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# Evaluation of Soybean Production Practices that Impact Yield Losses from Simulated Insect Defoliation

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By

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Soybean, *Glycine max* (L.) Merr., is planted across a vast amount of land in the Mid-Southern U.S. (Arkansas, Louisiana, Mississippi, and Tennessee), and yield responses to defoliation can vary. Experiments were conducted during 2015-2017 evaluating how soybean yield responds to multiple and continuous defoliation, as well as planting date and plant population. Multiple defoliation events were evaluated by defoliating soybean at varying levels at V3, V6, and both growth stages. There was no interaction between defoliation occurring at V3 and V6 growth stages, indicating that the impact of each defoliation event was independent of the other. The effect of continuous defoliation was evaluated by defoliating soybean weekly, beginning at V2. Defoliation continued throughout the vegetative growth stages or throughout the entire growing season, and was compared to the same defoliation level occurring one time at R3. Continuous defoliation during vegetative growth stages only, did not reduce yield at any of the levels tested. Defoliation occurring throughout the growing season reduced yields more than a one-time defoliation event at R3, but only when defoliation levels exceeded the 20% defoliation threshold. This indicates that thresholds do not need to be modified to

account for multiple or continuous defoliation. To evaluate the effect of planting date on yield loss from defoliation, soybean was planted at six planting dates beginning in early-April and continuing through mid-June. Each planting date included a defoliated treatment and an undefoliated control. It was determined that later planted soybean lose a greater amount of yield than earlier planted. Higher yielding soybean also lost more yield than lower yielding soybean at every planting date until Mid-June. It was concluded that late planted soybeans could benefit from a lower treatment threshold. The effect of plant population on yield loss from defoliation was evaluated by planting soybean at five populations ranging from 123,500 seeds/ha to 420,070 seeds/ha. A undefoliated control and a defoliated treatment was included for each plant population. Defoliation significantly reduced yields only where final plant populations were lower than 192,800 plants/ha. This indicates that fields with substandard plant populations are more susceptible to yield loss from defoliating pests.

## DEDICATION

I would like to dedicate this dissertation to my wife, Caitlin, who has stuck by me through all of my years of school, and my parents, Joe and Renee, for helping to support me in my ongoing education, without them, this would not have been possible.

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# EFFECTS OF MULTIPLE AND CONTINUOUS DEFOLIATION ON MID-SOUTH SOYBEAN YIELD


## Abstract

Defoliating insects are responsible for causing more damage to Mid-South soybean, *Glycine max* (L.) Merr., than any other feeding guild of insects. Currently, percent defoliation rather than insect density is used to evaluate if treatment is necessary. It is not known if multiple defoliation events or continuous defoliation can compound to further increase yield loss. Multiple defoliation events were evaluated by defoliating soybean during V3 at levels of 0, 33, 67, or 100% and during V6 at levels of 0, 33, 67, or 100%, as well as, all combinations of defoliation levels at both V3 and V6. Continuous defoliation was evaluated at levels of 16.5, 33, and 67%, with defoliation beginning at V2 and continuing through either the vegetative growth stages, or throughout the growing season. A one-time defoliation event at R3 was also included with the same defoliation levels. There was no interaction between defoliation levels at V3 or V6 indicating that multiple defoliation events do not compound to further reduce yield in vegetative soybeans. Continuous defoliation resulted in yield loss greater than a single defoliation event; but only when the defoliation occurred at levels greater than the current 20% defoliation threshold. These results suggest that current thresholds do not require adjustment for multiple or continuous defoliation events.

## Introduction

In 2016, soybean, *Glycine max* (L.) Merr., was planted across 3,261,000 hectares of land throughout the Mid-South (AR, LA, MS, TN) with a value totaling almost 3.7 billion dollars (USDA-NASS 2017). Injury from defoliating insects was responsible for more yield loss to Mid-South soybean than any other feeding guild of insects. In 2016, defoliating insects alone cost Mid-South producers an estimated 173 million dollars (Musser et al. 2017, USDA-NASS 2017).

In the U.S., defoliators comprise the most diverse feeding guild of insect pests in soybean (Turnipseed and Kogan 1976). Defoliating insects can occur throughout the entire growing season in the southern U.S. Commonly problematic defoliating pests in Mid-South soybean include the looper complex, comprised of soybean looper, *Chrysodeixis includens* (Walker), and cabbage looper, *Trichoplusia ni* (Hübner); velvetbean caterpillar, *Anticarsia gemmatalis* (Hübner), green cloverworm, *Hypena scabra* (F.), bean leaf beetle, *Ceratoma trifurcata* (Förster), and fall armyworm, *Spodoptera frugiperda* (J.E. Smith).

The looper complex comprises the second most damaging insect in Mid-South soybean. In 2016 the complex cost Mid-South growers 81.1 million dollars in losses plus costs (Musser et al. 2017). The looper complex found in soybean in the Mid-South is made up of mostly soybean looper with a relatively small percentage being cabbage looper (Canerday and Arant 1966, 1967, Martin et al. 1976). Of these two species, soybean looper is more difficult to control because of resistance to multiple classes of insecticides (Boethel et al. 1992). Because of these factors and the inability to distinguish the larvae of these species in the field, cabbage looper is often combined with soybean looper when making treatment decisions.

Historically, fall armyworm is a minor pest of soybean, preferring to feed on grasses (Baldwin 1994, Funderburk et al. 1999). However, occasional outbreaks can result in large amounts of acreage being treated for this pest. For instance, Arkansas in 2014 had 45% of its soybean area treated for armyworms (Musser et al. 2015). Fall armyworm is commonly seen in fields with large amounts of grass weed species and becomes a problem once the field is treated with a herbicide (Catchot et al. 2016a). The caterpillars move from their dying grass hosts onto the soybean to survive. Substantial defoliation can occur rapidly in these situations because the larvae are already at late instars when their foliage consumption rates are greatest (Luginbill 1928).

Bean leaf beetle is the most damaging coleopteran found in soybean and is currently the fourth most damaging pest overall in terms of losses plus costs in Mid-South soybean (Musser et al. 2017). The adults emerge from overwintering in April and feed on soybean as early as cotyledon growth stage (VC), and through late reproductive stages (Pedigo 1994). As leaves become tougher and less palatable during late growth stages the beetles may begin feeding on soybean pod walls and stems, causing further damage (Hunt et al. 1994, Pedigo 1994).

Velvetbean caterpillar and green cloverworm frequently contribute to defoliation in Mid-South soybean (Baur et al. 2000). From 2014-2016 these pests were the sixth and seventh most damaging insects, respectively, in Mid-South soybean (Musser et al. 2017). During the mid to late portion of the growing season, when damaging populations of these pests occur, soybean are at sensitive reproductive growth stages and defoliation during these periods can cause extensive yield losses (Owen et al. 2013).

Other defoliators that are often encountered, but typically contribute minimal amounts of defoliation to soybean include beet armyworm, *Spodoptera exigua* (Hübner), yellowstriped armyworm, *Spodoptera ornithogalli* (Guenée), grape colaspis, *Colaspis brunnea* (F.), saltmarsh caterpillar, *Estigmene acrea* (Drury), garden webworm, *Achyra rantalis* (Guenée), spotted cucumber beetle, *Diabrotica undecipunctata howardi* (Barber), banded cucumber beetle, *Diabrotica balteata* (LeConte), blister beetles (Coleoptera: Meloidae), and grasshoppers (Orthoptera: Caelifera) (Musser et al. 2017). Because injury is similar for all of these pests, the actual amount of defoliation occurring in a field is more important when making a treatment decision than the number of insects present. However, knowledge about what species are causing the defoliation is still important to determine the best management strategy.

The amount of yield reduction from defoliation in soybean is a function of the growth stage at which the injury occurs, the amount of defoliation, the ability of a cultivar to tolerate or compensate for defoliation, and environmental factors (Pedigo et al. 1986). Previous research conducted by Owen (2012) indicated that while soybean can tolerate a relatively large amount of defoliation during the vegetative growth stages, excessive foliage loss during the R3-R5 growth stages significantly reduces yield (Owen et al. 2013). According to Goli and Weaver (1986), defoliation occurring at R4 and R5 decreased yield primarily by reducing the number of pods per plant. Defoliation occurring at R6 reduced yield primarily by reduction in pod numbers and reduced seed weight, depending on the variety evaluated. Others noted reduced pod number, seed per pod, or seed size from defoliation occurring during reproductive growth stages (Todd and Morgan 1972, Thomas et al. 1976, Fehr et al. 1981). Thomas et al. (1976) reported that excessive defoliation during specific reproductive growth stages reduced oil content and germination rate of harvested seed.

Current Mid-South recommendations set treatment thresholds for defoliation at 35% pre-bloom and 20% during and after bloom (Catchot et al. 2016b). However, a producer may need to treat for defoliating pests multiple times during a single growing season. In these situations, the impact of multiple compounding defoliation events on soybean yield is not known. For instance, if a pest defoliates a soybean crop 30% during the vegetative stage then another pest defoliates the crop an additional 15% during the reproductive stage, the latter of the two defoliation events may need a lower treatment threshold due to the injury that occurred earlier in the season.

Another situation producer's encounter is continuous sub-threshold levels of defoliation over extended periods of time. Currently, no information exists about the impact of low levels of defoliation occurring over time on soybean. As a result, research is needed to quantify the impact of sub-threshold defoliation that occurs over multiple weeks on soybean yields. The purpose of this research is to further refine defoliation treatment thresholds in soybean by evaluating the effects of multiple and continuous sub-threshold defoliation events on yield. Results from these experiments will allow growers to make more informed treatment in regard to defoliating pests.

## Materials and Methods

All experiments were conducted during the 2015 and 2016 growing seasons at the R.R. Foil Plant Science Research Center in Starkville, MS and the Delta Research and

Extension Center in Stoneville, MS. In 2015, soybean were planted on 30 Apr and 2 Jun at the Starkville and Stoneville locations, respectively. In 2016, soybean were planted on 9 May in Starkville and 10 May in Stoneville. Trials were planted at 275,000 seed per hectare with 97-cm row spacing in Starkville and 102-cm spacing in Stoneville using Asgrow® 5335 (Monsanto Co., St. Louis, MO), which has an indeterminate growth habit. Plot sizes were four rows wide by 3.05-m in length. All treatments were arranged in a randomized complete block design and replicated four times. All plots were treated with either 1,022 ml/ha of chlorantraniliprole (Prevathon®, DuPont, Wilmington, DE) or 365 ml/ha of thiamethoxam + lambda-cyhalothrin (Endigo®, Syngenta Crop Protection, Greensboro, NC) at the first sign of insect pests and treated with 438 ml/ha of fluoxastrobin (Fortix®, Arysta LifeScience North America, Cary, NC) fungicide at the R3 growth stage. The middle two rows of each plot were hand defoliated at the specified growth stages and levels for each experiment. Plots were harvested using a two-row Kincaid 8XP combine and yields were adjusted to 13 percent moisture content.

**Effects of multiple defoliation events in vegetative soybean**

Experiment used a complete factorial treatment arrangement with factors including defoliation at V3 (0, 33, 67, or 100%) and defoliation at V6 (0, 33, 67, or 100%) for a total of 16 treatments. Percentages were determined by removing either one (33%), two (67%), or three (100%) leaflets from of each trifoliate. When defoliations occurred during both the V3 and V6 growth stages, the V6 defoliation rate was applied to the whole plant, including the part that had previously been defoliated at V3. For instance if a plant had been defoliated 33% at V3, then an additional 33% at V6, the upper three trifoliates would all have one leaflet removed from each and then one leaflet removed from two of the lower three nodes. Because there are six total leaflets left on the lower three nodes, removing two leaflets from the six total gives an additional 33% defoliation.

**Effects of continuous defoliation in vegetative and reproductive soybean**

In order to simulate continuous defoliation, plants were defoliated weekly at three levels (16.5, 33, and 67%) beginning at V2 growth stage. The weekly defoliation treatments were terminated either when plants began blooming (through vegetative) or when plants ceased leaf production (through season) which was typically between the R3 and R4 growth stages. Defoliation was also carried out on plots at the R3 growth stage in a one-time defoliation event at all three defoliation levels (16.5, 33, and 67%) (R3). An undefoliated control (UDC) was also included in the study, resulting in ten total treatments.

Defoliation for 33% and 67% was applied as described previously, but only to new growth (trifoliates that still retained all three leaflets). Defoliation for 16.5% treatments was applied by averaging the number of newly emerged trifoliates on five plants within the plot, multiplying the average by the number of plants in the row, and then multiplying that number by 0.165 to determine the number of trifoliates that needed to be removed. This amount of defoliation was then applied to the upper quarter of the canopy in weekly defoliation events, evenly down the entire row. For the 16.5% defoliation at R3 treatment a similar process was followed, except the average number of trifoliates on five whole plants was calculated, multiplied by the number of plants in the row, and then multiplied by 0.165 to find the number of trifoliates that need to be removed from the row. This amount of defoliation was then applied to the entire row and evenly throughout the plants.

For each site year, leaf area index (LAI) was determined post-defoliation during the V6 and R3 growth stages. This provided a measure of leaf area present in relation to ground area (Klubertanz et al. 1996). Numerous reports indicate that LAI correlates with defoliation (Higley 1992, Klubertanz et al. 1996, Board et al. 1997a, Malone et al. 2002). LAI was calculated using a Decagon AccuPAR LP-80 (Decagon Devices 2001). A single measurement of photosynthetically active radiation (PAR) (light between 400 and 700 nm) was recorded above canopy and below canopy for each plot. Above canopy PAR measurements were taken approximately 25-cm above the canopy and below canopy measurements were taken by placing the device at ground level, in parallel with the third row of each plot, keeping the device approximately 7.5-cm to the left of that row. LAI (L) was calculated from these measurements using the formula:

$$L = \frac{\left[\left(1 - \frac{1}{2K}\right)f_b - 1\right]\ln\tau}{A(1 - 0.47f_b)}$$

Where $f_b$ is the fraction of incident PAR which is beam, $K$ is the extinction coefficient for the canopy, $\tau$ is the ratio of PAR measured below canopy to PAR above canopy, and $A$ = 0.86 (Decagon Devices 2001). All LAI measurements were taken between 1100 and 1400 h central time. Stand density, final plant heights, and yield were recorded for all plots.

Data for the vegetative defoliation experiment were analyzed using JMP 12 (1989-2007) with a mixed model analysis of variance. This allowed for comparisons between individual defoliation levels. Defoliation level at V3, defoliation level at V6 and their interactions were set as fixed effects, while year, location, replication, and their interactions were set as random factors. Yield was analyzed as kg/ha then converted to percent of the UDC in order to better display the yield responses across site-years with varying yield potentials. Means were separated using Tukey's HSD ($P < 0.05$).

Data for the second experiment from all locations were analyzed using regression analysis (Proc GLIMMIX, SAS Version 9.4 SAS Institute Inc., Cary, NC). Cooks distance was used to evaluate the influence of data points on the model. Three points had a Cooks distance greater that 0.04 were considered outliers. Yield was analyzed in kg/ha and converted to percent of the UDC in the figures in order to better display the results across site-years which had varied yield potentials. Defoliation level, defoliation timing, and their interactions were set as fixed effects while location, year, and replication were set as random effects. Contrasts were used to compare slopes of LAI and yield by defoliation timings across defoliation levels. The slicediff function for LS-means was used to evaluate the defoliation level at which defoliation timings statistically separated from each other. Degrees of freedom were calculated using the Kenward-Roger method. Differences were considered significant at $P < 0.05$. LAI measurements taken at V6 and R3 were correlated to yield using JMP 12 (1989-2007).

## Results and Discussion

### Effects of multiple defoliation events in vegetative soybean

Mean yield within a site-year in the undefoliated control ranged from 5550 kg/ha to 4148 kg/ha. There was no significant interaction between defoliation levels during the V3 and V6 growth stages (Table 1.1). Yield reductions were only observed in plots that were defoliated 100% at V3 or 100% at V6 (Table 1.2). There were no differences in yield loss between V3 and V6 defoliation timings when comparing each growth stages reciprocal defoliation level (Table 1.3). Our results were similar to Caviness and Thomas (1980), as well as, Owen (2012) in that both studies observed yield reductions from defoliation occurred during the V5 or V6 growth stages, respectively. Conversely, both of these studies found no yield loss from 100% defoliation occurring at V3, but yield loss was observed in the current study.

The main objective of this experiment was to evaluate whether multiple defoliation events compound to increase yield loss compared to a single defoliation event in vegetative soybean. The absence of an interaction indicates that the defoliation were independent of each other and therefore the threshold does not need to be modified in later defoliation events to account for earlier ones. For example, if a grower incurs 35% defoliation at V3 and treats his field, a non-economical amount of yield has been lost and cannot be recovered. Therefore, the field has a somewhat reduced yield potential. The grower would not benefit from reducing his threshold at V6, because yield loss does not increase at a greater rate per unit of additional defoliation. In order to economically justify another application the grower must reach threshold again. Because of this, thresholds do not need to be adjusted to account for defoliation that has occurred in prior vegetative growth stages. Talekar and Lee (1988) found similar results where soybean defoliated 10, 25, or 50% at V2 and/or V4 growth stages did not incur significant yield losses. Hunt et al. (1994) found that removal of the cotyledons at VC combined with sequential defoliation resulted in a detectable yield loss in all site years, whereas sequential defoliation without removing the cotyledons significantly reduced yield in 2 out of 3 site years. However, when equivalent amounts of defoliation were applied in a single event, no yield losses were detected.

LAI was used as an independent measure of leaf area across defoliation levels and growth stages. This was used to confirm the amount of leaf area that was removed from each plot. A significant interaction was observed between defoliation events occurring at V3 and V6 LAI at V6 (Table 1.1). Defoliation of 100% at V3 reduced LAI at V6 values below that in the UDC regardless of the amount of defoliation that occurred during the V6 growth stage (Tables 1.1 and 1.2). Defoliation levels of 67% and 100% during the V6 growth stage reduced LAI values below those of the UDC regardless of how much defoliation occurred in the V3 growth stage. Although an interaction was observed between V3 and V6 defoliation levels for LAI at V6, the interaction between these two factors was no longer significant when LAI was calculated for R3 (Table 1.1). Although no interaction was present for LAI at R3, values were lower in plots where 100% defoliation was applied at the V3 or V6 growth stage (Table 1.2). Several studies have reported that a LAI value of 3.5 – 4.0 is needed during the early reproductive stages of soybean to maximize yield (Higley 1992, Board et al. 1997b, Malone et al. 2002). This study reflects those findings in that all treatments that resulted in an LAI value lower than 3.5 at R3 correspondingly resulted in significantly lower than the UDC. LAI measurements recorded at R3 ($R^2 = 0.55$) had a much stronger correlation to yield than that determined at V6 ($R^2 = 0.07$) (Figure 1.1). During the early reproductive growth stages soybean is more sensitive to leaf area than those during vegetative growth stages, which is why the later measurements correlate better with yield (Todd and Morgan 1972, Fehr et al. 1981, Talekar and Lee 1988, Owen 2012).

Defoliation at V3, V6, or V3 and V6, affected final plant height in this study (Table 1.1). Hunt et al. (1994) found consistent reductions in the heights of reproductive stage soybean from sequential defoliation occurring from the V1 to the V3 during the vegetative growth stages. However, when defoliation was applied all at one time instead of sequentially, height was reduced in only 1 out of 4 site-years.

**Effects of continuous defoliation in vegetative and reproductive soybean**

Mean yield in the UDC ranged from 5678 kg/ha to 4081 kg/ha among site-years. All season and R3 defoliation levels negatively impacted yield, while defoliation occurring only during vegetative growth stages did not (All: $F = 32.08$, df = 1, 61, $P < 0.01$, y = 5441.4399 – 31.404159x; R3: $F = 13.21$, df = 1, 61, $P < 0.01$, y = 5350.5379 – 19.731173x; Veg: $F = 0.24$, df = 1, 61, $P = 0.63$, y = 5218.787 – 2.5473205x) (Figure 1.2). Contrasts of estimated yield losses were significantly different between season long and R3 defoliation only at defoliation levels ≥ 30% (All vs. R3: $t = -2.06$, df = 168, $P = 0.04$). This indicates that continuous sub-threshold (20% defoliation) levels of defoliation in reproductive soybean do not reduce yield any more than an equivalent level of defoliation during a single defoliation event at R3. Yield loss sustained from the one time defoliation at R3 was similar to that found by Owen et al. (2013). This study was different from others in that defoliation was maintained at a specific percentage over an extended period of time. Others have applied defoliation to the whole plant over time, slowly building to a specified level. With that being said, a reasonable comparison can be made to a study by Talekar and Lee (1988), who found that defoliation rates of 25 or 50% applied at both V2 and V4 did not reduce yield. However, when 25 or 50% defoliation was applied at V2, V4, and R2 growth stages, yield was significantly reduced in 1 out of 2 site-years and 2 out of 2 site years, respectively. This is similar to our study in that vegetative defoliation, up to 67%, did not significantly affect yield, but defoliation continued into the reproductive growth stages did.

Both season long and R3 defoliation negatively influenced R3 LAI values (All: $F = 21.93$, df = 1, 62, $P < 0.01$, y = 4.081 – 0.0165x; R3: $F = 36.20$, df = 1,62, $P < 0.01$, y = 4.147 – 0.0204x) (Figure 1.3). LAI values at R3 were the same between all season and R3 defoliation plots (All vs. R3: $t = 0.46$, df = 166.2, $P = 0.64$), confirming that the all season defoliation plots received similar levels of defoliation as the R3 defoliation plots at each respective defoliation level. It also provides evidence that leaf size and number was not affected in all season plots as compared to the R3 defoliation. Defoliation occurring during the vegetative growth stages did not affect R3 LAI (Veg: df = 1, 62, $F = 0.12$, $P = 0.74$, y = 3.936 – 0.0011x). This indicates that after defoliation ceased, plants were able to compensate by regaining leaf area that was previously removed.

Final plant heights were impacted only by the all season treatments (All: $F = 18.20$, df = 1, 62, $P < 0.01$, y = 99.304 – 0.329x; R3: $F = 2.63$, df = 1, 62, $P = 0.11$, y = 99.946 – 0.1504x; Veg: $F = 0.10$, df = 1, 62, $P = 0.76$, y = 97.103 – 0.0267x). This may be partially due to reduced light interception throughout the R2 growth period, which is a time of rapid dry matter accumulation in the leaves, stems, petioles, and roots (Ritchie et al. 1985). Plots defoliated during the vegetative growth stages were able to recover after defoliation ceased, allowing plants to attain a normal height. Plants defoliated at R3 were near their final height when defoliation occurred so height was not affected.

## Conclusion

Both of the experiments presented support the current defoliation threshold recommendations in Mid-South soybean. Both experiments included multiple or sustained defoliation during vegetative growth stages and both failed to produce a detectable yield response at defoliation levels < 67%. Based on these data and that of Owen (2012), current Mid-South defoliation thresholds for vegetative soybean are fairly conservative, being set at 35% defoliation.

Season-long, continuous defoliation of soybean at greater than threshold levels is an unlikely scenario in the Mid-South. Normally, a grower will treat a field prior to or at threshold (20% reproductive) allowing at least some time where defoliation is not occurring. Comparison of the most realistic treatments in this experiment (16.5% all season vs. 16.5% R3) demonstrated no difference between continuous all season defoliation and a one-time R3 defoliation event. These results indicate that defoliation does not compound to further increase yield loss from defoliation. Producers only need to consider the total amount of defoliation on the plant at the time of scouting when making a treatment decision.

Table 1.1 Analysis of variance statistics for percent yield loss, leaf area index at V6 and R3 growth stages, and final plant height from simulated insect defoliation on soybean at V3 and V6 growth stages and their interactions for experiments conducted in 2015 and 2016 in Mississippi

| **Growth Stage** | ***F*** | **df** | ***P*** [1] |
|---|---|---|---|
| | | **Yield** | |
| **V3** | 2.8668 | 3, 225 | 0.04 |
| **V6** | 4.4681 | 3, 225 | <0.01 |
| **V3*V6** | 0.2442 | 9, 225 | 0.99 |
| | | **Leaf Area Index @ V6** | |
| **V3** | 17.2565 | 3, 225 | <0.01 |
| **V6** | 36.2592 | 3, 225 | <0.01 |
| **V3*V6** | 2.6971 | 9, 225 | <0.01 |
| | | **Leaf Area Index @ R3** | |
| **V3** | 2.7176 | 3, 225 | 0.046 |
| **V6** | 5.2799 | 3, 225 | <0.01 |
| **V3*V6** | 0.4291 | 9, 225 | 0.92 |
| | | **Final Plant Height** | |
| **V3** | 1.5034 | 3, 225 | 0.21 |
| **V6** | 2.3273 | 3, 225 | 0.08 |
| **V3*V6** | 0.3821 | 9, 225 | 0.94 |

[1]Data were considered significantly different if $P < 0.05$ according to Tukey HSD

Table 1.2 Impact of simulated insect defoliation occurring at the V3 and V6 soybean growth stages on the yield (displayed as percent yield relative to the UDC), leaf area index values at V6 and R3 growth stages, and final plant heights, from experiments conducted in Mississippi in 2015 and 2016

| | **% Defoliation @ V6** | | | | |
|---|---|---|---|---|---|
| **% Defoliation @ V3** | **0%** | **33%** | **67%** | **100%** | **Mean** |
| | | | **Yield (% of UTC) Means ± SEM[1]** | | |
| 0 | 100% ± 4.1 | 94.1% ± 5.0 | 90.6% ± 5.5 | 80.2% ± 5.0 | 91.2% ± 2.6a |
| 33 | 99.6% ± 5.3 | 92.9% ± 3.2 | 90.3% ± 6.0 | 81.9% ± 4.1 | 90.9% ± 2.5ab |
| 67 | 93.3% ± 4.9 | 90.3% ± 4.0 | 93.0% ± 5.4 | 82.0% ± 5.8 | 89.6% ± 2.5ab |
| 100 | 84.8% ± 4.2 | 77.4% ± 4.3 | 77.4% ± 5.1 | 68.9% ± 5.1 | 77.1% ± 2.4b |
| **Mean** | 94.2% ± 2.4a | 88.7% ± 2.2ab | 87.8% ± 2.8ab | 78.2% ± 2.5b | |
| | | | **Leaf Area Index @ V6 Means ± SEM** | | |
| 0 | 1.96 ± 0.15a | 1.80 ± 0.15ab | 1.36 ± 0.14bcd | 0.73 ± 0.07efg | 1.46 ± 0.09 |
| 33 | 1.89 ± 0.15a | 1.80 ± 0.15ab | 1.31 ± 0.10cd | 0.63 ± 0.08efg | 1.41 ± 0.09 |
| 67 | 1.58 ± 0.13abc | 1.76 ± 0.13abc | 1.38 ± 0.14bcd | 0.62 ± 0.08fg | 1.33 ± 0.08 |
| 100 | 1.13 ± 0.11de | 0.94 ± 0.10def | 0.76 ± 0.06efg | 0.41 ± 0.06g | 0.81 ± 0.05 |
| **Mean** | 1.64 ± 0.08 | 1.57 ± 0.08 | 1.2 ± 0.07 | 0.6 ± 0.04 | |
| | | | **Leaf Area Index @ R3 Means ± SEM** | | |
| 0 | 4.06 ± 0.15 | 3.57 ± 0.21 | 3.59 ± 0.20 | 3.15 ± 0.22 | 3.59 ± 0.10a |
| 33 | 3.92 ± 0.15 | 3.83 ± 0.14 | 3.57 ± 0.19 | 3.26 ± 0.23 | 3.65 ± 0.10ab |
| 67 | 3.84 ± 0.15 | 3.64 ± 0.2 | 3.57 ± 0.21 | 3.26 ± 0.24 | 3.59 ± 0.10ab |
| 100 | 3.45 ± 0.21 | 3.36 ±0.21 | 3.36 ± 0.23 | 2.78 ± 0.29 | 3.23 ± 0.05b |
| **Mean** | 3.8 ± 0.09a | 3.62 ± 0.10ab | 3.53 ± 0.12ab | 3.11 ± 0.05b | |

Table 1.2 (continued)

| | | | **Final Plant Heights (cm) ± SEM** | | |
|---|---|---|---|---|---|
| 0 | 93.0 ± 4.59 | 90.8 ± 4.22 | 89.2 ± 4.75 | 84.3 ± 4.46 | 89.3 ± 2.24 |
| 33 | 94.9 ± 4.2 | 90.2 ± 4.51 | 89.2 ± 3.89 | 84.3 ± 3.50 | 89.7 ± 2.03 |
| 67 | 91.1 ± 3.37 | 90.5 ± 5.36 | 91.0 ± 4.29 | 79.9 ± 3.11 | 88.1 ± 2.10 |
| 100 | 87.9 ± 3.67 | 83.0 ± 4.12 | 82.4 ± 2.53 | 75.6 ± 4.57 | 82.2 ± 1.05 |
| **Mean** | 91.8 ± 1.97 | 88.6 ± 2.27 | 87.9 ± 1.97 | 81.0 ± 1.98 | |

[1] Means within sections followed by the same letter are not different ($P < 0.05$)

Table 1.3 Statistics for soybean yield contrasts comparing the impact of defoliation levels at V3 and V6 growth stages from experiments conducted in Mississippi during the 2015 and 2016 growing season

| % Defoliation at V3, V6 x % Defoliation at V3, V6 | *F* | df | *P*[1] |
|---|---|---|---|
| 100, 67 x 67, 100 | 0.6138 | 1, 225 | 0.4342 |
| 100, 33 x 33, 100 | 0.6063 | 1, 225 | 0.437 |
| 100, 0 x 0, 100 | 0.633 | 1, 225 | 0.4271 |
| 67, 33 x 33, 67 | 0 | 1, 225 | 0.9993 |
| 67, 0 x 0, 67 | 0.2187 | 1, 225 | 0.6405 |
| 33, 0 x 0, 33 | 0.6089 | 1, 225 | 0.436 |

[1]Data were considered significantly different if $P < 0.05$

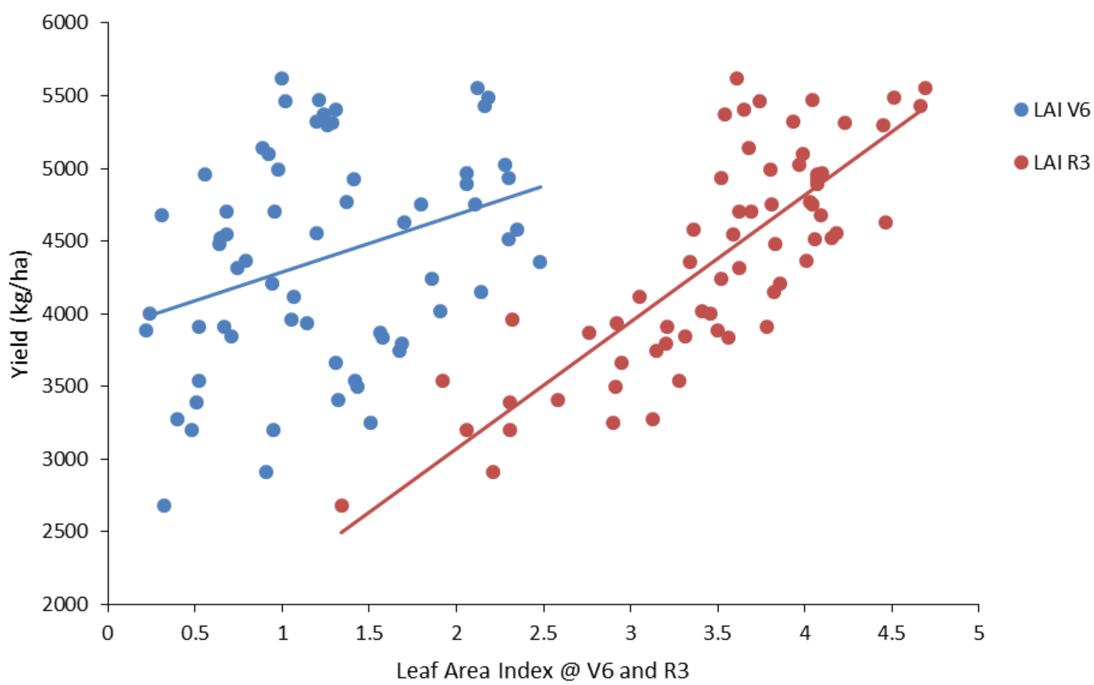


Figure 1.1 Correlations of leaf area index values taken at V6 and R3 growth stages to yield (kg/ha) from experiments conducted in 2015 and 2016 growing seasons in Mississippi

V6 LAI ($R^2 = 0.07$)
R3 LAI ($R^2 = 0.55$)

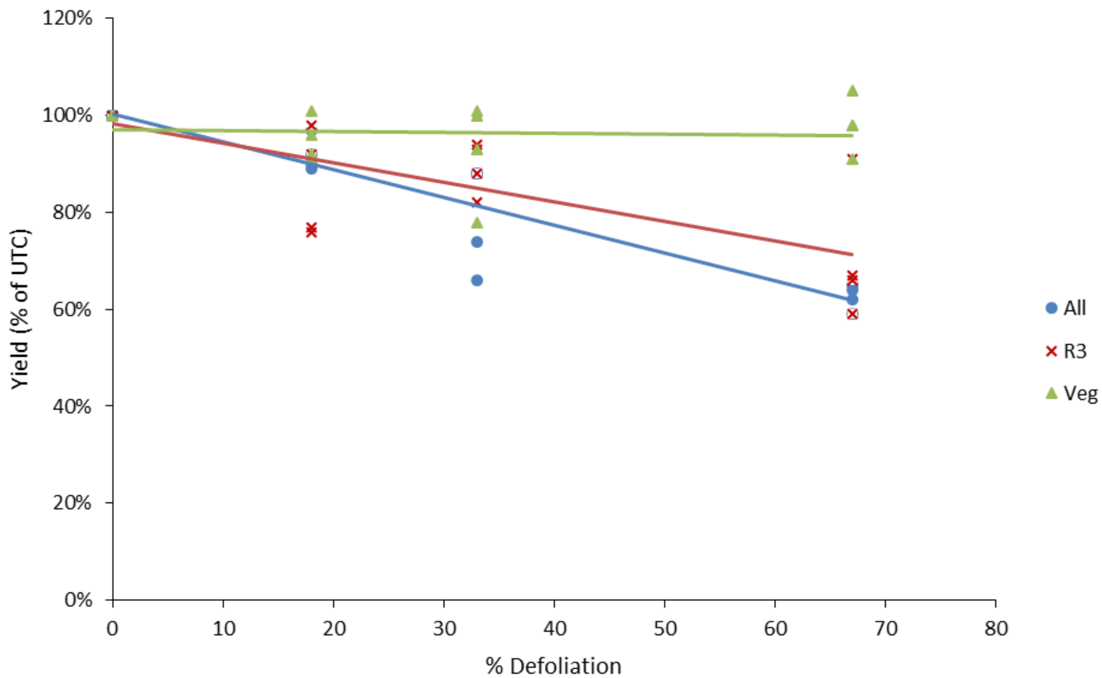


Figure 1.2 Mean yield loss in soybean across percent defoliation applied one time at the R3 growth stage (R3), continuously throughout the vegetative growth stages (Veg) and throughout the entire growing season (All), from experiments conducted in the 2015 and 2016 growing seasons in Mississippi

All: $F = 32.08$, df = 1, 61, $P = <0.01$, y = 5441.4399 – 31.404159x
R3: $F = 13.21$, df = 1, 61, $P = <0.01$, y = 5350.5379 – 19.731173x
Veg: $F = 0.24$, df = 1, 61, $P = 0.63$, y = 5218.787 – 2.5473205x

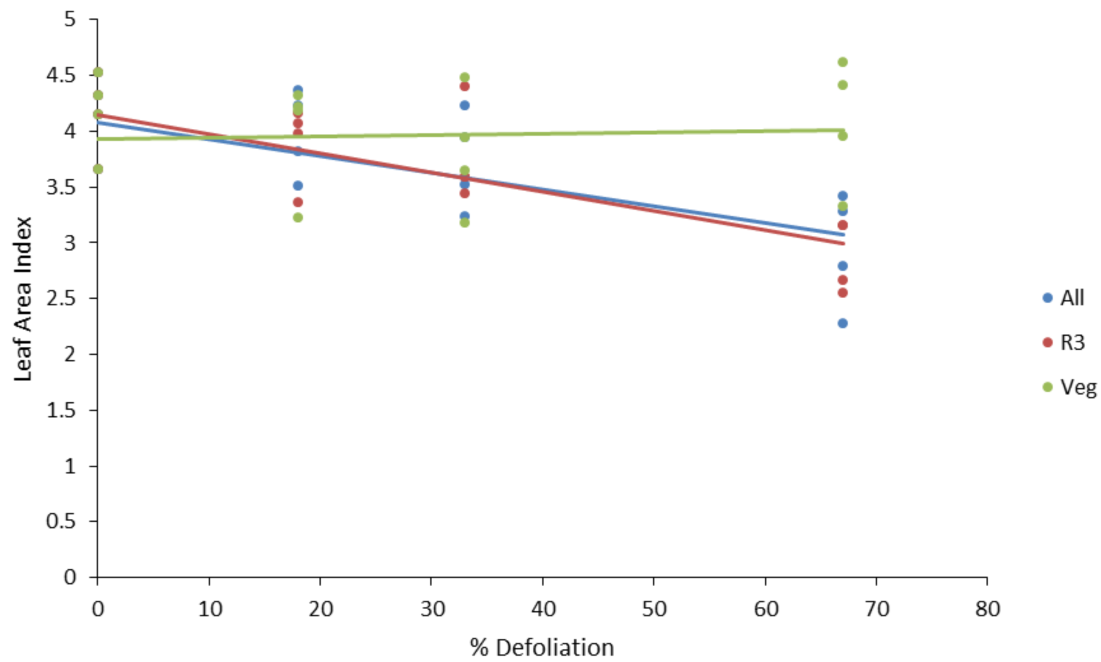


Figure 1.3 Mean leaf area index values at the R3 growth stage in soybean across percent defoliation applied one time at the R3 growth stage (R3), continuously throughout the vegetative growth stages (Veg), and throughout the entire growing season (All), from experiments conducted in the 2015 and 2016 growing seasons in Mississippi

All: $F = 21.93$, df = 1, 62, $P = <0.01$, $y = 4.081 - 0.0165x$
R3: $F = 36.20$, df = 1, 62, $P = <0.01$, $y = 4.147 - 0.0204x$
Veg: $F = 0.12$, df = 1, 62, $P = 0.73$, $y = 3.936 - 0.0011x$

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# CHAPTER II

# EFFECTS OF SOYBEAN PLANTING DATE ON YIELD LOSS FROM DEFOLIATION


## Abstract

Soybean, *Glycine Max* (L.) Merr., is planted over a three and a half to four month period across the Mid-South. Currently, no information exists about the impact of planting date on yield loss from early season defoliation in soybean. To evaluate the effects of planting date on yield loss from defoliation, soybean was planted at two week intervals from early-April to mid-June, for a total of six planting dates. Each planting date included an undefoliated control and a 100% defoliation treatment at the V4 growth stage. Average yield losses from defoliation ranged from 572 kg/ha for mid-April plantings to 904 kg/ha for early-June planting dates. Percent yield reduction from defoliation increased as planting dates increased suggesting that defoliation thresholds may need to be adjusted based on planting date and yield potential. However, more research is needed at lower levels of defoliation to accurately define what those thresholds should be.


## Introduction

Historically, recommended soybean, *Glycine max* (L.) Merr., planting dates in the Mid-South region of the U.S. (Arkansas, Louisiana, Mississippi, Tennessee) began in May and continued into June with the dominant cultivars being maturity groups V, VI, and VII (Heatherly 1999). However, the widespread adoption of the early soybean production system (ESPS) in the early 2000's expanded this planting window and shifted the predominant cultivars to earlier maturing, indeterminate maturity group IV and V varieties. Currently, planting begins in late March and ends in early July (USDA-NASS 2017). Since 2000, the Mid-South has averaged 50 and 90 percent of its total soybean crop planted by mid-May and mid-June, respectively (USDA-NASS 2017).

Research has shown that the optimum planting date for maximizing soybean yields in Mississippi is roughly 20 Apr (Bateman 2017). After this date, soybean yield potential decreases at an average rate of 26.9 kg/ha each day planting is delayed. To put this into perspective, a soybean field planted on 20 Apr has potentially a 1,130 kg/ha yield advantage over a field planted on 1 Jun. While most producers strive to plant early, many factors such as unfavorable weather, can delay planting. Logistical issues are also common problems, where growers with large tracts of land may not have enough equipment or labor to plant in a timely manner. Likewise, planting can intentionally be delayed in order to spread harvest evenly for producers with many hectares of land, allowing for a timely harvest at the end of the season. Soybean double-cropped after winter wheat crops will also result in late planting because the wheat must be harvested before planting can begin.

Defoliating insects tend to be more prevalent in later planted soybean during both vegetative and reproductive growth stages, whereas early planted soybean are likely to escape many defoliating pests (Baur et al. 2000, Bateman 2017). Fall armyworm, *Spodoptera frugiperda* (J.E. Smith), is a pest that commonly infests fields where weed control is delayed which can result in a large amount of weedy grass species being present (Catchot et al. 2016a). The fall armyworm infests the grass, the preferred host. After the field is treated with an herbicide, the armyworms move from the dying grass host to soybean in order to survive. If this occurs when larvae are in their late instars, which is when their foliage consumption rates are greatest, the damage to soybean can occur rapidly and be quite substantial (Luginbill 1928).

At present, little information exists about the impact of defoliation from insects during vegetative stages of soybean at different planting dates. Current thresholds for defoliating insects in the Mid-South are based on percent defoliation. Treatment thresholds are set at 35% pre-flowering and 20% during and after bloom (Catchot et al. 2016b). Yield reductions from defoliation in soybean is a function of the growth stage when defoliation occurs, the amount of defoliation, the ability of a cultivar to tolerate or compensate for defoliation, and environmental factors (Pedigo et al. 1986). Planting date influences which environmental factors soybean will be exposed to throughout the growing season. Later planted soybean will likely be exposed to drier and hotter weather conditions for a longer period of time and at critical growth stages compared to earlier planted soybean, potentially affecting how much yield loss will occur (Heatherly 1999).

Another possible mechanism for increased yield loss from defoliation at vegetative stages in late planted soybean is a reduction in the length of the vegetative growth stages. Zhang et al. (2004) reported maturity group 5.4 soybean planted on 15 Apr in Mississippi averaged 53 days from planting to flowering, but the same variety planted on 14 Jun only took 41 days to reach flowering. The main cue for soybean to begin reproductive development is scotoperiod or night length with the shortest night of the year typically being 21 Jun (Ashlock and Purcell 1998). However, weather, planting date, and maturity group also play a large role in initiating reproductive stages (Board 1985, Ashlock and Purcell 1998). Earlier planted soybean that experience defoliation during their vegetative growth stages have more time to recover lost leaf area prior to the beginning of sensitive reproductive stages. These differences in leaf area recovery time prior to the initiation of the reproductive growth stages could prove to be an important factor with respect to treatment threshold.

The objective of this study was to evaluate whether soybean planting date is an important factor when making treatment decisions for defoliating insect pests.

## Materials and Methods

Soybean were planted in 2015 and 2016 in both Starkville and Stoneville, MS with an additional site in Marianna, AR in 2016. An indeterminate Asgrow® 5335 (Monsanto Co., St. Louis, MO) cultivar was used for all locations and planting dates. Plots were planted at 271,810 seed per hectare and were 3.05-m long, four rows wide with 97-cm row spacing at the Starkville and Marianna locations, and 102-cm row spacing at the Stoneville location. A strip-block design was used in this experiment to facilitate harvest of each planting date without damaging later plantings. For each site year, there were six total planting dates, (with the exception of Stoneville in 2015 where the last planting was excluded due to a poor plant emergence) with six replications. Planting dates were approximately 2 weeks apart and ranged from 5 Apr for the earliest planting to 21 Jun for the latest (Table 2.1). Every planting included an undefoliated control (UDC) and a treatment defoliated 100% at the V4 growth stage (Fehr et al. 1981) for a total of 12 treatments. Defoliation was applied to the middle two rows of each plot by removing each trifoliate by hand. Two site years, Marianna and Starkville in 2016, contained an additional treatment where plots were defoliated 100% at the R1 growth stage. Yield data for these are included at the end of this dissertation in Appendix A. The defoliation level of 100% was chosen because it was the only level that Owen (2012) consistently observed yield losses in vegetative soybean. Defoliation levels lower than this applied to V4 soybean may not result in detectable yield loss. All plots were treated with either 1022 ml/ha of chlorantraniliprole (Prevathon®, DuPont, Wilmington, DE) or 365 ml/ha of thiamethoxam + lambda-cyhalothrin (Endigo®, Syngenta Crop Protection, Greensboro, NC), at the first sign of insect pests and treated with 438 ml/ha of fluoxastrobin (Fortix®, Arysta LifeScience North America, Cary, NC) fungicide at the R3 growth stage. Plant heights were recorded at the R7 growth stage with the terminal being used to indicate of the top of the plant. Plots were harvested by planting date using a two row Kincaid 8XP combine. Yields were adjusted to 13 percent moisture content.

Data from all locations were combined and analyzed using JMP 12 (1989-2007). A mixed model analysis of variance was used to analyze yields and heights from defoliated and undefoliated treatments for each planting date (Tables 2.2 and 2.4). Location, year, replication, and their interactions were random factors. Final plant heights were not recorded for the 2015 Stoneville location. Yield loss (kg/ha), across planting date was analyzed using an analysis of covariance with yield potential (yield of the UDC for each planting date) as the covariate (Table 2.3). Yield losses were displayed as percent of the UDC. No plot yielded ≥ 6500 kg/ha in mid-Jun plantings, and no plot yielded ≥ 7500 kg/ha in early to mid-Jun plantings, so yield difference was not displayed for these cells (Table 2.3). Differences for all analyses were considered significant if $P < 0.05$. Outliers for the regression analysis were identified in yield analysis using Cooks distance. Eight total data points had an influence value > 0.04 and were eliminated from the analysis.

**Results and Discussion**

Mean yields in non-defoliated plots across site years ranged from 5980 ± 450 kg/ha to 2630 ± 211 kg/ha in the mid-Apr and mid-Jun plantings, respectively. In defoliated plots, mean yields ranged from 5407 ± 459 kg/ha in mid-Apr plantings to 1840 ± 170 kg/ha in mid-Jun plantings. Actual yield loss from defoliation across all planting dates averaged 752 ± 73 kg/ha. Mean yield loss from defoliation across site years ranged from 572 ± 199 kg/ha for the mid-May planting period to 904 ± 140 kg/ha in the early-Jun planting period. Significant yield loss from defoliation was observed in all planting periods (Table 2.2). Mean percent yield difference ranged from +9 to -29% across yield potentials and planting dates (Table 2.3). Mid-Apr plantings experienced the least amount of yield loss from defoliation. Both yield potential and planting date had a significant effect on yield loss from defoliation (Planting date: $F = 14.23$, df = 1, 140.7, $P < 0.01$; Planting date$^2$: $F = 6.08$, df = 1, 135.9, $P = 0.01$; Yield potential: $F = 32.88$, df = 1, 83.11, $P < 0.01$). Yield potential had a greater influence on yield differences in earlier planted soybean than later planted soybean. Mean yield differences across yield potentials in early-Apr plantings ranged from -9 to +16%; whereas, mid-June plantings had a consistent 29% yield loss. Percent yield differences across the earliest three planting dates, early-Apr, mid-Apr, and early-May, were fairly consistent, with means for each yield potential varying a maximum of 3%. However, percent yield difference increased substantially across the latest three planting periods.

Mean final plant heights across site years in undefoliated plots ranged from 97.5-cm to 62.6-cm in the early-May and early-Apr plantings, respectively (Table 2.4). Mean plant heights in defoliated plots ranged from 88.7-cm in mid-May plantings to 55.4-cm in the early-Apr plantings. Mean height reduction between defoliated and undefoliated plots ranged from 14.8-cm in early-June plantings to 2.7-cm in mid-Apr plantings. Significant height reductions were observed in all planting periods except mid-Apr. Plant height had a significant quadratic relationship across planting date in both undefoliated and defoliated plots (Undefoliated: $F$ = 112.89, df = 1, 111.2, $P < 0.01$; Defoliated: $F$ = 97.25, df = 1, 110, $P < 0.01$). Regression estimated plant height, for undefoliated and defoliated plots, being the greatest for plantings between mid-May and early-Jun. Plant height continually decreased the earlier or later soybean was planted, relative to this time period. Delays in leaf drop because of defoliation were observed in several instances, but were inconsistent, likely due to differences in environmental conditions across planting dates, locations, and years.

Soybean planted during mid to late-Apr yielded greatest in this study and yield potential declined steadily thereafter which parallels the results of Bateman (2017). Early plantings with low yield potentials (2,500-3,500 kg/ha) experienced the least amount of yield loss from defoliation and in many instances mean yield increased. In these plots, factors other than leaf area were limiting yield, so defoliation did not affect yield. In some of the lower yielding plots defoliation increased yield, meaning the additional leaf area was actually costing the plant more yield than it was contributing. In the higher yield potential plots (4,500-7,500 kg/ha) however, defoliation was a yield limiting factor even at early planting dates. Defoliation decreases water loss in plants through reduced transpiration (Ostlie and Pedigo 1984). Decreased plant stress from reduced water loss in lower yielding plots could partially explain the defoliation related yield increase. Many of the lower yielding plots were in the Starkville location which had sandy soil and although they did receive irrigation the soil dried out quickly possibly stressing the plants. Across all yield potentials, defoliation after mid-Apr resulted in greater yield losses across planting dates. This indicates that leaf area becomes an increasingly important factor the longer planting is delayed.

Because yield potential was determined to be a factor in determining yield loss, knowledge of a particular fields yield potential would be crucial in defining an accurate threshold. Yield potential is difficult to predict, but knowledge of a fields history can provide some insight of what to expect in a current year. In non-irrigated systems however, weather is a primary driver of yield and is near impossible to predict. But, in many cases a general estimation can still be made on whether a field will yield 5,500 kg/ha or 2,500 kg/ha.

## Conclusion

Soybean planted after early-May experienced a consistent increase in yield loss the longer planting was delayed. This indicates late planted soybean would benefit from a lower threshold than earlier planted soybean. However, in order to determine an exact threshold more defoliation levels need to be evaluated across planting dates. Yield potential was also an important factor in this experiment with higher yielding soybean losing greater amounts of yield than soybean with lesser yield potential. Yield potential may be a useful factor in the creation of future thresholds, allowing them to be more dynamic.

**Acknowledgements**

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Table 2.1 List of soybean planting dates (Julian date) for soybean at Marianna, AR, Starkville and Stoneville, MS in 2015 and 2016

| | Planting Date (Julian Date) | | | | |
|---|---|---|---|---|---|
| | Marianna, AR | Starkville, MS | | Stoneville, MS | |
| Planting Period | 2016 | 2015 | 2016 | 2015 | 2016 |
| Early Apr | 5-Apr | 9-Apr | 5-Apr | 8-Apr | 5-Apr |
| Mid Apr | 25-Apr | 23-Apr | 19-Apr | 22-Apr | 19-Apr |
| Early May | 5-May | 6-May | 9-May | 6-May | 6-May |
| Mid May | 17-May | 21-May | 19-May | 21-May | 19-May |
| Early Jun | 7-Jun | 4-Jun | 10-Jun | 4-Jun | 10-Jun |
| Mid Jun | 21-Jun | 18-Jun | 20-Jun | - | 20-Jun |

Table 2.2 Mean yields (kg/ha) ± SE and yield losses (kg/ha) in soybean with analysis of variance statistics comparing the undefoliated control and defoliated plots at each planting period for experiments in Mississippi and Arkansas in 2015 and 2016

| | Yield ± SE (kg/ha) | | | | | |
|---|---|---|---|---|---|---|
| Planting Period | Undefoliated | Defoliated | Loss | *F* | df | *P*[1] |
| Early Apr | 5450 ± 548 | 4725 ± 508 | 724 ± 242 | 8.85 | 1,23.18 | < 0.01 |
| Mid Apr | 5980 ± 450 | 5407 ± 459 | 572 ± 199 | 8.26 | 1,27 | < 0.01 |
| Early May | 5815 ± 380 | 5161 ± 357 | 654 ± 182 | 12.84 | 1,29 | < 0.01 |
| Mid May | 5196 ± 242 | 4389 ± 263 | 807 ± 153 | 27.72 | 1,29 | < 0.01 |
| Early Jun | 4724 ± 255 | 3821 ± 300 | 904 ± 140 | 41.51 | 1,29 | < 0.01 |
| Mid Jun | 2630 ± 211 | 1840 ± 170 | 862 ± 146 | 25.21 | 1,22 | < 0.01 |

[1]Data were considered significantly different if $P < 0.05$

Table 2.3 Percent yield difference compared to the undefoliated control from 100% defoliation at V4 growth stage at each planting period for each yield potential (kg/ha) for experiments in Mississippi and Arkansas in 2015 and 2016

| Yield | Planting Date | | | | | |
|---|---|---|---|---|---|---|
| Potential | Early-Apr | Mid-Apr | Early-May | Mid-May | Early-Jun | Mid-Jun |
| 2500 | +9% | +12% | +10% | +3% | -11% | -29% |
| 3500 | +2% | +1% | -1% | -6% | -16% | -29% |
| 4500 | -8% | -6% | -7% | -11% | -19% | -29% |
| 5500 | -12% | -10% | -11% | -15% | -21% | -29% |
| 6500 | -14% | -13% | -14% | -17% | -22% | |
| 7500 | -16% | -15% | -16% | -18% | | |

Percent yield difference is based of the equation: y = -2304.98 + 0.2887*yield potential + 10.191 * planting date + (planting date - 133.29)*((planting date - 133.29)*0.3022)

Table 2.4 Mean final plant height (cm) ± SE and height reduction (cm) in soybean with analysis of variance statistics comparing the undefoliated control and defoliated plots at each planting period for experiments in Mississippi and Arkansas in 2015 and 2016

| Planting | Final Height ± SE (cm) | | | | | |
|---|---|---|---|---|---|---|
| Period | Undefoliated | Defoliated | Reduction | *F* | df | *P*[1] |
| 1 | 62.6 ± 2.0 | 55.4 ± 1.3 | 7.2 ± 2.5 | 8.35 | 1,17.86 | < 0.01 |
| 2 | 79.1 ± 2.9 | 76.4 ± 2.3 | 2.7 ± 2.2 | 1.48 | 1,21 | 0.24 |
| 3 | 97.5 ± 3.5 | 87.9 ± 3.7 | 9.6 ± 2.1 | 21.13 | 1,23 | < 0.01 |
| 4 | 95.7 ± 5.1 | 88.7 ± 5.0 | 7.0 ± 2.7 | 7.06 | 1,23 | < 0.01 |
| 5 | 84.9 ± 5.9 | 70.1 ± 5.6 | 14.8 ± 1.4 | 113.88 | 1,23 | < 0.01 |
| 6 | 69.4 ± 7.4 | 57.7 ± 5.8 | 11.7 ± 2.9 | 16.67 | 1,22 | < 0.01 |

[1]Data were considered significantly different if $P < 0.05$

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CHAPTER III

# EFFECTS OF SOYBEAN PLANT POPULATION ON YIELD LOSS FROM DEFOLIATION

## Abstract

Plant densities in Mid-South soybean, *Glycine max* (L.) Merr., fields can vary widely due to a wide range of factors and although soybean yields are generally insensitive to variations in density, it is unknown if yield loss from defoliation varies across populations. Soybean was planted at seeding rates ranging from 123,500 seeds/ha to 420,070 seeds/ha in 74,130 seeds/ha increments. Each seeding rate had an undefoliated plot and a plot that was defoliated 67% at R1. Defoliation significantly reduced yield where plant populations fell below 192,800 plants/ha. Plant populations greater than this were not significantly impacted by defoliation. These results indicate fields with substandard plant populations may benefit from a more intense management strategy for defoliating pests.

## Introduction

Soybean, *Glycine max* (L.) Merr., planting densities vary widely across the Mid-South region of the United States (AR, LA, MS, TN) due to a myriad of factors. However, variations in plant densities typically have minimal effects on soybean yield (Robinson and Conley 2007, Lee et al. 2008). The major objective of a grower is to acquire the minimum plant population needed for optimal yield when determining a seeding rate (Board et al. 2013). Rising seed costs, with the current U.S. average cost being $150.72 per hectare, have made the issue of achieving an optimum seeding rate increasingly important (ASA 2017).

Although soybean yields are relatively insensitive to variations in plant density, an excessive plant population can result in problems aside from increased seed costs. A common problem in fields with excessively high plant densities is plant lodging (Boquet 1990, Ashlock et al. 1998). This slows harvest, may reduce seed quality, and generally increases harvest losses. Too sparse of a plant population can lead plants to set pods close to the ground making harvest more difficult and can also result in some pods being left on stubble in the field (Quick and Buchele 1974, Lueschen and Hicks 1977). Low seeding rates can also lead to increased weed problems if the canopy fails to close in a timely manner; leaving areas for weeds to intercept light and grow (Arce et al. 2009, Place et al. 2009).

Many factors should be considered when deciding the ultimate plant populations. A few of these include row spacing, irrigation, and planting date. Recommendations for final plant population based on row spacing in Mississippi varies from 247,000 plants/ha to 370,500 plants/ha in fields with 91 and 15-cm row spacings, respectively (Koger 2012). In Louisiana, Board et al. (2013) concluded that growers should strive for a final plant population of 228,600 plants/ha and should not exceed 317,500 plants/ha because this can result in plant death with no increase in yield. Ability to irrigate is also of considerable importance when evaluating the desired final plant population. Higher plant densities require more nutrients and water than lower plant densities. For example, Arkansas recommends 50,800 fewer plants/ha in dryland fields than irrigated fields

(Ashlock et al. 1998). Planting date should also be taken into consideration when deciding target plant population. Later plantings tend to have reduced branching and overall shorter plants when compared to earlier plantings, and higher plant populations can help later plantings compensate for these limitations (Heatherly et al. 1999, Lee et al. 2008).

Once the desired final plant population has been established, the seeding rate needed to achieve it must be determined, which again is affected by a many factors. Germination rate is important to consider because seed with lower germination rates need higher seeding rates in order to meet the desired plant population. Seeding rates may also need to be increased in situations where the seedbed is less than optimal due to low soil moisture, cloddiness, or where no-till practices are being implemented (Heatherly et al. 1999, Board et al. 2013). For example, Tennessee recommends increasing seeding rates from 20–26 seed/m in a tilled field to 26–30 seed/m when planting in a no-till field (Flinchum 2003).

After planting, there are numerous other dynamics that can affect final plant population. Poor seedling vigor or excessive planting depth can contribute additional stresses leading to uneven plant emergence. Poor weather conditions early in the growing season, such as cool weather or excessive amounts of precipitation, can reduce plant stands on their own or exacerbate other problems. Poor weather promotes seedling pathogens such as *Phytophthora*, *Rhizoctonia*, *Pythium*, and *Fusarium* which can reduce plant stands (Coker et al. 1998, Kirkpatrick et al. 2006, Allen 2012, Faske 2015). Misapplication or adverse weather conditions can also cause pre-emerge herbicides to result in seedling death (Allen et al. 2013, Bond and Allen 2014, Faske 2015). Many insects also cause damage to soybean in early growth stages, resulting in plant stand reductions or reduced plant vigor. These insects include armyworms, *Spodoptera* spp.; bean leaf beetle, *Ceratoma trifurcata* (Förster); cutworms, *Agrotis* and *Feltia* spp.; pea leaf weevil, *Sitona lineatus* L.; lesser cornstalk borer, *Elasmopalpus lignosellus* Zeller; spotted cucumber beetle, *Diabrotica undecipunctata howardi* Barber; threecornered alfalfa hopper, *Spissistilus festinus* (Say); and wireworms, Coleoptera: Elateridae (Steffey et al. 1994, Price III et al. 2009, Catchot et al. 2016b).

Because so many factors go into the resulting final plant population, it inevitably will vary widely across an area as large as the Mid-South. As plant population decreases, seed yield per plant increases (Ethredge Jr. et al. 1989, Boquet 1990, Edwards and Purcell 2005). Soybean also produces more vegetative growth per plant at lower populations than at higher ones in order to support the increased yield per plant. Defoliation on a percent basis would remove more leaves per plant at low populations, as compared to high populations. So a plant in a lower population field would likely have to recover more leaf area per plant than one grown at a higher population. This difference has the potential to affect how much defoliation soybean can tolerate based on plant population.

Populations of 197,680 – 296,520 plants/ha are adequate for optimizing yield in most Mid-South fields (Heatherly et al. 1999). However, the vast number of factors that can affect final plant populations will inevitably result in fields that have more or less than optimal plant stands. Ashlock et al. (1998) found that there was no difference in the yields of soybean planted at various seeding rates between 152,400 plants/ha and 609,600 plants/ha. Board et al. (2013) found in some situations that populations as low as 44,196 plants/ha resulted in no discernable yield difference when compared to higher seeding rates. Because of the ability of soybean to compensate, a grower may decide to keep a sub-optimal plant stand rather than replant. Currently, it is not known whether defoliation thresholds should be modified to respond to differences in plant population.

## Materials and Methods

Studies were conducted at the R.R. Foil Plant Science Research Center in Starkville, MS and the Delta Research and Extension Center in Stoneville, MS during the 2016 and 2017 growing seasons. In 2016 soybean were planted at the Starkville and Stoneville locations on 9 May and 10 May, respectively. In 2017 soybean were planted on 2 May in Starkville and 9 May in Stoneville. Trials were planted using Asgrow® 5335 (Monsanto Co., St. Louis, MO) which is an indeterminate cultivar. Plot sizes were four rows wide, 3.05-m in length, with 97-cm row spacing in Starkville and 102-cm row spacing in Stoneville. Treatments were arranged in a randomized complete block design and replicated four times. All plots were treated with either 1,022 ml/ha of chlorantraniliprole (Prevathon®, DuPont, Wilmington, DE) or 438 ml/ha of clothianidin (Belay®, Valent U.S.A. Corporation, Walnut Creek, CA) + 0.84 kg/ha acephate (Orthene®, AMVAC Chemical Corporation, Los Angeles, CA) at the first sign of insect pests and treated with 438 ml/ha of fluoxastrobin (Fortix®, Arysta LifeScience North America, Cary, NC) fungicide at the R3 growth stage to prevent any other defoliation than what was intended within the study parameters.

Soybean were planted at rates ranging from 123,500 seeds/ha to 420,070 seeds/ha in 74,130 seeds/ha increments, resulting in 5 total seeding rates. Within each seeding rate an undefoliated control and a treatment where plants were defoliated 67% at the R1 growth stage were included, as described by Fehr et al. (1971), resulting in 10 total treatments.  In treatments where defoliation was required, the middle two rows of each plot were hand defoliated by pulling 2 leaflets off of every trifoliate.  Plant population was recorded by counting all plants within one row of each plot when plants were between the V2 and V4 growth stages.

Leaf area index (LAI) was calculated from photosynthetically active radiation (PAR) (light between 400 and 700 nm) readings after defoliation at the R1 growth stage and at the R3 growth stage.  This provides a measure of leaf area present in relation to ground area (Klubertanz et al. 1996).  Several studies have shown that LAI correlates with defoliation (Higley 1992, Board et al. 1997a, Owen 2012).   LAI was calculated using a Decagon AccuPAR LP-80 (Decagon Devices 2001).  A single PAR measurement of was recorded above and below the canopy in each plot.  Above canopy PAR measurements were taken approximately 25-cm above the canopy and below canopy measurements were taken by placing the device at ground level, parallel with the third row of each plot, keeping the device approximately 7.5-cm to the left of that row.  LAI was calculated from these measurements using the formula:

$$L = \frac{\left[\left(1 - \frac{1}{2K}\right)f_b - 1\right]\ln\tau}{A(1 - 0.47f_b)}$$

Where *fb* is the fraction of incident PAR which is beam, *K* is the extinction coefficient for the canopy, τ is the ratio of PAR measured below canopy to PAR above canopy, and *A* = 0.86 (Decagon Devices 2001).  All PAR measurements were taken between 1100 and 1400 h central time.  Leaf expansion rate (LER) was defined as LAI at R3 minus LAI at R1, divided by the number of days between measurements.  Board

(2000) previously described this as a method for evaluating LER between two growth stages.

Yield, R1 LAI, R3 LAI, plant height, and LER, were analyzed across site-years using regression analysis with the mixed procedure in Proc GLIMMIX (SAS Version 9.4, SAS Institute Inc., Cary, NC). Defoliation, plant population (plants/ha), and their interaction were set as fixed effects while location, year, replication, and their interactions were set as random factors. Yield was also analyzed using the previous method with defoliation, R3 LAI, and their interaction or defoliation, LER, and their interaction being set as fixed effects, with location, year, and replication set as random factors. Cook's distance was used to evaluate the influence of individual data points on the yield model. Three data points had a Cook's distance > 0.04; they were considered outliers and eliminated from analysis. Degrees of freedom were calculated using the Kenward-Roger method. The slicediff function for LS-means was used to evaluate the plant population at which yield and LER of the defoliated plots statistically separated from the undefoliated plots. Differences were considered significant at $\alpha$=0.05.

**Results and Discussion**

Mean plant populations across site years ranged from 61,839 plants/ha to 421,319 plants/ha. Mean yields for undefoliated plots ranged from 3284 kg/ha to 5041 kg/ha; while yields for defoliated plots ranged from 2985 kg/ha to 4852 kg/ha. A significant interaction between plant population and defoliation was observed for yield (Table 3.1). A significant linear relationship was observed between plant population and yield in the undefoliated plots, where yield increased as plant population increased ($F$ = 14.68, df = 1, 95.28, $P$ < 0.01, y = 3928.2 + 0.00140x) (Figure 3.1). In the defoliated plots, there was a significant quadratic relationship, in which yield increased as plant population increased, up to ca. 350,000 plants/ha, and thereafter flattened ($F$ = 7.18, df = 1, 98.73, $P$ < 0.01, y = 3518.2164 + 0.00293x + -0.0000000179(x - 241.67)$^2$). Analysis indicated that defoliation, when compared to undefoliated plots, significantly reduced yields at plant populations ≤ 192,800 plants/ha ($t$ = 1.97, df = 1, 207, $P$ = 0.049). Defoliation that occurred to plants at populations greater than this did not result in yield reductions at the tested level of defoliation. A plant population of 286,000 plants/ha had the least likelihood of suffering yield reduction from defoliation ($t$ = 0.57, df = 1, 207.5, $P$ = 0.57).

The presence of an interaction between defoliation and plant population indicated that plant population influenced the amount of yield loss that could result from defoliation. A plant population of 286,000 plants/ha was considered the "optimal" plant population for minimizing yield reduction from defoliation, because it had the least likelihood of having a yield reduction. In plots with < 192,800 plants/ha, yield was reduced by defoliation, indicating that lower plant populations have a reduced ability to compensate for defoliation. Plant populations at the upper end of tested levels resulted in no greater ability to compensate for defoliation than the "optimal" plant population. This is likely due to increased interplant competition at the higher densities. Yield in undefoliated plots increased as plant population increased where a four-fold increase in plant population resulted in a 12.5% increase in seed yield. Following defoliation, plants could be using an increased amount of resources per plant to produce not only seed, but also replace the lost foliage. This would explain why yield plateaued in the defoliated plots, but not the undefoliated plots.

No significant interaction between defoliation and plant population was observed for LAI at R1 (Table 3.1). However, significant main effects of both defoliation and plant population were observed. LAI determined at R1 increased in both undefoliated and defoliated plots as plant population increased (Undefoliated: $F = 56.06$, df = 1, 100.1, $P < 0.01$, y = 1.004 + 0.00000263x; Defoliated: $F = 56.06$, df = 1, 98.79, $P < 0.01$, y = 0.488 + 0.00000157x) (Figure 3.2). As expected, defoliation significantly reduced LAI values at R1 when compared to the undefoliated plots, with a mean reduction of 0.78 LAI across plant populations (Defoliated vs. Undefoliated: $F = 17.24$, df = 1, 209.9, $P < 0.01$). No significant interaction between defoliation and plant population was observed for LAI at R3, but the main effects were significant (Table 3.1). Plant population had a significant impact on R3 LAI in defoliated plots but not the undefoliated plots (Undefoliated: $F = 2.40$, df = 1, 94.47, $P = 0.12$, y=2.998 + 0.00000801x; Defoliated: $F$=7.3, df = 1, 95.39, $P < 0.01$, y = 2.768 + 0.00000118x). Across plant populations, mean LAI values in plots that were defoliated were 0.16 lower at R3 than in undefoliated plots. No significant interaction between defoliation and R3 LAI was observed for yield, although both main effects were significant (Table 3.2). In both undefoliated and defoliated plots R3 LAI had a significant positive relationship with yield (Undefoliated: $F$ =155.1, df = 1, 27.56, $P < 0.01$, y = 2568.6 + 532.6x; Defoliated: $F = 108.12$, df = 1, 29.59, $P < 0.01$, y = 2386.0 + 541.0x) (Figure 3.3). When undefoliated and defoliated plots were compared at equivalent R3 LAI values, yields averaged approximately 161 kg/ha lower in defoliated plots.

As would be expected, defoliation significantly reduced LAI at R1 across plant populations. Significant differences in LAI were observed at R3 between defoliated and undefoliated plots. Board (2000) found similar results in undefoliated soybean where soybean at 80,000 plants/ha had significantly lower LAI at R1 than plant populations of 145,000 and 390,000 plants/ha, but when LAI was calculated at R3 differences were no longer observed. Reduced yield in defoliated plots when compared to undefoliated plots at equivalent R3 LAI values indicates that some resources were being used to replace the removed leaf area instead going toward producing yield.

A significant interaction between defoliation and plant population was observed for LER (Table 3.1). In defoliated plots no significant relationship between plant population and LER was observed, however a significant negative relationship to LER was observed between plant population and LER in undefoliated plots (Defoliated: $F$ = 0.59 ,df = 1, 95.61, $P$ = 0.45, y = 0.0791 + -0.0000000665x; Undefoliated: $F$ = 8.108, df = 1, 97.4, $P$ < 0.01, y = 0.0938 + -0.00000000128x) (Figure 3.4). Defoliated plots at all plant populations had significantly greater LER than undefoliated plots ($t$ = -1.97, df = 1, 209.1, $P$ = 0.0499). No interaction was present between LER and defoliation for yield, however both of the main effects were significant (Table 3.2). LER had a significant positive relationship with yield in both undefoliated and defoliated plots (Undefoliated: $F$ = 13.51, df = 1, 91.59, $P$ < 0.01, y = 3805.4 + 7396.08x; Defoliated: $F$ = 48.89, df = 1, 33.52, $P$ < 0.01, y = 2863.1 + 12960.22x) (Figure 3.5). Equivalent LER levels had lower returns on yield when compared to the undefoliated treatments.

LER in defoliated plots was greater than in the undefoliated plots across plant populations. This is evidence that soybean was compensating for the defoliation by increasing LER. Since the LER in defoliated plots did not increase along with plant population, it appears that, LER had been maximized at both low and high plant populations between the R1 and R3 growth stages. On the other hand, the difference in LER between defoliated and undefoliated plots did increase as plant population increased. Board (2000) found that higher plant populations resulted in greater LER from emergence to R1 because most leaf growth prior to R1 occurs on the main stem. After R1, leaf growth on the main stem ceases, and growth on the branches increases. Multiple studies have found increases in soybean branch number as plant population decreases (Lueschen and Hicks 1977, Boquet 1990, Carpenter and Board 1997). Plants at lower populations tend to have a greater amount of branches, which results in a greater LER after R1 (Board 2000). This would partially explain the reason for the negative relationship between LER in undefoliated plots and plant population in our study. Our study was different from Board (2000) in that we used soybean with an indeterminate growth habit, meaning main stem growth continues after the initiation of flowering (Ashlock and Purcell 1998). Higher plant populations resulted in greater LAI at R1, however interplant competition was also greater, which likely reduced the LER between R1 and R3. Predictably, LER had a positive correlation to yield. This indicates that soybean, which has the ability to produce/replace more leaf area (i.e. has adequate resources) will also be able to produce more yield. Equivalent LER values had lower returns on yield in defoliated plots when compared to the undefoliated plots. This was due to the defoliated plots having a lower LAI at R1. In order for a defoliated plot to produce yield equivalent to an undefoliated plot it must have an LER high enough that its R3 LAI will be greater than the comparable undefoliated plot. As mentioned previously this is because equal LAI values at R3 do not produce the same amount of yield in defoliated and undefoliated soybean.

No significant interaction between defoliation and plant population was observed for final plant height (Table 3.1). Across plant populations defoliation reduced plant height an average of 5.7-cm when compared to undefoliated treatments. A positive linear relationship between plant height and plant population was observed in both undefoliated and defoliated plots (Undefoliated: $F = 11.78$, df = 1, 93.24, $P < 0.01$, $y = 95.640 + 0.0000266x$; Defoliated: $F = 11.78$, df = 1, 95.23, $P < 0.01$, $y = 89.676 + 0.0000294x$).

Multiple studies have found reductions in plant height from defoliation. Fehr et al. (1981) found and average of 7-cm height reduction from defoliation occurring at the R4 growth stage. Hunt et al. (1994) also found defoliation during vegetative growth stages significantly reduced final plant height. In contrast, Goli and Weaver (1986) found no significant reduction in heights from defoliation occurring during the R4-R6 growth stages. Although this was likely due the late growth stage when defoliation occurred, and the plants were already near their final height. Several studies have also found positive relationships between plant population and plant height. Doss and Thurlow (1974) found that plants grown at higher populations had longer internodes which resulted in greater final plant heights. Boquet (1990) found greater main stem length when soybean was planted at higher populations, while lower populations had longer mean lateral branch stem lengths.

## Conclusion

Final plant population can be affected by numerous factors, but due to the ability of soybean to compensate for less than optimal plant populations, these fields can still produce satisfactory results when properly managed. These data indicate that defoliation can result in a greater rate of yield loss for soybean at a suboptimal plant populations when compared to soybean at optimal plant populations.  Generally, fields with poor stands can tolerate less injury from defoliating pest and fields with excessively high plant populations are not more tolerant of defoliation.  With that being said, more defoliation levels and growth stages would need to be evaluated in order to determine an accurate threshold across plant populations.

Table 3.1 Analysis of variance statistics for soybean yield, LAI at R1 and R3, LER from R1 to R3, and final plant height by defoliation and plant population and their interactions for experiments conducted in Mississippi during 2016 and 2017

| | ***F*** | **df** | ***P*[1]** |
|---|---|---|---|
| | | **Yield** | |
| **Defoliation (Defol)** | 12.22 | 1, 207.9 | < 0.01 |
| **Plant population (Pt Pop)** | 19.1 | 1, 209.9 | < 0.01 |
| **Pt Pop*Defol** | 7.29 | 1, 208 | < 0.01 |
| **Pt Pop*Plantpop** | 10.29 | 1, 209 | < 0.01 |
| **Pt Pop*Pt Pop*Defol** | 5.8 | 1, 208 | 0.02 |
| | | **LAI R1** | |
| **Defol** | 17.06 | 1, 209.9 | < 0.01 |
| **Pt Pop** | 61.4 | 1, 227.4 | < 0.01 |
| **Pt Pop*Defol** | 3.33 | 1, 210.2 | 0.07 |
| | | **LAI R3** | |
| **Defol** | 4.57 | 1, 209.1 | 0.03 |
| **Pt Pop** | 8 | 1, 210.9 | < 0.01 |
| **Pt Pop*Defol** | 1.92 | 1, 209.1 | 0.16 |
| | | **LER** | |
| **Defol** | 80.27 | 1, 208.9 | < 0.01 |
| **Pt Pop** | 6.72 | 1, 213.7 | 0.01 |
| **Pt Pop*Defol** | 6.87 | 1, 209.2 | < 0.01 |
| | | **Final Plant Height** | |
| **Defol** | 3.95 | 1, 209 | 0.048 |
| **Pt Pop** | 22.7 | 1, 210.4 | < 0.01 |
| **Pt Pop*Defol** | 0 | 1, 209.1 | 0.97 |

[1]Data were considered significantly different if $P < 0.05$

Table 3.2 Analysis of variance statistics for soybean yield by defoliation, LAI R3, and their interaction and defoliation, LER, and their interaction for experiments conducted in Mississippi during 2016 and 2017

| | *F* | df | *P*[1] |
|---|---|---|---|
| **Defol** | 4.65 | 1, 210.1 | 0.03 |
| **LAI R3** | 167 | 1, 34.86 | <0.01 |
| **LAI R3*Defol** | 0.2 | 1, 0.019 | 0.89 |
| **Defol** | 23.04 | 1, 225 | <0.01 |
| **LER** | 21.05 | 1, 169.5 | <0.01 |
| **LER*Defol** | 0.08 | 1, 0.075 | 0.78 |

[1]Data were considered significantly different if P < 0.05

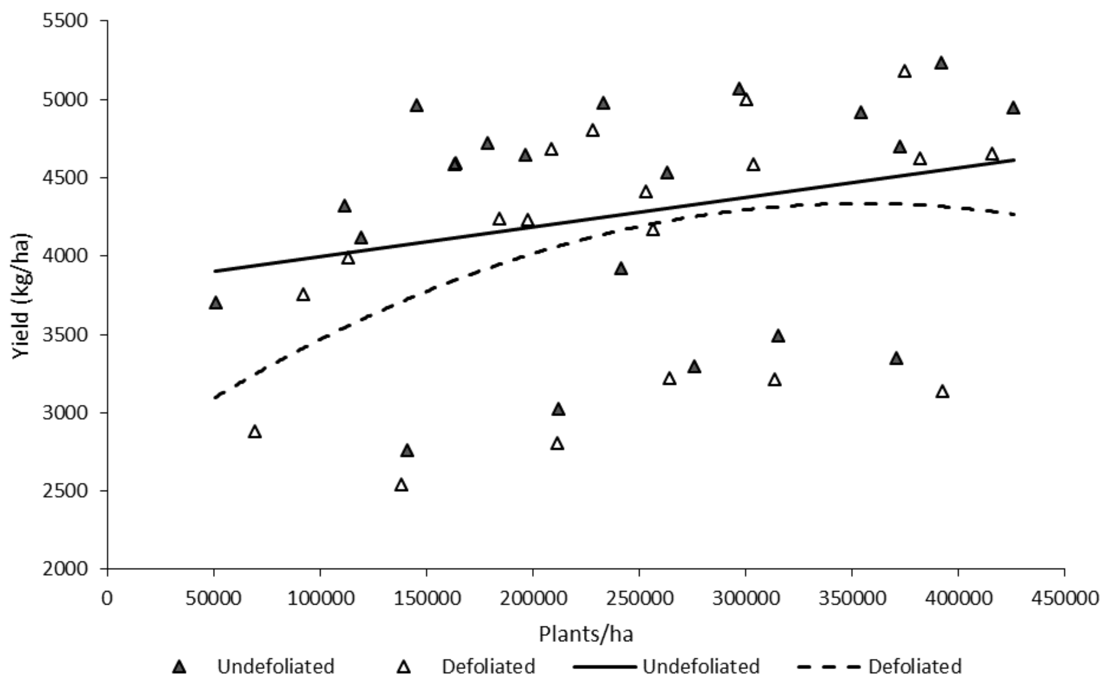


Figure 3.1 Regression of yield (kg/ha) in undefoliated and defoliated soybean plots across plant population for experiments conducted in Mississippi during 2016 and 2017

Undefoliated: $F = 7.18$, df = 1, 98.73, $P < 0.01$, y = 3928.2 + 0.00140x;
Defoliated: $F = 14.68$, df =1, 95.28, $P < 0.01$; y = 3518.2164 + 0.00293x + -0.0000179(x - 241.67)^2

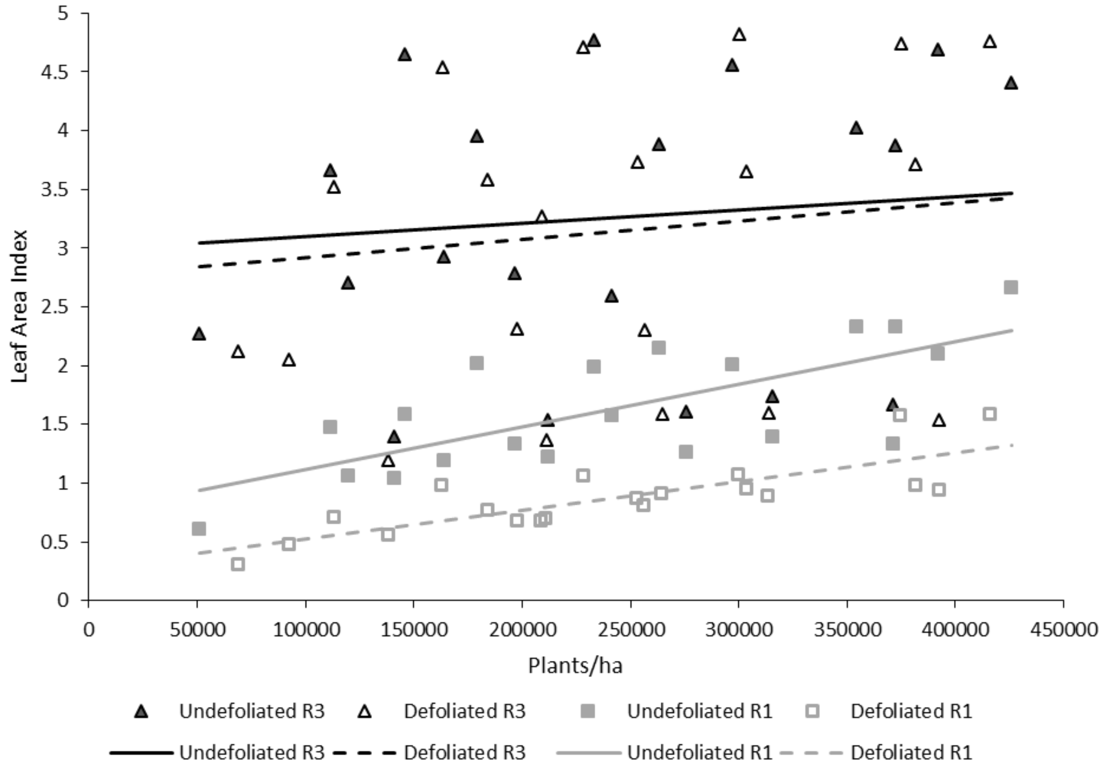


Figure 3.2 Regression of leaf area index at R1 and R3 growth stages in undefoliated and defoliated soybean plots across plant population for experiments conducted in Mississippi during 2016 and 2017

R1 Undefoliated: $F = 56.06$, df = 1, 100.1, $P < 0.01$, y = 1.004 + 0.00000263x
R1 Defoliated: $F = 44.63$, df = 1, 98.79, $P < 0.01$, y = 0.488 + 0.00000157x
R3 Undefoliated: $F = 2.40$, df = 1, 94.47, $P = 0.12$, y=2.998 + 0.000000801x
R3 Defoliated: $F = 7.30$, df = 1, 95.39, $P < 0.01$, y = 2.768 + 0.00000118x

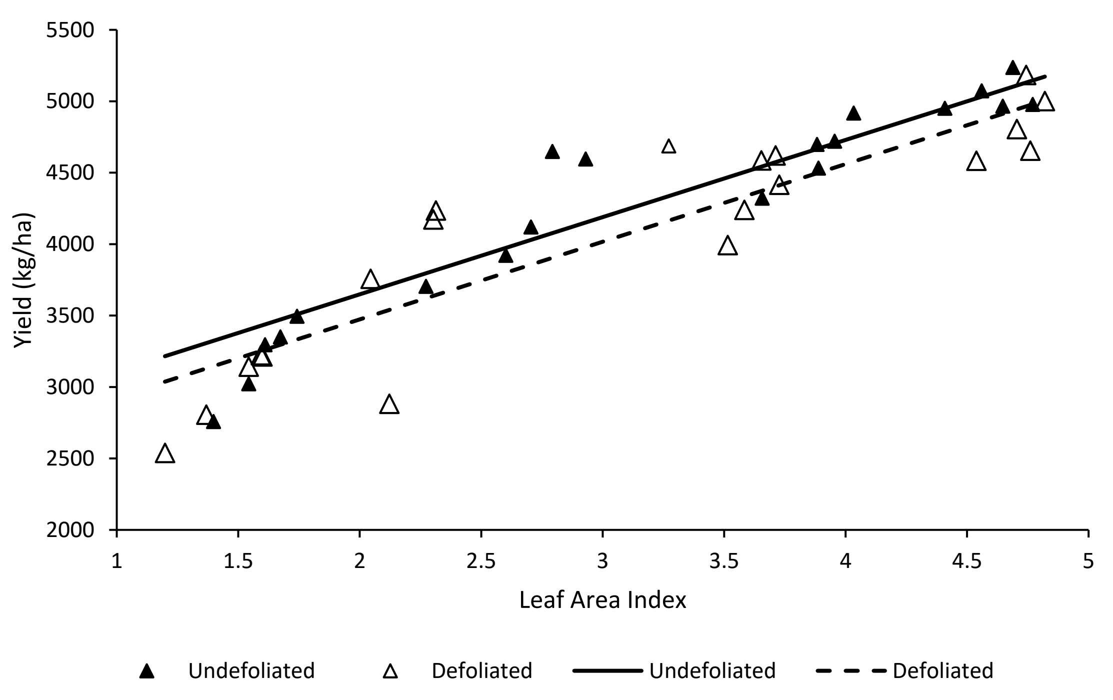


Figure 3.3 Regression of yield (kg/ha) in undefoliated and defoliated soybean plots across R3 leaf area index for experiments conducted in Mississippi during 2016 and 2017

Undefoliated: $F$ =155.1, df = 1, 27.56, $P < 0.01$, y = 2568.6 + 532.6x
Defoliated: $F$ = 108.12, df = 1, 29.59, $P < 0.01$, y = 2386.0 + 541.0x

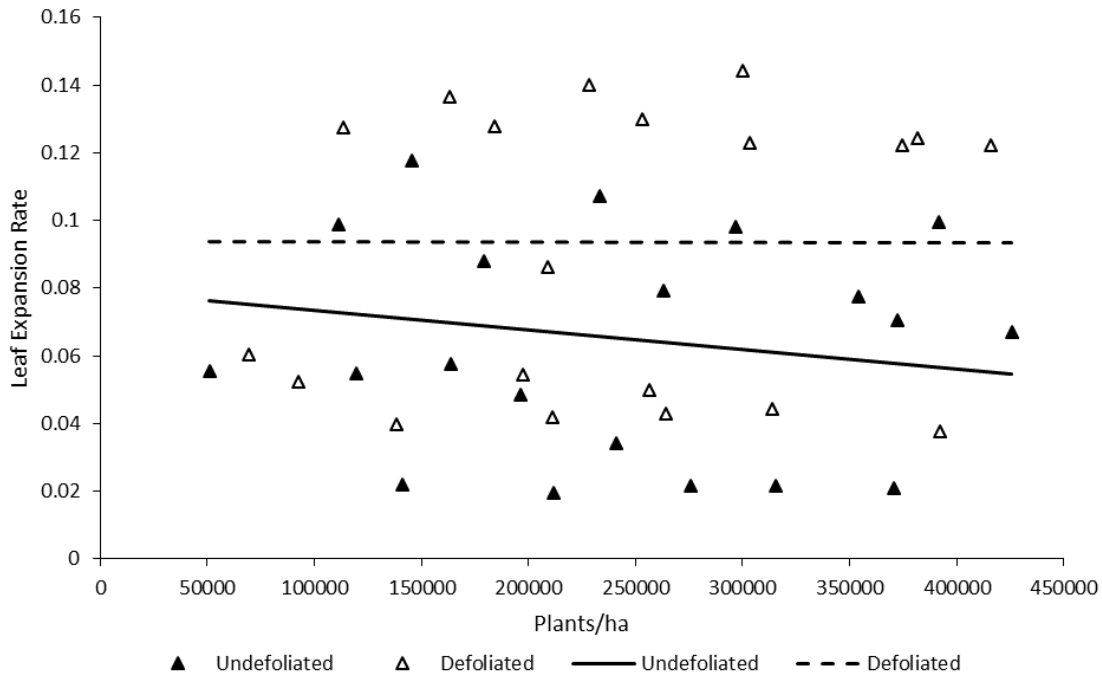


Figure 3.4 Regression of leaf expansion rate in undefoliated and defoliated soybean plots across plant population for experiments conducted in Mississippi during 2016 and 2017

Undefoliated: $F = 0.59$, df = 1, 97.40, $P = 0.45$, y = 0.0938 + -0.00000128x
Defoliated: $F = 8.11$, df = 1, 95.61, $P < 0.01$, y = 0.0791 + -0.00000665x

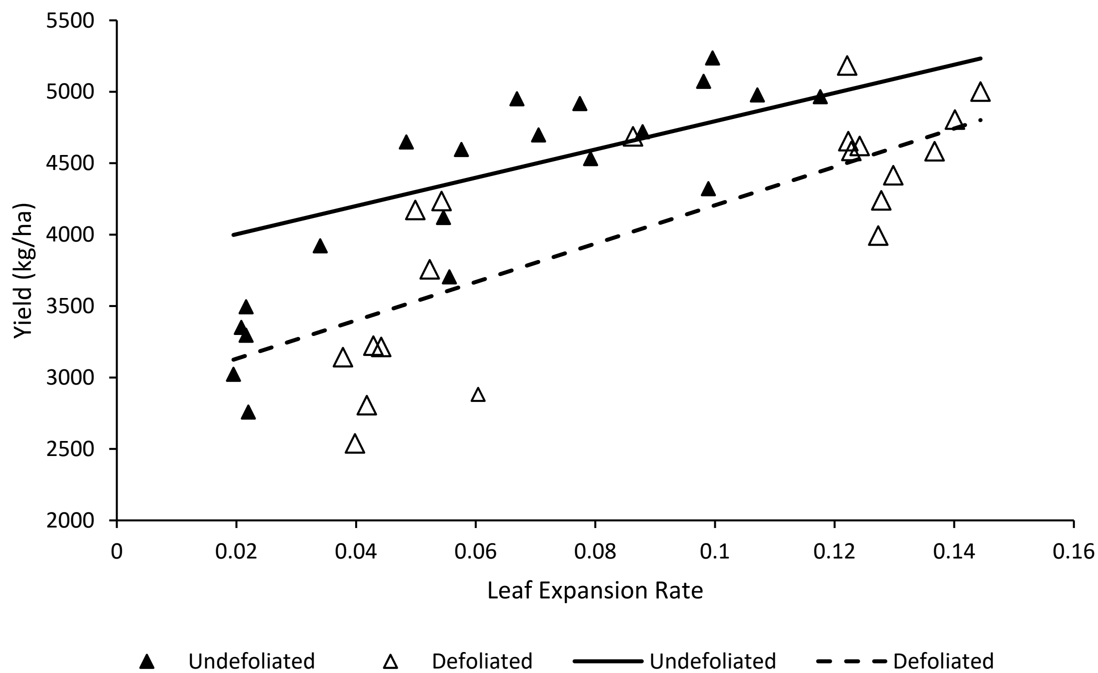


Figure 3.5 Regression of yield (kg/ha) in undefoliated and defoliated soybean plots across leaf expansion rate for experiments conducted in Mississippi during 2016 and 2017

Undefoliated: $F = 13.51$, df = 1, 91.59, $P < 0.01$, y = 3805.4 + 7396.08x
Defoliated: $F = 48.88$, df = 1, 33.52, $P < 0.01$, y = 2863.1 + 12960.22x

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# CHAPTER IV

# SUMMARY

Defoliation occurs to a certain extent in most Mid-South soybean fields every year. Growth stage, the extent of the defoliation, as well as each field's individual environmental conditions can affect how much, if any, yield loss will occur. When and how the defoliation occurs, very quickly, slowly, or at multiple times throughout the growing season, can also vary. Experiments were conducted in the 2015 to 2017 growing seasons to evaluate yield responses to defoliation in different simulated conditions commonly seen in grower fields. This included evaluating whether multiple or continuous defoliation events compounded to further reduce yield and if planting date or plant population impacts yield losses from defoliation.

Two separate experiments were included in the first chapter of this dissertation. The first experiment evaluated whether multiple defoliation events in vegetative soybean compound to increase yield loss over that of a single defoliation event. Soybean was defoliated during V3 at levels of 0, 33, 67, or 100% and during V6 at levels of 0, 33, 67, or 100%, and every combination of defoliation level at V3 and V6. There was no interaction between defoliation occurring at V3 and V6, indicating that multiple defoliation events do not interact, but the yield loss from each defoliation is independent of other defoliation events vegetative stage soybean. The second experiment evaluated the effects of continuous defoliation on soybean yield. Continuous defoliation was evaluated at levels of 16.5, 33, and 67%, with defoliation beginning at V2 and continuing through either the vegetative growth stages, or throughout the growing season; a one-time defoliation event at R3 was also included with the same defoliation levels. Continuous defoliation caused greater yield loss than a single defoliation event, but only when defoliation levels were greater than the recommended threshold. Both of these experiments indicate that defoliation thresholds do not need to be adjusted to compensate for multiple or continuous defoliation events in vegetative or reproductive soybean.

The second chapter contains experiments on how soybean yield responds to defoliation across planting dates. Soybean were planted at six dates, spaced approximately two weeks apart, beginning in early-April and ending in mid-June. Each planting date contained an undefoliated control and a treatment that was defoliated 100% at V4. Percent yield loss increased the longer planting was delayed. Yield loss also increased as yield potential increased. This suggest that later planted soybean would benefit from a reduced threshold that takes into consideration yield potential.

Experiments in chapter three evaluated the response of soybean yield to defoliation across plant populations. Soybean was planted at densities ranging from 123,500 seeds/ha to 420,070 seeds/ha, in 74,130 seed increments, for a total of 5 seeding rates. Each seeding rate contained at undefoliated control and a treatment that was defoliated 67% at R1. It was determined that a plant population of 286,000 plants/ha had the least likelihood of yield loss from defoliation. Soybean populations below 192,800 plants/ha incurred a significant yield reduction from defoliation, whereas populations greater than this did not incur any yield loss from defoliation. These data suggest that fields with substandard plant populations may benefit from a lowered defoliation threshold in order yield to be maximized.

In conclusion, multiple and continuous defoliation events in soybean did not significantly increase the amount of yield loss incurred when compared to a single defoliation event. Similarly, yield loss from defoliation was not impacted by planting date. The only suggestion that can be made to improve the quality of current recommendations is that in order to maximize yield, soybean fields with poor stands need to be more carefully managed for defoliating pests than would normally be required. These data as a whole suggest that existing thresholds are fairly robust and can be implemented with confidence to the vast majority of Mid-South soybean fields.

# APPENDIX A

# EFFECT OF SOYBEAN PLANTING DATE ON YIELD LOSS FROM DEFOLIATION AT R1

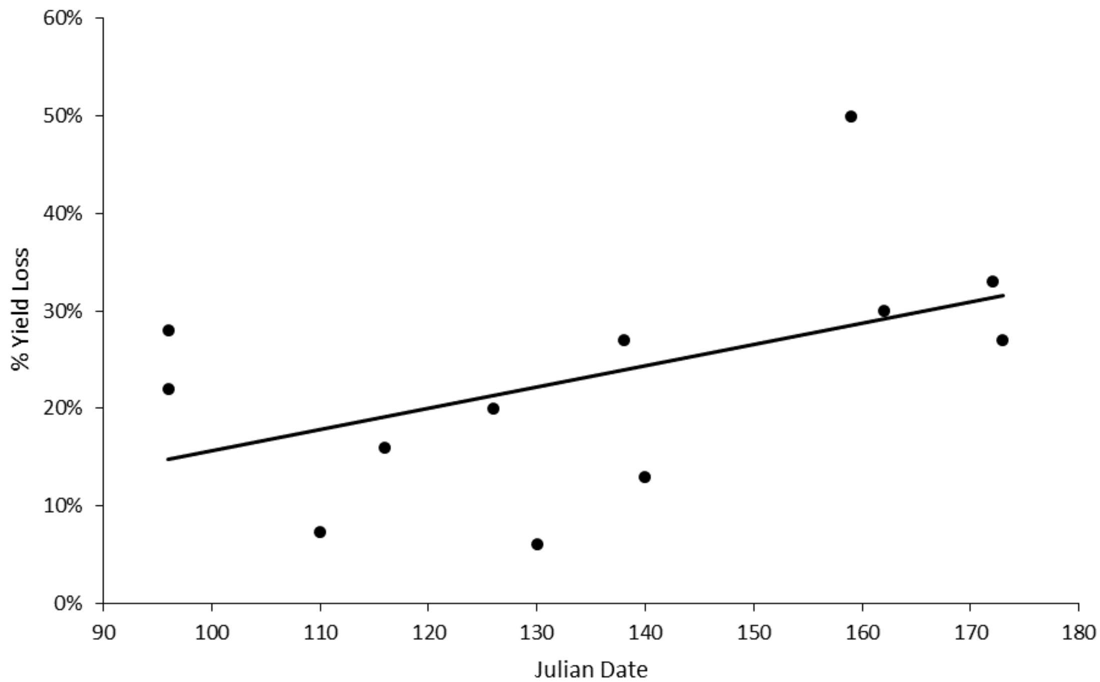


Figure 4.1 Regression of mean percent yield loss in soybean from 100% defoliation compared to the undefoliated control across planting date for experiments in Mississippi and Arkansas in 2016

Regression statistics for percent yield loss across planting date: ($F$ = 3.85, df = 1, 59.15, $P$ = 0.054, y=-0.08207 + 0.00232x)

# APPENDIX B

# EFFECTS OF SEED TREATMENT ON YIELD REDUCTIONS FROM EARLY SEASON DEFOLIATION

## Objective

The objective of this study was to evaluate whether seed treatments had any impact on the ability of soybean to recover from early season defoliation.

## Materials and Methods

Studies were conducted at the R.R. Foil Plant Science Research Center in Starkville, MS and the Lon Mann Cotton Research and Extension Center in Marianna, AR during the 2015 growing season. Soybean were planted at 271,810 seed/ha at the Starkville and Marianna locations on 2 Jun. Trials were planted using Asgrow® 4934 (Monsanto Co., St. Louis, MO) which is an indeterminate cultivar. Plot sizes were four rows wide with 97-cm row spacing and 3.05-m in length. Seed were treated with an insecticide seed treatment; 37.85 ml thiamethoxam (Cruiser 5FS®, Syngenta Crop Protection, Greensboro, NC) per 43.56 kg seed, fungicide seed treatment; 147.87 ml mefenoxam + fludioxonil (Apron Maxx® RTA® + Moly, Syngenta Crop Protection, Greensboro, NC) per 45.36 kg seed or the combination of both insecticide and fungicide seed treatments; a control containing untreated seed was also included resulting in four total seed treatments. Each seed treatment contained an undefoliated control or was defoliated 100% at V4, for a total of eight treatments. Treatments were arranged in a randomized complete block design and replicated 6 times. All plots were treated with either 1,022 ml/ha of chlorantraniliprole (Prevathon®, DuPont, Wilmington, DE) or 365 ml/ha of thiamethoxam + lambda-cyhalothrin (Endigo®, Syngenta Crop Protection, Greensboro, NC) at the first sign of insect pests.

Data for the were analyzed using JMP 12 (1989-2007) with a mixed model analysis of variance. Seed treatment, defoliation and their interaction were set as fixed effects, while year, location, and replication were set as random factors. Differences were considered significant if $P < 0.05$.

## Results

Mean yields in undefoliated treatments ranged from 3329 kg/ha in the insecticide only treated seed to 3067 kg/ha in the control (Table 4.2). Mean yields for defoliated treatments ranged from 2401 kg/ha for insecticide only treated seed to 2004 kg/ha for the control (Table 4.2). Mean yield losses ranged from 1177 kg/ha in the control to 854 kg/ha in the fungicide only treated seed plot. Defoliation significantly reduced yield across the check and all seed treatments (Table 4.1). Seed treatment did not significantly affect yield (Table 4.1). No interaction was present between seed treatment and defoliation (Table 4.1).

Table 4.1 Analysis of variance statistics for soybean yield by seed treatment, defoliation, and seed treatment by defoliation for experiments conducted in 2015 in Mississippi

| | *F* | df | *P*[1] |
|---|---|---|---|
| Seed treatment | 1.78 | 3,77 | 0.16 |
| Defoliation | 87.93 | 1, 77 | < 0.01 |
| Seed treatment*Defoliation | 0.09 | 3, 77 | 0.97 |

[1]Data were considered significantly different if $P < 0.05$

Table 4.2 Mean yields (kg/ha) ± SE and yield losses (kg/ha) in soybean with analysis of variance statistics comparing the undefoliated and defoliated plots with seed either left untreated or treated with fungicide, insecticide, or a combination of both for experiments in Mississippi in 2015

| | Yield ± SE (kg/ha) | | |
|---|---|---|---|
| Seed Treatment | Undefoliated | Defoliated | Yield Loss |
| Fungicide | 3120 ± 451 | 2132 ± 430 | 854 ± 128 |
| Insecticide | 3329 ± 410 | 2401 ± 477 | 928 ± 141 |
| Insecticide + Fungicide | 3147 ± 444 | 2219 ± 444 | 1096 ± 121 |
| Untreated | 3067± 363 | 2004 ± 410 | 1177 ± 101 |