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Evaluation of defoliating caterpillar pests in Mississippi peanut

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Peanut, *Arachis hypogaea* (L.), provides good rotational benefits for subsequent crops. During 2017, 2018, and 2019, research was conducted to determine the defoliating caterpillar complex in peanut in Mississippi, create a sweep net threshold for the complex, and determine yield losses associated with defoliation. The complex is comprised of yellow-striped armyworm, *Spodoptera ornithogalli (Guenée);* soybean looper, *Chrysodeixis includens* (Walker); corn earworm, *Helicoverpa zea* (Boddie); fall armyworm, *S. frugiperda* (Coquillet); southern armyworm, *S. eridania* (Stoll); beet armyworm, *S. exigua* (Hübner); green cloverworm, *Hypena scabra* (Fabricius); velvetbean caterpillar, *Anticarsia gemmatalis* (Hübner); and granulate cutworm, *Feltia subterranea* (F.). There was a significant relationship between the number of caterpillars on a drop cloth and the number per 25 sweeps. Defoliation during vegetative and early reproductive stage peanut caused a delay in canopy closure for all levels of defoliation although yield losses of 11.2% only occurred when defoliation reached 100%. During late season, peanut yield was reduced by 13% when defoliation reached 50%. With these data, a sweep net sampling and defoliation threshold can be derived. Managing caterpillar pests all season is necessary to reduce chances of yield loss due to defoliation.

DEDICATION

I would like to dedicate this research to my late grandfather, Roy Etheridge. Thank you for instilling in me that hard work pays off no matter the difficulty of the task. To my parents, thank you for always pushing me to be my best. To my uncle Rusty Mitchell, thank you for teaching me to be an outstanding entomologist. Without the support and love each of you have provided all these years, I would not be the person I am today nor would I have the drive to better myself with each passing day.

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CHAPTER I

EVALUATION OF DAMAGE FROM DEFOLIATING CATERPILLAR PESTS IN PRE-FLOWERING AND EARLY REPRODUCTIVE STAGE PEANUT

Abstract

Although damage is not always severe, caterpillars that make up the defoliating complex are consistent pests of peanut in the southern U.S. Current thresholds for caterpillars are based on insect count data only, and defoliation thresholds are needed to improve management decisions. Two experiments were conducted at two locations in Mississippi during 2017, 2018, and 2019 to evaluate the impact of simulated defoliation on peanut yield. In the first experiment, peanut plants were manually defoliated by hand 25 days after emergence. Defoliation treatments included 25, 50, 75 and 100% foliage removal to evaluate yield losses compared to a non-defoliated control. In the second experiment, three weed control timings were initiated 20, 27, and 34 days after emergence, as well as, a weed-free treatment which all weeds were controlled. Three levels of defoliation consisted of 0, 50, and 100% defoliation, which occurred 20 days after emergence and one week after each weed control timing, to evaluate yield losses due to defoliation compared to a non-defoliated control. One, two, three, or four leaflets were removed from each tetra-foliate to correspond with percent defoliation. In the first experiment, a reduction in fractional green canopy was observed up to 35 days after 100% defoliation. Defoliation treatments of 25 to 75% were variable with respect to reduction of fractional green canopy coverage. Although defoliation impacted peanut growth as indicated by fractional green canopy

coverage, peanut yield was not impacted until defoliation reached 100% at 25 days after emergence. In the second experiment, peanut yield was not impacted until defoliation levels of 100% were reached regardless of weed control timing, suggesting peanut had the ability to compensate for some defoliation that occurred during the vegetative growth stage but not for severe defoliation.

Introduction

The Unites States is the third largest producer of peanut, *Arachis hypogaea* (L.), behind China and India, with exports mainly going to Canada and Mexico (National Peanut Board 2019). Peanut is grown commercially in 11 states in the United States grouped into three regions: Southeast Region (Alabama, Florida, Georgia, and Mississippi), Virginia-Carolina Region (North Carolina, South Carolina, and Virginia), and the Southwest Region (Arkansas, New Mexico, Oklahoma, and Texas). Of these regions, the Southeast Region produces over 70% of United States peanut (National Peanut Board 2019). Additionally, Louisiana and Missouri are minor peanut-producing states, accounting for less than 1% of total United States production (National Peanut Board 2019). Harvested area of peanuts in the United States has risen from a little over 400,000 ha in 2013 to 600,000 ha in 2019 (NASS 2019). Since 2013, the area planted to peanut in Mississippi has fluctuated from just over 8,000 ha to approximately 20,000 ha. Peanut is an important rotational commodity in Mississippi's cropping system due to profitability and rotational benefits such as reduced disease, insect, and nematode pressure in subsequent cotton, *Gossypium hisutum* (L.), corn, *Zea mays* (L.), and soybean, *Glycine mac* (L.), crops (Jordan et al. 2008).

Numerous insect pest species infest and feed on peanut throughout the season and are typically grouped into two ecological categories; soil pests and foliar pests (Smith and Barfield

1982). Although peanut plants fruit below the soil surface, plants produce flowers above ground that senesce and become a gynophore, more commonly called a peg (Stalker 1997). The peg grows toward the soil surface, enters the soil, and the embryo at the tip of the peg begins to grow and mature into what ultimately becomes the peanut pod (Stalker 1997). Because of this, several soil insects can be detrimental to yield (Abudulai et al. 2012), but most do not occur every year and tend to be localized and sporadic (Ahir et al. 2018). Foliar pests can be grouped into sap feeders with piercing sucking mouthparts or foliage feeders with chewing mouthparts (Smith and Barfield 1982). The most consistent economic damaging sap feeding insect pest in peanut production is tobacco thrips, *Frankliniella fusca* (Hinds), (Abney 2019).

Foliage feeding caterpillar pests occur annually in peanut fields (Todd et al.1991). Several species comprise the defoliating caterpillar pest complex in peanut. They include corn earworm, *Helicoverpa zea* (Boddie); fall armyworm, *Spodoptera frugiperda* (J. E. Smith); southern armyworm, *S. eridania* (Stoll); yellow-striped armyworm, *S. ornithogalli (*Guenée*);* velvetbean caterpillar, *Anticarsia gemmatalis* (Hübner); green cloverworm, *Hypena scabra* (F.); cabbage looper, *Trichoplusia ni* (Hübner); and soybean looper, *Chrysodeixis includens* (Walker) among others (Smith and Barfield 1982). Defoliating caterpillars feed on foliage causing indirect yield losses due to reduced leaf area and reduced photosynthetic capacity (Boote et al. 1980). Studies have suggested that younger leaves intercept and process light more efficiently than older leaves within the canopy, and that older leaves lack the ability to recover to full photosynthetic capacity after defoliation (Beuerlein and Pendleton 1971). As defoliation of the canopy occurs, stems intercept more sunlight and are capable of carrying out photosynthesis to partially compensate for foliage loss (Puckridge 1968). This is important when evaluating foliage consumption by fall armyworm, which prefers young tender leaves and terminal foliage as opposed to older leaves and stems lower in the canopy (Deitz et al. 1992). Defoliation can also delay maturity of the crop leading to harvest difficulties (Smith and Barfield 1982).

Previous research showed that early-season defoliation can reduce canopy height and width, in turn delaying canopy closure, later in the season (Abbott et al. 2019). Vegetative growth directly affects canopy closure, which influences plant architecture and the ability to suppress weeds (Leon et al. 2016). Environmental factors, application errors, and herbicide-resistant weeds make early-season weed management important in peanut. Because of that, preemergence and postemergence herbicides are important components of early-season weed management programs (Leon et al. 2016). Hauser and Buchanan (1981) reported that a weed-free period of 0 to 5 weeks reduced sicklepod, *Senna obtusifolia* (L.), biomass by 32% to 59%. Early-season weed suppression is not only important to minimize yield losses, but early-season weeds can host numerous insect and disease pests. Fall armyworm prefers grasses in the family Poaceae for feeding (Luginbill 1928). Although peanut is a not a preferred host for fall armyworm, large larvae will migrate to peanut following an herbicide application and can rapidly cause severe defoliation (Wiseman and Davis 1979).

The current threshold for defoliating caterpillars, regardless of species, is when four or more larvae per 0.31-m of row are present early season or when plants are stressed from drought, and when eight or more larvae per 0.31-m of row are present late season when plants are larger and growing normally (Catchot et al. 2019). Huffman and Smith (1979) reported that corn earworm consumed 179 cm^2 of leaf area per larva. In contrast, fall armyworm consumed 94.6 cm^2 of leaf area per larva (approximately 5 leaves) with 82% of that leaf area consumed during the last two instars of development (Garner and Lynch 1981). Because of potential differences in consumption rates among species and instars, a threshold based on foliage loss would be beneficial in addition to the current threshold based on larval densities.

With the recent increase in area planted with peanut in the mid-southern U.S., research evaluating and refining thresholds is needed. Threshold research in peanut was done decades ago with older, lower-yielding cultivars. Reexamining defoliation on peanut with new higher yielding cultivars is necessary. Until recently, no research has been conducted to evaluate thresholds based on defoliation in peanut. Additionally, the impact of defoliation from insect pests during the seedling stage on peanut growth and yield has not been determined. With new high-yield potential cultivars available, variation in pest complex from year to year, and increasing cost of insect control, research is needed to understand the defoliating caterpillar complex and their impact on yields in peanut.

Materials and Methods

Peanut Plot Management

Cultivar Georgia 06-G (Branch 2007) peanut were planted in Stoneville and Starkville, MS, using a John Deere MaxEmerge2 four-row vacuum planter (John Deere, Moline, Illinois) at a rate of 20 seed per m of row. Plot size was 3.05 meters in length by 4.06 meters wide (four rows on 101.6 cm beds). Irrigation was utilized at both locations. Weeds were managed using preemergence herbicide applications of *S*-metolachlor (Dual II Magnum, Syngenta Crop Protection, Greensboro, NC) at 1.16 L/ha, or pendimethalin (Prowl, BASF Corporation, Research Triangle Park, NC) at 2.8 L/ha, in conjunction with flumioxazin (Valor, Valent U.S.A. Corporation, Walnut Creek, CA) at 0.44 L/ha or diclosulam (Strongarm, Dow AgroSciences LLC, Indianapolis, IN) at 0.03 L/ha. After planting, weed management was achieved with a premix of bentazon and acifluorfen (Storm, United Phosphorus, Inc., King of Prussia, PA) or acifluorfen (Blazer, United Phosphorus, Inc., King of Prussia, PA) alone at 1.75 L/ha for either application. Seed were treated with azoxystrobin, fludioxonil, and mefenoxam fungicide seed treatment (Dynasty, Syngenta Crop Protection, Greensboro, NC). A fungicide program containing azoxystrobin (Abound, Syngenta Crop Protection, Greensboro, NC) and a premix of prothioconazole and tebuconazole (Provost, Bayer CropScience, Research Triangle Park, NC) at 0.88 L/ha and 0.78 L/ha, respectively, were alternatively applied starting 45 days after crop emergence until 115 days after crop emergence to minimize disease from pathogens. Physiological maturity was determined by collecting random peanut samples throughout the entire plot area. The hull-scrape maturity profile method (Williams and Drexler 1981) was used to determine digging date. When physiological maturity was reached by a majority of the plot area, plots were inverted using a two-row KMC digger-shaker-inverter (Kelley Manufacturing, Tifton, GA) (Table 1.1). Inverted plants were allowed to dry for 5 to 7 days, depending on environmental conditions. Once dry, plants were threshed and bagged using a two row KMC plot peanut picker modified with a chute system for small plot research (Kelley Manufacturing, Tifton, GA) (Table 1.1). Bags of peanut pods from each plot were then weighed and weights were recorded.

Early-Season Defoliation without Weed Competition

Two separate experiments were conducted from 2017 to 2019 to determine the impact of foliage reduction from defoliating caterpillar pests on peanut yield. The first experiment was conducted during 2017 and 2018 at the R. R. Foil Research and Demonstration Center in Starkville, MS, at two locations on the research center and at the Delta Research and Extension Center in Stoneville, MS. The experimental design was a randomized complete block with six replications in Starkville North 2017 and Starkville South 2017 locations and four replications in

Starkville 2018 and Stoneville 2018. Peanut were planted 9 May in Starkville North 2017 and South 2017, 11 May in Starkville 2018, and 17 May in Stoneville 2018 (Table 1.1). All insect pests were managed according to the Mississippi State University Extension Service Insect Control Guide for Agronomic Crops (Catchot et al 2019). In Starkville 2017, an application of chlorantraniliprole (Prevathon, FMC Corporation, Philadelphia, PA) was applied to reduce natural infestations of corn earworm and soybean looper. Imidacloprid (Admire Pro, Bayer CropScience, Research Triangle Park, NC) was applied in-furrow at 0.72 L/ha at planting to minimize injury from tobacco thrips and other early-season insect pests.

Treatments consisted of hand removal of leaves at 25 days after emergence to represent 0, 25, 50, 75, and 100 percent defoliation levels (Table 1.1). Defoliation was performed on the center two rows of each plot leaving a two row non-defoliated buffer between defoliated rows. Defoliation percentages were achieved by removing one, two, three or four leaflets from each tetra-foliate leaf on every plant. Twenty-five percent was achieved by removing one leaflet from each tetra-foliate, 50% was achieved by removing two leaflets from each tetra-foliate, 75% was achieved by removing three leaflets from each tetra-foliate, and 100% was achieved by removing all leaflets from each tetra-foliate throughout the canopy. Reduction in foliage due to defoliation was determined by estimating fractional green canopy using the Canopeo Application (http://canopeoapp.com, last accessed 31-Oct-2019) for iPhone weekly three to four times after defoliation. Canopeo was developed by Oklahoma State University and analyzes a digital image that is converted to black pixels which correspond to non-green matter and white pixels which correspond to green matter (Patrignani and Ochsner 2015). Digital photographs were taken of the center two rows at the front of each plot. Photographs were taken 122 cm above the canopy by pointing the lens of a photographic camera from an iPhone down towards the canopy, capturing approximately 1 m^2 of row. Canopeo measures the fractional green canopy coverage and reports that measure as a percentage of green to not green (white to black).

Fractional green canopy coverage and peanut yield were analyzed using a general linear mixed model analysis of variance (PROC GLIMMIX, SAS 9.4). Fractional green canopy coverage was analyzed by site year to demonstrate how each test responded to defoliation and due to differences in fractional green canopy coverage between the site years. For fractional green canopy coverage analyses, replication was considered a random effect. Defoliation percentage was considered a fixed effect. Degrees of freedom were calculated using the Kenward-Roger method. Means and standard errors were determined with the PROC MEANS (SAS 9.4) statement. Fisher's protected LSD was used to separate means at the 0.05 level of significance. Fractional green canopy coverage was not collected during 2018 at the Stoneville location. Only three measurements were recorded during 2017 at the Stoneville location due to timing of canopy closure. In the yield analyses, site year and replication nested in site year were considered random effects. Defoliation percentage was considered a fixed effect. Degrees of freedom were calculated using the Kenward-Roger method. Means and standard errors were determined using the PROC MEANS (SAS 9.4) statement. Fisher's protected LSD was used to separate means at the 0.05 level of significance. Experimental sites during 2018 at the Starkville location were excluded from all analyses because of severe injury and yield losses from lesser cornstalk borer, *Elasmopalpus lignosellus* (Zeller), infestations.

Early-Season Defoliation with Weed Competition

To determine the impact of foliage reduction from defoliating caterpillar pests on peanut yield due to lack of control of early-season grasses, the second experiment was conducted during 2017, 2018, and 2019 at the R. R. Foil Research and Demonstration Center in Starkville, MS, and at the Delta Research and Extension Center in Stoneville, MS. Peanut were planted on 17 May in Stoneville during 2017, 10 May in Starkville during 2018, 6 May in Stoneville on the North side of the research station during 2019, and 10 June in Stoneville on the South side of the research station during 2019. The experiment was designed as a randomized complete block design replicated four times at each location. Treatments consisted of weed control timing and level of defoliation. Four weed control timings occurred 20, 27, and 34 days after emergence as well as a control in which all weeds were managed using pre and post emergence herbicide applications. Three levels of defoliation consisted of 0, 50, and 100% defoliation, which were initiated 20 days after emergence and one week after each weed control application timing to represent defoliating larvae moving from senescing grasses to lush green peanut vegetation. Browntop millet, *Urochloa ramosa* (L.), was broadcast in weedy plots at peanut planting using a portable spreader (Solo Inc. Newport News, VA) and compared to control plots. Preemergence applications of diclosulam (Strongarm, Dow AgroSciences LLC, Indianapolis, IN) at a rate of 0.03 L/ha was applied to all plots for broadleaf control. Control of browntop millet was achieved with clethodim (Select Max, Valent U.S.A. Corporation, Walnut Creek, CA) at 0.88 L/ha using a tractor mounted sprayer calibrated to deliver 93.54 L ha^{-1} at 8.04 km h^{-1} through flat-fan spray nozzles.

Defoliation was performed on the center two rows of each plot leaving a two row non-defoliated buffer between defoliated rows. Defoliation percentages were achieved by hand removing zero, two, or four leaflets from each tetra-foliate leaf on every plant. Fifty percent was achieved by removing two leaflets from each tetra-foliate and 100% was achieved by removing all leaflets from each tetra-foliate throughout the canopy. No leaflets were removed from the 0% defoliation treatments.

Peanut yields were analyzed using a general linear mixed model analysis of variance (PROC GLIMMIX, SAS 9.4). In the yield analyses, site year, replication nested in site year, and replication by weed control timing nested in site year were considered random effects. Defoliation percentages, weed control timing, and their interaction were considered fixed effects. Degrees of freedom were calculated using the Kenward-Roger method. Means and standard errors were determined by using the PROC MEANS (SAS 9.4) statement. Fisher's protected LSD was used to separate means at the 0.05 level of significance.

Results and Discussion

Impact of Defoliation on Peanut Growth

During 2017 at the Starkville North location, defoliation level had an effect on mean fractional green canopy coverage at 7 (F=4.67; df=4, 20; $P<0.01$), 23 (F=2.69; df=4, 25; $P=0.05$), and 35 (F=4.79; df=4, 20; $P<0.01$) days after defoliation, but not 51 (F=1.30; df=4, 20; $P=0.30$) days after defoliation (Fig. 1.1). Fractional green canopy coverage for plots that received 100% defoliation was less than that observed following all other defoliation levels at 7 days after defoliation. Fractional green canopy coverage for plots with 0 or 25% defoliation was greater than 100% defoliation, but not different than plots with 50 or 75% defoliation at 23 days after defoliation. Fractional green canopy coverage for plots with 25% defoliation was greater than 50, 75, or 100% defoliation, but not different than plots with 0% defoliation 35 days after defoliation.

During 2017 at the Starkville South location, defoliation level had an effect on mean fractional green canopy coverage at 7 (F=3.26; df=4, 25; $P=0.03$), 23 (F=4.07; df=4, 25; $P=0.01$), and 35 (F=7.96; df=4, 20; $P<0.01$) days after defoliation, but not 51 (F=2.67; df=4, 20; $P=0.06$) days after defoliation (Fig. 1.2). Fractional green canopy coverage for plots that received 0 or 25% defoliation was greater than that observed following plots with 100% defoliation, but not different than plots with 50 or 75% defoliation at 7 days after defoliation. Fractional green canopy coverage for plots with 0, 25, or 75% defoliation was greater than 100% defoliation but not different than plots with 50% defoliation at 23 days after defoliation. Fractional green canopy coverage for plots with 0% defoliation was greater than plots with 50, 75, or 100% defoliation but not different than plots with 25% defoliation at 35 days after defoliation.

During 2017 at the Stoneville location, defoliation level had an effect on mean fractional green canopy coverage 7 ($F=20.46$; $df=4, 20$; $P<0.01$) and 21 ($F=8.62$; $df=4, 20$; $P<0.01$) days after defoliation, but not 38 days after defoliation ($F=1.09$; $df=4, 25$; $P=0.38$) (Fig. 1.3). Fractional green canopy coverage for plots that received 0 or 25% defoliation was greater than that observed following plots with 50 or 100% defoliation, but not different than plots with 75% defoliation at 7 days after defoliation. Fractional green canopy coverage for plots with 25% defoliation was greater than plots with 50, 75, or 100% defoliation, but not different than plots with 0% defoliation at 21 days after defoliation.

Canopy closure is important for many reasons such as weed suppression, and maintaining consistent soil temperature and moisture (Kvien and Bergmark 1987, Butzler et al. 1998, and Richburg III et al. 2006). Peanut typically initiates reproductive growth approximately 30 to 35 days after planting (Boote 1982). Because peanut is an indeterminate crop with continuous flowering, plants in an adequate environment have the potential to compensate for defoliation if it occurs early during the growing season. During that compensation period, growth of the plant may be slowed resulting in a delay in canopy closure. Previous research reported a reduction in canopy height and width at multiple levels of defoliation 40 days after emergence compared to the non-defoliated control (Abbott et al. 2019). These reductions in canopy height and width resulted in delayed canopy closure later in the season similar to what was observed in the current study based on fractional green canopy coverage. Canopy closure is important in peanut for several physiological processes (Kvien and Bergmark 1987). Canopy closure encourages increased plant height, less branching, increased root biomass and a greater percentage of flowers becoming pegs. Increased plant height was important because it allowed for better light interception for increased photosynthesis (Suzuki and Furukawa 1958). Increases in root biomass allowed for more efficient water uptake which is important for pod production, especially in drought stress situations. Delaying canopy closure during the early season can decrease the weed-free period reducing peanut biomass and increasing weed biomass (Hauser and Buchanan 1981). In the current study, canopy coverage was reduced by an average of 52% at one week after defoliation, 29% at three weeks after defoliation, 19% at five weeks after defoliation and, 9% at seven weeks after defoliation compared to the non-defoliated area.

Canopy architecture allows more sunlight to be absorbed by plants and less sunlight penetrating the canopy. Less sunlight penetrating the canopy allows soil temperatures to remain constant and minimizes moisture evaporation from soil, making water more available for uptake by plants. Butzler et al. (1998) observed soil temperatures 8 to 9°C greater in plots that were pruned with a rotary hoe 88 days after planting compared to plots that were not pruned. Canopy coverage permitted moisture to remain in the soil longer allowing availability over longer periods of time (Kvien and Bergmark 1987). Increasing water availability for uptake can be beneficial during periods of drought, especially during peak reproductive fruit development (Kvien and Bergmark 1987).

In this study, fractional green canopy coverage was affected by all levels of defoliation, which delayed canopy closure throughout the season. Although plants were able to compensate by 38 to 51 days after defoliation, defoliation did impact overall plant canopy growth. A delay in canopy closure during the seedling stage may lead to reductions in yield. Yield losses due to defoliation delaying canopy closure have been observed in other research (Abbott 2018).

Impact of Defoliation on Peanut Yield

In the first experiment, defoliation level during the seedling stage of peanut had an effect on yield. (F=2.63; df=4, 101; *P*=0.04). Mean yield of peanut for plots with 0 or 25% defoliation was greater than that for plots with 100% defoliation, but no different than plots with 50 or 75% defoliation (Fig. 1.4). In the second experiment, regardless of weed control timing (F=0.90; df=3, 38; *P*=0.44), defoliation had an effect on mean yield of peanut (F=7.70; df=2, 112; *P*<0.01). Mean yield of peanut for plots with 0 or 50% defoliation was greater than plots with 100% defoliation (Fig 1.5). There was no interaction between weed control timing and defoliation level (F=1.85; df=6, 111; *P*=0.10). This suggests that yield loss associated with defoliating caterpillar pests can be significant regardless of timing of the infestation. Timing of simulated defoliation performed 20 days after emergence up until 40 days after emergence had no impact on peanut yield.

Although defoliating caterpillars can be sporadic pests in peanut, yield response to defoliation can vary depending on the time of defoliation. Defoliation events occurring early in the growing season at low percentages allow plants time to compensate from reduced canopy closure. In situations where fields are 100% defoliated, yield losses can occur. In a separate experiment, manual hand defoliation of 100% was performed at 15-day intervals from 35 to 110 days after emergence (Abbott 2018). That research showed a reduction in yield by at least 13%

due to 100% defoliation regardless of timing. Yield reductions were more noticeable in reproductive stage peanut than vegetative stage peanut. Yield was reduced by 15% at 35 to 65 days after emergence compared to 31% at 80 to 110 days after emergence. Although there was a reduction in yield throughout the early- and mid-season, peanut was able to compensate from these defoliation events unlike late-season defoliation events (Abbott 2018). In a greenhouse, 75% defoliation resulted in a reduction in leaflet number, leaf area, leaf mass, stem mass, root mass, peg number, peg mass, and pod mass (Endan et al. 2006). Similar to the current experiments, Enyi (1974) found that peanut yield was reduced greatest when plants were completely defoliated compared to where half of the leaves were removed during late vegetative stages and early pod development stages. Although little research has been conducted on insect defoliation in peanut, considerable research has been done to evaluate the impact of herbicide injury during the seedling stages on peanut development and yield (Richburg, III et al. 1985, Richburg, III et al. 2006, Dotray et al. 2010, Ferrell et al. 2013, Johnson, III and Davis 2016). Those studies showed similar results to the current study where no yield loses were observed except in extreme cases (i.e. 100% defoliation).

Defoliation thresholds in Mississippi peanut need to be developed to provide current information with newer peanut cultivars. This is due to increasing cost of insect control and availability of higher yielding cultivars. For accuracy and ease of use to consultants and farmers, a defoliation threshold would be more beneficial than the current sampling method and threshold based on caterpillars per m of row. Nominal counts of caterpillars from traditional sampling methods can be misleading because defoliation or injury can vary based on the size and number of larvae feeding. A defoliation threshold would allow for a more accurate estimate of damage to the peanut crop and account for multiple species being present in a field. From these data, we can suggest that canopy growth may be slowed and time to canopy closure can be delayed with minimal impact to peanut yield when defoliation percentages are low. Although peanut has the ability to compensate from minor foliage loss during vegetative growth, severe defoliation did cause an 11.2% to 13% reduction in yield. Controlling caterpillar pests during the early season can decrease chances of yield loss associated with defoliation events.

Table 1.1 Planting dates, defoliation dates, invert dates and harvest dates for all locations of manual defoliation on pre-flowering peanut in Mississippi.

Location	Planting Date	Defoliation Date	Invert Date	Harvest Date
Starkville North 2017	9-may-2017	6-jun-2017	6-oct-2017	18-oct-2017
Starkville South 2017	9-may-2017	6-jun-2017	6-oct-2017	18-oct-2017
Stoneville 2017	17-may-2017	19-jun-2017	5-oct-2017	12-oct-2017
Stoneville 2018	11-may-2018	18-jun-2018	3-oct-2018	9-oct-2018

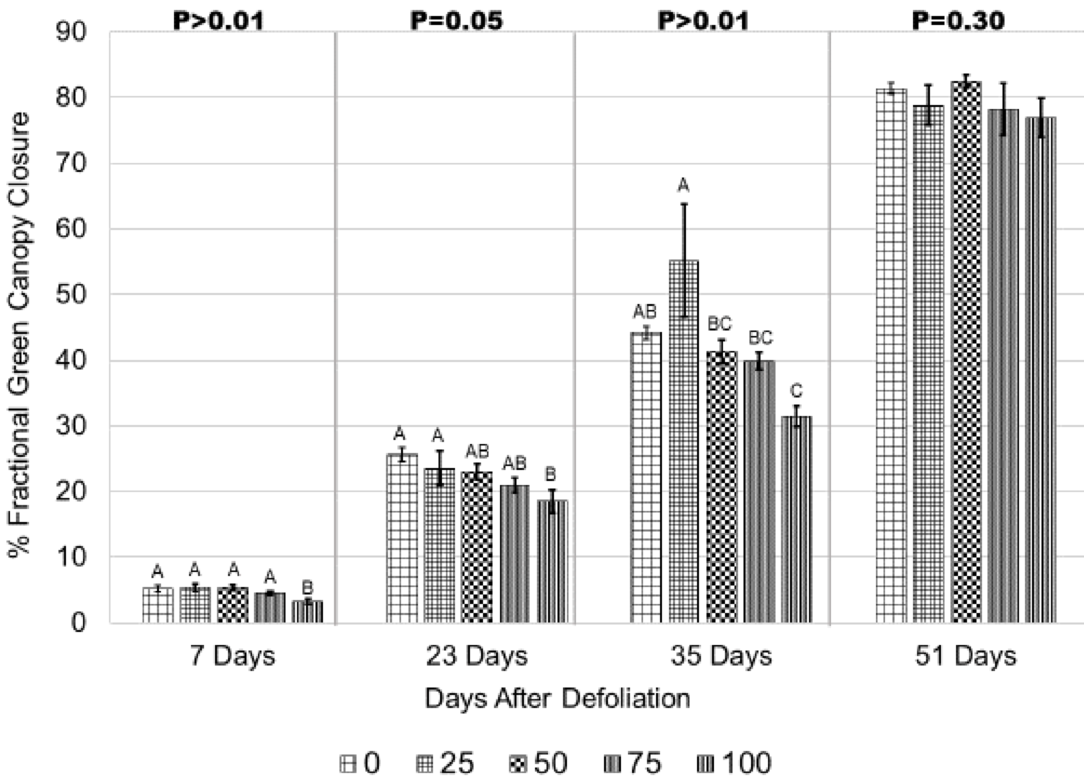

Figure 1.1 Impact of manual defoliation during the pre-flowering stages of peanut development on fractional green canopy coverage in Starkville (North), MS during 2017.

*Means with a common letter are not significantly different (α=0.05).

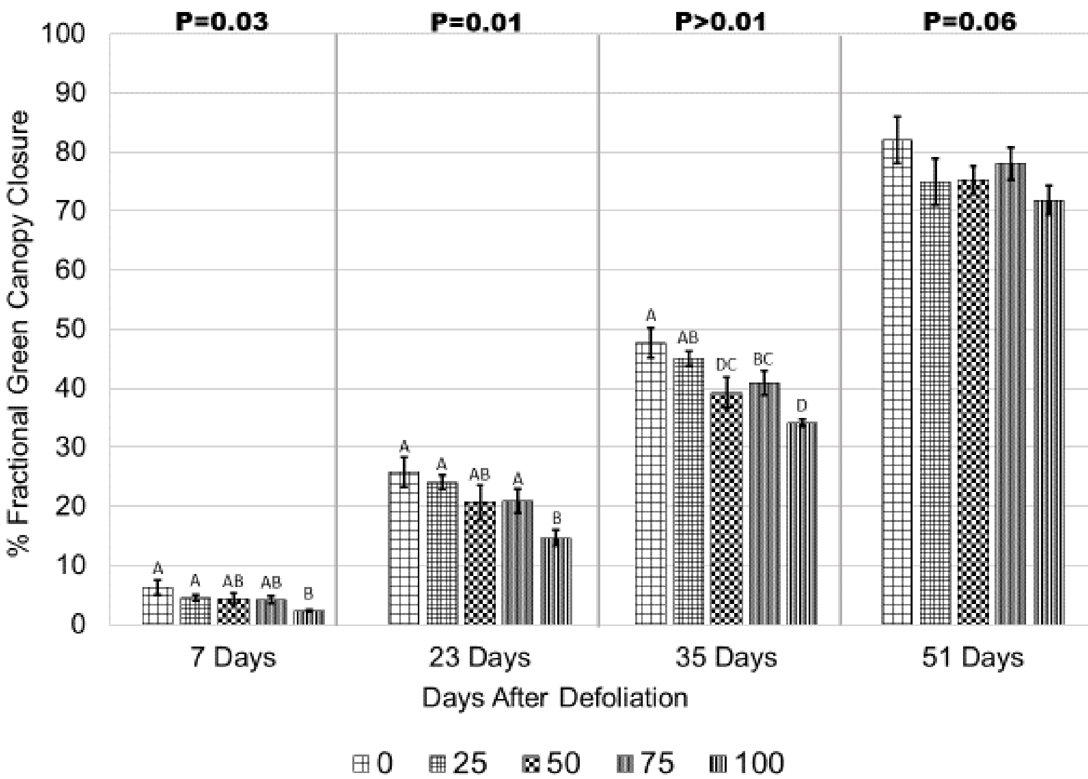

Figure 1.2 Impact of manual defoliation during the pre-flowering stages of peanut development on fractional green canopy coverage in Starkville (South), MS during 2017.

*Means with a common letter are not significantly different (α=0.05).

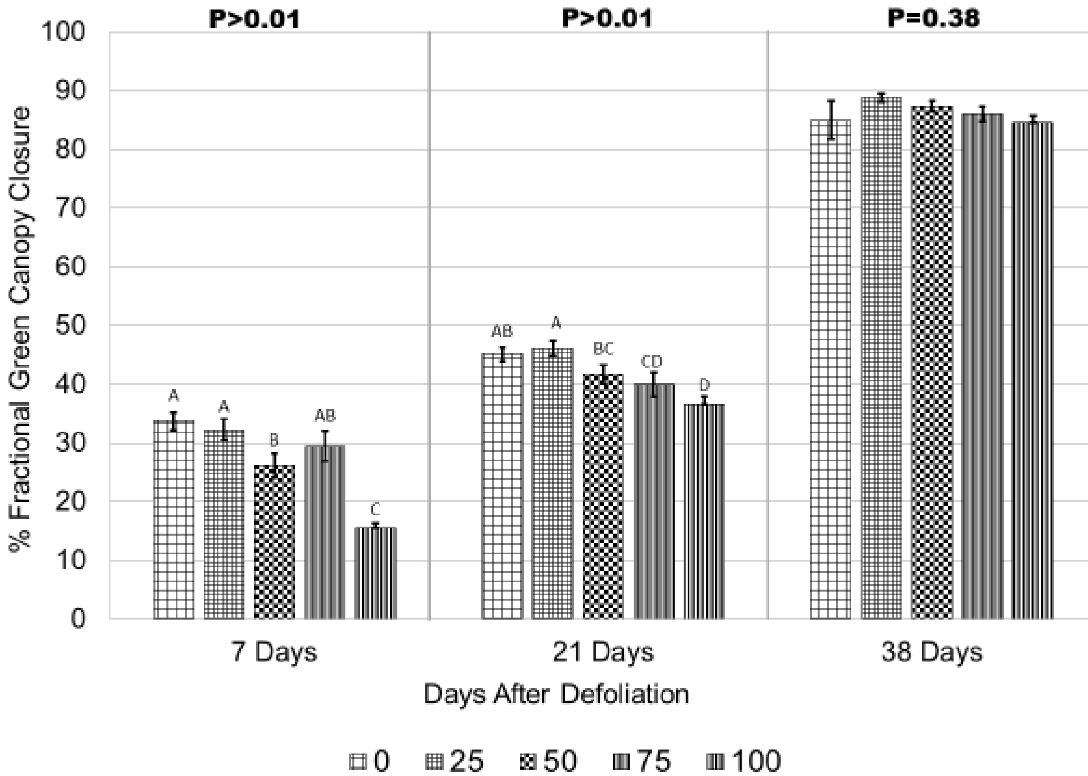

Figure 1.3 Impact of manual defoliation during the pre-flowering stages of peanut development on fractional green canopy coverage in Stoneville, MS during 2017.

*Means with a common letter are not significantly different (α=0.05).

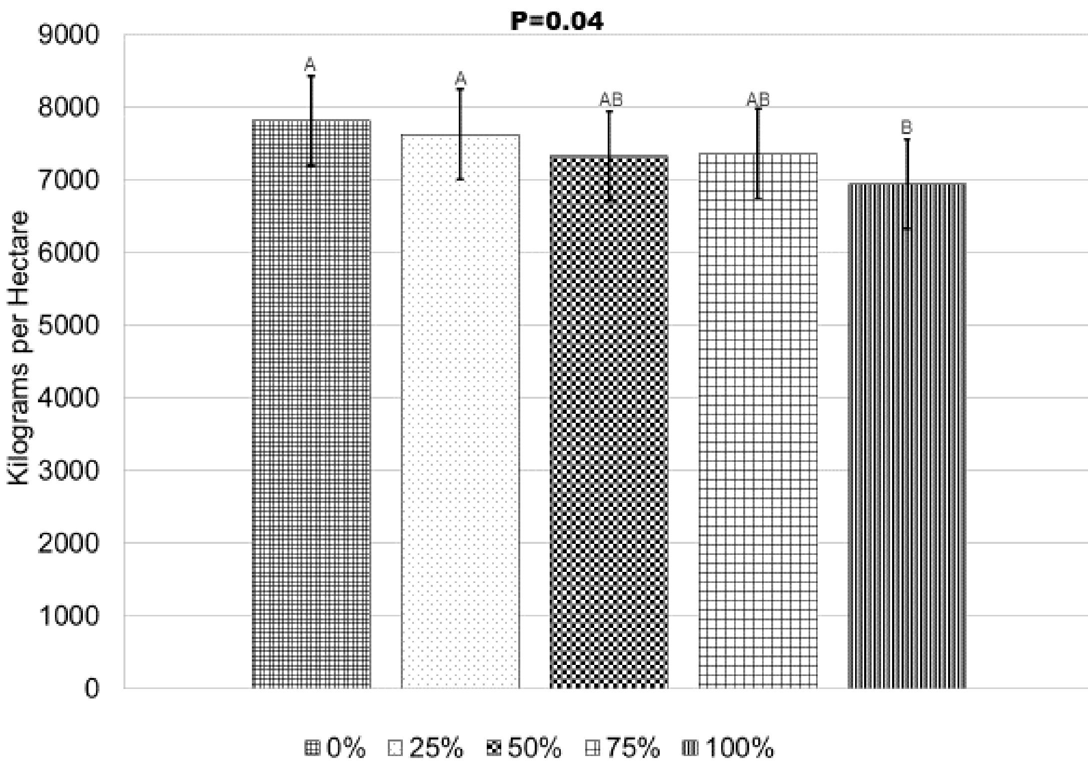

Figure 1.4 Impact of manual defoliation during the pre-flowering stages of peanut development on yields during 2017 at the Starkville North, Starkville South and, Stoneville location and during 2018 at the Stoneville location.

*Means with a common letter are not significantly different (α=0.05).

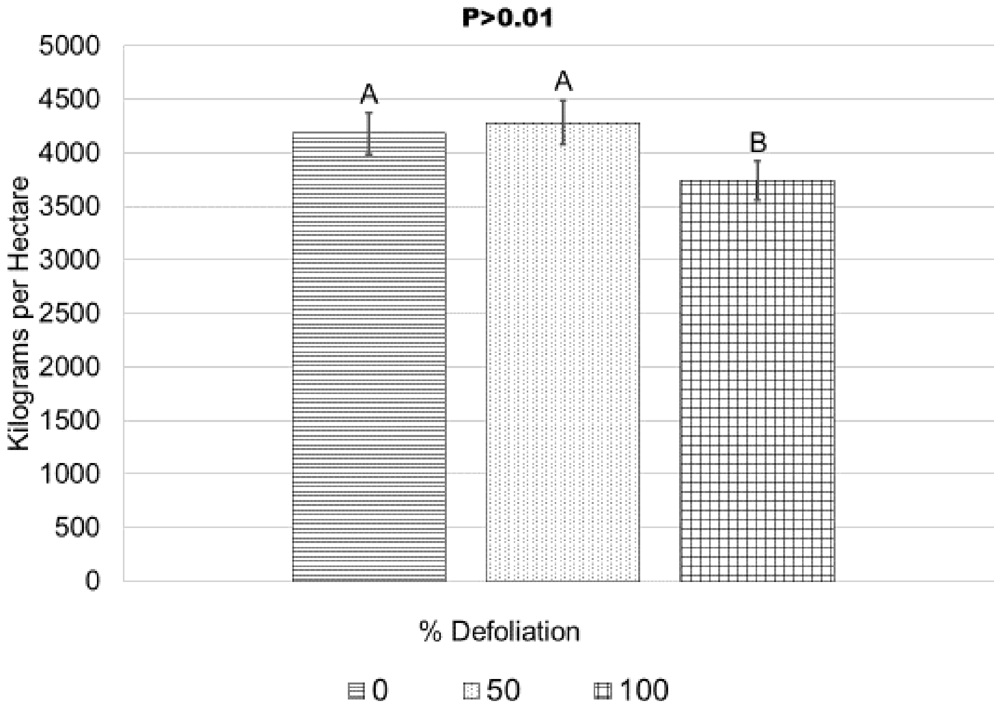

Figure 1.5 Impact of manual defoliation on seedling stages of peanut development on yields during 2017, 2018, and 2019 at the Stoneville, MS and Starkville, MS locations.

*Means with a common letter are not significantly different (α=0.05).

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CHAPTER II

SURVEY OF CATERPILLAR PESTS OF PEANUT IN MISSISSIPPI AND RELATIONSHIP BETWEEN DROP CLOTH SAMPLES AND SWEEP NET SAMPLES

Abstract

Although sporadic, defoliating caterpillars are consistent pests of peanut in the southern United States. Current thresholds are based on larval counts per 0.31m of row and sweep net thresholds would be beneficial to improve management decisions. Surveys were conducted during 2017 and 2019 in Mississippi across 189 grower fields. Fields were chosen randomly and surveyed bi-monthly throughout the growing season. Each field was sampled by sweep net and drop cloth sampling methods for defoliating caterpillar pests. Four sets of 25 sweeps with a sweep net and 4 drops (each measuring 1.5 m of row) using a drop cloth were performed. After each sampling method, all defoliating caterpillar pests were identified, counted, and recorded. Defoliating caterpillar pest complex consisted of yellow-striped armyworm, *Spodoptera ornithogalli (Guenée);* soybean looper, *Chrysodeixis includens* (Walker); corn earworm, *Helicoverpa zea* (Boddie); fall armyworm, *S. frugiperda* (J. E. Smith); southern armyworm, *S. eridania* (Stoll); beet armyworm, *S. exigua* (Hübner); green cloverworm, *Hypena scabra* (F.); velvetbean caterpillar, *Anticarsia gemmatalis* (Hübner); and granulate cutworm, *Feltia subterranea* (F.). The relationship between drop cloth samples and sweep net samples was significant for several species and total number of caterpillars, suggesting that the sweep net method can be used to sample some defoliating caterpillar pests in peanut. Based on the

relationship for total caterpillars, the sweep net thresholds would be 18 and 34 per 25 sweeps during early and late seasons, respectively.

Introduction

Harvested area of peanut in the Unites States has risen from 400,000 hectares in 2013 to over 600,000 hectares in 2016 (NASS 2019). Of the peanut growing regions in the United States, the Southeast consisting of Alabama, Florida, Georgia, and Mississippi, accounts for 70% of the total U.S. peanut production (National Peanut Board 2019). Planted hectares in Mississippi has fluctuated greatly since 2013 although peanut is a good fit in Mississippi's cropping systems due to profitability and rotational benefits such as reduced insect and disease pressure as well as reduced nematode pressure in subsequent crops (Jordan et al. 2008).

Peanut grown in the southern U.S. have the potential to be infested by numerous insect species throughout a growing season (Smith and Barfield 1982). Unlike most legumes, peanut flowers above ground, but produces fruit below ground. Therefore, caterpillar pests typically cause indirect damage to peanut (Smith and Barfield 1982, Stalker 1997). Indirect damage by defoliating caterpillar pests is caused by a reduction in leaf area and a corresponding reduction in photosynthesis (Boote et al. 1980). Annually, foliage feeding caterpillar pests are present in all fields at some point during the season (Todd et al. 1991). The defoliating caterpillar pest complex includes yellow-striped armyworm, *Spodoptera ornithogalli* (Guenée); soybean looper, *Chrysodeixis includens* (Walker); corn earworm, *Helicoverpa zea* (Boddie); fall armyworm, *S. frugiperda* (J. E. Smith); southern armyworm, *S. eridania* (Stoll); beet armyworm, *Spodoptera exigua* (Hübner); green cloverworm, *Hypena scabra* (F.); and velvetbean caterpillar, *Anticarsia gemmatalis* (Hübner) (Smith and Barfield 1982). Reduced leaf area can result in yield reductions but can also delay maturity of the crop leading to harvest difficulties at the end of the year (Smith and Barfield 1982).

Regardless of species, current thresholds for all caterpillars recommends treatment when four or more larvae per 0.31 m of row are present during the early season or when plants are stressed from drought, and eight or more larvae per 0.31 m of row are present during the late season when plants are more lush (Catchot et al. 2019). Because of differences in feeding site preferences between species, different methods have been used to sample for defoliating caterpillar pests. Sweep net sampling uses a pendulum swing of a 39.1-cm diameter mesh net, taking one swing per step while walking at a normal pace (Metcalf and Luckmann 1994). After a set number of sweeps are performed, insects caught within the net are identified, counted and released (Metcalf and Luckmann 1994). Sweep net sampling has been used for many years in multiple crops and continues to be used due to ease of use, efficiency, and minimal cost or damage to a crop (Kogan and Pitre 1980). This method can be effective on small plants and drilled or lodged plants (Kogan and Pitre 1980). Drop cloth sampling requires plant material to be vigorously shaken or beaten with a wooden stick over a 1.5-m long heavy-duty cloth. Plant material and insect pests fall to the cloth where they are identified and counted (Metcalf and Luckmann 1994). This method can be ineffective when plants are small or begin to senesce due to foliage falling on the sheet possibly covering insects which ultimately escape before being counted (Kogan and Pitre 1980). Although both methods are easy to perform, require minimal effort, and are more efficient than most other sampling methods, differences can be present between the two methods.

Differences in feeding site preference, growth stage of the crop, and size of the insect can impact sampling method effectiveness (Musser et al. 2009). Deitz et al. (1992) found fall armyworm prefer young tender, terminal leaves opposed to older canopy leaves in peanut unlike corn earworm which prefer young fresh tissue but will feed on older growth. Musser et al. (2009) reported sweep net estimates strongly correlated with drop cloth estimations of tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois) populations in cotton, *Gossypium hirsutum* (L.). In another study, sweep net sampling method caught more adults and total tarnished plant bugs per sample than drop cloth or whole plant sampling in cotton (Musser et al. 2007). In contrast, more tarnished plant bug nymphs were caught per sample using a drop cloth than a sweep net or whole plant visual samples (Musser et al. 2007). In previous field studies, a correlation between drop cloth sampling and sweep net sampling was observed for corn earworm populations in soybean *Glycine max* (L.) (Adams et al. 2016). Traditional thresholds were based on a nominal count per m-row using drop cloth sampling for corn earworm in soybean (Adams et al. 2016). These data were then used to calculate an economic injury level for sweep net sampling ranging from 2.4 to 34.32 larvae per 25 sweeps depending on cost of control and crop value (Adams et al. 2016). Currently, the only thresholds for caterpillar pests in peanut are based on numbers per row-m and a sweep net threshold is needed.

Recent increases in planted peanut area in Mississippi establish a need to evaluate and refine thresholds, as well as, examine the defoliating caterpillar pest complex across Mississippi. Variation in species composition can have an important effect on the amount of defoliation which can occur in a field, therefore providing research to identify the complex will be beneficial for refining thresholds. With the release of new higher yielding cultivars, research on older lower yielding cultivars is outdated. Threshold research is needed to evaluate sampling methods for accuracy and ease of use to consultants and farmers. Additionally, variation in pest complex from year to year, and increasing cost of insect control make research to understand the defoliating caterpillar complex and sampling methods of this complex important.

Materials and Methods

During the 2017 and 2019 growing seasons across Mississippi, a total of 189 grower fields from several peanut growing regions within Mississippi were sampled for defoliating caterpillar pests. Fields were chosen randomly throughout east, northwest, west central, and southeast regions of the state to account for differences in the pest landscape. Each field was surveyed twice per month throughout the growing seasons. Sampling consisted of sweeping a net through the peanut canopy or vigorously shaking plants over a black drop cloth. At each location, each sampler was responsible for performing a set of 25 sweeps and one drop to discourage discrepancies in sampling variance among samplers. After each sample was taken, all defoliating caterpillar pests were identified, counted, and recorded. Four sets of 25 sweeps with a sweep net and four drops (each measuring 1.5 m of row) using a drop cloth were performed at each field. For comparison of drop cloth numbers to the current threshold, all drop cloth samples were converted to number of caterpillar pests per 30.5 cm of row.

Pest numbers were analyzed with regression analysis (PROC GLM, SAS 9.4) to determine the relationship between drop cloth and sweep net sampling methods for each caterpillar pest and total number of caterpillars. In the model, pest number using drop cloth sampling was the independent variable and pest number using sweep net was the dependent variable. Extremely high numbers of velvetbean caterpillars were observed at one location on one date. Because the numbers were 16X greater than the other samples, this one location had more influence on the regression than other locations and was excluded from the analysis.

Results and Discussion

Over the 2 years of this survey, caterpillar pests were observed in 72% of the fields sampled. Species found during this survey consisted of yellow-striped armyworm, soybean looper, corn earworm, fall armyworm, southern armyworm, beet armyworm, green cloverworm, velvetbean caterpillar, and granulate cutworm, *Feltia subterranea* (F.) (Table 2.1). During 2017, caterpillar pests were found in 115 fields of 164 sampled. Predominant species found were soybean looper and corn earworm, and these were collected in 77 and 80 fields, respectively. Soybean looper, which is known to be a late-season caterpillar pest was found mostly during the months of July, August, and September. In contrast, corn earworm was found mostly during June, July and August. During 2019, caterpillar pests were found in 21 of 25 fields sampled. The predominant species were yellow-striped armyworm, soybean looper, and velvetbean caterpillar, collected in 9, 12, and 9 fields, respectively. Yellow-striped armyworm was found consistently throughout the months of June through September. In contrast, soybean looper and velvetbean caterpillar were found mostly during July, August, and September. These differences can be attributed to species migration. Corn earworm is a resident species which overwinters in Mississippi, whereas soybean looper and velvetbean caterpillar are migratory species which do not commonly overwinter in Mississippi (Funderburk et al. 1998).

There was not a relationship observed between drop cloth sample and sweep net sample for yellow-striped armyworm, southern armyworm, beet armyworm, or granulate cutworm. (Table 2.2). In contrast, there was a relationship between drop cloth sample and sweep net sample for soybean looper, corn earworm, fall armyworm, green cloverworm, velvetbean caterpillar, and total caterpillars (Table 2.2). This suggests that sweep net sampling may be appropriate for some caterpillar species. For species where relationships were significant, slopes ranged from 2.32 to 8.68 (Figs. 2.1 to 2.6). This suggests that sweep net thresholds will range from 9.3 to 34.8 caterpillars per 25 sweeps early season and 18.6 to 69.51 caterpillars per 25 sweeps late season. The greatest slope was for velvetbean caterpillar which for every one caterpillar found per 30.5 cm of row, 8.7 were caught using a sweep net (Fig. 2.5). Similar to soybean looper, corn earworm, and green cloverworm, 4.2 total caterpillars were caught using a sweep net for every one caterpillar found per 30.5-cm of row. The sweep net threshold for total caterpillars would be 17 early season and 34 late season per 25 sweeps.

Caterpillars are sporadic pests of peanut, but have been known to cause yield losses depending on timing and severity of infestation. Accurately evaluating pest densities in peanut is critical to reduce chances of yield loss from defoliation and also prevent unneeded sprays for sub-threshold populations. Current thresholds for caterpillar pests in peanut are based on number of insects per m-row, however drop cloth sampling can be difficult when canopy closure has occurred. After canopy closure, inserting a drop cloth under peanut foliage can dislodge caterpillar pests prematurely resulting in inaccurate insect counts (Kharboutli and Mack 1993). As a result of pulling back canopy foliage to evaluate sampling, reproductive structures such as pegs and mature pods may be damaged. Sampling using a sweep net is assumed to cause less damage to a crop while accurately sampling for pests (Kogan and Pitre 1980). Studebaker et al. (1991) reported drop cloth samples were more efficient at dislodging larvae from soybean than sweep net samples depending on the growth stage of soybean plants. Rudd and Jenson (1977) reported sweep net samples to be more efficient when sampling smaller soybean plants early in the season or when pest densities were low. In contrast, drop cloth samples were more accurate later in the season when soybean plants were larger or when population densities were high. They also determined that sampling with a drop cloth had more variation than sampling with a sweep net, so more samples were required with a drop cloth than with a sweep net to obtain an accurate population estimate (Rudd and Jenson 1977). Sampling was likely more accurate with a drop cloth because of the inability of the sweep net to sample in the lower canopy (Kharboutli and Mack 1993). Unlike soybean, the canopy of peanut plants is compact which allows a sweep net to sample a greater percentage of the canopy instead of the top third (Kharboutli and Mack 1993). Both sweep net and drop cloth methods can provide accurate estimates of pest densities (Linker et al. 1984). Similarly, we found more soybean looper, corn earworm, fall armyworm, green cloverworm and velvetbean caterpillar and total number of caterpillars using a sweep net.

Feeding site preference of an insect can impact sampling method accuracy. Shepard et al. (1974) observed greater numbers of green cloverworm in soybean when using a sweep net and greater numbers of soybean looper when using a drop cloth. Differences in estimates were attributed to feeding site preference for these caterpillar pests (Shepard et al. 1974). Green cloverworm typically show no feeding site preference until fifth instar when they are more commonly found in the upper third of the canopy (Pedigo et al. 1973). In contrast soybean looper larvae generally feed on the lower half of soybean canopy (Herzog 1980).

Due to risk of damage to peanut reproductive structures when sampling with a drop cloth, inconvenience of the drop cloth sampling method, and larger sample size needed when using a drop cloth, growers tend to make unnecessary insecticide applications to peanut for defoliating caterpillar pests. With increased cost of insect control and availability of new higher yielding cultivars, sampling methods need to re-evaluated. Based on data collected in this study, sweep net thresholds equaled 17 total caterpillars per 25 sweeps early season and 34.4 total caterpillars per 25 sweeps late season. However, samples rarely approached current thresholds, so these numbers fell outside of the range of values caught in peanut fields. These values provide a good estimate for a sweep net threshold, but caution should be used because they are based on extrapolation beyond the range of these data. As a result, more research is needed to validate these sweep net thresholds. Some relationships between drop cloth and sweep net sampling were not significant; therefore, monitoring defoliation in a field will be important. Although drop cloth sampling method is a reliable sampling method, a threshold for sweep net sampling method would be beneficial for ease of use and reduce sampling time.

Table 2.1 Number of fields with each species and total species of caterpillar pests found in Mississippi peanut production fields during 2017 and 2019.

Pest	**2017** (164 fields)						**2019** (25 fields)				
	May	June	July	Aug.	Sept.	**Total Fields**	June	July	Aug.	Sept.	**Total Fields**
Yellow-striped Armyworm	2	8	9	10	2	**31**	3	2	1	3	**9**
Soybean Looper	0	2	28	29	18	**77**	0	4	4	4	**12**
Corn Earworm	3	10	33	26	8	**80**	0	2	1	2	**5**
Fall Armyworm	0	0	14	3	8	**25**	0	1	1	0	**2**
Southern Armyworm	0	0	5	4	5	**14**	1	3	0	0	**4**
Beet Armyworm	0	0	5	0	0	**5**	0	0	0	0	**0**
Green Cloverworm	0	0	3	2	5	**10**	0	2	1	2	**5**
Velvetbean Caterpillar	0	0	0	12	15	**27**	0	4	1	4	**9**
Granulate Cutworm	0	0	7	5	0	**12**	1	0	0	0	**1**
Total Caterpillars	4	17	40	32	22	**115**	3	8	4	6	**21**

Table 2.2 Regression equations and statistics comparing drop cloth samples to sweep net samples for caterpillar pests of peanut in Mississippi during 2017 and 2019.

Pest	**Slope (SE)**	**Intercept (SE)**	**F**	**df**	***P***	**R^2**
Yellow-striped Armyworm	0.6756 (0.0215)	0.6756 (0.0215)	3.60	1, 186	= 0.06	0.0190
Soybean Looper	4.3868 (0.3491)	0.1720 (0.0613)	157.86	1, 186	< 0.01	0.4591
Corn Earworm	4.7167 (0.4641)	0.3487 (0.0778)	103.26	1, 186	< 0.01	0.3570
Fall Armyworm	2.3209 (0.3563)	0.0457 (0.0167)	42.44	1, 186	< 0.01	0.1858
Southern Armyworm	-0.0075 (0.0310)	0.0121 (0.0048)	0.06	1, 186	= 0.81	0.0003
Beet Armyworm	-0.1075 (0.5156)	0.0054 (0.0027)	0.04	1, 186	= 0.84	0.0002
Green Cloverworm	3.6699 (0.6452)	0.0119 (0.0097)	32.36	1, 186	< 0.01	0.1482
Velvetbean Caterpillar	8.6794 (0.5730)	0.0790 (0.0744)	284.83	1, 185	< 0.01	0.6062
Granulate Cutworm	0.0564 (0.0416)	0.0009 (0.0014)	1.84	1, 186	= 0.18	0.010
Total Caterpillars	4.2084 (0.4765)	0.7600 (0.1935)	77.99	1, 186	<0.01	0.2965

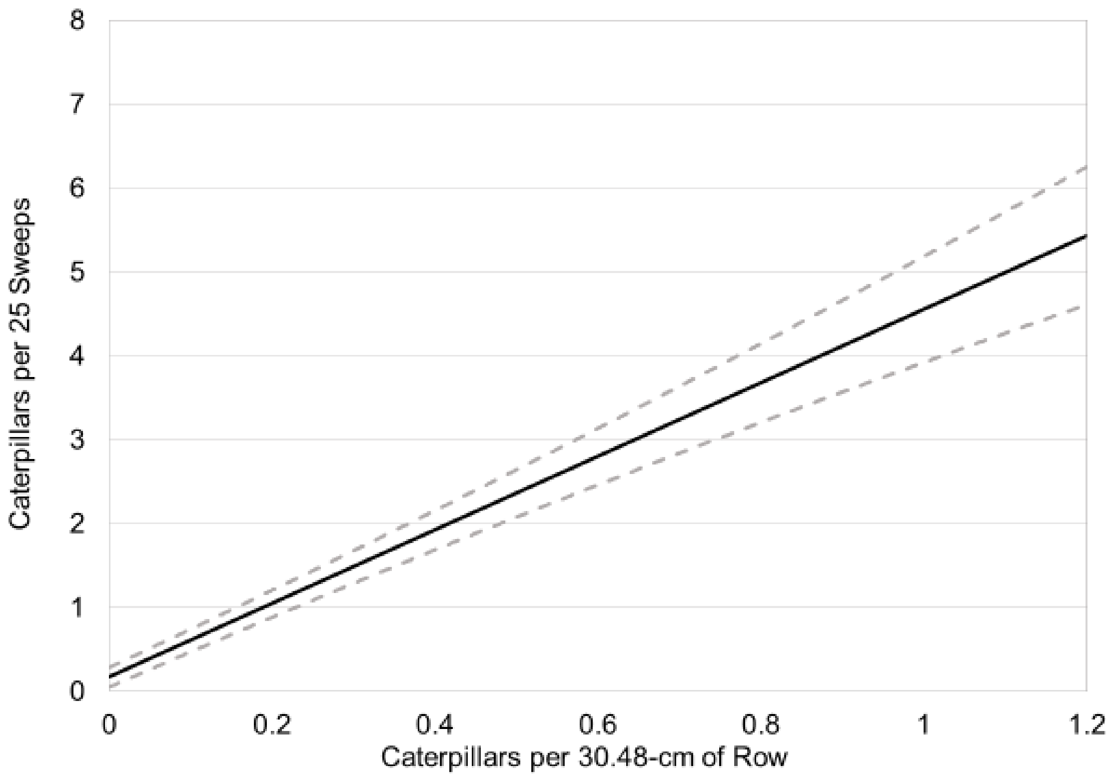

Figure 2.1 Relationship between drop cloth (30.48 cm) and sweep net (25 sweeps) samples on soybean looper numbers in peanut during 2017 and 2019 in Mississippi. Solid line represents the regression equation. (Slope 4.3868, Intercept 0.1720) Dotted lines represent upper and lower 95% confidence intervals.

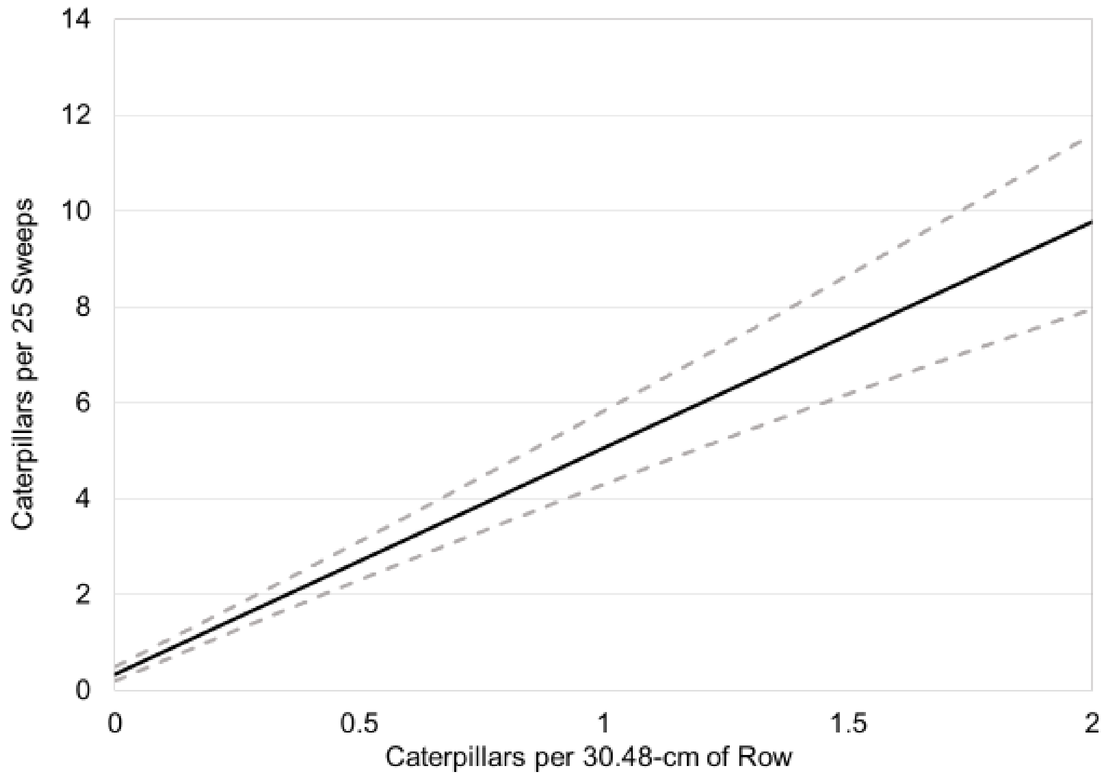

Figure 2.2 Relationship between drop cloth (30.48 cm) and sweep net (25 sweeps) samples on corn earworm numbers in peanut during 2017 and 2019 in Mississippi. Solid line represents the regression equation. (Slope 4.7167, Intercept 0.3487) Dotted lines represent upper and lower 95% confidence intervals.

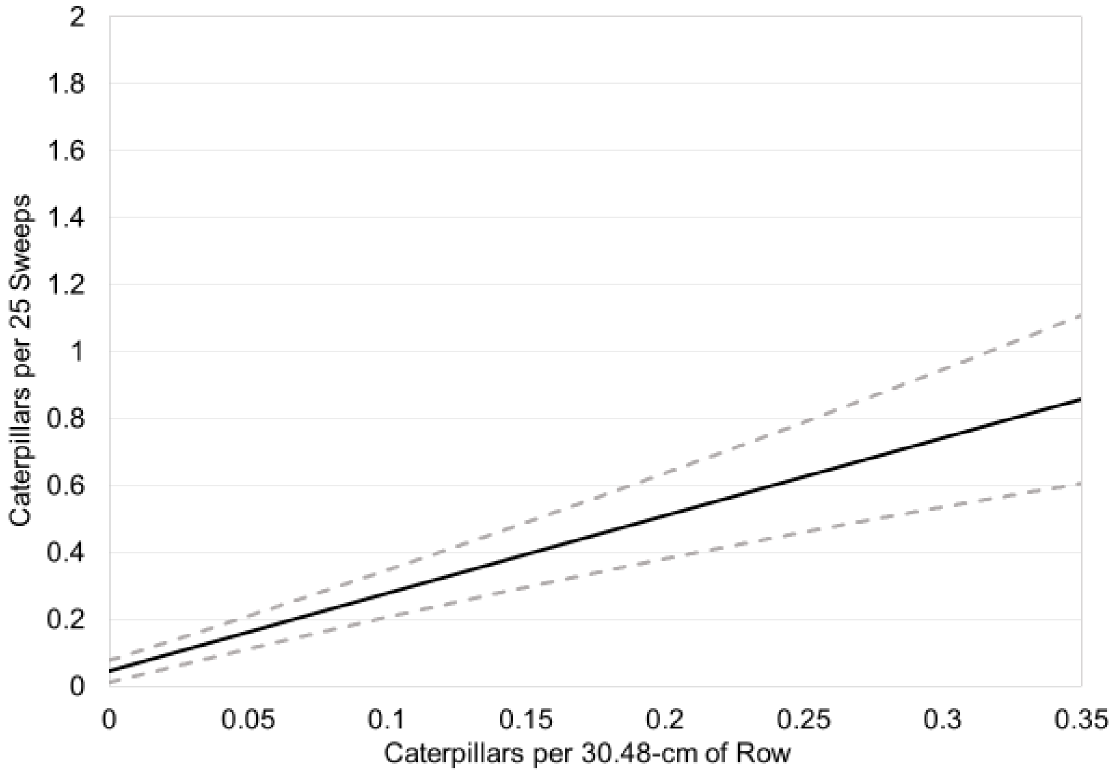

Figure 2.3 Relationship between drop cloth (30.48 cm) and sweep net (25 sweeps) samples on fall armyworm numbers in peanut during 2017 and 2019 in Mississippi. Solid line represents the regression equation. (Slope 2.3209, Intercept 0.0457) Dotted lines represent upper and lower 95% confidence intervals.

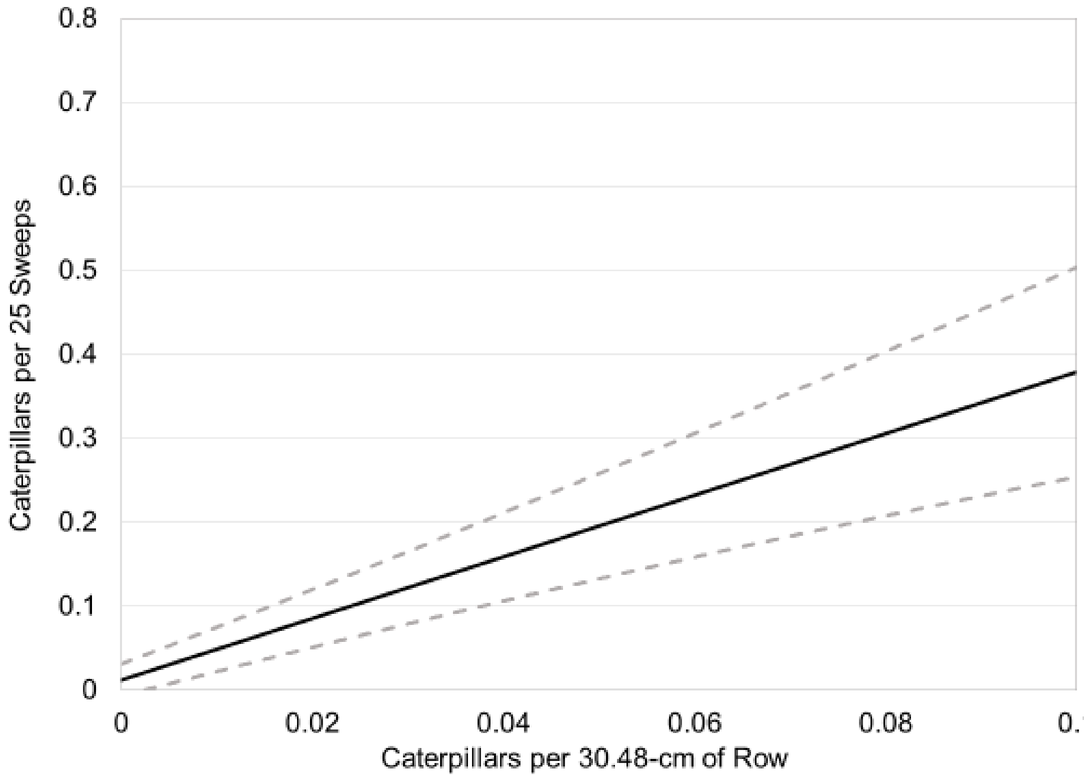

Figure 2.4 Relationship between drop cloth (30.48 cm) and sweep net (25 sweeps) samples on green cloverworm numbers in peanut during 2017 and 2019 in Mississippi. Solid line represents the regression equation. (Slope 3.6699, Intercept 0.0119) Dotted lines represent upper and lower 95% confidence intervals.

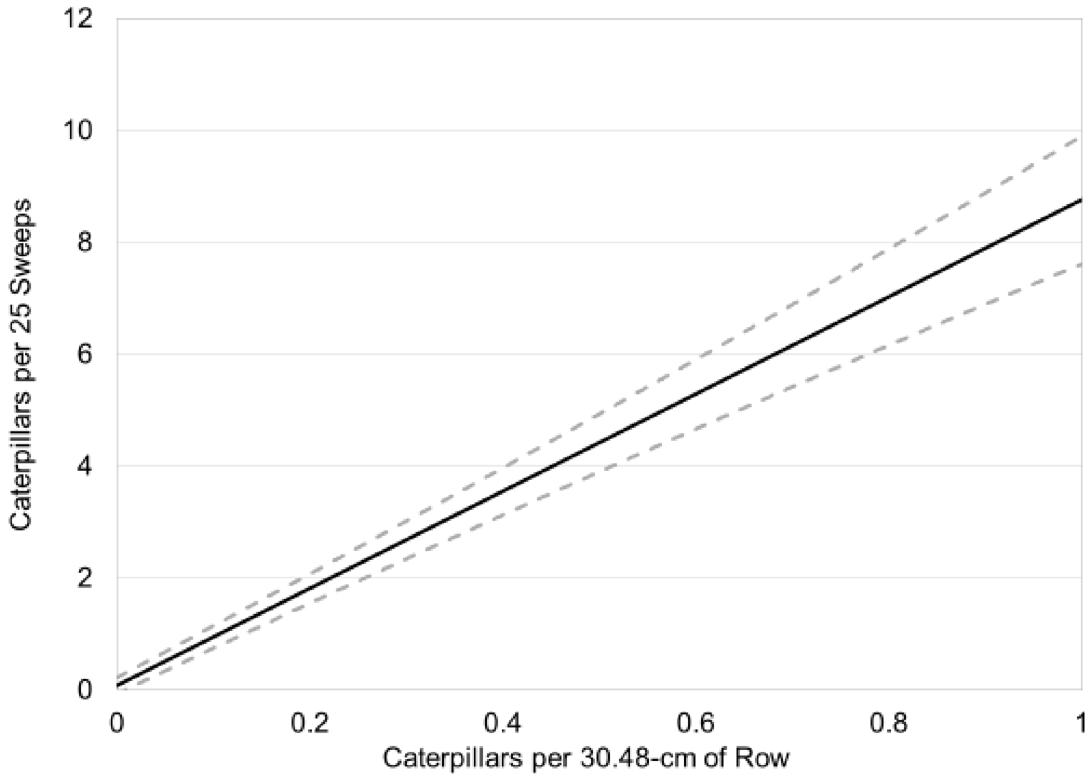

Figure 2.5 Relationship between drop cloth (30.48 cm) and sweep net (25 sweeps) samples on velvetbean caterpillar numbers in peanut during 2017 and 2019 in Mississippi. Solid line represents the regression equation. (Slope 8.6794, Intercept 0.0790) Dotted lines represent upper and lower 95% confidence intervals.

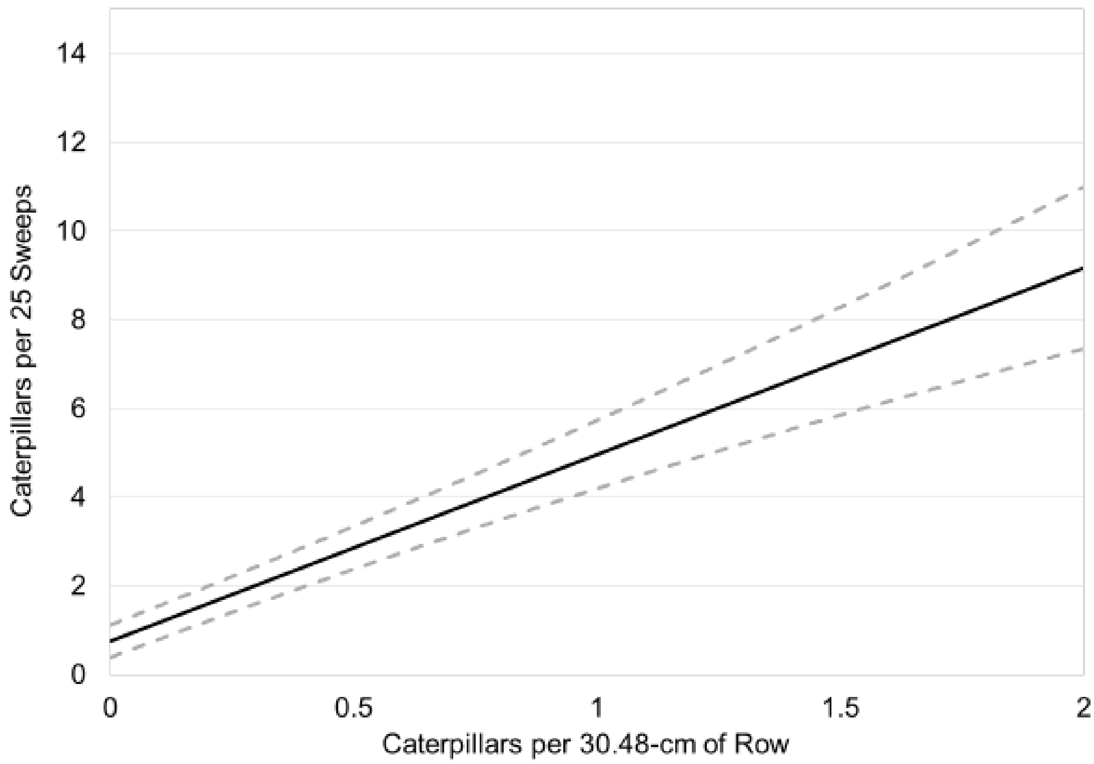

Figure 2.6 Relationship between drop cloth (30.48 cm) and sweep net (25 sweeps) samples on total caterpillars' numbers in peanut during 2017 and 2019 in Mississippi. Solid line represents the regression equation. (Slope 4.2084, Intercept 0.7600) Dotted lines represent upper and lower 95% confidence intervals.

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CHAPTER III

EVAULATION OF SEASON LONG DAMAGE FROM DEFOLIATING CATERPILLAR PESTS

Abstract

Defoliating caterpillars are consistent pests of peanut although damage is not always severe. Current action thresholds are based on insect count data only, and defoliation thresholds are needed to improve management decisions. An experiment was conducted at two locations in Mississippi during 2017, 2018, and 2019 to evaluate the impact of caterpillar defoliation on peanut yields. Fall armyworm were released at the Stoneville location during 2017 and 2019 at two timings, 40 to 80 days after emergence and 80 to 110 days after emergence. At the Starkville location during 2018, three timings, were used 40 to 75 days after emergence, 80 to 95 days after emergence and 100 to 120 days after emergence. Fall armyworm egg masses and neonates to second instar larvae were placed on the foliage of the center two rows in each plot leaving a two-row buffer between infested plots. Insect defoliation was measured by taking visual estimates of defoliation weekly and totaling those weekly ratings to represent a total level of defoliation. Peanut yield was not impacted by insect defoliation that occurred 40 to 80 days after emergence although defoliation level never exceeded 10%. Defoliation that occurred 80 to110 days after emergence resulted in 12% yield loss when insect defoliation reached 50%.

Introduction

Many species of insects feed on peanut throughout the season (Smith and Barfield 1982).

Of those species, caterpillars comprise the defoliating pest complex in peanut. They include corn earworm, *Helicoverpa zea* (Boddie); fall armyworm, *Spodoptera frugiperda* (J. E. Smith); southern armyworm, *S. eridania* (Stoll); yellow-striped armyworm, *S. ornithogalli (Guenée);* velvetbean caterpillar, *Anticarsia gemmatalis* (Hübner); green cloverworm, *Hypena scabra* (F.); cabbage looper, *Trichoplusia ni* (Hübner); and soybean looper, *Chrysodeixis includens* (Walker) (Smith and Barfield 1982). Although foliage feeding caterpillar pests are sporadic and inconsistent, they occur in most peanut fields annually (Todd et al. 1991). Determining the growth stage of peanut when injury occurs is critical to assessing the extent of injury to the crop (Abbott 2018).

Peanut growth stages are divided into two categories: vegetative and reproductive (Boote 1982). Vegetative stages of peanut growth focus on main stem and lateral branch growth (Boote 1982). Some critical stages of reproductive growth of peanut include beginning pod (R3), seed fill (R6), and beginning maturity (R7) which occur approximately 40, 80, and 100 days after emergence (Boote 1982). These stages are important for maximizing yield and more research is needed to determine how peanut responds to stress, such as foliage loss at those timings.

Foliage feeding caterpillar pests cause indirect damage to the peanut crop and require periodic insecticide applications to minimize potential yield losses from reduced leaf area and photosynthesis (Boote et al. 1980). Minor defoliation occurring during vegetative and early reproductive stages affects plant architecture, reducing canopy height and width (Leon et al. 2016). Studies have shown that peanut has the ability to compensate for minor foliage loss during these growth stages, but canopy closure may be delayed (Abbott et al. 2019). Defoliation not only can delay canopy closure, but also delay maturity of the peanut crop leading to harvest difficulties at the end of the year (Smith and Barfield 1982).

Current thresholds recommend treatment of defoliating caterpillars when four or more larvae per 0.31-m of row are present early season or when plants are stressed from drought, and eight or more larvae per 0.31 m of row are present late season when plants are more lush (Catchot et al. 2019). Garner and Lynch (1981) found fall armyworm consume 94.56 cm^2 of leaf area per larva with 82% of that being consumed in the last two instars. In contrast, Huffman and Smith (1979) found corn earworm can consume 179 cm^2 of leaf area per larva. Because of differences in feeding site preference, size of larvae feeding and species of larvae, nominal larvae count thresholds do not account for the amount of damage present in peanut during a defoliation event. A defoliation threshold based on plant injury would be more beneficial to accurately predict yield losses due to defoliation. Previous studies have evaluated the impact of manual defoliation on peanut yields, but more information is needed to determine the impact of defoliation from caterpillars.

Materials and Methods

Experiments were conducted during 2017, 2018, and 2019 at the R. R. Foil Research and Demonstration Center in Starkville, MS, and at the Delta Research and Extension Center in Stoneville, MS, to determine the impact of insect defoliation on peanut yield. Cultivar Georgia 06-G (Branch 2007) peanut were planted using a John Deere MaxEmerge2 four-row vacuum planter (John Deere, Moline, Illinois) at a rate of 20 seed per m of row on 17 May in Stoneville during 2017, 10 May in Starkville during 2018, 8 May in Stoneville during 2019 (Table 3.1).

Plot size was 3.05 meters in length by 4.06 meters wide (four rows on 101.6 cm beds) in Stoneville during 2017, 3.05 meters in length by 3.86 meters wide (four rows on 0.97 cm beds) in Starkville during 2018, and 1.52 meters in length by 4.06 meters wide (four rows on 101.6 cm beds) in Stoneville during 2019. Furrow irrigation was utilized at both locations to minimize drought stress. Seed were treated with azoxystrobin, fludioxonil, and mefenoxam fungicide seed treatment (Dynasty, Syngenta Crop Protection, Greensboro, NC). A foliar fungicide program containing azoxystrobin (Abound, Syngenta Crop Protection, Greensboro, NC) at 0.88 L/ha and a premix of prothioconazole and tebuconazole (Provost, Bayer CropScience, Research Triangle Park, NC) at 0.78 L/ha were alternatively applied starting 45 days after crop emergence until 115 days after crop emergence to minimize disease from pathogens. Imidacloprid (Admire Pro, Bayer CropScience, Research Triangle Park, NC) was applied in-furrow at 0.72 L/ha at planting to minimize injury from tobacco thrips and other early season soil insect pests.

Weeds were managed using preemergence herbicide applications of S-metolachlor (Dual II Magnum, Syngenta Crop Protection, Greensboro, NC) at 1.16 L/ha, or pendimethalin (Prowl, BASF Corporation, Research Triangle Park, NC) at 2.8 L/ha, in conjunction with flumioxazin (Valor, Valent U.S.A. Corporation, Walnut Creek, CA) at 0.44 L/ha. After planting, weed management was achieved with a premix of bentazon and acifluorfen (Storm, United Phosphorus, Inc., King of Prussia, PA) or acifluorfen (Blazer, United Phosphorus, Inc., King of Prussia, PA) alone at a 1.75 L/ha for either application.

The experiment was designed as a randomized complete block with a factorial arrangement of treatments and replicated four times at locations in Stoneville during 2017 and Starkville during 2018 and, replicated three times in Stoneville during 2019. Factor A and B consisted of insect infestation timing and insect defoliation level. At the Stoneville location during 2017 and 2019, two insect infestation timings, 40 to 80 (beginning pod to seed fill growth stages) days after emergence and 80 to 110 (seed fill to beginning maturity growth stages) days after emergence were used (Table 1). At the Starkville location during 2018, three infestation timings, 40 to 75 days after emergence, 80 to 95 days after emergence and 100 to 120 days after emergence were used (Table 3.1). For this study, fall armyworm were used as the defoliating insect due to ease of rearing. During insect infestation timings, fall armyworm were released daily during each time period by leaving egg sheets within the canopy foliage and releasing neonates and first to second instar larvae into the foliage of the center two rows in each plot, a two-row buffer was included between infested plots. Insect defoliation was measured by taking visual estimates of defoliation weekly and totaling those weekly evaluations to represent a total level of defoliation. A set defoliation level was predetermined (ie. 25, 50, 75, 100%) at which caterpillar pests would be terminated when the set defoliation percentage was achieved. Defoliation percentage in all plots never exceeded 15% except in one treatment during one site year which reached 50% during one visual evaluation timing. Therefore, defoliation percentages represented in graphs are defoliation percentages which each treatment accumulated not when caterpillar insects were terminated. Due to this, there are variations within the defoliation percentages between tests.

Physiological maturity was determined by collecting random peanut samples throughout the entire plot area. The hull-scrape maturity profile method (Williams and Drexler 1981) was used to determine digging date. When physiological maturity was reached by a majority of the plot area, plots were inverted using a two-row KMC digger-shaker-inverter (Kelley Manufacturing, Tifton, GA). Inverted plants were allowed to dry for 5 to 7 days depending on environmental conditions. Once dry, plants were threshed and bagged using a two row KMC plot peanut picker modified with a chute system for small plot research (Kelley Manufacturing, Tifton, GA). Bags of peanut pods from each plot were then weighed and recorded.

Peanut yields were analyzed using a general linear mixed model analysis of variance (PROC GLIMMIX, SAS 9.4). In this analysis, replication was considered a random effect. Insect defoliation level was considered a fixed effect. Degrees of freedom were calculated using the Kenward-Roger method. Means and standard errors were determined by using the PROC MEANS (SAS 9.4) statement. Fisher's protected LSD was used to separate means at the 0.05 level of significance. Yield was analyzed by site year and timing because of differences in defoliation levels among tests and timings. Experimental sites in Starkville 2017 were excluded from the study due to lack of insect defoliation.

Results and Discussion

During 2017 at the Stoneville location, insect defoliation had an effect on mean yield depending on timing (F=8.30; df=1; 33, P<0.01) (Fig. 3.1). Insect defoliation occurring forty to eighty days after emergence had no effect on mean yield (F=0.36; df=2, 16; P=0.70), but did when defoliation occurred eighty to one hundred and ten days after emergence (F=3.83; df=3, 12; P=0.04). Peanut yields for plots with 0% or 10% insect defoliation were greater than plots with 50% defoliation but not different than plots with 25% defoliation.

During 2018 at the Starkville location, insect defoliation had no effect on mean yield, regardless of timing (F=01.69; df=7, 42; P=0.14) (Fig 3.2). During 2019 at the Stoneville location, insect defoliation had no effect on mean yield regardless of timing (F=0.70; df=2, 20; P=0.36) (Fig. 3.3). This is likely due to the fact insect defoliation never exceeded 15% at these two locations.

Several studies have shown manual hand defoliation occurring during the vegetative and early reproductive growth stages resulted in yield losses when infestations are severe (Enyi 1974, Endan et al. 2006, Abbott 2018). In another study performed by Abbott et al. (2019), researchers found no relationship between manual defoliation at 40 days after emergence and pod yield. In contrast when defoliation occurred at 80 days after emergence, a significant relationship between manual defoliation and pod yield was found (Abbott et al. 2019).

Similar to Abbott et al. (2019), yield reductions were observed in the current study during 2017 at the Stoneville location when 50% caterpillar defoliation occurred at 80 to 110 days after emergence. There were no yield reductions observed from 25% caterpillar defoliation occurring 80 to 110 days after emergence during 2017 at the Stoneville location. There were no yield reductions 40 to 80 days after emergence at any location, and caterpillar defoliation never exceeded 10%. These data are inconclusive suggesting further research is needed to determine impact of defoliation on peanut yield for defining a threshold for caterpillar defoliation in late reproductive stage peanut. Abbott et al. (2019) suggested an economic injury level of 3 to 11% for manually defoliated peanut. However, results from the current study using caterpillar infestations indicate that these values are too low. The economic injury level for manually defoliated peanut could be much lower than expected due to unintended damage to peanut plants during the defoliation process such as breaking pedicels from maturing pods, removal of pegs from the soil, or accidental removal of flowers and terminals. Although extreme levels of defoliation from insects were not achieved in the current study, these data do suggest that low levels (<15%) of defoliation do not impact peanut yields at any timing.

With increased area planted to peanut in Mississippi, increased cost of control and new higher yielding cultivars available, action thresholds is needed. Current thresholds are based on nominal insect counts per m-row which can be misleading due to the lack of consideration for varying species and sizes of larvae feeding within a field. Therefore, creating a threshold based on injury level would be a more accurate estimation of damage to peanut. This research will allow specialists to provide farmers with data-based defoliation threshold recommendations.

Although not always severe, caterpillars infest peanut fields yearly. We can conclude peanut has the ability to compensate for minor foliage loss in early reproductive growth stages, but 50% defoliation occurring during late reproductive growth stage can result in a 12% yield reduction. Controlling caterpillar pests in late reproductive stage peanut when defoliation is severe is essential to minimize chances of yield loss due to caterpillar defoliation.

Table 3.1 Planting date, date peanut reached 40, 80, and 100 days after emergence, invert date and harvest date for all locations of infesting peanut during 2018 and 2019 in Mississippi.

Location	Planting Date	40 Days after Emergence	80 Days after Emergence	100 Days after Emergence	Invert Date	Harvest Date
Stoneville, 2017	17-May-2017	7-Jul-2017	16-Aug-2017	4-Sep-2017	5-Oct-2017	12-Oct-2017
Starkville, 2018	10-May-2018	2-Jul-2018	11-Aug-2018	31-Aug-2018	9-Oct-2018	19-Oct-2018
Stoneville, 2019	8-May-2019	6-Jul-2019	15-Aug-2019	3-Sep-2019	19-Sep-2019	26-Sept-2019

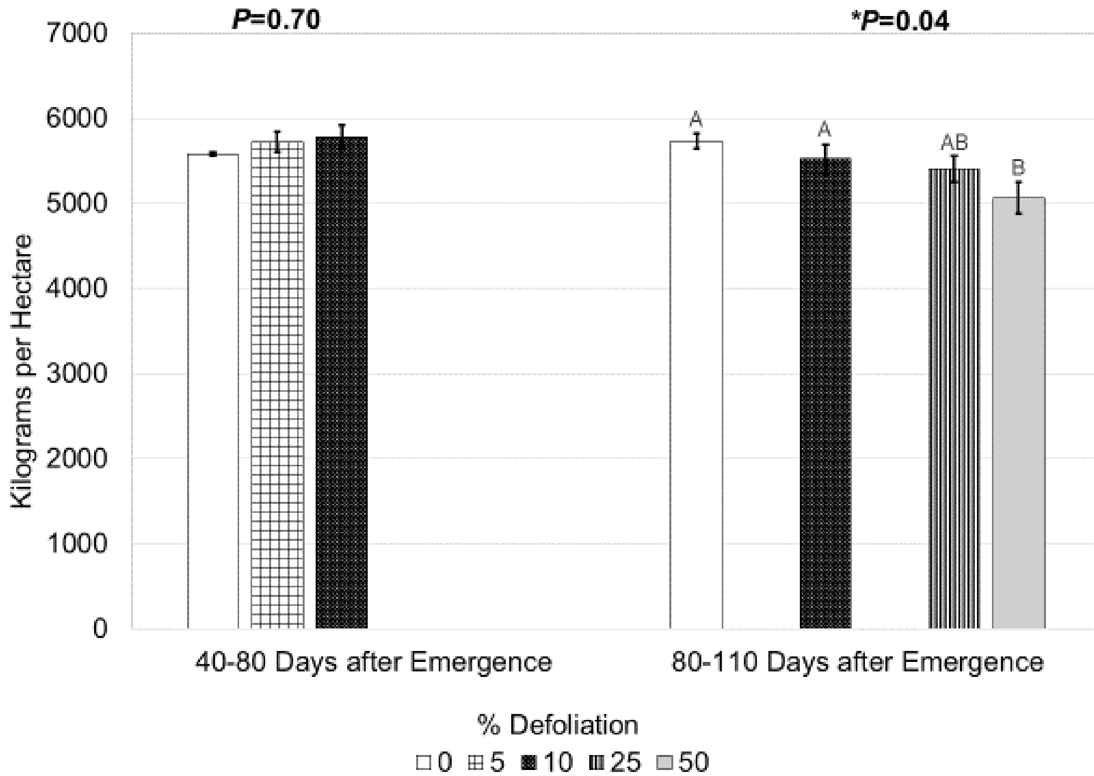

Figure 3.1 Impact of insect defoliation during early and late reproductive stages on peanut on yields at the Stoneville, MS location during 2017.

*Means with a common letter are not significantly different (α=0.05).

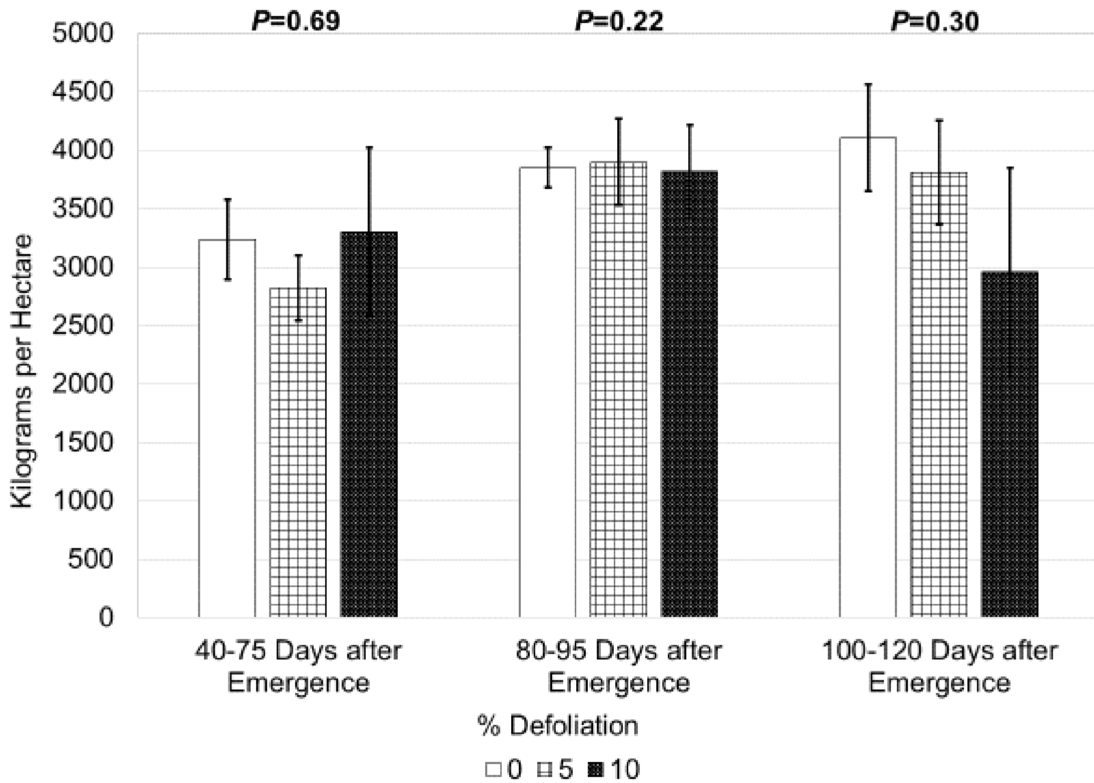

Figure 3.2 Impact of insect defoliation during early and late reproductive stages on peanut on yields at the Starkville, MS location during 2018.

*Means with a common letter are not significantly different (α=0.05).

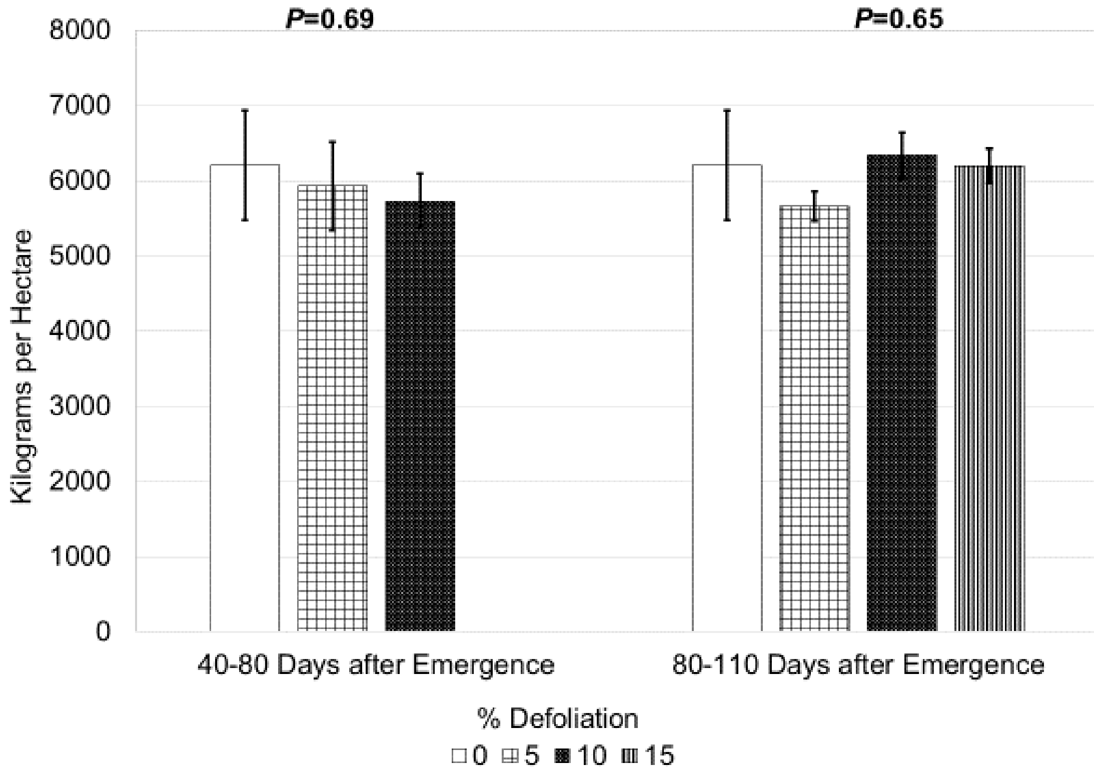

Figure 3.3 Impact of insect defoliation during early and late reproductive stages on peanut on yields at the Stoneville, MS location during 2019.

*Means with a common letter are not significantly different (α=0.05).

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CHAPTER IV

SUMMARY

Defoliating caterpillar pests infest peanut fields in Mississippi yearly and have been known to cause severe yield losses in several crops. Because of this, the defoliating caterpillar complex of peanut needs to be evaluated. Since the development of new cultivars, yield losses associated with defoliating caterpillar pests has not been researched. Current thresholds are based on nominal larval counts per row-m, which can be cumbersome and require more man hours for consultants and farmers; therefore, unnecessary insecticide applications are common. Due to increasing costs of insecticides, data are needed to make better insecticide application decisions in peanut. This prompted the need for a sweep net sampling threshold as well as defoliation threshold for early and late season peanut. The defoliating caterpillar pest complex in Mississippi consisted of yellow-striped armyworm, *Spodoptera ornithogalli (Guenée);* soybean looper, *Chrysodeixis includens* (Walker); corn earworm, *Helicoverpa zea* (Boddie); fall armyworm, *S. frugiperda* (J. E. Smith); southern armyworm, *S. eridania* (Stoll); beet armyworm, *S. exigua* (Hübner); green cloverworm, *Hypena scabra* (F.); velvetbean caterpillar, *Anticarsia gemmatalis* (Hübner); and granulate cutworm, *Feltia subterranea* (F.). There was a significant relationship between drop cloth samples and sweep net samples for caterpillars meaning sweep net thresholds can be established for those species and total caterpillars. In comparison to the current drop thresholds, sweep net thresholds will be 17.6 larvae per 25 sweeps early season and 34.4 larvae per 25 sweeps late season. Any level of defoliation occurring during vegetative and early reproductive peanut growth stages prolongs canopy closure beginning after a defoliation event until 21-35 days after a defoliation event. Although canopy closure was affected at all levels of defoliation, 11-13% yield losses occurred only when defoliation was severe reaching 100%. Defoliation occurring 80-110 days after emergence resulted in 12% yield reduction when defoliation reached 50% likely due to the importance of leaf area during late reproductive stages. Managing caterpillar pests early and late season will be necessary to reduce likelihood of yield losses due to defoliation.