**MISSISSIPPI SOYBEAN PROMOTION BOARD**
**PROJECT NO. 77-2016 (YEAR 3)**
**FINAL REPORT**

**TITLE: Effect of Incremental Sub-Threshold Levels of Insect Defoliation on Yield of Soybeans in Mississippi**

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## Evaluation of soybean production practices that impact yield losses from simulated insect defoliation

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### Introduction

Injury from defoliating insects is responsible for more yield loss to Mississippi soybean producers than any other feeding guild of insects. In 2014, defoliating insects alone cost Mississippi producers $37,081,635 (Musser et al. 2015). Insects contributing to defoliation include bean leaf beetle, soybean looper, velvetbean caterpillar, green cloverworm, armyworm, grape colaspis, flea beetle, and grasshopper. Previous research conducted by Owen (2012) has shown that while soybeans in the vegetative growth stages can tolerate a relatively large amount of defoliation, excessive foliage loss that occurs during the R3-R5 growth stages can have devastating effects on yield.

Current Mississippi recommendations put treatment thresholds for defoliation at 35% pre-bloom and 20% during and after bloom (Catchot et al. 2016). However, a producer may be required to treat for defoliating pests multiple times during a single growing season. In these situations, it isn't known if multiple defoliation events compound to further increase yield loss. For instance, if a pest defoliates a soybean crop 30% during the vegetative stage then another pest defoliates the crop an additional 20% during the reproductive stage, these two events could have a great or no effect at all on each other. The question is whether or not the latter of the two defoliation events needs to have a lower treatment threshold due to the damage that occurred earlier in the season.

Another potential factor affecting yield loss in soybean is planting date. Soybeans are planted over a relatively lengthy period, with acceptable planting dates ranging from mid-March to mid-July. About April 20$^{th}$ typically is the optimum planting date for maximum yield (MSU Ext 2014). Earlier-planted soybeans that have defoliation occur during their vegetative growth stages should have more time to recover lost leaf area before reaching the more sensitive reproductive stages, as opposed to later-planted soybeans that only have a short time to recover. These differences in recovery time could prove to be an important factor with respect to treatment timing.

Another agronomic factor that could prove important to estimating yield loss from defoliation is plant population. Soybean planting densities vary widely across Mississippi due to myriad factors. However, variations in plant densities typically have minimal effects on soybean yield (Robinson and Conley 2007, Lee et al. 2008). Soybean produces more vegetative growth per plant at lower populations than at higher ones in order to support increased yield potential per plant. Defoliation on a percent basis would remove more leaves per plant at low plant populations than at 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 soybeans can tolerate based on plant population.

The objective of these tests was to refine treatment recommendations by determining the effects of compounding defoliation, planting date, and plant population on yield loss associated with insect defoliation of soybeans.

## Materials and Methods

### Objectives 1 and 2.

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, soybeans were planted on 30 Apr and 2 Jun at the Starkville and Stoneville locations, respectively. In 2016, soybeans were planted on 9 May in Starkville and 10 May in Stoneville. Trials were planted at 110,000 seeds/acre in 38-in.-wide rows in Starkville and in 40-in.-wide rows in Stoneville using indeterminate Asgrow® AG5335 (Monsanto Co., St. Louis, MO). Plots were four rows wide and 10 ft. long. The middle two rows of each plot were hand-defoliated at the specified growth stages and at designated levels for each experiment. Plots were harvested using at two-row Kincaid 8XP combine and yields were adjusted to 13% moisture content.

### Objective 1. Effects of multiple defoliation events in vegetative soybean.

Experiments were arranged as a complete factorial with factors being defoliation at V3 (0, 33, 67, or 100%) and V6 (0, 33, 67, or 100%) growth stages 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.

### Objective 2. 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.

**Objective 3. Effects of planting date on yield loss from defoliation.**

Soybeans were planted in 2015 and 2016 in both Starkville and Stoneville, MS with an additional site in Marianna, AR in 2016. Indeterminate Asgrow® AG5335 (Monsanto Co., St. Louis, MO) cultivar was used for all locations and planting dates. Plots were planted at 110,000 seeds/acre and were 10 ft long with four 38-in.-wide rows at the Starkville and Marianna locations four 40-in.-wide rows 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 stand establishment) with six replications. Planting dates were approximately 2 weeks apart and ranged from 5 Apr for the earliest planting to 21 June for the latest (Table 2). Every planting had an undefoliated control (UDC) and a treatment defoliated 100% at the V4 growth stage for a total of 12 treatments. Plots were harvested by planting date using a two row Kincaid 8XP combine. Post-harvest, yields were adjusted to 13% moisture content.

**Objective 4. Effects of plant population on yield loss from defoliation.**

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, soybeans were planted at the Starkville and Stoneville locations on 9 May and 10 May, respectively. In 2017, soybeans were planted on 2 May in Starkville and 9 May in Stoneville. Trials were planted using indeterminate Asgrow® AG5335 cultivar (Monsanto Co., St. Louis, MO). Plots were four rows wide and 10 ft. long, and row spacing was 38 in.in Starkville and 40 in. in Stoneville.

Soybeans were planted at rates ranging from 50,000 to 180,000 seed/acre in 30,000 seed/acre increments, resulting in 5 total seeding rates. Each seeding rate had a UDC and a treatment where plants were defoliated 67% at the R1 growth stage, 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 from 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.

## Results and Discussion

**Objectives 1 and 2.**

There was no significant interaction between defoliation levels occurring at V3 and V6 growth stages, and yield reductions were only observed in plots that were defoliated 100% at V3 or 100% at V6 (V3: $F = 2.86$, df = 3, 225, $P = 0.04$; V6: $F = 4.46$, df = 3, 225, $P < 0.01$; V3*V6: $F = 0.24$, df = 9, 225, $P = 0.99$) (Table 1). This indicates that multiple defoliation events are independent of each other. Therefore, the current threshold does not need to be modified in later defoliation events to account for earlier ones.

In objective 2, all-season and R3 defoliation levels negatively impacted yield while defoliation occurring throughout 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). Slopes of estimated yield losses were significantly different between all-season and R3 defoliation only when defoliation levels reached 30% or greater (All vs. R3: $t$ = -2.06, df = 168, $P$ = 0.04). This indicates that continuous sub-threshold (20% defoliation) levels of defoliation in reproductive soybeans does not reduce yield any more than a single defoliation event at R3.

The experiments for both objectives 1 and 2 support the current defoliation threshold recommendations in Midsouth soybeans. 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 Midsouth vegetative defoliation thresholds set at 35% are fairly conservative.

Season-long, continuous defoliation of soybean at greater than threshold levels is an unlikely scenario in the Midsouth. 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 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.

**Objective 3.**

Mean percent yield difference ranged from +9 to -29% across yield potentials and planting dates (Table 3). Mid-April 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 soybeans than later-planted soybeans. Mean yield differences across yield potentials in early-April 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-April, mid-April, 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 dates.

Soybeans planted during mid- to late-April yielded greatest in this study and yield potential declined steadily thereafter, which parallels the results of Bateman (2017). Early plantings with low yield potentials 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, however, defoliation was a yield limiting factor even at early planting dates.

Because yield potential was determined to be a factor in determining yield loss, knowledge of a particular field's yield potential would be crucial in defining an accurate threshold. Yield potential is difficult to predict, but knowledge of a field's history can provide some insight of what to expect in a current year. In nonirrigated 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.

**Objective 4.**

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 2). In the defoliated plots, there was a significant quadratic relationship, where yield increased as plant population increased up to about 140,000 plants/acre, and thereafter gradually declined ($F = 7.18$, 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 ≤ 78,000 plants/acre ($t = 1.97$, 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 116,000 plants/acre had the least likelihood of suffering yield reduction from defoliation ($t = 0.57$, df = 1, 207.5, $P = 0.57$).

Analysis indicated an interaction between defoliation and plant population, which suggests plant population influenced the amount of yield loss that resulted from defoliation. A plant population of 116,000 plants/acre 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 < 78,000 plants/acre, yield was reduced, 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.

Final plant population can be affected by numerous factors, but due to the ability of soybean to produce adequate yield at 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 soybeans at suboptimal plant populations compared to soybeans at optimal plant populations. Generally, fields with poor stands could benefit from more aggressive management of defoliating pests. 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.

## Conclusions

**Objectives 1 and 2.**

Multiple and continuous defoliation events in soybeans did not significantly increase the amount of yield loss incurred when compared to a single defoliation event. This suggests growers and consultants do not need to take into account multiple or continuous defoliation events when making treatment decisions.

**Objective 3.**

Soybeans planted after mid-May experienced a substantial increase in yield loss when compared to earlier-planted soybeans. Lower yielding soybeans suffered less yield loss or none at all from defoliation than higher yielding soybeans until mid-June, when percent yield losses were equal across all yield potentials. Yield potential was found to be a key factor in determining the amount yield loss incurred from defoliation in this study, and so incorporating this into future thresholds could be prove to be very valuable to growers.

**Objective 4.**

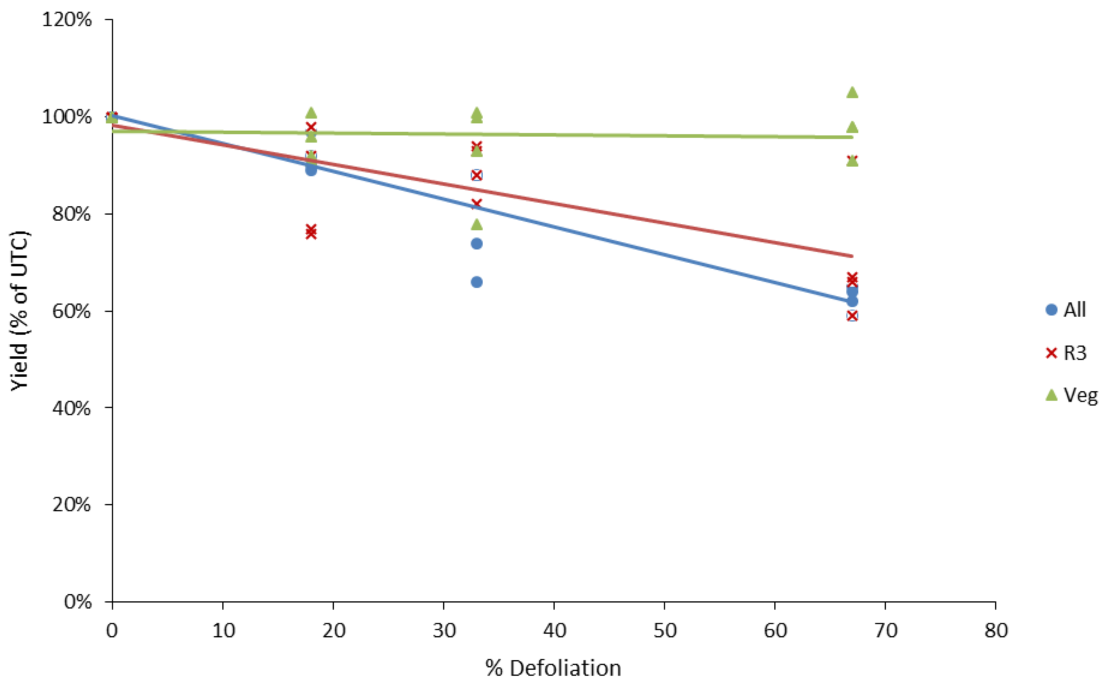
Our study found that soybeans with stands less than 78,000 plants/acre experienced a greater amount of yield loss from defoliation than soybeans in higher densities, although this actual number will likely vary among cultivars, planting dates, soil texture, etc. This indicates that soybean fields with poor stands need to be more carefully managed for defoliating pests than would normally be required.

**Table 1.** Impact of simulated insect defoliation occurring at the V3 and V6 soybean growth stages on the percent yield relative to the undefoliated control 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 | |

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

**Figure 1.** Mean yield loss in soybeans 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), in 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

**Table 2.** List of soybean planting dates (Julian date) for soybean at Marianna, AR, and Starkville and Stoneville, MS in 2015 and 2016

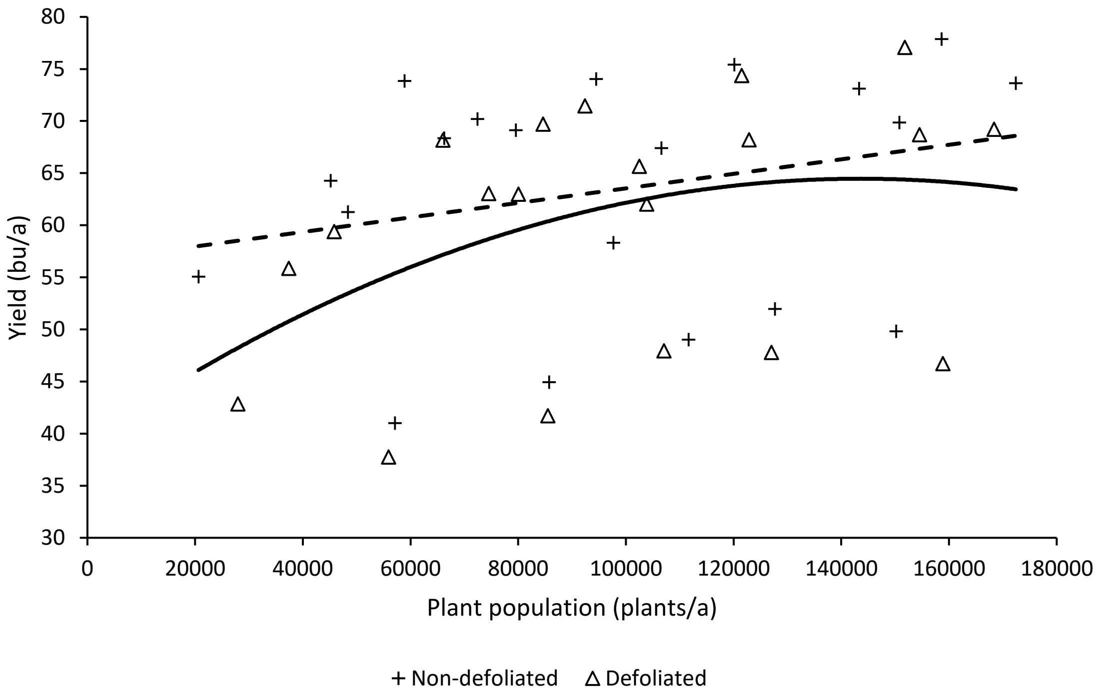
| | Planting Date (Julian Date) | | | | |
|---|---|---|---|---|---|
| Planting | Marianna, AR | Starkville, MS | | Stoneville, MS | |
| Period | 2016 | 2015 | 2016 | 2015 | 2016 |
| 1 | 5-Apr | 9-Apr | 5-Apr | 8-Apr | 5-Apr |
| 2 | 25-Apr | 23-Apr | 19-Apr | 22-Apr | 19-Apr |
| 3 | 5-May | 6-May | 9-May | 6-May | 6-May |
| 4 | 17-May | 21-May | 19-May | 21-May | 19-May |
| 5 | 7-Jun | 4-Jun | 10-Jun | 4-Jun | 10-Jun |
| 6 | 21-Jun | 18-Jun | 20-Jun | - | 20-Jun |

**Table 3.** Percent yield difference compared to the undefoliated control from 100% defoliation of soybeans at V4 growth stage at each planting period for each yield potential for experiments in Mississippi and Arkansas in 2015 and 2016

| Yield Potential | Planting Date | | | | | |
|---|---|---|---|---|---|---|
| bu/acre | Early-Apr | Mid-Apr | Early-May | Mid-May | Early-June | Mid-June |
| 37 | +9% | +12% | +10% | +3% | -11% | -29% |
| 52 | +2% | +1% | -1% | -6% | -16% | -29% |
| 67 | -8% | -6% | -7% | -11% | -19% | -29% |
| 82 | -12% | -10% | -11% | -15% | -21% | -29% |
| 97 | -14% | -13% | -14% | -17% | -22% | |
| 112 | -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)

**Figure 2.** Regression of yield (bu/acre) 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

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