m x 1.8 m field cages were set up a few days prior to infestation, with each cage covering two rows of soybean. Cages were set up in a randomized complete block design. The number of cages used varied from four to eight (half infested and half uninfested), depending on the availability of threecornered alfalfa hoppers. The treatments consisted of cages infested with 720 adult threecornered alfalfa hoppers (200 hoppers per row meter) and uninfested cages. Threecornered alfalfa hoppers were collected from soybean fields in the region using a 38 cm diameter sweep net within 24 hours of infestation. Three days prior to infesting cages, an insecticide application was made to each cage to eliminate predators and natural populations of threecornered alfalfa hoppers. Cages were infested for 14 days and insecticide was applied to all cages after 14 days to eliminate surviving threecornered alfalfa hoppers. Both insecticide applications were with Karate Z 2.08 CS (Syngenta Crop Protection, U.S.) at the rate of 9.46 ml/ha or Orthene 90S (Amvac Chemical Company, U.S.) at a rate of 0.45 kg/ha. Three days after the second insecticide was applied, 5 plants were removed from each cage and observed for girdling on the main stem, lateral branches, leaf petiole, peduncle, and pod. The number of girdles and location of girdles was recorded. Once the soybean plants reached maturity, plots were harvested with a combine. Weight and moisture were measured to estimate yield. All data were subjected to analysis of variance using PROC GLIMMIX of SAS program version 9.3 (SAS Institute 2012). Infestation was designated as a fixed effect. Soybean growth stage, location and location nested in year were designated as random effects. Infestation was randomly applied to various reproductive growth stages of soybean making growth stage a random effect. Differences were considered significant for $P<0.05$. Degrees of freedom were calculated using the Kenwood-Roger Method.

Sampling Efficiency

Experiments were performed at the R. R. Foil Plant Science Research Center in Starkville, MS during 2012, 2013 and 2014. The planting dates and varieties were the same as used for the other trial (Table 2.1). Soybeans were planted on 96 cm rows with plant density of 26 plants per row meter as recommended by Mississippi State University. 6 m x 6 m x 1.8m field cages were set up during or after the R3 growth stage on six rows of soybeans. Cages were set up in a randomized completed block design. Treatments consisted of four pest densities (0, 8.2, 16.40, 24.61 adult threecornered alfalfa hoppers per row meter) caged on soybeans for several days. Four treatments of 0, 6.56, 13.12, and 19.69 threecornered alfalfa hopper adults per row meter were used in earlier infestations when threecornered alfalfa hopper field populations were low. Threecornered alfalfa hoppers for the infestations were collected using a 38 cm diameter sweep net from nearby soybean fields. Infestation dates for 2012 in Starkville were 07, 14 and 20 Aug., and 10, 19 and 28 Sept. (Soybeans planted on 18, June 2012). Infestation dates for 2013 in Starkville were 01, 08, 15 and 23 Aug., and 05 and 17 Sept. (Soybeans planted on 13, June 2014 and 29, July 2014). Infestation dates during 2014 were 05, 12 and 26 Aug. (Soybeans planted on 18, June 2014 and 17, July 2014). Cages were moved within the field between all infestations, resulting in 15 independent infestations. One day after infestation, a 20 sweep sample was taken from each cage. After enumeration, the insects were released back into the cage. An additional sample was taken on each of the next 3 days, resulting in four sweep net samples for each cage. All data collected were subjected to analysis of variances using PROC GLIMMIX of SAS program version 9.3 (SAS Institute 2012). Soybean growth stage, number released per meter of row and their interaction were designated as fixed effects. Release date was designated as a random effect. Differences were considered significant for $P<0.05$. Degrees of freedom were calculated using the Kenwood-Roger Method.

Table 2.1 Location, planting date, variety and infestation date of threecornered alfalfa hopper threshold trials.

Location	Planting Date	Variety	Infestation Dates	Growth Stage When Infested
Starkville	18-Jun-2012	Asgrow 5605	10-Aug-12	R3
Starkville	18-Jun-2012	Asgrow 5605	6-Sep-12	R5.5
Stoneville	18-Jun-2012	Asgrow 4605	10-Aug-12	R3
Starkville	13-Jun-2013	Asgrow 5332	16-Aug-13	R4
Starkville	29-Jul-2013	Asgrow 5332	9-Sep-13	R3
Stoneville	13-Jun-2013	Pioneer 94Y82	21-Aug-13	R4
Starkville	18-Jun-2014	Asgrow 5332	24-Jul-14	R3
Starkville	17-Jul-2014	Asgrow 5332	19-Aug-14	R3
Starkville	17-Jul-2014	Asgrow 5332	17-Sep-14	R4

Results and Discussion

Girdling

The mean number of girdles over all locations was significantly greater in infested cages than in uninfested cages (F=10.74; df=1, 45.54; P=0.002). However, yield did not vary between infested and uninfested cages (F=0.56; df=1, 48.04; P=0.46). When analyzing each infestation independently, it was observed that the mean number of girdles varied for infested and uninfested treatments for three release dates, but not at the other 5 infestations (Fig. 2.1). Threecornered alfalfa hopper adults can feed without creating girdles, so the absence of girdles does not indicate the absence of threecornered alfalfa hopper feeding (Sparks and Newsom 1984). The conditions that stimulate threecornered alfalfa hoppers to create girdles are unknown. When evaluating locations independently, yield did not vary at any location (Fig. 2.2). These 3 sites years with significant girdling were analyzed together to obtain more statistical power in observing differences in yield. However there was still no significant yield difference between infested and uninfested cages for these three locations when analyzed together (F=1.17; df=1, 21.4; P=0.29). There wasn't even a trend toward yield loss as the average yield in the infested cages (2,224 kg/ha) was numerically higher than in the uninfested cages (2,121 kg/ha). When threecornered alfalfa hoppers are present in reproductive soybean, they are found in the canopy, feeding on lateral branches and leaf petioles. Because they do not feed on the main stem of the plant at this time, the possibility of the plant breaking over due to threecornered alfalfa hopper injury is negligible. Threecornered alfalfa hoppers injury was not observed on peduncles and pods at any time throughout this experiment. With overall yield not varying using a threecornered alfalfa hopper density higher than what is observed in the field, it can be concluded that threecornered alfalfa hopper feeding by adults during reproductive growth stages has no impact on soybean yield.

Our results are comparable with Pulakkatu-thodi (2010) in that the mean number of girdles varied significantly with threecornered alfalfa hopper density, but there was no significant reductions in yield seen from threecornered alfalfa hopper injury while soybean were in reproductive growth stages. Sparks and Boethel (1987) stated that late-season damage from threecornered alfalfa hopper reduced soybean yield. Through their observations they suggested pod feeding was the primary role in the decrease in yield due to low numbers of petiole girdles. We, as well as Pulakkatu-thodi (2010), did not observe girdling on peduncles, pedicels or pods. This is in agreement with Mitchell and Newsom (1984) that girdling rarely occurs on these structures. Reduction in yield does not appear to be associated with pod shedding or abortion of seed from girdling because threecornered alfalfa hoppers rarely girdle reproductive structures (Pulakkatu-thodi

2010). The role of nymphs in reproductive growth stages of soybean was not addressed in this study. It is important to understand the role nymphs play in girdling soybean plants, especially late instars because they girdle plants similar to adults (Moore and Mueller 1975). Nymphs feed similarly to adults, so unless they girdle pods, it is unlikely they cause yield damage during reproductive stages. Pulakkatu-thodi (2010) observed no pod shedding due to girdling of the pedicel by threecornered alfalfa hopper nymphs.

Sweep Net Sampling

The sweep net is an effective tool for estimating adult threecornered alfalfa hopper densities. The regression of released adults with captured adults in a sweep net was significant ($F= 140.64$; $df= 1, 44.4$; $P= <0.0001$) and explained 45% of the observed variability (Fig 2.3). The number of threecornered alfalfa hoppers collected increased by 0.6 ± 0.3 per 20 sweeps for each additional threecornered alfalfa hopper released per row meter. Based on this recapture rate, the number of threecornered alfalfa hoppers released in the threshold trials described previously was equivalent to 5.8 threecornered alfalfa hoppers per sweep. This is approximately three times the current threshold of 2 threecornered alfalfa hoppers per sweep, and still no yield loss was observed. Limitations for sweep net efficiency included threecornered alfalfa hopper mortality after release into cages and incidents when threecornered alfalfa hoppers rested on cage walls and were not captured by the sweep net. However, both threshold trials and sweep net trials were conducted under the same conditions, so any impact of experimental conditions impacted both, so the sweep net equivalence does not change.

Threecornered alfalfa hopper has been labeled a pest of reproductive stage soybean for many years. While early season threecornered alfalfa hopper injury may negatively impact yield in vegetative soybeans, it appears that any yield reduction from threecornered alfalfa hopper feeding during reproductive soybean stages is at most a rare event. Research in the 1970's and 1980's created awareness for this pest and treatment thresholds were established based on limited research showing the potential to decrease yield when high numbers of threecornered alfalfa hopper were present. The pest status of threecornered alfalfa hopper was not challenged for a number of years until thresholds were re-evaluated in light of the numerous changes in soybean production practices. Pulakkatu-thodi (2010) conducted research on threecornered alfalfa hopper to understand the nature of the threecornered alfalfa hopper as a pest in early soybean production systems. In his research, no reductions in yield were observed from threecornered alfalfa hopper adult and nymph injury in field and greenhouse trials when soybean were infested during reproductive growth stages. Our experiments had similar results. Because no reductions in yield were seen at different reproductive growth stages, our data suggests it is not economically beneficial to target this insect once soybeans reach the reproductive growth stage. However, reductions in yield from threecornered alfalfa hopper feeding may occur when soybeans are in vegetative growth stage. Soybean seed treatments provide protection during vegetative growth and some yield benefit from this protection has been observed in the Mid-South where threecornered alfalfa hopper are common (Catchot et al 2014). However, further studies are needed to better understand threecornered alfalfa hopper injury in vegetative soybean and their impact on yield. Results of this study have confirmed that adult threecornered alfalfa hopper is not an economic pest of reproductive soybeans and therefore treatment thresholds can be removed from recommendations. In this study threecornered alfalfa hopper nymphs were not addressed. It is important to understand the role nymphs play in girdling soybean plants because of how similar they girdle compared to adults. In reproductive growth stage soybean, threecornered alfalfa hopper nymphs will girdle leaf petioles and lateral branches, but tend to feed mainly on stem structures (Pulakkatu-thodi 2010). It is possible that threecornered alfalfa hopper nymphs will girdle peduncles and pedicels, but Pulakkatu-thodi (2010) observed no pod shedding due to girdling of pedicel. The main issue with threecornered alfalfa hopper nymphs is the inability to effectively sample nymphs with a sweep net. Sparks and Boethel (1987) observed how inefficient a sweep net was for collecting threecornered alfalfa hopper nymphs. They indicated that the inefficiency of a sweep net to collect nymphs allowed for a damaging population to be established and develop through nymphal stages before being detected. To accurately refine the economic threshold for threecornered alfalfa hopper nymphs, sampling techniques for nymphs and measurement of a threshold density based on nymph populations is needed (Sparks and Boethel 1987).

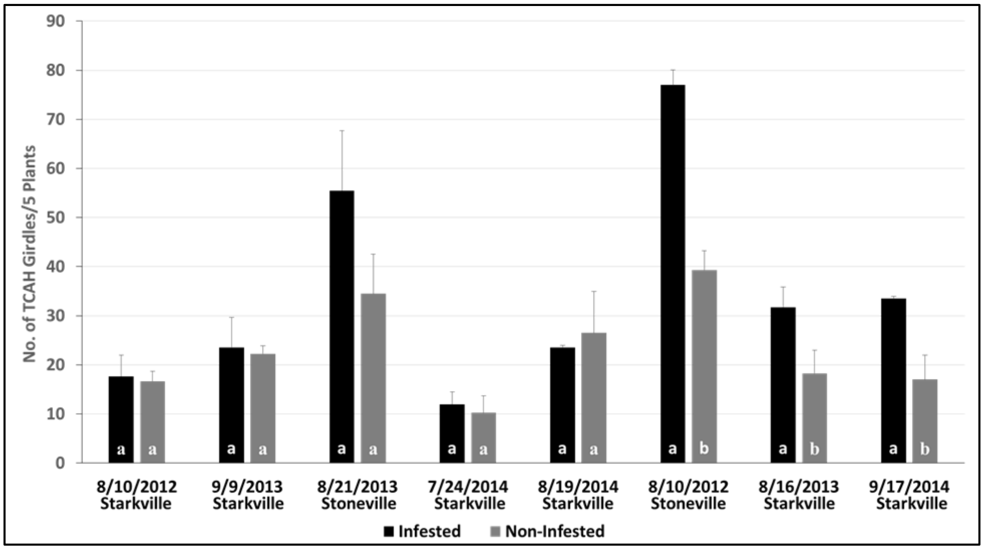

Figure 2.1 Mean number of girdles ± SEM/5 plants

Cages were either infested with 200 threecornered alfalfa hoppers/row m or non-infested for two weeks during reproductive growth. Bars sharing the same letter within an infestation location are not significantly different ($P<0.05$). (Starkville and Stoneville, MS)

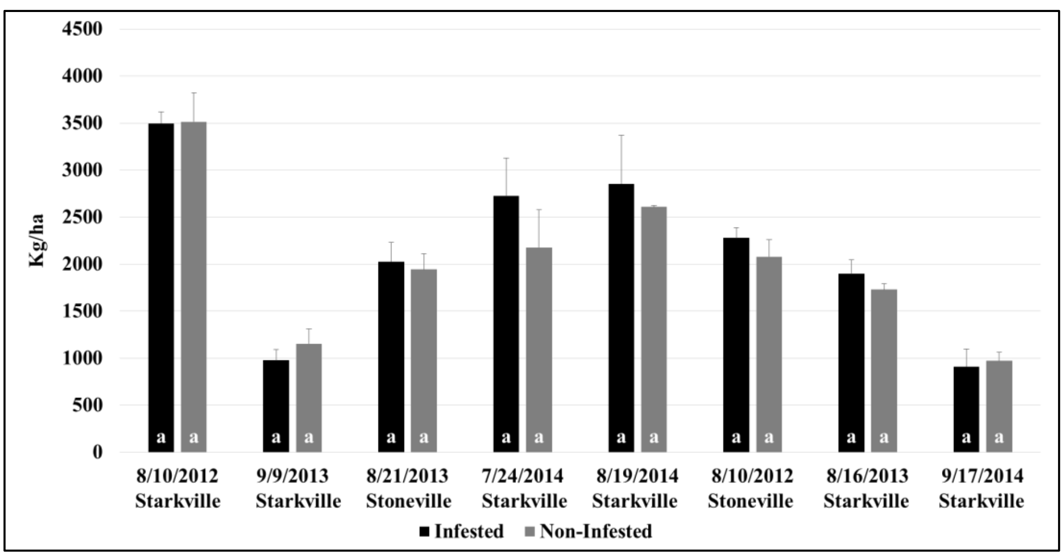

Figure 2.2 Mean yield ± SEM (kg/ha) for infested and non-infested soybeans

Caged soybeans were either infested with 200 threecornered alfalfa hoppers/ row m or non-infested for two weeks during reproductive growth. Bars sharing the same letter within an infestation location are not significantly different ($P<0.05$). (Starkville and Stoneville, MS)

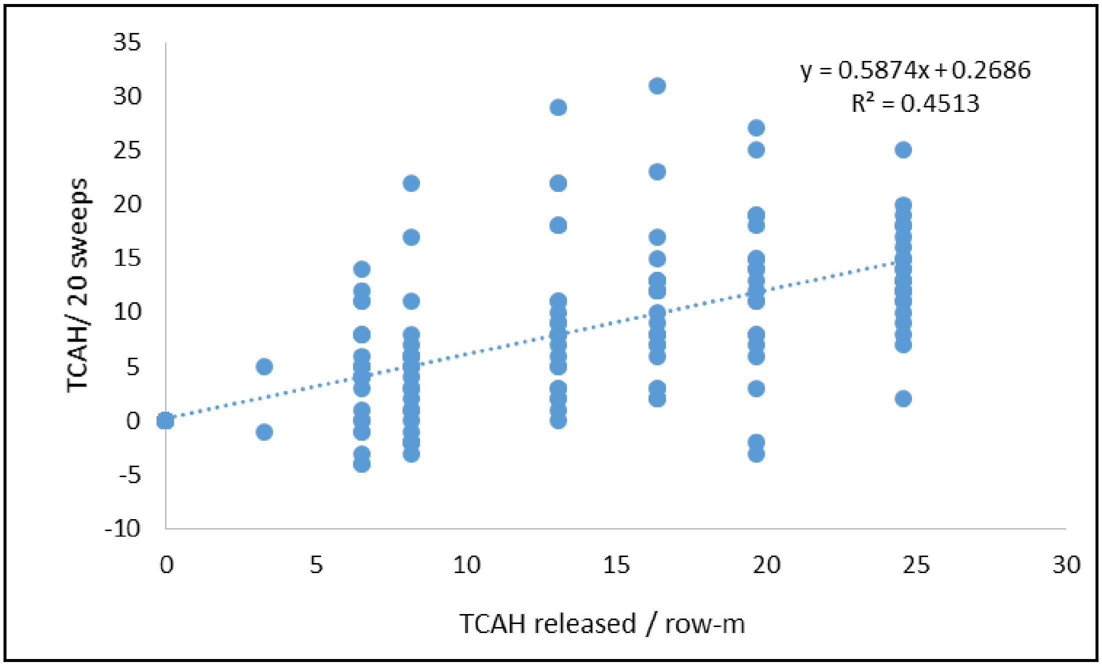

Figure 2.3 Regression of the number of threecornered alfalfa hoppers caught per 20 sweeps with the number of threecornered alfalfa hopper released in field cages.

Data shown corrected for the number of naturally occurring threecornered alfalfa hoppers in the field as estimated by the number caught in cages where no insects were released. (Starkville, MS 2012, 2013, 2014)

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CHAPTER III

DETERMINING THE IMPACT OF THREECORNERED ALFALFA HOPPER ON SEEDLING COTTON

Abstract

Experiments were conducted during 2013 and 2014 at the R.R. Foil Plant Science Research Center at Starkville, MS and the Black Belt Experiment Station in Brooksville, MS to determine the impact of threecornered alfalfa hopper injury to seedling cotton on yield. Plants with main stem girdles were identified as damaged and nearby plants without girdles were identified as undamaged to give paired observations. Threecornered alfalfa hopper injury to seedling cotton plants impacted yield on a per plant basis, but further research is needed to understand the ability for undamaged cotton plants to compensate for damaged cotton plants. In 2014, surveys were conducted in the Hills and Delta regions of Mississippi looking for threecornered alfalfa hopper damage to seedling cotton. Injury from threecornered alfalfa hoppers was confined to field edges rather than entire cotton fields.

Introduction

Threecornered alfalfa hopper, *Spissistilus festinus* (Say) is primarily a pest of soybeans, but recently has been observed infesting cotton. Problems with threecornered alfalfa hopper in Mississippi cotton are primarily concentrated in the Hills region of

Mississippi and the south Delta region (Catchot 2012). Mississippi is split geographically into two regions, the Hills and Delta. The Hills consist of small cultivated fields, with a low percentage of land devoted to row crop agriculture. The Delta, in contrast is made up of large cultivated fields with a majority of land dedicated to row crop agriculture (NASS 2007). Ewing and McGarr (1933) observed high numbers of threecornered alfalfa hoppers in cotton, but saw no reduction in yield. Feeding in cotton is similar to that of soybean. They insert their sharp mouth parts into the main stem to extract plant juices. Cotton plants injured by threecornered alfalfa hopper can have one girdle or more girdles on the main stem below the cotyledons. Girdling from the threecornered alfalfa hopper interferes with the flow of nutrients through the phloem. This interference allows nutrients to concentrate just above the girdle, which is consumed by the threecornered alfalfa hopper feeding in the phloem tissue (Mitchell and Newsom 1984b). Other indicators of injury from threecornered alfalfa hopper is a stunted appearance of cotton plants, leaf veins become dark red and leaves turn a red to orange color. Unlike soybean, which for the most part are capable of overcoming injury from threecornered alfalfa hopper, cotton plants bend over and break or can be killed outright (Catchot 2012).

There is no research based threshold for threecornered alfalfa hopper in cotton. Treatment is recommended when the plant stand has been reduced below desired plant population. Catchot (2012) recommended treatment when one threecornered alfalfa hopper could be observed every 0.6 to 0.9 meters of row or 10 threecornered alfalfa hoppers caught per 25 sweeps when cotton has 5 nodes or less. Treatment for threecornered alfalfa hopper in cotton is not recommended after the plant has 8 nodes because main stem girdling usually stops after plants reach 6 to 8 nodes (Catchot 2012).

When treating threecornered alfalfa hopper in cotton, control options are the same as they are in soybean. Pyrethroids and acephate work well at controlling threecornered alfalfa hopper in cotton, but are only recommended in severe cases due to the potential to flare spider mites in cotton (Catchot 2012).

This experiment looked at the impact threecornered alfalfa hoppers have on yield in cotton. We hypothesize that main stem girdling injury from threecornered alfalfa hoppers to seedling cotton will have an impact on yield. To test this hypothesis, we identified damaged seedling cotton plants with threecornered alfalfa hopper injury and compared them to nearby undamaged seedling cotton plants. We also conducted surveys in the Hills and Delta regions of Mississippi looking at threecornered alfalfa hopper damage. We hypothesize that threecornered alfalfa hopper damage is confined to field edges rather than being distributed across entire cotton fields.

Materials and Methods

Feeding Impacts

Experiments were conducted in 2013 and 2014 at the R. R. Foil Plant Science Research Center in Starkville, MS and the Black Belt Experiment Station in Brooksville, MS. Cotton fields were scouted at the 3-leaf stage to identify plants damaged by threecornered alfalfa hopper. Phytogen 499 and Phytogen 315 cotton varieties were planted at Starkville in 2013 and 2014 respectively. Phytogen 499 was planted at the Brooksville location in both 2013 and 2014. Cotton plants were planted on 96 cm rows with a plant density of 13 plants per row meter as recommended by Mississippi State University (Catchot 2015). During 2013, plants with main stem girdles were considered damaged and marked with yellow flags and an undamaged plant were randomly chosen at least 3 plants away from the nearest damaged plant and marked with a blue flag to create a paired observation. Eighty eight damaged plants were identified over eight rows at the Starkville location and one hundred plants were identified over 15 rows at the Brooksville location. In 2014, seventy two damaged plants were identified over 12 rows at the Brooksville location and twenty eight plants were identified over 15 rows at the Starkville location. In contrast to 2013, the two undamaged plants adjacent to the damaged were marked with blue flags in 2014, instead of one more distant plant as performed in 2013. Each plant had unique identifiers and height and node for each pair was recorded every two weeks throughout the growing season. After cotton was defoliated, each flagged plant was cut off at ground level by hand and lint was hand harvested and weighed to determine yield. All data collected were subjected to analysis of variances using PROC GLIMMIX of SAS program version 9.3 (SAS Institute 2012). The experimental design was a randomized complete block design. Plant status (girdled or non-girdled) was designated as a fixed effect. Location and row nested within location were designated as random effects. Differences were considered significant for $P<0.05$. Degrees of freedom were calculated using the Kenwood-Roger method.

Distribution in Field

In 2014, surveys were performed in cotton fields in the Delta and Hill regions of Mississippi looking for threecornered alfalfa hopper damage. A total of twenty seven cotton fields were surveyed. Eighteen cotton fields were surveyed in the delta and nine cotton fields were surveyed in the hills. Fields were surveyed while cotton plants were at the 3-leaf and 4-leaf stage of growth. Each field was sampled at the distances of 0, 20, 50 and 100 meters from the edge of the field. At each distance into the field, 8 meters of row were measured counting the number of girdled plants on an individual row. All data collected were subjected to analysis of variances using PROC GLIMMIX of SAS program version 9.3 (SAS Institute 2012). The experimental design was a split plot design. Region, distance and their interaction were designated at fixed effects. Fields were selected by county, which was a random effect. Differences were considered significant for $P<0.05$. Degrees of freedom were calculated using the Kenwood-Roger method.

Results and Discussion

Girdling

Yield from girdled plants was significantly less than yield from undamaged plants in 2013 and 2014 (2013 $F=60.54$; $df=1, 278.8$; $P=<0.0001$) (2014 $F=82.88$;$df=1, 207.7$; $P=<0.0001$). In 2013, a 50 percent yield reduction in seed cotton was seen for individual girdled plants compared to non-girdled plants (Fig. 3.1). 2014 results showed a 67 percent yield reduction in seed cotton for individual girdled cotton plants compared to adjacent non-girdled cotton plants (Fig. 3.1). Mortality was observed in 25% and 22% of girdled plants in 2013 and 2014 respectively over both locations. In addition to yield loss, girdling from threecornered alfalfa hoppers on seedling cotton plants significantly reduced height for damaged plants compared to undamaged plants (Fig. 3.2, 3.3). Our results show that threecornered alfalfa hopper damage has an impact on yield of damaged cotton plants, but further research is needed to determine if overall yield is impacted from threecornered alfalfa hopper damage as we did not evaluate if compensation occurs. Our 2014 data could possibly show that undamaged cotton plants compensate for girdled plants. Yield was analyzed with lint that was handpicked from damaged and neighboring adjacent cotton plants and compared with undamaged cotton plants that were harvested with a cotton picker. Yield was higher from the plants adjacent to a damaged plant, but because the harvest methods were different, it is impossible to know how much compensation occurred. To accurately understand injury from threecornered alfalfa hopper on seedling cotton and the ways they affect yield, undamaged cotton plants should be handpicked to compare with damaged and neighboring adjacent plants. The ability for undamaged cotton plants to compensate for damaged plants due to threecornered alfalfa hopper girdling would be beneficial in understanding how yield is affected.

Region and Edge Effects

The number of girdled plants per 8 meters of row varied significantly between the Delta and Hills regions of Mississippi ($F=13.04$; $df=1, 95$; $P=0.0005$) (Fig. 3.4). Distance into the field was not significant for the number of girdled plants per 8 meters of row in either region (Hills $F=3.11$; $df=1, 32.8$; $P=0.089$) (Delta $F=2.51$; $df=1, 63.01$; $P=0.118$). The highest number of girdled plants observed was from a field in Noxubee County, Mississippi. There were 11 girdled plants at 0 meters, 10 girdled plants at 20 meters and 2 girdled plants at 50 meters recorded from this location, respectively. No other fields had more than 5 damaged plants out of approximately 250 plants. While this survey did not find an edge effect for threecornered alfalfa hopper damaged plants, most fields had little damage anywhere, so the statistical power to detect such a distribution was poor. Future surveys will need to find more heavily infested fields to detect a distribution trend within the field.

Conclusion

Threecornered alfalfa hopper can girdle cotton plants and girdled plants are less productive. Further understanding the ability of adjacent undamaged cotton plants to compensate for damaged plants is needed to know the extent to which threecornered alfalfa hopper injury affects total yield per field. Further understanding of this pest in cotton is needed due to the limited amount of published data for this pest in cotton.

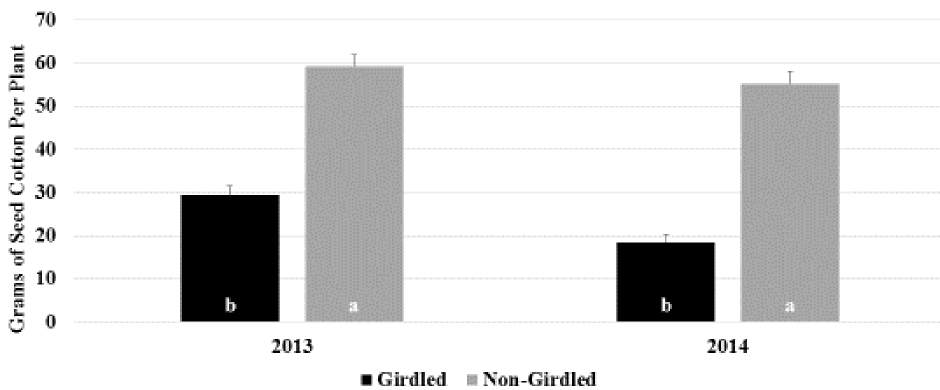

Figure 3.1 Yield ± SEM (g/plant) for girdled plants compared to non-girdled plants. Bars sharing the same letter grouping do not significantly differ (P<0.05). (Starkville and Brooksville 2013 and 2014)

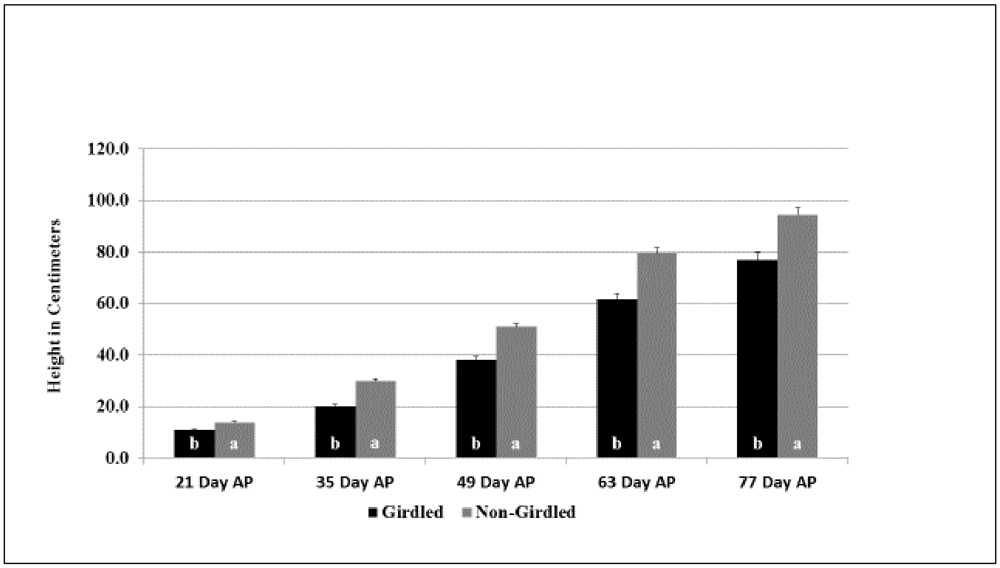

Figure 3.2 Mean height ± SEM of height of girdled cotton plants versus non-girdled cotton plants with measurements taken every two weeks after planting throughout growing season

Bars sharing the same letter group do not significantly differ ($P<0.05$). (Starkville and Brooksville 2013).

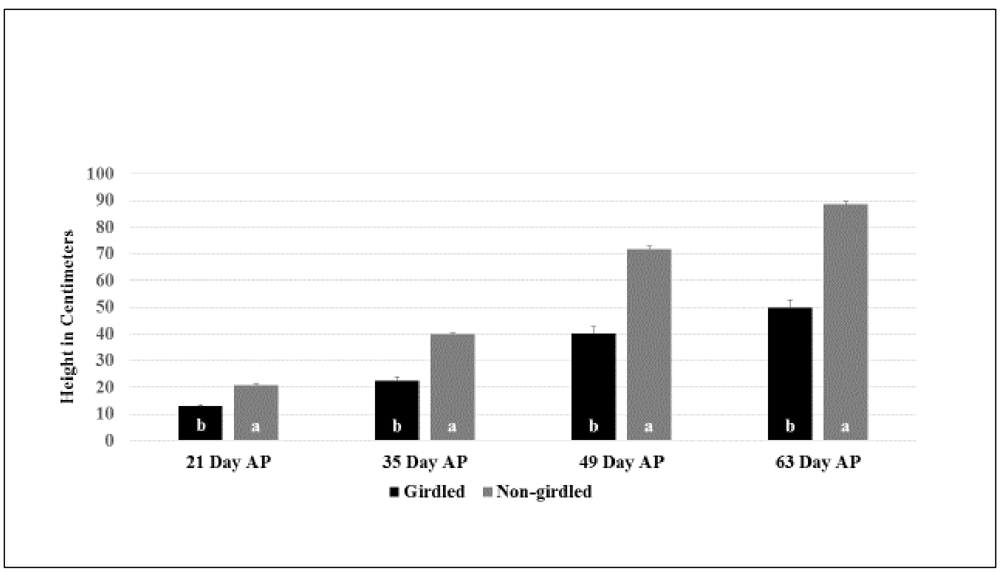

Figure 3.3 Mean height ± SEM of height of girdled plants versus non-girdled plants with measurements taken every two weeks after planting throughout growing season.

Bars sharing the same letter grouping do not significantly differ ($P<0.05$). (Starkville 2014; Brooksville 2014)

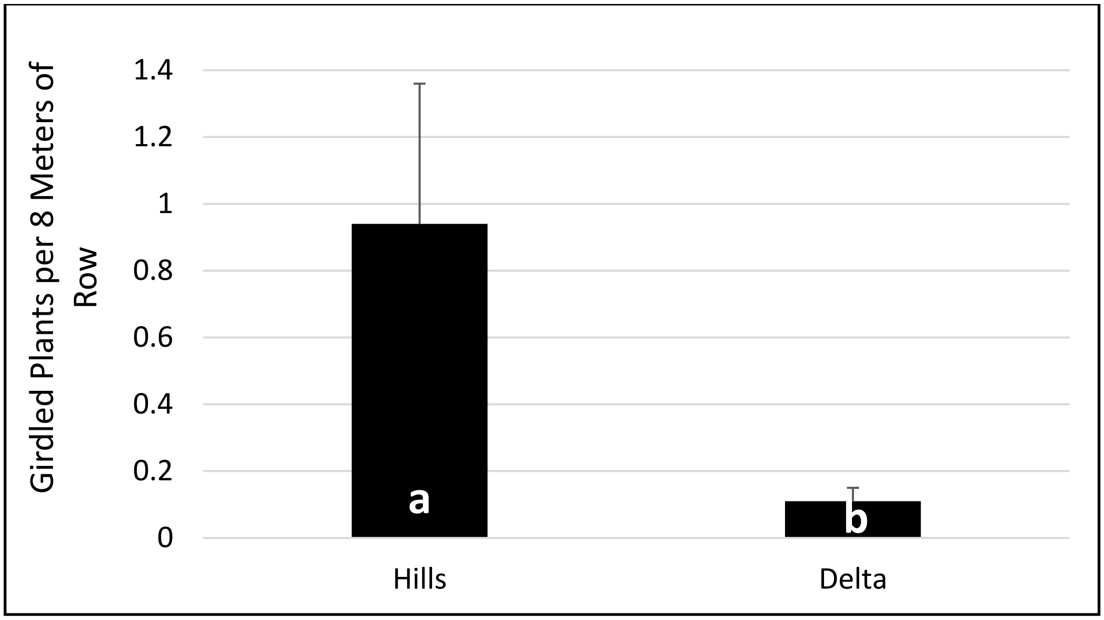

Figure 3.4 Mean number of girdled plants ± SEM per 8 meters of row for hills and delta region of Mississippi.

Bars sharing the same letter group do not significantly differ ($P<0.05$). (2014)

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