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Effect of Stand Loss on Soybean [*Glycine Max* (L.) Merrill] Yield at Different Timings and Plant Populations in Mid-South Soybean

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EXECUTIVE SUMMARY

Experiments were conducted in 2016 and 2017 at Starkville and Stoneville, Miss.

The objective was to identify how soybean plant populations can compensate for stand loss resulting from simulated insect damage during early vegetative development.

Planting dates at Starkville were May 9, 2016 and Apr. 26, 2017. Planting dates at Stoneville were Apr. 26 and May 4, 2016, and May 8, 2017 at each of two locations.

Plots at Stoneville were furrow-irrigated, while those at Starkville were not. All plots were maintained insect-free during the growing seasons.

The experiments were composed of three factors, which were: 1) seeding rates of 75, 100, 125, 150, 175, and 200 thousand/acre; 2) percentage stand loss of 0, 20, and 40 percent; and 3) stand loss timing at V1 and V4 growth stages.

Plant populations were determined for each treatment at the V6 stage of development. Across all tests, final plant populations were within 86% of the targeted plant population based on seeding rate and plant loss percentages.

Final analyses were conducted by individual tests (6 total site years). There was a significant seeding rate by stand loss interaction in four of the six site years. Results from those tests follow.

Starkville 2016.
With 0 or 20% stand loss, all seeding rates produced equivalent yields. With 40% stand loss, yield increased with increased seeding rate.

Starkville 2017.
With 0% stand loss, all seeding rates produced equivalent yields. With 20 and 40% stand loss, yields increased with increased seeding rate.

Stoneville Location 1 2016.
With no stand loss, yield decreased with increased seeding rate from 75 to 200 thousand seed/acre. With 20% stand loss, yields were equivalent across all seeding rates. With 40% stand loss, yields increased up to the 150,000 seeds/acre rate.

Stoneville Location 2 2017.
With 0 and 40% stand loss, yields were equivalent across seeding rates. With 20% stand loss, yields declined slightly as seeding rate increased.

Overall Conclusions. When no stand loss occurred (0% treatment), yields were equivalent across all seeding rates. This confirms that a seeding rate that will result in 80 to 100 thousand plants/acre is sufficient for maximum soybean yield. Thus, significant economic risk is incurred if higher seeding rates are used and no stand loss occurs.

With 20% stand loss, yield results with increasing seeding rate were highly variable across locations and cannot be generalized. In general, the 40% stand loss treatment resulted in lower soybean yields at the lower seeding rates in these studies, but this became less important as seeding rate increased. Thus, where stand loss from insect damage is anticipated, higher seeding rates (e.g. 140 to 150 thousand seeds/acre) are advisable.

Timing of stand loss (V1-V2 vs. V3-V4) in these studies had little impact on soybean yield.

The results from these studies show that: 1) yield response to seeding rate is highly variable and unpredictable; 2) soybean yields can be maximized at low plant populations if little or no stand loss occurs; 3) increasing seeding rate to compensate for expected stand loss to such factors as insects may not be economically feasible if the anticipated stand loss does not occur; and 4) increasing the soybean seeding rate may not be a viable economic alternative to insecticide seed treatments that will guard against such stand losses at lower, more economical seeding rates.

Abstract

Soybean, *Glycine max* L. Merrill, production has shifted to the early soybean production system, resulting in greater yields. Earlier plantings increased the risk of experiencing sub-optimal plant populations from multiple factors. One major factor that can contribute to sub-optimal soybean plant populations is stand loss from insect pests. The purpose of this study was to simulate 0%, 20%, or 40% stand loss at V1 and V4 across six seeding rates. Stand loss timing impacted yield at one location where the impact was greater at V1-V2 than V3-V4. Yields decreased as seeding rate increased with no stand loss in two site years, increased in one site year, and did not change

in three site years. This suggests that there may have been risk from increasing seeding rate if stand loss did not occur. The response was highly variable where a seeding rate by percent loss interaction occurred. In general, 40% stand loss resulted in lower soybean yields at the lower seeding rates compared to the no stand loss treatment. The impact of 40% stand loss became less important at higher seeding rates. For 20% stand loss, soybean yields decreased at higher seeding rates relative to lower seeding rates at one location and remained stable at one location. Soybean yields were improved by 20% stand loss at higher seeding rates for two locations. This study shows that the impact of seeding rate, stand loss timing, and stand loss percentage on soybean yield is highly variable and not predictable across site years.

Key Words: plant population, neonicotinoid, soybean, stand loss

Introduction

Mississippi soybean, *Glycine max* (L.) Merrill, producers have largely adopted the early season production system (ESPS) where early maturing indeterminate soybean varieties are planted from March through early May (Heatherly 1999). The ESPS is utilized to minimize exposure to drought and high temperatures during pod development stages and minimize insect infestations later in the growing season (Kane and Grabau 1992, Bowers 1995, Sweeney et al. 1995, Heatherly 1999). Insect damage to soybean during the seedling growth stages is magnified and more detrimental to yield potential at early planting dates due to delayed growth from cooler temperatures (Baur et al. 2000). The early season pest complex that can reduce plant populations in soybean includes white grubs, *Phyllophaga* and *Cyclocephala* species; wireworms, *Melanotus* spp., *Limonius* spp., and *Agiotes mancus* (Say); lesser cornstalk borer, *Elasmopalpus lignosellus* (Zeller); three-cornered alfalfa hopper, *Spissistilus festinus* (Say); and pea leaf weevil, *Sitoma lineatus* (L.) (Davis et al. 2009, Davis et al. 2010).

North et al. (2016) showed a 135 kg ha^{-1} response where a neonicotinoid insecticide seed treatment was used compared to fungicide only seed treatments in the Mid-South. Seed treatments can also minimize early season soybean disease pressure which is often related to wet, cool soils associated with the ESPS. This is often observed at earlier plantings including the mid-April planting window that is correlated with maximum yield potential (Heatherly 2005a, Heatherly 2005b). Early season pathogens that may cause disease include *Phytophthora*, *Rhizoctonia*, *Pythium*, and *Fusarium* spp. (Coker et al. 1998, Kirkpatrick et al. 2006, Hartman and Hill 2010, Allen 2012, Faske 2015). Insecticide plus fungicide seed treatments provide effective management of early season insect and seedling disease outbreaks resulting in plant populations an average of 20% greater than non-treated seed (Gaspar et al. 2014). Insect and disease infestations are important factors that often decrease final plant stands (Murillo-Williams and Pederson 2008). However, other factors can influence plant stand including dry soils that cause the seed to imbibe water, but not fully germinate (Helms et al. 1996), heavy rains resulting in soil crusting (Johnson and Wax 1979), and low vigor seed (Johnson and Wax 1979). Multiple factors can impact the establishment of a final plant population from targeted seeding rates. This makes scouting and timely replant decisions due to stand loss difficult.

Many producers have opted to utilize higher seeding rates to achieve optimal harvestable plant populations, especially in less than optimal planting environments (Cox et al. 2010). Various planting densities have been shown to have minimal effect on soybean yield (Robinson and Conley 2007, Lee et al. 2008). The primary goal of a soybean producer is to obtain the minimum plant population while maximizing soybean yield when determining seeding rates (Board et al. 2013). The cost of soybean seed increased from around \$27 ha^{-1} in 1996 to \$80 ha^{-1} in 2005 with the introduction of glyphosate-resistant (Roundup Ready®, Monsanto Company, St. Louis, MO) cultivars (USDA-NASS 2007, Lee et al. 2008). Glyphosate [N-(phosphonylmethyl)-glycine] herbicide controls a wide range of weed species, usually without injury or phytotoxicity to glyphosate-resistant cultivars (Nelson and Renner 1999). However, technology fees and increased weed management costs to control herbicide resistant weeds (Bradley et al. 2000, Johnson et al. 2000) have led to greater investments at the time of planting. Determining a seeding rate has become more important due to increased seed costs, with an average current U.S. cost of \$150.72 ha^{-1} (ASA 2017), up considerably from that in 2008. This has resulted in the adoption of neonicotinoid insecticide plus fungicide seed treatments to help minimize the risk of stand loss and replanting due to seedling disease or early season insect pests (North et al. 2016).

Neonicotinoid seed treatments have enhanced soybean yield throughout the Mid-South but have also added to the upfront overall cost of seed at planting (North et al. 2016). Neonicotinoids are also under public scrutiny due to pollinator health issues and potential loss of registration in the future. Increasing plant populations may be a viable alternative to avoid complications from early season soybean stand loss in the absence of neonicotinoid seed treatments. Many experiments have been conducted on neonicotinoid seed treatments and various soybean plant populations, however, there is a shortage of data that addresses the influence of stand loss from insect pests on yield at various plant populations. Therefore, an experiment was conducted in Mississippi to quantify how soybean plant populations can compensate for stand loss at different early season growth stages. Also, this study assessed the profitability of various seeding rates to provide producers with data to determine replant decision options early in the growing season in order to maximize soybean yield.

Materials and Methods

An experiment was conducted at multiple locations in 2016 and 2017 to identify how soybean plant populations can compensate for stand loss from simulated insect damage during the early vegetative growth stages. Soybean were planted at one location in Starkville and at two locations in Stoneville in 2016 and 2017 for a total of six site years. Soybean were planted at the R. R. Foil Experiment station in Starkville, MS and at the Delta Research and Extension Center in Stoneville, MS. The planting dates in Starkville were 9 May in 2016 and 26 April in 2017. The planting dates in Stoneville were 26 April and 4 May in 2016 and 8 May across both tests in 2017. Plot sizes in Starkville, MS were four rows by 12.2 meters and planted on 96.5 cm centers. Plot sizes in Stoneville, MS were four rows by 12.2 meters and planted on 101.6 cm centers.

Furrow irrigation was utilized for all tests in Stoneville, MS. The plots in Starkville were not irrigated. Plots across all locations were maintained weed free throughout the entire growing season using pre-emergence and post-emergence herbicides and hand weeding. Fertilizer applications were applied based on soil test recommendations across each location. Also, plots were maintained insect free and harvest aids were applied based on Mississippi State University Extension Service recommendations.

Field experiments were arranged in a randomized complete block design with a 6 x 3 x 2 factorial arrangement of treatments and replicated four times. Factor A, B, and C consisted of seeding rate, percent stand loss, and stand loss timing, respectively. The six seeding rates were 185,250, 247,000, 308,750, 370,000, 432,250, and 494,000 seeds ha^{-1}. The percent stand loss treatments were 0%, 20%, and 40% of the initial seeding rate. Stand loss timing was imposed at V1 and V4 growth stages (Fehr et al 1971). Percent stand loss was achieved by mixing 0%, 20%, or 40% seed of a non-Roundup Ready soybean cultivar with seed of a glyphosate [N-(phosphomethyl) glycine] (Roundup®, Monsanto Company, St. Louis, MO) resistant soybean maturity group IV cultivar (ASGROW® 4835, Monsanto Company, St. Louis, MO) into a seed mix for each planting row within each plot. The Roundup Ready and non-Roundup Ready seed were thoroughly mixed to ensure random distribution of both traits within the plot. A total of four packages were planted for each plot (1 per row) with an Almaco planter equipped with research plot-type cones (Almaco, Nevada, IA. Glyphosate (Roundup®, Monsanto Company, St. Louis, MO) was applied at a rate of 1.54 kg ai ha^{-1} to each designated plot at soybean vegetative growth stages (V1) or (V4) to remove non-Roundup Ready tolerant plants to achieve percent stand loss for each plot. ASGROW® 4835 was pre-treated with CruiserMaxx (thiamethoxam [0.0762 mg ai per seed], mefenoxam [0.0039 mg ai per seed], and fludioxonil [0.0039 mg ai per seed]) (Syngenta Crop Protection, Greensboro, NC). The fungicides included in the seed treatment package target *Pythium*, *Phytophthora*, *Fusarium*, and *Rhizoctonia* spp. Seed treatments were used across all locations to minimize additional stand loss from insect and disease pests.

Plant populations were determined for each plot at the V6 growth stage to determine actual plant populations. Stand counts were conducted by counting all live plants in the third row of each plot. Fractional green canopy cover was measured using Canopeo (Mathworks, Inc., Natick, MA). Canopeo was developed by Oklahoma State University and analyzes fractional green canopy cover (FGCCC) from a digital image (Patrignani and Ochsner 2015). This analysis records a binary image where white pixels correspond to pixels of green canopy and black pixels correspond to not green canopy which can range from 0 (no green canopy) to 1 (100% green canopy cover) (Patrignani and Ochsner 2015). One image was taken per plot exactly, 6.1 m into the plot and 188 cm above the ground, using a photographic camera with the lens pointing down and recording the two inside rows in an area of approximately 1 m^2 at R3 growth stage.

Soybean were harvested from the two center rows of each plot using small plot combines equipped with weigh system to measure grain weight and moisture content. Different combines were used at Starkville and Stoneville. Yields were converted to kg per hectare and adjusted to 13% moisture.

Data for yields were analyzed with analysis of variance (PROC GLIMMIX, SAS ver. 9.4, SAS Institute; Cary, NC) to determine the impact of seeding rate, stand loss percentage, and stand loss timing on soybean yields. In the initial analysis, seeding rate, stand loss timing, seed loss percentage, and all interactions were considered fixed effects. Site-year, replication nested in site-year, replication by seeding rate nested in site-year, and replication by seeding rate by stand loss timing nested in site-year were random. Degrees of freedom were calculated using the Kenward-Roger method. Means and standard errors were determined using PROC MEANS statement. In the initial analysis, none of the main effects or interactions were significant for soybean yield, so a separate analysis was conducted where test (year*location) was included as a fixed effect in the model. In that analysis, there was a significant test by stand loss timing by stand loss percentage interaction and a test by seeding rate by stand loss percentage interaction (Table 1). Because of those interactions and the variability in responses across tests, a final analysis was conducted by test. In those analyses, plant population, stand loss percentage, stand loss timing and all interactions were considered fixed effects. Replication and replication nested in site year was considered random effects. Degrees of freedom were calculated using the Kenward-Roger method. Means and standard error for yield and canopy closure were determined using the PROC MEANS statement. For tests where the seeding rate by stand loss percentage interaction was significant, soybean yields and canopy closure were analyzed with regression analysis (PROC GLM, SAS ver. 9.4, SAS Institute; Cary, NC) by percent stand loss to determine the relationship between seeding rate and soybean yields at each of the stand loss percentages. In those analyses, seeding rate was included in the model as the explanatory variable and soybean yields were included as the response variable. Both linear and quadratic terms were included to determine the best fit of the model.

Results

The method of mixing glyphosate tolerant seed and glyphosate susceptible seed and spraying the plots with glyphosate appeared to be an adequate method for simulating plant loss from insect pests in soybean. Across all tests and treatments, the final plant populations were within 86 percent of the targeted plant populations based on seeding rates and plant loss percentages (data not shown). The effect of seeding rate and stand loss percentage on soybean yields was highly variable across site years. There was a significant seeding rate by stand loss percentage interaction for four of the six site years. These include Stoneville 1 in 2016, Starkville in 2016, Stoneville 2 in 2017, and Starkville in 2017 (Table 2).

Stoneville 1 Location 2016

There was a linear relationship (F = 9.33; df = 1, 42; $P = 0.01$) between seeding rate and soybean yields where no stand loss occurred. Soybean yields decreased as seeding rates increased (Fig. 1A, Blue Line). The relationship between seeding rate and soybean yields was not significant (F = 3.70; df = 1, 43; $P = 0.06$) at the 20% stand loss level. At the 40% stand loss level, there was a quadratic relationship (F = 7.10; df = 2, 46; $P = 0.01$) between seeding rate and soybean yields. Soybean yields increased until 375,000 seed ha^{-1}, but the amount of yield increase declined at higher seeding rates (Fig. 1A, Black Line). The impact of stand loss timing was also significant (Table 2). Stand loss at V3-4 had greater impact on soybean yields than stand loss at V1-2. There was a significant linear relationship between seeding rate and canopy closure for the 0% (F = 40.84; df = 1, 47; $P < 0.01$), 20% (F = 87.75; df = 1, 47; $P < 0.01$), and 40% (F = 66.56; df = 1, 45; $P < 0.01$) stand loss levels (Fig. 2A). Canopy closure increased as seeding rate increased at all three stand loss levels.

Starkville Location 2016

There was no relationship between seeding rate and soybean yields at the 0% stand loss percentage (F = 0.07; df = 1, 43; P = 0.80) or at the 20% stand loss percentage (F = 2.73; df = 1, 43; P = 0.11). At the 40% stand loss percentage, there was a linear relationship (F = 8.01; df = 1, 42; P = 0.01) between seeding rate and soybean yields (Fig. 1B, Black Line). The interaction between stand loss timing and stand loss percentage also was significant (Table 2). There was a significant quadratic relationship between seeding rate and canopy closure for the 0% (F = 5.37; df = 2, 47; P = 0.03) stand loss level (Fig. 2B). There was a significant linear relationship between seeding rate and canopy closure for the 20% (F = 11.23; df = 1, 47; P = 0.01) and 40% (F = 9.01; df = 1, 47; P = 0.01) stand loss levels (Fig. 4.2B). Canopy closure increased as seeding rate increased at all three stand loss levels, but rate of increase at 0% stand loss declined at the higher seeding rate.

Stoneville 2 Location in 2017

There was not a relationship between seeding rate and soybean yields where 0% stand loss (F = 1.56; df = 1, 43; P = 0.21) or 40% stand loss (F = 0.54; df = 1, 43; P = 0.46) occurred (Fig. 1C). A linear relationship between seeding rate and soybean yields was observed (F = 7.53; df = 1, 41; P = 0.01) at the 20% stand loss level. Soybean yield decreased as seeding rate increased (Fig 1C, Red Line). Also, there was a linear relationship between seeding rate and canopy closure for the 0% (F = 44.42; df = 1, 47; P < 0.01), 20% (F = 65.56; df = 1, 47; P < 0.01), and 40% (F = 30.55; df = 1, 47; P < 0.01) stand loss levels (Fig. 2C). Canopy closure increased as seeding rate increased at all three stand loss levels.

Starkville Location 2017

There was no relationship between seeding rate and soybean yields (F = 0.42; df = 1, 41; P = 0.52) at the 0% stand loss percentage. There was a quadratic relationship between seeding rate and soybean yields at the 20% stand loss percentage (F = 4.93; df = 2, 44; P = 0.03). Soybean yields increased over the different seeding rates, but the amount of yield increase became less at higher seeding rates (Fig. 1D, Red Line). At the 40% stand loss percentage, there was a significant linear relationship between seeding rate and soybean yields (F = 23.00; df = 1, 40; P < 0.01). Soybean yields increased at higher seeding rates (Fig. 1D, Black Line). Also, at There was a linear relationship between seeding rate and canopy closure for the 0% (F = 8.11; df = 1, 47; P = 0.01) and 40% (F = 24.29; df = 1, 47; P < 0.01) stand loss levels. Canopy closure increased as seeding rate increased at these stand loss levels (Fig. 2D). There was a quadratic relationship between seeding rate and canopy closure for the 20% (F = 8.17; df = 2, 47; P = 0.01) stand loss level. Canopy closure increased as seeding rate increased up to 375,000 before declining, but the amount of canopy closure increase became less at higher seeding rates (Fig. 2D)

Discussion

Soybean seed costs have increased dramatically over the past 15 years due to the inclusion of herbicide tolerance traits (Rawlinson and Martin 1998) and increased input costs for management of resistant weeds and early season insect pests (Bradley et al. 2000, Johnson et al.

2000). Higher seed costs combined with the early soybean production system has made early season insect pest management in soybean more important. Pest occurrences and environmental factors vary each year and producers must adopt intense management inputs at the time of planting to maximize chances for greater returns. One important change has been the use of insecticide seed treatments to protect soybean seedlings (North et al. 2016, Musser et al. 2017).

Increased seeding rate has been proposed as an alternative to neonicotinoid seed treatments in soybean to compensate for stand loss from early season insect damage. Previous studies have shown that the yield potential of soybean did not change among a wide range of seeding rates (Pederson and Lauer 2002, Norsworthy and Frederick 2002, Bertram and Pederson 2004). In contrast, other studies have shown that seeding rate can have an impact on soybean yields. Some studies have shown that soybean yields were greater at lower seeding rates (Lee et al. 2008, DeBruin and Pederson 2008a); whereas, other studies have shown that soybean yields were greater at higher seeding rates (Oplinger and Philbrook 1992, Devlin et al. 1995, Bertram and Pedersen 2004, Edwards and Purcell 2005, De Bruin and Pederson 2008b). There was considerable variation in the response of soybean yields to seeding rates and stand loss in the current experiment. Yields decreased as seeding rate increased with no stand loss in two tests, increased in one test, and did not change in the other three tests. This suggests that significant economic risks can result from increasing the seeding rate if stand loss does not occur. Among the site years where there was a seeding rate by percent loss interaction for soybean yields, the response to these two factors was highly variable. In general, the 40% stand loss treatment resulted in lower soybean yields at lower seeding rates compared to where no stand loss occurred. Additionally, the impact of 40% stand loss became less important as seeding rate increased. For the 20% stand loss, soybean yields decreased at the higher seeding rates relative to the lower seeding rates at one location and remained relatively stable at one location. In contrast, soybean yields were improved by 20% stand loss at the higher seeding rates for two of the locations.

Timing of the stand loss had little impact on final soybean yields. However, stand loss timing had an impact at one location, where stand loss at V1-V2 had a greater impact on soybean yields than stand loss at V3-V4. This is similar to previous research where soybean plant stand losses significantly reduced soybean yield during the early vegetative growth stages (Hintz and Fehr 1990, Hintz et al. 1991). Hintz and Fehr (1990) showed 5 and 15% yield losses when 33 and 66% of soybean plants were removed at V3 and V6 soybean growth stages. Hintz et al. (1991) observed 7 and 18% yield losses when soybean plants were removed at 33 and 66% at the V3 and V6 soybean growth stages.

Recently, soybean producers have opted to utilize lower seeding rates due to increased seed costs without sacrificing yield (Cox et al. 2010). Also, many producers report more uniform emergence and less stand loss from insect pests where neonicotinoid seed treatments are used (North et al. 2016). These studies combined with previous studies cited earlier showed that the response of soybean to different seeding rates is highly variable and unpredictable. In general, soybean yields can be maximized at low plant populations but must be protected and have minimal stand loss when low final plant stands are achieved. Increasing seeding rates to compensate for early season plant loss may not be economically feasible due to seed costs, and provides a significant level of risk if stand loss does not occur. Currently, the reasons for the wide range of responses to seeding rate and stand loss are not understood and more research is needed. The results of this experiment show that planting higher rates of seed can provide significant risk of yield and economic losses with uniform emergence if no stand loss occurs. As a result, increasing seeding rate in soybean may not be a viable alternative to neonicotinoid seed treatments.

Conflict of Interest

Funds were provided by Mississippi Soybean Promotion Board to conduct the research reported in this manuscript. No funds were provided by agrichemical/seed businesses to conduct the research in this manuscript, but all the authors conduct research in collaboration with pesticide manufacturers.

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Table 1. Results of the analysis of variance evaluating the impact of seeding rate, stand loss timing, and stand loss percentage on soybean yields across 6 site years in Mississippi in 2016 and 2017.

Effect	**F**	**df**	***P***
Seeding Rate	1.48	5, 805	0.19
Timing	0.12	1, 805	0.73
Seeding Rate*Timing	0.22	5, 805	0.95
Percent Loss	1.01	2, 805	0.36
Seeding Rate*Percent Loss	1.26	10, 805	0.25
Percent Loss*Timing	0.08	2, 805	0.92
Seeding Rate*Percent Loss*Timing	0.16	10, 805	0.99

Table 2. Results of the analysis of variance evaluating the impact of site year, seeding rate, stand loss timing, and stand loss percentage on soybean yields in Mississippi in 2016 and 2017.

Effect	**F**	**df**	***P***
Test	554.38	5, 62	< 0.01
Seeding Rate	7.19	5, 626	< 0.01
Test*Seeding Rate	3.11	25, 626	< 0.01
Timing	1.09	1, 626	0.30
Test*Timing	1.49	5, 626	0.19
Seeding Rate*Timing	1.05	5, 626	0.39
Test*Seeding Rate*Timing	1.02	25, 626	0.43
Percent Loss	5.99	2, 626	0.01
Test*Percent Loss	12.78	10, 626	< 0.01
Seeding Rate*Percent Loss	5.63	10, 626	< 0.01
Test*Seeding Rate*Percent Loss	1.38	50, 626	0.05
Percent Loss*Timing	0.71	2, 626	0.49
Test*Percent Loss*Timing	2.12	10, 626	0.02
Seeding Rate*Percent Loss*Timing	0.64	10, 626	0.78
Test*Seeding Rate*Percent Loss*Timing	0.91	50, 626	0.64

Table 3. Analysis of variance for the impact of seed rate, stand loss timing, and stand loss percentage on soybean yields in Mississippi in 2016 and 2017 when analyzed by site year.

Site Year	Location	Year	Effect	F	df	*P*
1	Delta 1	2016	Seeding Rate	1.23	5, 103	0.29
			Timing	7.80	1, 103	0.01
			Percent Loss	11.47	2, 103	<0.01
			Seeding Rate*Timing	0.71	5, 103	0.62
			Seeding Rate*Percent Loss	3.27	10, 103	0.01
			Timing* Percent Loss	0.87	2, 103	0.42
			Seeding Rate*Timing*Percent Loss	0.51	10, 103	0.88
2	Delta 2	2016	Seeding Rate	1.73	5, 103	0.13
			Timing	1.66	1, 103	0.20
			Percent Loss	0.20	2, 103	0.82
			Seeding Rate*Timing	1.06	5, 103	0.38
			Seeding Rate*Percent Loss	1.63	10, 103	0.10
			Timing* Percent Loss	0.36	2, 103	0.69
			Seeding Rate*Timing*Percent Loss	1.36	10, 103	0.20
3	Hills	2016	Seeding Rate	2.43	5, 104	0.03
			Timing	0.29	1, 104	0.59
			Percent Loss	7.52	2, 104	0.01
			Seeding Rate*Timing	1.35	5, 104	0.24
			Seeding Rate*Percent Loss	2.30	10, 104	0.01
			Timing* Percent Loss	5.23	2, 104	0.01
			Seeding Rate*Timing*Percent Loss	1.03	10, 104	0.42
4	Delta 1	2017	Seeding Rate	3.70	5, 104	0.01
			Timing	0.53	1, 104	0.46
			Percent Loss	1.83	2, 104	0.16
			Seeding Rate*Timing	0.42	5, 104	0.83
			Seeding Rate*Percent Loss	0.55	10, 104	0.84
			Timing* Percent Loss	1.18	2, 104	0.31
			Seeding Rate*Timing*Percent Loss	1.29	10, 104	0.24
5	Delta 2	2017	Seeding Rate	2.56	5, 103	0.03
			Timing	1.78	1, 103	0.18
			Percent Loss	13.44	2, 103	<0.01
			Seeding Rate*Timing	0.48	5, 103	0.78
			Seeding Rate*Percent Loss	2.40	10, 103	0.01
			Timing* Percent Loss	0.37	2, 103	0.69
			Seeding Rate*Timing*Percent Loss	0.47	10, 103	0.90
6	Hills	2017	Seeding Rate	8.46	5, 97	<0.01
			Timing	0.08	1, 97	0.78
			Percent Loss	24.58	2, 97	<0.01
			Seeding Rate*Timing	1.39	5, 97	0.23
			Seeding Rate*Percent Loss	2.44	10, 97	0.01
			Timing* Percent Loss	0.95	2, 97	0.39
			Seeding Rate*Timing*Percent Loss	0.91	10, 97	0.52

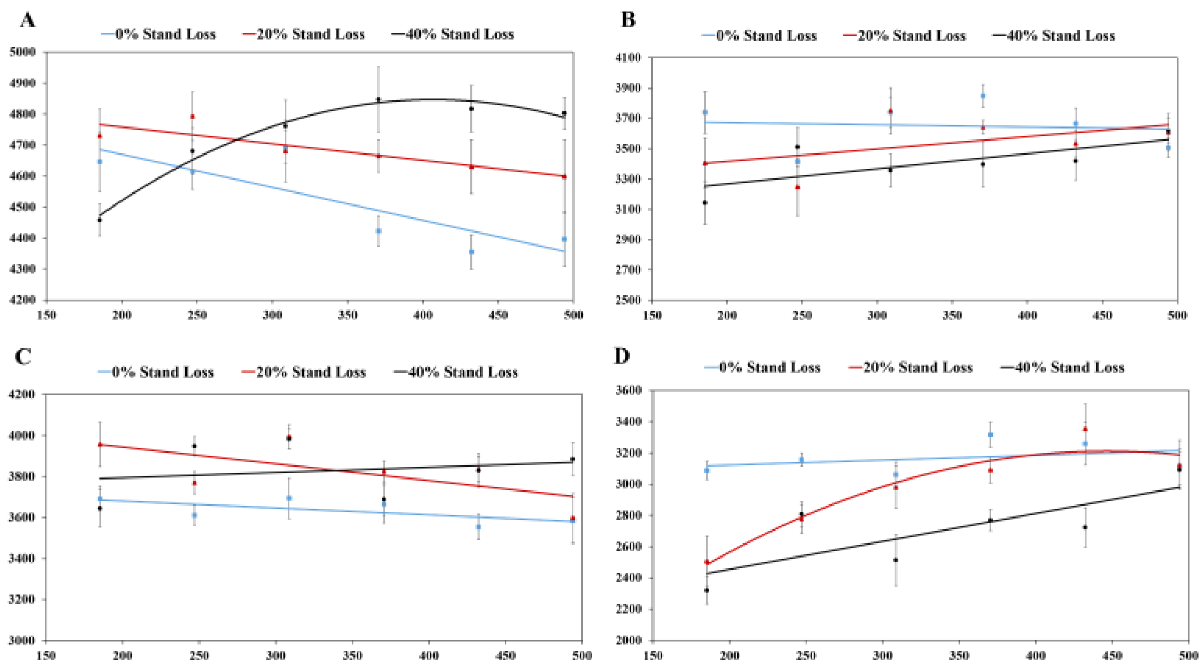

Figure 1. Impact of the interaction between seeding rate and stand loss percentage on soybean yields at Stoneville, MS in 2016 (A, Delta 1), Starkville, MS in 2016 (B, Hills), Stoneville, MS in 2017 (C, Delta 2), and Starkville, MS in 2017 (D, Hills).

A: 0%: y = -1.06x + 4882.37; *P* = 0.01; 20%: y = -0.54 + 4865.37; *P* = 0.06; 40%: y = 6.23x + 3582.24; *P* = 0.01

B: 0%: y = -0.14x + 3698.23; *P* = 0.01; 20%: y = 0.82x + 3251.78; *P* = 0.01; 40%: y = 0.99x + 3071.11; *P* = 0.01

C: 0%: y = -0.34x + 3748.53; *P* < 0.01; 20%: -0.80x + 4098.81; *P* < 0.01; 40%: y = 0.25x + 3743.67; *P* < 0.01

D: 0%: y = 0.33x + 3050.52; *P* = 0.01; 20%: y = 9.51x + 1090.32; *P* = 0.01; 40%: y = 1.95x + 2023.36; *P* = 0.01.

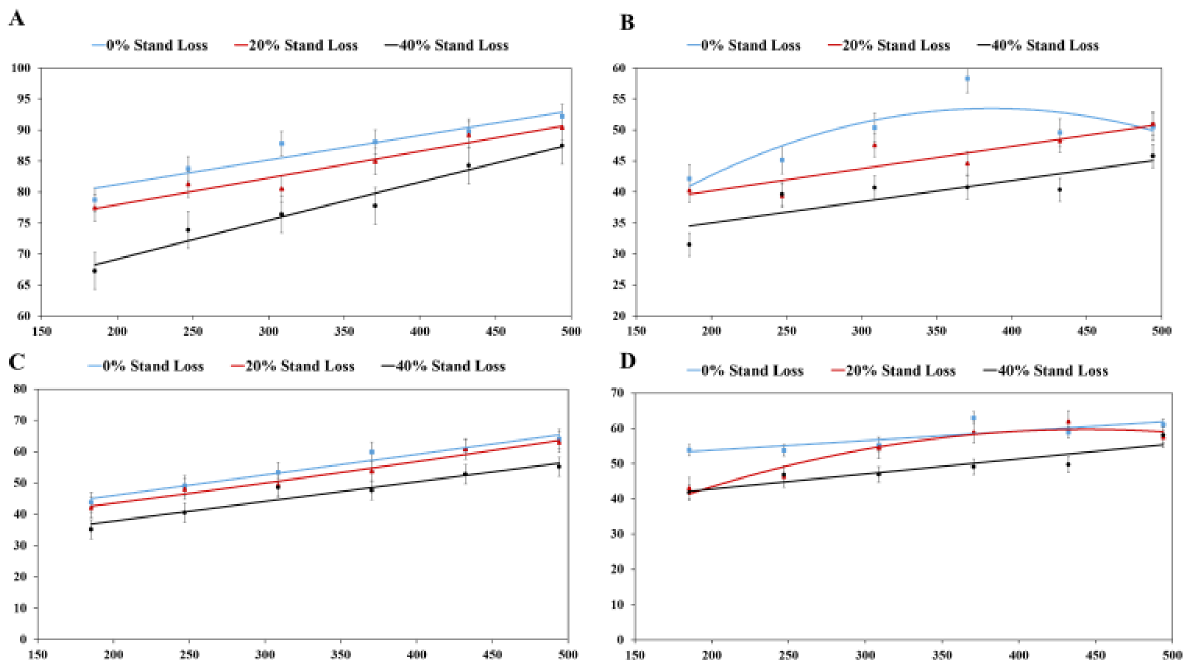

Figure 2. Impact of the interaction between seeding rate and stand loss percentage on soybean canopy closure at Stoneville, MS in 2016 (A, Delta 1), Starkville, MS in 2016 (B, Hills), Stoneville, MS in 2017 (C, Delta 2), and Starkville, MS in 2017 (D, Hills).

A: 0%: $y = 0.11x + 62.16$; $P < 0.01$; 20%: $y = 0.02x + 72.88$; $P < 0.01$; 40%: $y = 0.07x + 56.33$; $P < 0.01$

B: 0%: $y = 0.24x + 7.21$; $P = 0.03$; 20%: $y = 0.03x + 32.89$; $P = 0.01$; 40%: $y = 0.09x + 18.88$; $P = 0.01$

C: 0%: $y = 0.14x + 21.21$; $P < 0.01$; 20%: $0.05x + 31.74$; $P < 0.01$; 40%: $y = 0.15x + 12.61$; $P < 0.01$

D: 0%: $y = 0.06x + 42.96$; $P = 0.02$; 20%: $y = 0.24x + 5.61$; $P = 0.01$; 40%: $y = -0.01x + 43.48$; $P = 0.01$