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## Establishing Defoliation Thresholds in Peanut (*Arachis Hypogaea* (L.)) in Mississippi

Chadwick Cameron Abbott

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Establishing defoliation thresholds in peanut (*Arachis hypogaea* (L.)) in Mississippi

By

Chadwick Cameron Abbott

A Thesis  
Submitted to the Faculty of  
Mississippi State University  
in Partial Fulfillment of the Requirements  
for the Degree of Master of Science  
in Agronomy  
in the Department of Plant and Soil Sciences

Mississippi State, Mississippi

May 2018

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2018

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Pages in Study 53

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Foliage feeding insects like fall armyworm (FAW) [*Spodoptera frugiperda* (J. E. Smith)], granulate cutworm (GCW) [*Feltia subterranean* (F.)], velvetbean caterpillar (VBC) [*Anticarsia gemmatalis* (Hübner)] and corn earworm (CEW) [*Helicoverpa zea* (Boddie)] in peanut (*Arachis hypogaea* (L.)) and their effects on canopy defoliation and the resultant yield loss is outdated and essentially non-existent in Mississippi. With the expansion of peanuts throughout the state since 2012, growers struggle to manage foliage-feeding pests in peanut. The lack of current information regarding insect pressure and economic injury levels is troublesome; especially with newer, high yielding, disease resistant cultivars. Research was required to understand how peanuts respond to complete canopy removal at different times during the growing season. Consequently, we evaluated the severity of canopy defoliation causing significant levels of yield loss during key physiological growth periods. This information will assist growers and extension personnel streamline management decisions for canopy defoliation in peanut throughout Mississippi.

## DEDICATION

I dedicate this research to my parents, Steve and Susan Abbott. You both have supported me with unwavering dedication. I cannot thank you both enough for the constant support to follow my dreams. You have given advice, love, and support when I needed it most. You have taught me to appreciate what we have and to work hard no matter what. I would also like to dedicate this research to my Uncle Butch and Aunt Michelle. I would not be the man I am today without the love, guidance, long talks and many wonderful memories we have shared. Lastly, I would like to dedicate this research to my older brother, Chase Abbott. We've been through a lot and you have always been there for me. I couldn't ask for a better best friend. I love you all.

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## TABLE OF CONTENTS

DEDICATION .....	ii
ACKNOWLEDGEMENTS .....	iii
LIST OF TABLES .....	vi
LIST OF FIGURES .....	vii
CHAPTER	
I. INTRODUCTION .....	1
References .....	7
II. EVALUATING THE IMPACT OF COMPLETE CANOPY DEFOLIATION IN PEANUT ( <i>ARACHIS HYPOGAEA</i> (L.)) WITH MULTIPLE DEFOLIATION TIMINGS IN MISSISSIPPI .....	10
Abstract.....	10
Introduction .....	11
Materials and Methods .....	13
Results and Discussion .....	15
Yield and grade.....	15
Plant growth characteristics.....	16
Summary and Conclusions .....	18
References .....	28
III. ESTABLISHING DEFOLIATION THRESHOLDS IN PEANUT ( <i>ARACHIS HYPOGAEA</i> (L.)) IN MISSISSIPPI .....	31
Abstract.....	31
Introduction .....	32
Materials and Methods .....	34
Results and Discussion .....	38
Yield and grade.....	38
Plant growth characteristics.....	38
Economic Injury Levels .....	41
Summary and Conclusions .....	42



References .....51

## LIST OF TABLES

2.1	Planting, inversion and harvest dates for all site-years.....	19
3.1	Planting, inversion and harvest dates for all site-years.....	44
3.2	Plant heights and widths following an 40 days after emergence defoliation event across four site-years in Mississippi. ....	45
3.3	Plant heights and widths measured two and four weeks following an 80 day after emergence defoliation event across four site-years in Mississippi. ....	46
3.4	Above-ground and pod biomass following 40 DAE defoliation event.....	47
3.6	Economic injury levels for canopy defoliation in peanut 80 days after emergence. ....	49

## LIST OF FIGURES

2.1	Effect of complete canopy defoliation on peanut pod yield ( $\text{kg/ha}^{-1}$ ) across six different timings. ....	20
2.2	Effect of complete canopy defoliation on peanut canopy height (centimeters) at 50 days after complete emergence. ....	21
2.3	Effect of complete canopy defoliation on peanut canopy width (centimeters) at 50 days after complete emergence. ....	22
2.4	Effect of complete canopy defoliation on peanut canopy height (centimeters) at 95 days after complete emergence. ....	23
2.5	Effect of complete canopy defoliation on peanut canopy width (centimeters) at 95 days after complete emergence. ....	24
2.6	Effect of complete canopy defoliation on peanut canopy biomass (g/plant) at 50 days after complete emergence. ....	25
2.7	Effect of complete canopy defoliation on peanut canopy biomass (g/plant) 95 days after complete emergence. ....	26
2.8	Effect of complete canopy defoliation on peanut pod biomass (g/plant) 95 days after complete emergence. ....	27
3.1	Yield regressions for the 40 and 80 DAE defoliation timing across all site-years. ....	50

## CHAPTER I

### INTRODUCTION

Potential yield and economic profitability drive management decisions for peanut (*Arachis hypogaea* (L.)) producers. With world population estimated to be 9 billion in the year 2050 (U.S. Census Bureau, 2015), it is vital to improve crop production and to understand factors that promote loss of productivity, with an ultimate goal of maximizing crop production efficiency. Peanut, which is widely considered an inexpensive form of protein, could play a significant role in feeding a growing world population.

In the United States, peanut is grown in three distinct regions, the Virginia-Carolinas, the southwest, and the southeast. The southeast represents the largest peanut growing area in the country. In 2014, the southeast produced about 3.7 billion pounds, that is, 72% of the 5.2 billion pounds of peanuts produced in the United States (NASS, 2015). The majority of the southeastern acreage has historically been in Georgia, Alabama, and Florida; however, production has expanded in Mississippi since 2011 (NASS, 2015). While the original expansion into Mississippi was in large part to record prices entering the 2012 season, growers in the state have discovered that they can profitably grow peanuts even at crop prices below those received in 2012. Peanuts also fit well in rotation with crops currently being grown in the state, as peanut reduces disease, insect, and nematode pressure in rotation with other crops (Jordan et al., 2008).

To maximize production efficiency and profitability, factors that curtail yield potential must be minimized. Common factors that influence yield are planting date (Stewart et al., 1997), irrigation management (Augusto and Brenneman, 2011), precipitation and drought stress (Augusto and Brenneman, 2011; Phakamas et al., 2008), weed (Hauser and Buchanan, 1981), disease (Pixley et al., 1990) and insect (Deitz et al., 1992; Stewart et al., 1997) pressure throughout the growing season, and mechanical operations during harvest (Jackson et al., 2011; Rowland et al., 2008; Thomas et al., 1983).

With ever-expanding production in Mississippi, concerns about insect and disease pressure are at the forefront when making management decisions. Defoliation of peanut vegetation by insects and foliar disease pathogens is a concern for peanut growers in Mississippi and across the southeast. Data are scant regarding threshold levels for defoliating caterpillars in the state or how much defoliation a peanut crop can withstand before an economic yield loss warrants pest control. Since peanut is a relatively new crop in much of the state, there is a dearth of information concerning optimum management decisions and economic injury level thresholds for defoliators. Moreover, there is also a general lack of understanding across the southeast on damage thresholds on newer, high-yielding cultivars (Abney, 2015; Gore, 2015).

Peanut plants have tetrafoliate, arranged as pinnately compound leaves with two opposite pairs of leaflets (Bourgeois and Boote, 1992), and the canopy is susceptible to a range of insects and diseases. Since these leaves are the major photosynthetic unit of the plant, defoliation by pests can impede the plant's photosynthetic potential by reducing leaf area, and in turn, light interception and photosynthesis (Boote et al., 1980; Bourgeois

and Boote, 1992). The reduction in photosynthates directly reduces vegetative and reproductive growth (Boote et al., 1980; Bourgeois and Boote, 1992). According to Stalker and Campbell (1983), pest damage varies from incidental feeding to near plant consumption, with the intensity of defoliation determining the amount of yield loss. Impacts from foliage feeding insects are generally unpredictable from year to year and from field to field.

Corn earworm (CEW) [*Helicoverpa zea* (Boddie)], fall armyworm (FAW) [*Spodoptera frugiperda* (J. E. Smith)], granulate cutworm (GCW) [*Feltia subterranean* (F.)], and velvetbean caterpillar (VBC) [*Anticarsia gemmatalis* (Hübner)] are all pests that can have detrimental impacts to the plant canopy from physical defoliation (Deitz et al., 1992; Jones et al., 1982; Lynch, 1996; Minton et al., 1991; Stalker and Campbell, 1983). Insects have varying feeding behaviors at different crop growth stages, and not every insect listed invades the peanut plant at the same time or damages the plant the same way. Some insects prefer young folded or recently unfolded terminal vegetation. Other pests, based on nutrient requirements, favor older vegetation (Deitz et al., 1992; Stalker and Campbell, 1983). Information regarding foliage feeders like the FAW, GCW, VBC, and CEW in peanut and their effects on canopy defoliation and the resultant yield loss is outdated regionally and non-existent in Mississippi. The paucity of data regarding insect pressure and economic injury levels is troublesome; especially with newer, high-yielding, disease resistant cultivars (Abney, 2015; Branch et al., 2015).

Small-scale, defoliation research offers insight into the feeding behaviors of defoliating caterpillars and the difficulty in establishing thresholds (Deitz et al., 1992; Endan et al., 2006; Garner and Lynch, 1981; Todd et al., 1991). Labeled thresholds

according to Deitz et al., (1992) for the FAW, GCW, and CEW are 13 larvae per row meter in the state of South Carolina. Accurate sampling was difficult, however, because of feeding site preference between the larvae and time of day the sampling occurred. Some defoliating larvae, such as GCW, are often located in the upper soil surface which is undetectable from sweeps or shake cloths, making sampling at the soil surface the only way to determine pest presence (Deitz et al., 1992). Moreover, the impact of larval defoliation can be underestimated because feeding in the axillary bud region, especially by GCW, retards further development of new leaves and reproductive branches. While those tests help to explain feeding patterns, more field-scale research is required to quantify yield consequences of larval feeding.

Genetics and the environment affect crop growth rate (Phakamas et al., 2008), which is a function of the crop's capacity to convert light, water, and nutrients to biomass (Phakamas et al., 2008). While not studying defoliation explicitly, Hang et al. (1984) reported that reduced light interception from shading reduced growth, partitioning, and yield components in peanut. Reduced light interception during specific vegetative and reproductive periods resulted in significant yield loss from both a reduced number of pods and reduced seed weight. Similarly, research conducted on soybean [*Glycine max* (L.) Merr.] by Owen et al. (2013) determined how feeding on stems, roots, and foliage, by an insect complex reduced yield and seed quality. They noted that current economic injury levels in soybean are based on a collection and count of insects in a given field or sample area from within a field. They concluded, however, that yield loss in soybean from defoliating insect complexes could more accurately be determined by quantifying plant damage rather than insect counts. We submit that a similar approach, i.e.,

quantifying plant injury rather than insect counts, could be beneficial for determining optimum management decisions for peanuts under various levels of defoliation.

Research focuses more on peanut defoliation from pathogens than insect populations, and the effect of pathogen defoliation on peanut is, generally, more predictable than that by insects. While disease pressure is not entirely understood, research has shown how crop rotation, cultivar selection, plant population, row pattern, field history, tillage, and irrigation determines the incidence of disease organisms in a given field (Kemerait et al., 2015).

Early and late leaf spot, i.e., *Cercospora arachidicola* S. Hori and *Phaeoisariopsis personatum* (Berk & M. A. Curtis), respectively, are the most common defoliating fungal pathogens across the southeastern peanut belt (Adomu et al., 2005; Boote et al., 1980; Bourgeois et al., 1991; Bourgeois and Boote, 1992). Defoliation from leaf spot in the absence of preventative and curative measures reduced yield up to 50% (Bourgeois et al., 1991). Yield loss up to 10% occurs even when preventative and curative measures in peanut for leaf spot are employed (Pixley et al., 1990). Although the defoliation mechanism(s) differ between pathogen and insect pests, previous research on the leaf spot diseases in peanut may help refine defoliating-insect management decisions.

Research that establishes defoliation thresholds in peanuts is required for Mississippi and the southeast. Larval feeding and infestations are difficult to predict both spatially and temporally, and scouting for defoliating pests in peanut is problematic. Therefore, the objectives of this research are to determine the temporal sensitivity of



peanut to defoliation, and to establish a temporally based economic threshold for peanut defoliation.

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CHAPTER II  
EVALUATING THE IMPACT OF COMPLETE CANOPY DEFOLIATION IN  
PEANUT (*ARACHIS HYPOGAEA* (L.)) WITH MULTIPLE  
DEFOLIATION TIMINGS IN MISSISSIPPI

**Abstract**

Defoliation of peanut by foliage-feeding insects reduces photosynthetic capacity, and in turn, may reduce pod yield; however, the temporal effect of canopy defoliation on plant biomass and yield components requires elucidation. The objective of this research was to determine the effect of 100% canopy removal at six timings including 35, 50, 65, 80, 95, 110 d after full plant emergence (DAE) on canopy height and width, plant biomass, pod grade, and yield. Research was conducted at the Delta Research and Extension Center in Stoneville, MS and the R. R. Foil Research Farm in Starkville, MS in 2015 and 2016. The experimental design was a randomized complete block, with four replications per site-year. Defoliation, regardless of timing, reduced canopy height and canopy width at least 6% up to 3 weeks post treatment ( $P \leq 0.0148$ ). Similarly plant biomass was decreased by at least 24% at all sample periods ( $P \leq 0.0424$ ) except for the two week post treatment sample at 95 DAE ( $P \leq 0.0814$ ). Defoliation did not affect peanut grade or maturity ( $P \geq 0.0675$ ). Pod yield was negatively correlated with defoliation timing, and decreased in the order of non-defoliated > 35 DAE = 50 DAE = 65 DAE > 80 DAE = 95 DAE = 110 DAE. These data indicate that complete canopy defoliation of

peanut negatively affects canopy height and width, plant biomass, and yield, and that peanut sensitivity to complete defoliation is greater during reproductive growth stages than during vegetative growth stages.

### **Introduction**

Defoliation of the peanut canopy by insects is a concern for producers across the southeastern United States. There is a paucity of data, however, for the effect of defoliating caterpillars on peanut in Mississippi. While no research on defoliation thresholds in Mississippi peanut exists, there is also a general lack of understanding of peanut susceptibility to catastrophic defoliation during various growth stages across the Southeast, especially on newer cultivars.

The peanut canopy is susceptible to a multitude of insects and pathogens. Defoliation by pests decreases photosynthetic potential by reducing leaf area, which diminishes light interception and photosynthesis (Boote et al., 1980; Bourgeois and Boote, 1992). Reducing photosynthate production decreases vegetative and reproductive growth (Boote et al., 1980; Bourgeois and Boote, 1992).

Foliage feeding insects will defoliate plants from minor leaf removal to near plant consumption (Stalker and Campbell 1983). Corn earworm (CEW) [*Helicoverpa zea* (Boddie)], fall armyworm (FAW) [*Spodoptera frugiperda* (J. E. Smith)], granulate cutworm (GCW) [*Feltia subterranean* (F.)], velvetbean caterpillar (VBC) [*Anticarsia gemmatalis* (Hübner)], and other Lepidoptera species are pests that negatively impact the plant canopy via physical defoliation (Deitz et al., 1992; Jones et al., 1982; Lynch, 1996; Minton et al., 1991; Stalker and Campbell, 1983). When foliage is completely removed from the canopy, the crop partitions growth to vegetative structures for photosynthesis.

Plant canopies provide functions beyond photosynthesis including soil temperature and moisture regulation (Dow et al., 1988). For example, canopy defoliation allows more sunlight to reach the soil surface and weed pressure can become a severe problem if not handled properly (Wehtje et al., 1984). Knowing the impact of complete defoliation at various timings throughout the season will impact a grower's choice on which management decisions should be made, and perhaps more importantly, the severity of yield loss that can be expected in catastrophic defoliation scenarios (Wilkerson et al., 1984). An educated decision on fungicide or insecticide applications in response to defoliation is key. The effect of defoliation on peanut physiology at the micro-plot scale has been evaluated; however, to predict yield and profit loss at the production scale, peanut defoliation must be correlated with economic injury thresholds throughout the growing season (Deitz et al., 1992; Endan et al., 2006; Garner and Lynch, 1981; Todd et al., 1991).

To elucidate the effect of canopy defoliation on pod yield, a complete canopy removal study was needed to determine when peanut was most susceptible to defoliation. The objective of this research was to determine the impact of 100% canopy removal at six different timings (35, 50, 65, 80, 95, or 110 days after complete stand emergence) on canopy height and width, plant biomass, market grade, and yield. Upon completion of this research project, the data acquired pertaining to economic injury level thresholds will be accessible to specialists, extension agents, producers, and researchers; guiding more efficient and economical peanut production and pesticide usage.

## Materials and Methods

Research was conducted on a Leeper silty clay loam (fine, smectitic, nonacid, thermic Vertic Epiaquepts) (USDA-NRCS, 2016) at the Mississippi State University R.R. Foil Research Center in Starkville, MS and on a Bosket very fine sandy loam (fine-loamy, mixed, active, thermic Mollic Hapludalfs) (USDA-NRCS, 2016) at the Mississippi State University, Delta Research Extension Center (MSU DREC) near Stoneville, Mississippi in 2015 and 2016 (Table 1). Both locations were furrow irrigated.

Land preparation at the Starkville location included a ripper-hipper single bed formation, with a do-all over the top prior to planting, and a roller packer to firm the seed bed. Single beds were 0.97-m wide. Soil preparation at MSU DREC was similar in that 1.02-m wide beds were ripped and hipped and then rolled to firm the seed bed. Fertilizer requirements and applications, which include calcium and boron, were based on MSU Extension recommendations (Oldham, 2017). Immediately after planting in 2015, a pre-emergent herbicide tank-mix of pendimethalin (930 g a. i. ha<sup>-1</sup>), diclosulam (27 g a. i. ha<sup>-1</sup>), and flumioxazin (107 g a.i. ha<sup>-1</sup>) was applied. Pre-emergent herbicides in 2016 consisted of a tank-mix of s-metolachlor (650 g a. i. ha<sup>-1</sup>) and flumioxazin (107 g a. i. ha<sup>-1</sup>). Fungicide programs were based on guidelines obtained from the medium risk model of the Peanut Disease Risk Index (Kemerait et al., 2015). Chlorantraniliprole (DuPont™ Prevathon®, 75 g a. i. ha<sup>-1</sup>, DuPont, Wilmington, DE) was applied once across all plots at both locations in 2016, due to fall armyworm pressure that could have potentially confounded results if left untreated.

Georgia-06G (Branch, 2007) peanut cultivar was planted in Starkville, MS with a two-row Monosem precision air planter (Monosem, Inc., Edwardsville, KS). Peanuts



were planted at a depth of 5.1 cm with a seeding rate of 20 seed/m of row in two row plots that were 1.94-m wide and 4.57-m long. A John Deere MaxEmerge2 four-row vacuum planter (John Deere, Moline, Illinois) seeded the same cultivar at a similar depth and rate as those at the Starkville location. Two-row plots at Stoneville measured 2.04-m wide and 6.10-m long. Seed at all locations were treated with Dynasty (azoxystrobin, fludioxonil, and mefenoxam) fungicide seed treatment (Syngenta Crop Protection, Greensboro, NC).

The experimental design was a randomized complete block with four replications at each location. Treatments included six defoliation timings that occurred 35, 50, 65, 80, 95, and 110 days after complete stand emergence, along with a non-defoliated control. Complete canopy removal was achieved by removing all open leaflets while leaving all flowers and unopened terminal leaflets.

Starkville experimental units were evaluated for above-ground plant and pod biomass immediately following defoliation and at one, two, and three weeks after defoliation. A minimum of 0.3-m of row was harvested for above-ground and pod biomass samples at each sample period, and samples were placed in forced air dryers for 48 hrs at 46 C before biomass readings were recorded. Canopy height and width measurements were determined one, two, and three weeks after defoliation. Plots were evaluated for pod yield and grade. Optimum harvest timing was determined at each site-year by the hull-scrape maturity profile method (Williams and Drexler, 1981). Plots were inverted using a two-row KMC digger-shaker-inverter (Kelley Manufacturing Company, Tifton, GA) and harvested using a two-row KMC peanut combine. Inversion and harvest dates are

reported in Table 1. Yield was adjusted to 10.5% moisture. Peanuts were graded at the R. R. Foil Research Farm in Starkville, MS.

To determine the impact of defoliation at multiple timings on market grade, biomass, canopy development, and pod yield; data were analyzed with analysis of variance (PROC GLM, SAS 9.4, SAS Institute, Cary, NC). Market grade, biomass, canopy development, and pod yield were dependent variables and defoliation timing was the independent variable. When effects were found to be significant, least significant differences (LSD,  $\alpha = 0.05$ ) were calculated to separate means. No significant interaction occurred between defoliation timings and site-years, so analyses are reported with all data combined across locations and years.

## **Results and Discussion**

### **Yield and grade**

Defoliation affected pod yield ( $P < 0.0001$ ). Regardless of timing, defoliation reduced pod yield by at least 13% relative to the control. Defoliation effects on pod yield were more dramatic during reproductive stages than vegetative stages. For example, mean reduction in pod yield during vegetative growth stages, i.e., 35 to 65 DAE, was 15% compared to 31% during reproductive growth stages, i.e., 80 to 110 DAE. The greater impact on yield from defoliation at 80 DAE and later can likely be explained by the fact that plants are at the height of reproductive growth during the 80 to 110 DAE period. Conversely, at 35, 50, or 65 DAE, plants are in late vegetative or early reproductive stages, giving them more time to compensate for injury. These results are consistent with findings reported in soybean [*Glycine max* (L.) Merr.], in which defoliation imposed at various levels in vegetative growth stages, i.e., V5, is less detrimental to yield potential

than defoliation imposed on soybeans during critical reproductive growth stages, i.e., R4 to R6 (Board et al., 2010; Caviness and Thomas, 1980; Fehr et al., 1983).

Defoliation did not affect market grade ( $P=0.0675$ ), with total sound mature kernels (TSMK) ranging from 73.5 to 74.2 across all treatments. Because grade can be correlated with maturity, we can postulate that defoliation, regardless of timing, did not affect optimum harvest timing (Court et al., 1984; Knauft et al., 1986; Mozingo et al., 1991).

### **Plant growth characteristics**

For brevity, plant growth data are reported only for defoliation treatments occurring at 50 and 95 DAE. Canopy height for the 50 DAE defoliation treatment was reduced at least 13% at sample periods 1, 2, and 3 weeks after defoliation (WAD) as compared to the non-defoliated treatment at 50 DAE (Figure 2). The non-defoliated treatment 50 DAE illustrates a positive trend in plant height growth during the sample period, whereas the defoliated plant height had a slower growth rate during the sample window. Canopy width was reduced at least 15% at sample periods 1, 2, and 3 WAD when compared to the non-defoliated treatment at 50 DAE (Figure 3). Row closure development was impeded by defoliation, with those defoliated plots showing a reduced lateral canopy growth rate. Canopy height was reduced at least 6% at sample periods 1, 2, and 3 WAD when compared to the non-defoliated treatment at 95 DAE (Figure 4). At the time of the 3 WAD sample after the 95 DAE defoliation, both the defoliated and non-defoliated treatments experienced a negative trend in overall plant canopy height (Figure 4). Canopy width was reduced at least 11% at sample periods 1, 2, and 3 WAD when compared to the non-defoliated treatment at 95 DAE (Figure 5). Row closure occurred

when plants reached 90 cm in width; however, plants defoliated at 95 DAE were unable to regain row closure within the sample window.

Complete canopy closure is beneficial to production for a number of reasons. Hauser and Buchanan (1981) found that earlier canopy closure increased weed suppression, which in turn resulted in fewer herbicide applications and increased yield. Butzler et al., (1998) reported that soil temperature was consistently 1 degree C warmer beneath plots that were pruned when compared to non-pruned peanut plots, with bare soil temperatures sometimes reaching 8 – 9 C warmer than non-pruned plots. These micro-climate differences were attributed to both increased sunlight penetration and air movement which increased soil temperature and moisture loss. Research conducted by Dreyer et al., (1981) found that pod weights were lower when soil temperatures reached 37 C when compared to optimal soil temperatures of 30 and 34 C, meaning that defoliation from insects could potentially affect yield in this way as well.

Above-ground plant and pod biomass samples provide further information on canopy and pod development following complete canopy defoliation at the 50 and 95 DAE timings. Figure 6 shows plant biomass response to defoliation at 50 DAE. During all sample timings, the defoliated treatment weighed significantly less than the non-defoliated control on a mass per plant basis and was reduced at least 24% at these sample periods. There were no measureable pods within the sample window of 50 DAE defoliation. Immediately following the 95 DAE defoliation, defoliated plant weight was significantly less than the non-defoliated treatment (Figure 7). Defoliated plant biomass was significantly less in sample periods 0, 1 and 3; sample period 2 had no significant difference in plant biomass between the non-defoliated and defoliated treatments.

Immediately following defoliation, pod biomass was not different between the defoliated and non-defoliated treatment (Figure 8). There was no difference in pod weights up to two weeks after defoliation at 95 DAE. However, pod weights differed greatly at the 3 week after defoliation sample period between the non-defoliated and defoliated treatment. The non-defoliated treatment had significantly higher pod weights per plant than the defoliated treatment (Figure 8).

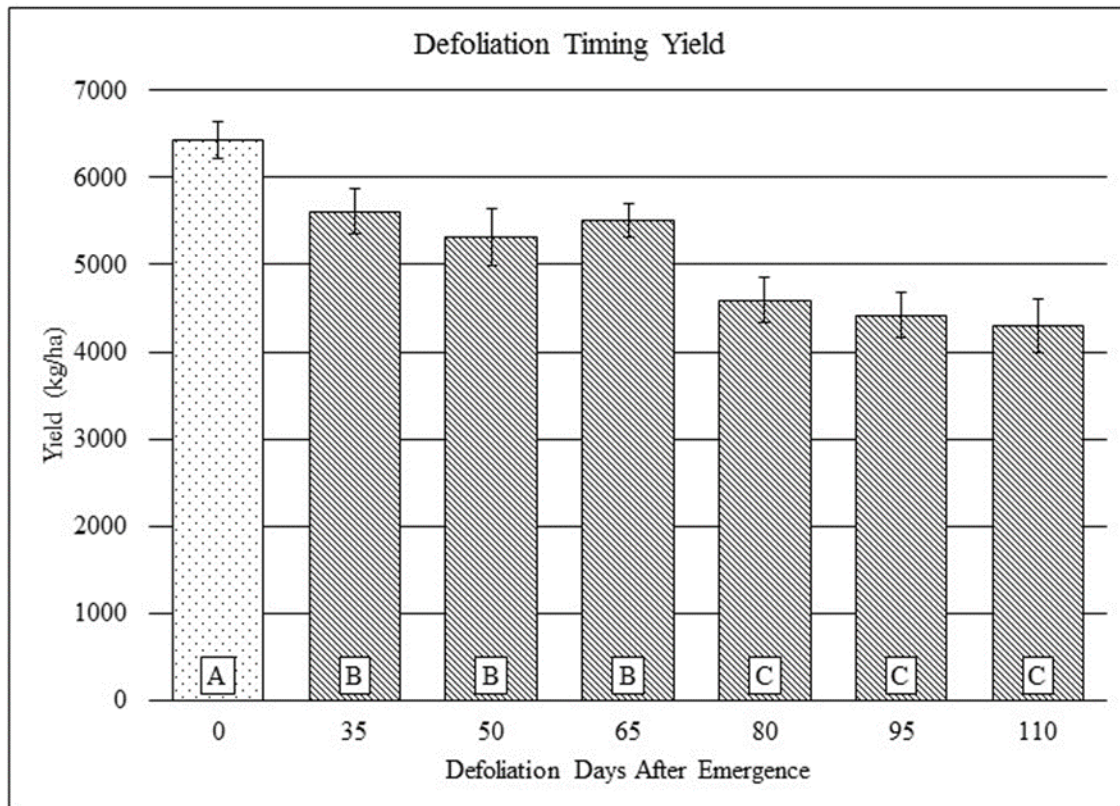
### **Summary and Conclusions**

Pod yield data indicate that complete canopy defoliation at any point during the growing season reduces yield by at least 13%. Moreover, the effect of defoliation on the yield reduction varies temporally. That is, complete defoliation during vegetative stages reduces pod yield on average of 13%, but when defoliation occurs during reproductive stages pod yield is reduced on average of 31%. Thus, peanut has a greater capacity to compensate for complete defoliation during vegetative stages relative to reproductive growth stages. Research is required, however, to determine if peanut yield and growth parameters responds differently to various defoliation levels when canopy damage occurs in vegetative and reproductive growth stages.

Table 2.1 Planting, inversion and harvest dates for all site-years.

	Starkville 2015	Stoneville 2015	Starkville 2016	Stoneville 2016
Planting	4- May	11- May	26- April	6- May
Inversion	21- September	24- September	26- September	11- October
Harvest	30- September	1- October	6- October	17- October

Figure 2.1 Effect of complete canopy defoliation on peanut pod yield ( $\text{kg/ha}^{-1}$ ) across six different timings.





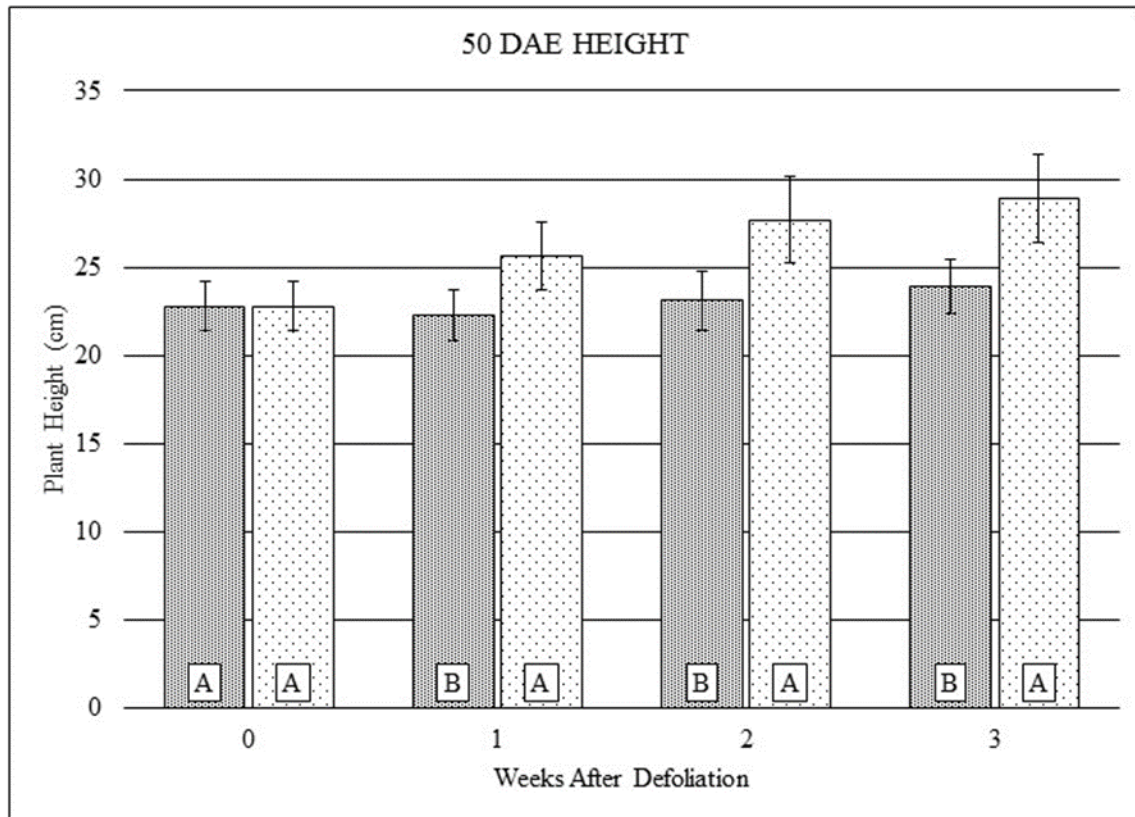
Yield is represented as  $\text{kg/ha}$ , based on complete canopy removal at six different times (35, 50, 65, 80, 95, and 110 DAE) during the growing season. The bar represented by  is the non-defoliated control. Each defoliation time bar is represented by . Means are separated by letters in the base of each bar and bars that have the same letter are not significantly different from each other. Standard error is located at the top of each bar.

Figure 2.2 Effect of complete canopy defoliation on peanut canopy height (centimeters) at 50 days after complete emergence.





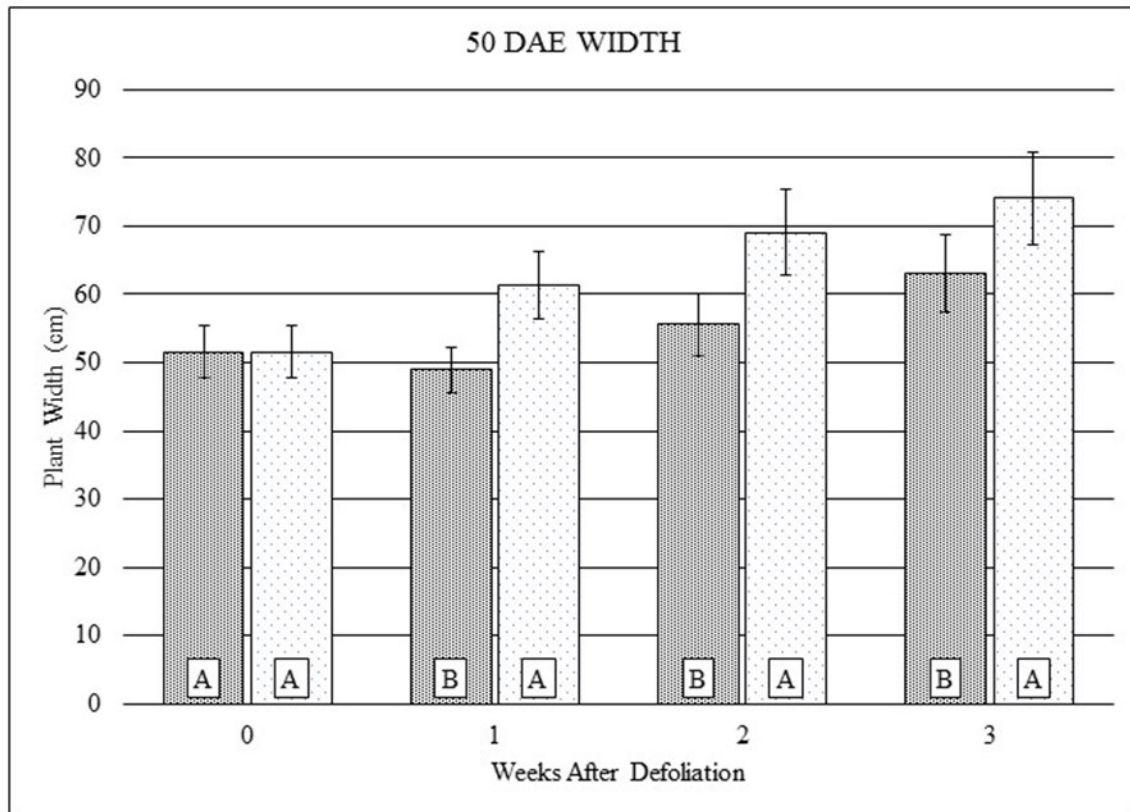
Plant heights for 50 DAE is reported in centimeters and is representative for 0, 1, 2, and 3 weeks following complete canopy removal. The bars represented by  is the non-defoliated treatment. 50 DAE defoliation time bar is represented by . Means are separated by letters in the base of each bar and bars that have the same letter are not significantly different from each other. Standard error is located at the top of each bar.



Figure 2.3 Effect of complete canopy defoliation on peanut canopy width (centimeters) at 50 days after complete emergence.





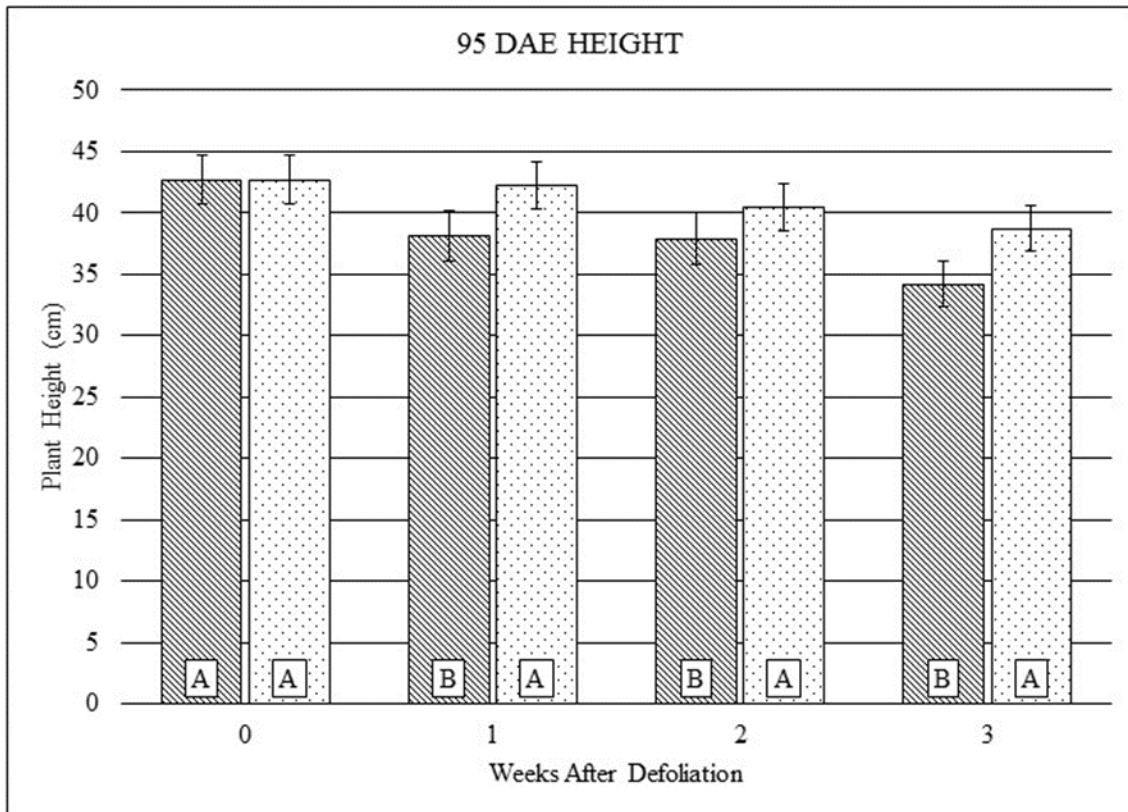
Plant widths for 50 DAE is reported in centimeters and is representative for 0, 1, 2, and 3 weeks following complete canopy removal. The bars represented by  is the non-defoliated treatment. 50 DAE defoliation time bar is represented by . Means are separated by letters in the base of each bar and bars that have the same letter are not significantly different from each other. Standard error is located at the top of each bar.

Figure 2.4 Effect of complete canopy defoliation on peanut canopy height (centimeters) at 95 days after complete emergence.





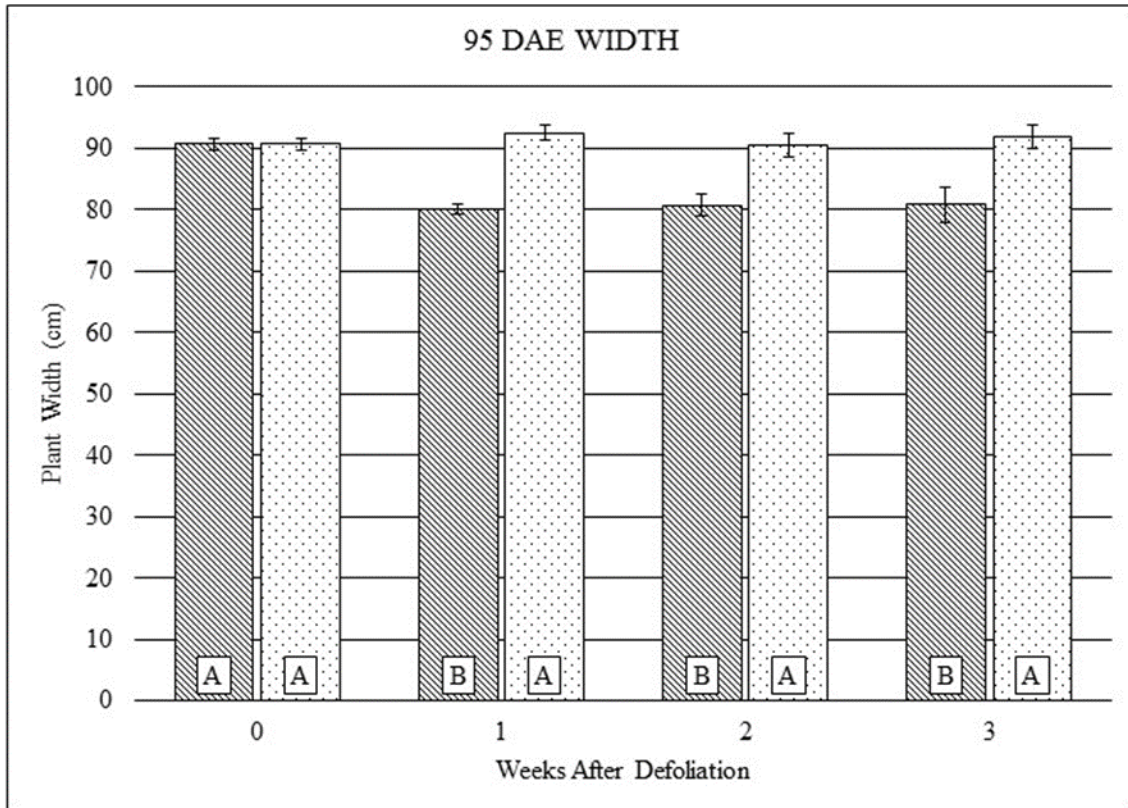
Plant heights for 95 DAE is reported in centimeters and is representative for 0, 1, 2, and 3 weeks following complete canopy removal. The bars represented by  is the non-defoliated treatment. 95 DAE defoliation time bar is represented by . Means are separated by letters in the base of each bar and bars that have the same letter are not significantly different from each other. Standard error is located at the top of each bar.

Figure 2.5 Effect of complete canopy defoliation on peanut canopy width (centimeters) at 95 days after complete emergence.





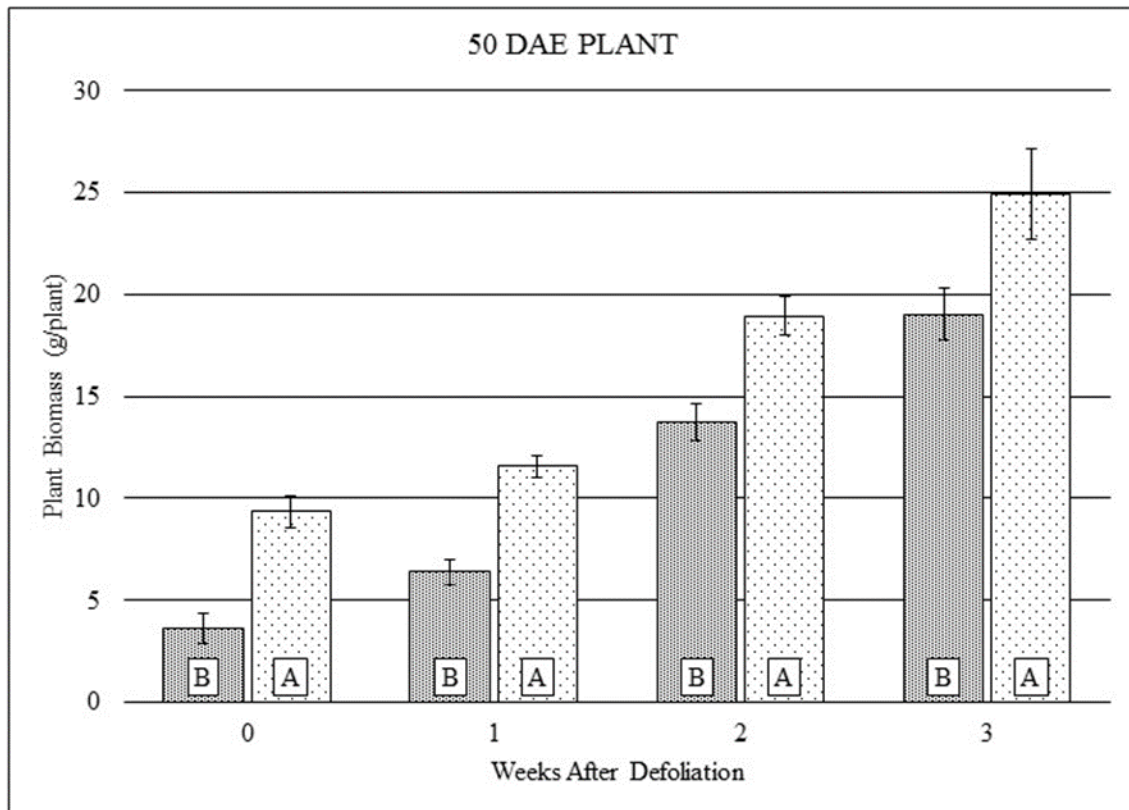
Plant widths for 95 DAE is reported in centimeters and is representative for 0, 1, 2, and 3 weeks following complete canopy removal. The bars represented by  is the non-defoliated treatment. 95 DAE defoliation time bar is represented by . Means are separated by letters in the base of each bar and bars that have the same letter are not significantly different from each other. Standard error is located at the top of each bar.

Figure 2.6 Effect of complete canopy defoliation on peanut canopy biomass (g/plant) at 50 days after complete emergence.





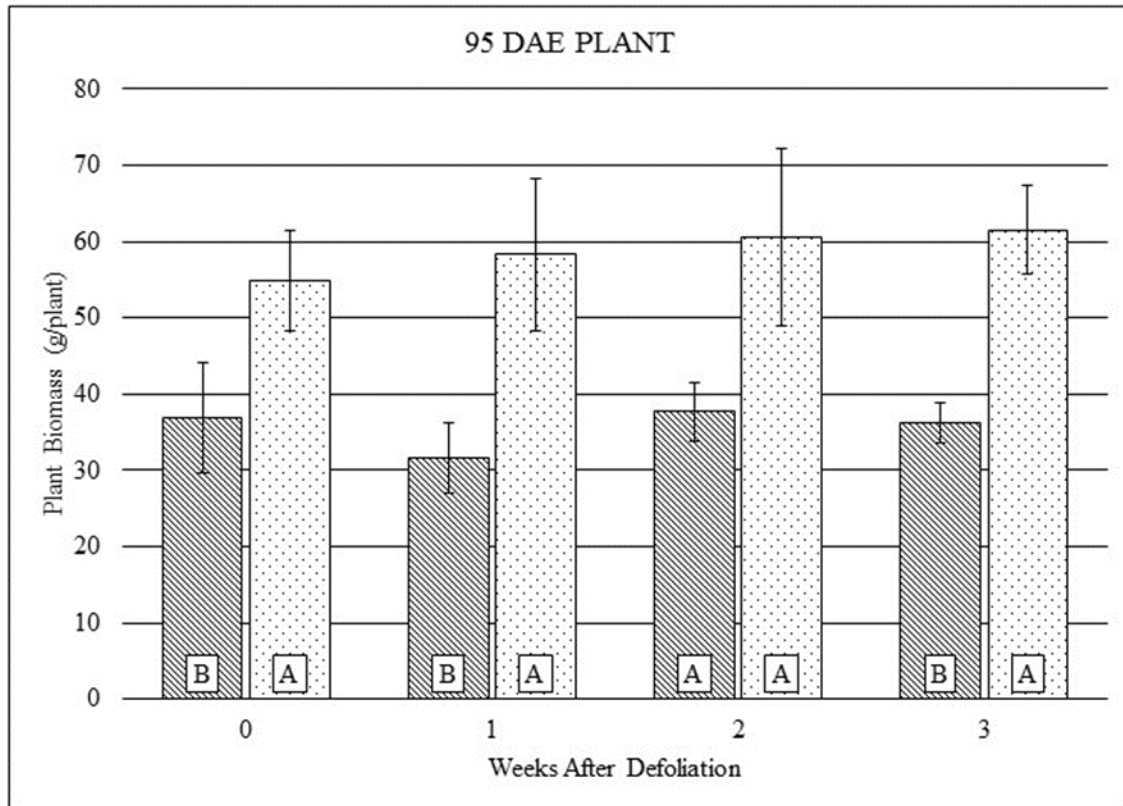
Plant biomass for 50 DAE is reported in grams/plant and is representative for 0, 1, 2, and 3 weeks following complete canopy removal. The bars represented by  is the non-defoliated treatment. 50 DAE defoliation time bar is represented by . Means are separated by letters in the base of each bar and bars that have the same letter are not significantly different from each other. Standard error is located at the top of each bar.

Figure 2.7 Effect of complete canopy defoliation on peanut canopy biomass (g/plant) 95 days after complete emergence.





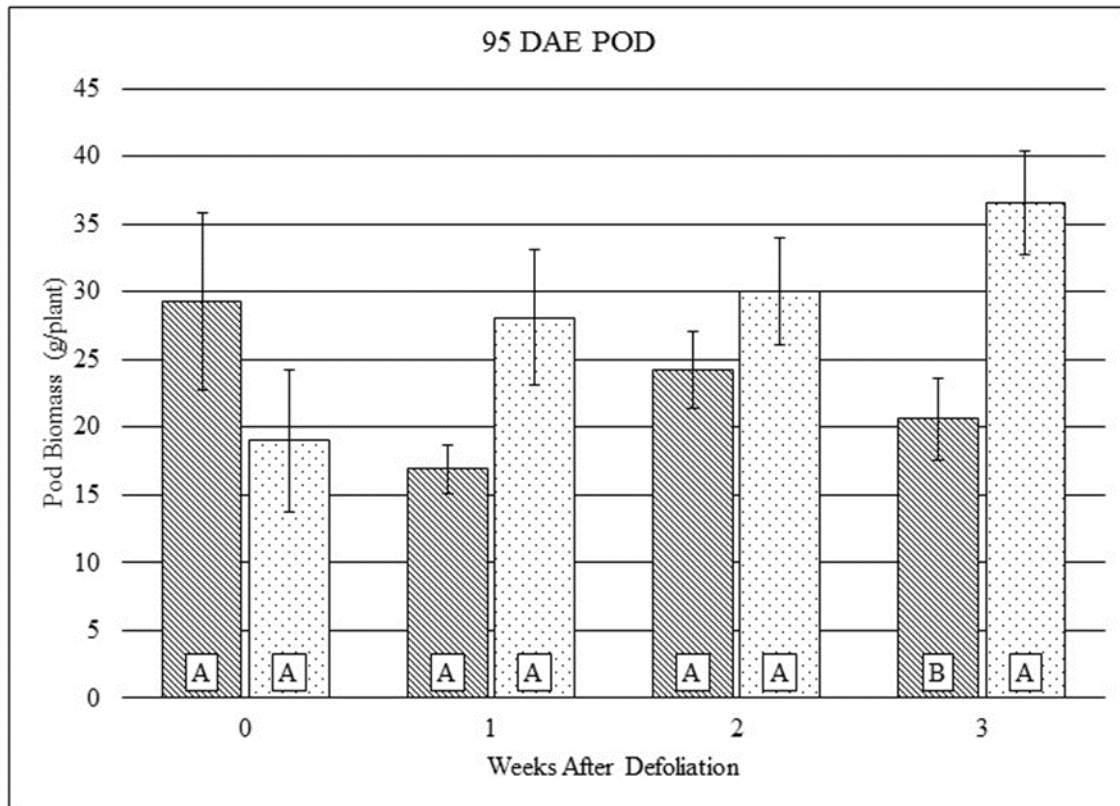


Plant biomass for 95 DAE is reported in grams/plant and is representative for 0, 1, 2, and 3 weeks following complete canopy removal. The bars represented by  is the non-defoliated treatment. 95 DAE defoliation time bar is represented by . Means are separated by letters in the base of each bar and bars that have the same letter are not significantly different from each other. Standard error is located at the top of each bar.



Figure 2.8 Effect of complete canopy defoliation on peanut pod biomass (g/plant) 95 days after complete emergence.



Pod weights for 95 DAE is reported in grams/plant and is representative for 0, 1, 2, and 3 weeks following complete canopy removal. The bars represented by  is the non-defoliated treatment. 95 DAE defoliation time bar is represented by . Means are separated by letters in the base of each bar and bars that have the same letter are not significantly different from each other. Standard error is located at the top of each bar.

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CHAPTER III  
ESTABLISHING DEFOLIATION THRESHOLDS IN PEANUT (*ARACHIS*  
*HYPOGAEA* (L.)) IN MISSISSIPPI

**Abstract**

Defoliation of peanut by foliage-feeding insects reduces photosynthetic capacity, and in turn, may reduce pod yield, particularly when canopy loss occurs at critical growth stages, i.e., 40 or 80 days after full plant emergence (DAE). The objective of this research was to determine the impact of peanut defoliation level, i.e., 0, 20, 40, 60, 80, and 100%, at 40 or 80 DAE on canopy height and width, plant biomass, market grade, yield, and economic injury level. Research was conducted at the Delta Research and Extension Center in Stoneville, MS and the R. R. Foil Research Farm in Starkville, MS in 2015 and 2016. For both locations the experimental design was a six (defoliation level) by two (defoliation timing) factorial arranged in a randomized complete block, with four replications per site-year. Up to four weeks after defoliation, canopy height, canopy width, and plant biomass were negatively correlated with defoliation level regardless of defoliation timing. Neither defoliation level nor timing had an effect on peanut grade or maturity. Similarly, defoliation at 40 DAE did not affect pod yield, when damage occurred 80 DAE, pod yield was reduced 18.6 kg/ha for every 1% increase in defoliation. Considering average crop value and insect control costs, the economic injury for peanut defoliation at 80 DAE is 5% defoliation. These data indicate that control of canopy-

feeding insects is only economically viable when defoliation exceeds 5% defoliation at 80 DAE.

### **Introduction**

Defoliation of peanut vegetation by insects is a concern for peanut growers across the southeastern United States. Little is known about peanut economic injury levels for defoliating caterpillars in Mississippi. While no research on defoliation thresholds in Mississippi peanuts exists, there is also a general lack of understanding across the Southeast on damage thresholds, especially on newer cultivars.

The peanut plant canopy is susceptible to a range of insects and diseases. Defoliation by pests can impede photosynthetic potential by reducing leaf area, and in turn, light interception and photosynthesis (Boote et al., 1980; Bourgeois and Boote, 1992). The reduction in photosynthates can reduce vegetative and reproductive growth (Boote et al., 1980; Bourgeois and Boote, 1992).

Pest damage from defoliating insects in peanut varies from incidental feeding to near plant consumption, with the level of defoliation determining yield loss (Stalker and Campbell 1983). Corn earworm (CEW) [*Helicoverpa zea* (Boddie)], fall armyworm (FAW) [*Spodoptera frugiperda* (J. E. Smith)], granulate cutworm (GCW) [*Feltia subterranean* (F.)], velvetbean caterpillar (VBC) [*Anticarsia gemmatalis* (Hübner)], and other Lepidoptera species are pests that negatively impact the plant canopy via physical defoliation (Deitz et al., 1992; Jones et al., 1982; Lynch, 1996; Minton et al., 1991; Stalker and Campbell, 1983). While all of these insects can affect the plant canopy, their feeding behaviors vary among species and crop growth stages, meaning not every insect

listed invades the peanut plant at the same time or damages the plant the same way. Some insects prefer young terminal vegetation, while other pests may favor older vegetation based on nutritional requirements (Deitz et al., 1992; Stalker and Campbell, 1983).

Previous research addressed the feeding behaviors of defoliating caterpillars in peanut (Deitz et al., 1992; Endan et al., 2006; Garner and Lynch, 1981; Todd et al., 1991). According to Deitz et al., (1992) appropriate thresholds for FAW, GCW, and CEW are 13 larvae per row meter in South Carolina, USA; however, sampling difficulty for these pest species was noted because of feeding site preference between the larvae and the time of day that sampling occurred. Moreover, the impact of larval defoliation was underestimated because feeding in the axillary bud region, especially by GCW, retarded development of new leaves and reproductive branches. While previous research helps to explain feeding patterns, more work is needed in a field-scale situation to quantify yield consequences of defoliation.

Defoliation from disease pathogens has received more attention than defoliation by insects in peanut. Early and late leaf spot (caused by *Cercospora arachidicola* S. Hori and *Phaeoisariopsis personatum* (Berk. & M.A. Curtis), respectively) are the two most common defoliating fungal pathogens affecting peanut fields across the southeastern peanut belt (Adomu et al., 2005; Boote et al., 1980; Bourgeois et al., 1991; Bourgeois and Boote, 1992). Defoliation resulting from severe incidence of leaf spot can reduce yield up to 50% if preventative and curative measures are not taken (Bourgeois et al., 1991). Even when precautions are taken and a high-risk fungicide plan incorporated, yield losses

up to 10% can occur (Pixley et al., 1990). Previous research on defoliation from the leaf spot diseases in peanut may help refine defoliating-insect management decisions.

Soybean experiences indirect feeding much like that of peanut. Owen et al., (2013) found that feeding on the foliage, stems, and/or roots of plants can lead to yield reductions by stressing the plant. Owen et al., (2013) used hand removal of foliage at different growth stages in soybean to simulate feeding by defoliating caterpillar pests and determine the impact on yield. Based on that research, they were able to establish accurate defoliation thresholds at different soybean growth stages regardless of insect species. Similarly, the erratic feeding patterns across species that affect peanut and the difficulty of accurately estimating caterpillar densities make it difficult to use insect counts as a trigger for control measures. As a result of this and a lack of recent work on insect defoliation effects on peanut, the objective of this research was to determine canopy defoliation thresholds at multiple growth stages in peanut. Ultimately, this work will be important for developing recommendations that will allow extension personnel, producers, and consultants to make informed management decisions when dealing with peanut canopy defoliation.

### **Materials and Methods**

Field research was conducted on a Leeper silty clay loam (fine, smectitic, nonacid, thermic Vertic Epiaquepts) (USDA-NRCS, 2016) at the Mississippi State University R.R. Foil Research Center in Starkville, Mississippi and on a Bosket very fine sandy loam (fine-loamy, mixed, active, thermic Mollic Hapludalfs) (USDA-NRCS, 2016) at the

Mississippi State University Delta Research and Extension Center (MSU DREC) near Stoneville, Mississippi in 2015 and 2016. Both locations were furrow irrigated.

Land preparation at the Starkville location included a ripper-hipper single bed formation, with a do-all over the top prior to planting, and a roller packer to firm the seed bed. Single beds were 0.97-m wide. Soil preparation at MSU DREC was similar in that 1.02-m wide beds were ripped and hipped and then rolled to firm the seed bed. Fertilizer requirements and applications, which include those for calcium and boron, were based on MSU Extension recommendations (Oldham, 2017). Immediately after planting in 2015, a pre-emergent herbicide tank-mix of pendimethalin (930 g a. i. ha<sup>-1</sup>), diclosulam (27 g a. i. ha<sup>-1</sup>), and flumioxazin (107 g a. i. ha<sup>-1</sup>) was applied. Pre-emergent herbicides in 2016 consisted of a tank-mix of s-metolachlor (650 g a. i. ha<sup>-1</sup>) and flumioxazin (107 g a. i. ha<sup>-1</sup>). Fungicide programs were based on guidelines obtained from the medium risk model of the Peanut Disease Risk Index (Kemerait et al., 2015). Chlorantraniliprole (DuPont™ Prevathon®, 75 g a. i. /ha, DuPont, Wilmington, DE) was applied once across all plots at both locations in 2016, due to fall armyworm pressure that could have potentially confounded results if left untreated.

Peanut cultivar Georgia-06G (Branch, 2007) was planted in Starkville, MS using a two-row Monosem precision air planter (Monosem, Inc., Edwardsville, KS). Seed were planted at a depth of 5.1 cm at a rate of 20 seed/m of row in two-row plots that were 1.94-m wide and 4.57-m long. At Stoneville, a John Deere MaxEmerge2 four-row vacuum planter (John Deere, Moline, Illinois) was used to seed the same cultivar at a similar seeding depth and rate as those at the Starkville site. Two-row plots at Stoneville measured 2.04-m wide and 6.10-m long. Seed at both locations were treated with

Dynasty (azoxystrobin, fludioxonil, and mefenoxam) fungicide seed treatment (Syngenta Crop Protection, Greensboro, NC). Planting dates for each site year are reported in Table 1.

For both locations the experimental design was a six (defoliation level) by two (defoliation timing) factorial arranged in a randomized complete block, with four replications per site-year. The levels of defoliation were 0, 20, 40, 60, 80, and 100% of the peanut foliage. Defoliation was achieved by hand removal, while ensuring that flowers on the plant and pods in the ground were undisturbed. The defoliation events occurred at either 40 or 80 days after emergence. These timings correspond closely with the beginning of pegging and peak pod fill, respectively.

Plots in Starkville were evaluated for above-ground plant and pod biomass immediately following each defoliation and at two and four weeks after defoliation. Above-ground biomass and pod samples were taken from a minimum of 0.3-m of row at each sample timing and were placed in forced air dryers for 48 hrs at 46 C before biomass readings were recorded. Canopy height and width measurements were taken at each site-year at two and four weeks after each defoliation event. Plots were also evaluated for pod yield and market grade. Harvest timing was determined at each site-year by the hull-scrape maturity profile method (Williams and Drexler, 1981). Plots were inverted using a two-row KMC digger-shaker-inverter (Kelley Manufacturing, Tifton, GA) and harvested using a two-row KMC peanut combine. Inversion and harvest dates are reported in Table 1. Yield was adjusted to 10.5% moisture. Peanuts were graded at the R. R. Foil Research Farm in Starkville, MS.

To determine the impact of defoliation on peanut grade, biomass, and canopy development; data were analysed with analysis of variance (PROC GLM, SAS 9.4, SAS Institute, Cary, NC). Peanut grade, biomass, and canopy development were dependent variables and defoliation level was the independent variable. When effects were found to be significant, least significant differences (LSD,  $\alpha = 0.05$ ) were calculated to separate means. For the purpose of determining the impact of defoliation on peanut yields, data were analysed with regression analysis (PROC GLM, SAS 9.4, SAS Institute, Cary, NC). Defoliation level was the independent variable and peanut yield was the dependent variable in the model. No significant interaction occurred between defoliation levels and site-years, so analyses are reported with all data combined across locations and years. Analysis of covariance was used to compare the slopes of the regression equations for levels of defoliation at each time of defoliation.

Data from the regression equations were used to estimate an economic injury level (EIL) for regression equations that had a significant relationship between level of defoliation and peanut yield. The equation:  $EIL = C/VbK$  (Pedigo et al., 1986) was used to calculate the EIL. In the equation, EIL is the economic injury level, C is the cost of control, V is the value of the crop in \$/metric tonne; *b* is the yield loss per 1% defoliation value derived from the slope of the regression equation; and K is the percent control assumed from a control tactic or application. This is not a specific guide to any one control measure or tactic, and K was assumed to have an 85% control level.



## **Results and Discussion**

### **Yield and grade**

The relationship between canopy defoliation at 40 DAE and pod yield of peanut was not significant ( $P = 0.16$ ,  $R\text{-squared} = 0.57$ ), suggesting that defoliation occurring at this timing does not impact peanut yield (Figure 1). In contrast, the relationship between canopy defoliation at 80 DAE and pod yield of peanut was significant ( $P < 0.01$ ,  $R\text{-squared} = 0.84$ ), suggesting that defoliation at 80 DAE impacts peanut yield (Figure 1). There was a significant interaction between timing of defoliation and level of defoliation ( $P = 0.01$ ) indicating that there was a difference between the slopes of the regression equations at 40 DAE and 80 DAE. At 80 DAE, the regression equation produced a slope of -18.6, indicating a yield decrease of 18.6 kg/ha for every one percent increase in canopy defoliation. The greater impact on yield from defoliation at 80 DAE relative to 40 DAE can likely be explained by the fact that plants are at the height of reproductive growth during the 80 DAE period. Conversely, at 40 DAE, plants are in late vegetative or early reproductive stages, giving them more time to compensate for injury.

Defoliation did not affect market grade at any defoliation timing or level ( $P = 0.99$ ). Market grades based on total sound mature kernels (TSMK) ranged from 71.7 to 73.8 across defoliation treatments and the control. Because grade can be correlated with maturity (Court et al., 1984; Knauff et al., 1986; Mazingo et al., 1991) we can reasonably assume that defoliation did not affect optimum harvest timing.

### **Plant growth characteristics**

Canopy height was reduced at all levels of defoliation compared to the non-defoliated treatment at 40 DAE. Plants receiving 80 and 100% defoliation were significantly

different from those defoliated 20 and 40% two weeks after defoliation occurred; however, there are no differences amongst defoliated treatments four weeks after the defoliation timing. This suggests that plants are able to respond similarly to severe defoliation events relative to more minor defoliation, when the defoliation event takes place early in the season, although none of the heights in defoliated plots were equal to those found in non-defoliated plots (Table 2). Canopy widths responded in a similar fashion at this timing. Plant widths were reduced when measured two weeks following defoliation across all treatments when compared to the non-defoliated control. Four weeks after the 40 DAE defoliation event, defoliated plant canopy widths were still significantly reduced when compared to the non-defoliated treatment, with the completely defoliated treatment seeing the largest reduction.

At 80 DAE, defoliation of 40% and greater reduced plant height when measured two weeks after defoliation (Table 3). At four weeks post-defoliation, plant heights in those plots receiving 40% defoliation were equal to the untreated, but defoliation of 60% or 80% still showed reductions in height. Plant widths measured two weeks post-defoliation were reduced at all levels of defoliation, with defoliation of 80 and 100% being impacted more severely than defoliations of 20 to 60%. At the four weeks post-defoliation, all treatments receiving defoliation of 60% or more had canopies narrower than those defoliated 20 and 40%, and the non-defoliated control. Canopies that received defoliation of 20 and 40% were not significantly narrower than the non-defoliated canopy four weeks after defoliation at 80 DAE. This data shows that peanut canopies are able to respond well to lower levels of defoliation imposed at peak pod filling growth stages.

Complete canopy closure is beneficial to production for a number of reasons. Hauser and Buchanan (1981) found that earlier canopy closure increased weed suppression, which in turn resulted in fewer herbicide applications and increased yield. Butzler et al., (1998) reported that soil temperature was consistently 1 degree C warmer beneath plots that were pruned when compared to non-pruned peanut plots, with bare soil temperatures sometimes reaching 8 – 9 C warmer than non-pruned plots. These micro-climate differences were attributed to both increased sunlight penetration and air movement which increased soil temperature and moisture loss. Research conducted by Dreyer et al., (1981) found that pod weights were lower when soil temperatures reached 37 C when compared to optimal soil temperatures of 30 and 34 C, meaning that defoliation from insects could potentially affect yield in this way as well.

Above-ground plant and pod biomass samples provided further information on canopy and pod development following defoliation at both the 40 and 80 DAE timings. Table 4 shows plant and pod response to defoliation 40 DAE at three intervals; 0, 2 and 4 weeks after defoliation. Immediately following defoliation, above-ground plants from all defoliated treatments weighed significantly less than the non-defoliated control on a mass per plant basis. Treatments that received 40% defoliation and greater had significantly less plant biomass than the non-defoliated control two weeks following defoliation. By four weeks following the defoliation event, plants receiving the 20, 40, and 60% defoliation treatments were equal in size to the non-defoliated control, while plots receiving the 80 and 100% defoliation treatments had not fully recovered. There were no differences in pod weight per plant at any time following the 40 DAE defoliation, perhaps because pod set had yet to begin at the time of the defoliation event.

Immediately following the 80 DAE defoliation, plant weights from all defoliated plots were significantly less than the non-defoliated control (Table 5). The 60, 80 and 100% treatments had less biomass than the 20 and 40% treatments. Two weeks after defoliation, plant weights for 60% defoliation and higher treatments were still less than those from the non-defoliated control, but were equal to 20 and 40% treatments. Four weeks following defoliation, plants from plots that received either 80% or 100% defoliation were still significantly reduced in weight when compared to the control plots. Two weeks following defoliation, the non-defoliated control plots had greater pod weights per plant than those receiving defoliation of 60% or greater (Table 5). Similar to the two week pod weights, the non-defoliated treatment had heavier pod weights per plant compared to 60, 80 and 100% defoliation treatments four weeks after defoliation. At this timing, pods of plants receiving 80 and 100% treatments weighed less than those receiving 20 and 40% defoliation.

### **Economic Injury Levels**

Because defoliation had an effect on peanut pod yield during 80 DAE, EIL's for peanuts based on canopy defoliation at this time were established. Based on the expected yield losses from the regression equation at 80 DAE, EIL's ranged from 2 to 10 percent depending on crop value and control costs (Table 6). These values fall well below the actual defoliation levels imposed on peanut plants in this experiment. These values are based on the assumption of a linear relationship for yield loss between 0 and 20 percent. To determine if that relationship is linear, more research is needed with multiple levels of defoliation between 0 and 20 percent defoliation during the pod filling stages.

## Summary and Conclusions

Yield and economic analyses show that peanut is able to compensate for various levels of defoliation early in the growing season. While not totally eliminating all cause for concern early in this season, this finding should allow producers to remain judicious with insecticide applications at this time period. From a practical perspective, however, growers should manage defoliating insects prior to high levels (>60%) being reached, in order to reduce insect numbers as the crop enters reproductive growth. Conversely, yield and economic loss estimates following defoliation around peak pod fill (80 DAE) show the importance in minimizing defoliation during reproductive growth. Generally, insect control measures have not often been employed at defoliation levels below 10%. These data suggest that managing defoliating caterpillars at lower levels than previously thought may be warranted.

A limitation of this work is that determining defoliation percentages in peanut fields is often difficult for consultants, growers, and Extension personnel as each person's opinion is subjective. In addition, data from this study represent defoliation levels that occur only once at one particular time, and do not represent the likelihood of previous or future damage that occurs over time. Lastly, figures obtained from the EIL analysis represent peanuts yielding over 6,000 kg/ha. Yield projections must be considered when using this analysis, as peanuts with a higher potential value may be more sensitive to defoliation, while a crop with a lower potential may be able to withstand more damage before an economic loss is reached.

Future research is needed to help validate these EIL's. Economic thresholds need to be developed using defoliation from insects as well as at other times in the crop growth

cycle that are outside the scope of this research. Understanding crop growth stages, crop price, control costs, and yield potential is imperative for those making management decisions in peanut. These data along with these careful considerations will allow for a more efficient integrated pest management strategy to be implemented in Mississippi, as well as the rest of the peanut producing belt.

Table 3.1 Planting, inversion and harvest dates for all site-years.

	Starkville 2015	Stoneville 2015	Starkville 2016	Stoneville 2016
Planting	4- May	11- May	26- April	6- May
Inversion	21- September	24- September	26- September	11- October
Harvest	30- September	1- October	6- October	17- October

Table 3.2 Plant heights and widths following an 40 days after emergence defoliation event across four site-years in Mississippi.

40 DAE	Plant Height (cm)		Plant Width (cm)	
	Weeks After Defoliation		Weeks After Defoliation	
	2	4	2	4
% Defoliation				
0	23.48 a <sup>a</sup>	29.97 a	56.98 a	78.82 a
20	20.91 b	26.92 b	50.50 b	74.55 b
40	20.37 bc	27.16 b	48.82 c	71.70 b
60	19.38 cd	26.70 b	45.45 c	71.58 b
80	18.67 d	27.23 b	43.77 cd	70.95 bc
100	18.59 d	25.75 b	41.78 d	67.31 c

<sup>a</sup> Means within a column followed by the same letter are not significantly different according to pairwise t-tests ( $\alpha = 0.05$ ).



Table 3.3 Plant heights and widths measured two and four weeks following an 80 day after emergence defoliation event across four site-years in Mississippi.

80 DAE	Plant Height (cm)		Plant Width (cm)	
	Weeks After Defoliation		Weeks After Defoliation	
	2	4	2	4
% Defoliation				
0	38.58 a <sup>a</sup>	37.62 a	90.81 a	90.78 a
20	37.32 ab	37.45 ab	85.38 b	88.89 ab
40	36.02 bc	37.10 ab	82.88 b	88.83 ab
60	36.20 bc	35.56 b	84.06 b	86.20 bc
80	35.23 bc	35.66 b	78.90 c	84.04 cd
100	34.93 c	35.99 ab	79.17 c	81.72 d

<sup>a</sup> Means within a column followed by the same letter are not significantly different according to pairwise t-tests ( $\alpha = 0.05$ ).

Table 3.4 Above-ground and pod biomass following 40 DAE defoliation event.

40 DAE	Above-Ground Biomass (g/plant) <sup>a</sup>			Pod Biomass (g/plant)		
	Weeks After Defoliation			Weeks After Defoliation		
% Defoliation	0	2	4	0	2	4
0	3.45 a <sup>b</sup>	12.34 a	25.45 a	0	0.031 a	1.17 a
20	2.60 b	11.25 ab	24.91 ab	0	0.025 a	1.37 a
40	2.30 bc	9.76 bc	25.69 a	0	0.010 a	2.08 a
60	1.93 cd	8.60 c	23.59 abc	0	0.027 a	1.18 a
80	1.87 cd	8.62 c	18.64 c	0	0.016 a	0.72 a
100	1.56 d	8.24 c	19.33 bc	0	0.042 a	1.09 a

<sup>a</sup> Biomass measurements are presented on a dry-weight basis

<sup>b</sup> Means within a column followed by the same letter are not significantly different according to pairwise t-tests ( $\alpha = 0.05$ ).

Table 3.5 Above-ground and pod biomass following an 80 DAE defoliation event across four site-years in Mississippi.

80 DAE	Above-Ground Biomass (g/plant) <sup>a</sup>			Pod Biomass (g/plant)		
	Weeks After Defoliation			Weeks After Defoliation		
% Defoliation	0	2	4	0	2	4
0	50.30 a <sup>b</sup>	59.70 a	56.95 a	9.55 ab	30.72 a	31.57 a
20	35.89 b	48.46 ab	49.25 ab	7.73 ab	20.26 abc	26.44 ab
40	39.74 b	48.53 ab	54.68 a	8.56 ab	26.76 ab	30.65 ab
60	37.82 b	43.57 b	45.55 abc	13.15 a	18.66 bc	24.28 bc
80	24.59 c	42.44 b	40.45 bc	5.14 b	16.42 bc	17.35 d
100	22.81 c	41.03 b	36.04 c	4.24 b	14.45 c	18.43 cd

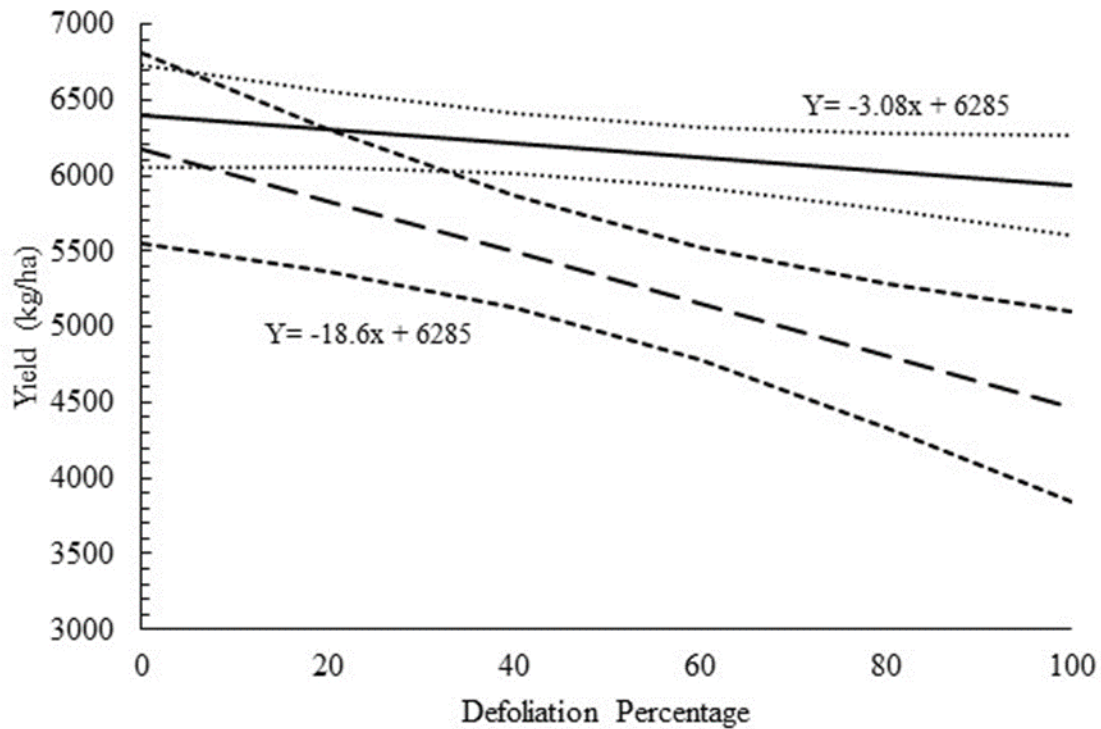
<sup>a</sup> Biomass measurements are presented on a dry-weight basis

<sup>b</sup> Means within a column followed by the same letter are not significantly different according to pairwise t-tests ( $\alpha = 0.05$ ).

Table 3.6 Economic injury levels for canopy defoliation in peanut 80 days after emergence.

Crop Value (\$/tonne)	Cost of control (\$/ha)					
	\$30	\$40	\$50	\$60	\$70	\$80
	80 DAE Economic Injury Level (% defoliation)					
450	4	6	7	8	10	11
500	4	5	6	8	9	10
550	3	5	6	7	8	9
600	3	4	5	6	7	8
650	3	4	5	6	7	8
700	3	4	5	5	6	7

Figure 3.1 Yield regressions for the 40 and 80 DAE defoliation timing across all site-years.



The solid line (—) is the linear trend line for predicted values with the upper and lower dotted lines (•••••) giving the 95% confidence interval for defoliation at each given level for 40 DAE. The 40 DAE trend line equation  $Y = -3.08x + 6285$  represents a pod yield reduction of  $3.08 \text{ kg ha}^{-1}$  per one percent of canopy defoliation. The long dashed line (— —) is the linear trend line for predicted values with the upper and lower short dashed lines (— — —) giving the 95% confidence interval for defoliation at each given level for 80 DAE. The 80 DAE trend line equation of  $Y = -18.6x + 6285$  represents a pod yield reduction of  $18.6 \text{ kg ha}^{-1}$  per one percent of canopy defoliation.

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