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Megacopta cribraria (Hemiptera: Plataspidae) Population Dynamics in Soybeans as Influenced by Planting Date, Maturity Group, and Insecticide Use

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Abstract

Since its unintentional introduction during 2009, *Megacopta cribraria* (F.) has spread rapidly throughout the southeastern United States, mainly feeding and reproducing on kudzu, *Pueraria montana* Loureiro (Merr.) variety *lobata* (Willdenow), and soybeans, *Glycine max* (L.) Merr. *Megacopta cribraria* has become a serious economic pest in soybeans, forcing growers to rely solely on insecticide applications to control this insect. The main objective of this study was to investigate if variation in planting date and maturity group of soybeans had an impact on management of *M. cribraria* populations. Three experimental fields were located in North Carolina (2) and South Carolina (1), and the tests replicated during 2012 and 2013. Treatments consisted of three planting dates, four maturity groups, and insecticide treated versus untreated, at each location. More *M. cribraria* were found in untreated early planted soybeans than late planted soybeans. Generally, maturity group did not influence population densities of *M. cribraria.* Yield was significantly influenced by the interaction between planting date and maturity group. There was a negative linear relationship between *M. cribraria* populations and soybean yield. Although early planted soybeans may avoid drought conditions and potentially large populations of defoliators, these fields may be at greater risk for infestation by *M. cribraria.*

Resumen

Desde su introducción accidental durante el 2009, *Megacopta cribraria* (F.) se ha distribuido rápidamente en el sureste de los Estados Unidos; alimentándose y reproduciéndose principalmente de kudzu *Pueraria montana* Loureiro (Merr.) variedad *lobata* (Willdenow) y soja *Glycine max* (L.) Merr. *Megacopta cribraria* se ha convertido en una plaga importante de soja, obligando a los agricultores a aplicar pesticidas para controlar este insecto. El objetivo principal de este estudio fue investigar si la variación en la fecha de siembra y la selección de grupos de madurez para la soja tuvieron impacto en el manejo de *M. cribraria.* Los experimentos fueron localizados en tres lugares de Carolina del Norte y del Sur, y repetidos durante los años 2012 y 2013. Los tratamientos consistieron en tres fechas de siembra, cuatro grupos de madurez, y parcelas aplicadas con insecticida o parcelas sin aplicar. Se encontró mayor número de *M. cribraria* en soja plantada temprano, en comparación con soja plantada al final de temporada. En general, el grupo de madurez de la soja no influenció las poblaciones de *M. cribraria.* El rendimiento de la soja estuvo influenciado por la interacción entre fecha de siembra y grupo de madurez. Existió una relación linear y negativa entre las poblaciones de *M. cribraria* y los rendimientos de grano. Soja sembrada temprano durante la temporada puede evitar daños por sequías y defoliadores; sin embargo, estos campos estarían con una mayor probabilidad de tener altas infestaciones de *M. cribraria.*

Key words: cultural practice, kudzu bug, invasive species, cumulative insect days, *Glycine max*

Soybean, *Glycine max* (L.) Merrill, is one of the most important crops in the United States, planted on over 31 million hectares in 2013, second only to corn, *Zea mays* L. The value of soybeans was estimated at US$41.8 billion of farm-gate value during 2013 (U.S. Department of Agriculture [USDA] 2015). Cultural practices, including varietal selection and planting date, can influence soybean yield (Parker et al. 1981, Board et al. 1996, Khaled et al. 2011). There are three soybean planting systems used in the midsouthern and southeastern United States: the early soybean production system, full-season soybeans, and double-cropped soybeans (Heatherly et al. 1998). Farmers using early soybean production systems usually plant soybeans in April. Full-season soybeans are generally planted in late April to May. Additionally, these two systems differ on the suggested maturity group. Maturity group (MG) in soybeans (expressed as Roman numerals from 00 to IX) can be defined as the plant's capacity to flower under specific photoperiod requirements, and it is expressed as days-to-flowering (Pedersen 2009). Group 00 is the earliest maturity group, and it is adapted to northern regions, whereas group IX is the latest and adapted to the southern United States (Pedersen 2009). Recommendation for maturity group selection under early soybean production system is to plant only early maturing soybeans (MG III and IV), compared with the full-season system where late maturing soybeans are selected (MG V–VII) (Bowers 1995, Heatherly and Spurlock 1999). Selection of planting date and maturity group in the full-season soybean production system depends on weather predictions and targeted harvesting time (Frederick et al. 1998). In a double-cropped system, soybeans are planted in June, immediately following the winter grain harvest (Frederick et al. 1998). Usually, MG VI and VII are planted under the double-cropped system (Frederick et al. 1998, Heatherly and Hodges 1999).

Varying soybean planting date can impact not only plant performance and yield potential, but also can influence insect densities in this crop (Buschman et al. 1984). Planting date is known to influence insect densities in many crops such as corn, *Zea mays* L. (Smith and Riley 1992), wheat, *Triticum aestivum* L. (Morril and Kushnak 1999), cowpea, *Vignia unguiculata* (L.) Walp (Asante et al. 2001), and cotton, *Gossypium hirsutum* L. (Slosser 1993, Bi et al. 2005). In soybeans, planting date and maturity group have been shown to affect seasonal abundance of insect pests and beneficial arthropods in Arkansas (Tugwell et al. 1973), Georgia (McPherson and Bondari 1991), and Louisiana (Boyd et al. 1997). In general, lower insect pest populations of velvetbean caterpillar (*Anticarsia gemmatalis* Hübner, Lepidoptera: Noctuidae), soybean looper (*Pseudoplusia includens* (Walker), Lepidoptera: Noctuidae), and stink bugs (Hemiptera: Pentatomidae) are found in early planted and early maturing soybeans (McPherson et al. 2001, Gore et al. 2006). Gore et al. (2006) suggested that one reason for this phenomenon could be the migratory nature of these defoliators, which do not overwinter in the continental United States. However, having pods available early in the season can attract nonmigratory pests such as stink bugs (McPherson and Bondari 1991, Baur et al. 2000, Smith et al. 2009). Once early planted soybeans senesce, stink bugs migrate to available and suitable host plants, including later planted soybeans (Smith et al. 2009, Herbert and Toews 2011).

Besides having a lower risk of late-season pest outbreaks, planting earlier may allow growers to avoid drought conditions during summer (Frederick et al. 1998, Heatherly and Hodges 1999, McPherson et al. 2001). The modification of selected cultural practices in soybeans, such as row spacing, can impact the populations of insect pests (Frederick et al. 1998, Heatherly and Hodges 1999). Soybeans planted on wide rows (row spacing $>$ 0.76 m) are more susceptible to infestations of *Helicoverpa zea* Boddie (Lepidoptera: Noctuidae) compared with narrow rows; canopy architecture influences oviposition, and the lack of canopy closure on wide rows makes the crop more attractive for oviposition when the crop is more susceptible to this pest (Bradley and Van Duyn 1979). Southern U.S. soybean growers have narrowed row spacings over time, reducing the risk of *H. zea* infestations.

Soybean pest status has changed in some parts of the United States since 2010, especially in the Southeast, due to the presence of an additional economic pest in the system. The kudzu bug, *Megacopta cribraria* (F.) (Hemiptera: Plataspidae), was accidentally introduced into the United States from Asia (Eger et al. 2010, Suiter et al. 2010). First reported in Georgia during 2009, *M. cribraria* has spread rapidly throughout the southeastern region of the United States (Ruberson et al. 2013), and was recently discovered in Arkansas and Kentucky (Gardner 2015). *Megacopta cribraria* is a piercing–sucking insect that undergoes five nymphal stadia in 40–50 d (Eger et al. 2010, Zhang et al. 2012, Del Pozo-Valdivia and Reisig 2013). Females deposit several capsules underneath egg masses containing a γ-protobacterium endosymbiont, *Candidatus ishikawaella capsulata* (Hosokawa et al. 2006). Following eclosion, first-instar nymphs feed on these capsules, acquiring the endosymbiont (Hosokawa et al. 2006). It is hypothesized that this endosymbiont is required by *M. cribraria* for growth and development on different host plants (Hosokawa et al. 2006, 2007).

Megacopta cribraria has two generations per year in the southeastern United States (Ruberson et al. 2013, Seiter et al 2013a). Adults begin to emerge from overwintering sites in early April. The first generation of adults typically peaks in June and the second peaks in August (Ruberson et al. 2013, Seiter et al 2013a). Although initially, *M. cribraria* was observed feeding on kudzu, *Pueraria montana* Loureiro (Merrill) variety *lobata* (Willdenow), it was recognized that it can also feed and reproduce on soybeans directly from overwintering (Del Pozo-Valdivia and Reisig 2013). This insect can be found feeding on other legumes, including lespedeza, *Lespedeza* spp., and wisteria, *Wisteria* spp. (Eger et al. 2010, Zhang et al. 2012); however, larger populations of *M. cribraria* have been found on kudzu and soybeans compared with these plants (Ruberson et al. 2013). Research on this insect has demonstrated that *M. cribraria* will aggregate alone soybean field edges (Seiter et al. 2013a) and can reduce soybean yield up to 60% when left uncontrolled in a confined environment, such as field cages (Seiter et al. 2013b). Furthermore, some early planted soybeans (especially those planted in April) are more prone to *M. cribraria* infestations and harbor more throughout the season, likely because they can support both generations of this putatively bivoltine pest (Blount et al. 2015). Currently, insecticide applications are the only short-term solution to manage this pest in soybeans (Seiter et al. 2015a).

The main objective of this study was to determine the impact of varying soybean planting dates and maturity groups on *M. cribraria* field populations using two different scouting procedures (sweep-net sampling and insect density per plant). This two-year, two-state, multisite field experiment also revealed how *M. cribraria* populations and soybean yield were affected by the application of selected insecticides.

Materials and Methods

North Carolina

There were two field sites, one was located at the North Carolina State University Sandhills Research Station, near Jackson Springs, NC, in Montgomery County and another at a commercial soybean field near Gibson, NC, in Scotland County during 2012 and 2013. Field experiments were set up with a split-split plot design with four replications per site, where the main plot was planting date (three dates), the split-plot was maturity group (MG; four groups), and the split-split-plot was insecticide treatment (sprayed or unsprayed). Experimental plots, four rows wide by 12.2 m long, were planted with 0.97-m row spacing using a four-row cone planter (John Deere model 1750, Deere and Co., Moline, IL) in Montgomery County, where the targeted seeding rate was 29 seeds per row meter. In Scotland County, experimental plots were planted with 0.91-m row spacing using a two-row disc planter (White model 6700, AGCO Corporation, Duluth, GA). Plot dimensions and seeding rate in Scotland County were the same as Montgomery County plots. For both locations, planting dates were 16–17 April 2012, 17–18 May 2012, 18–19 June 2012, 16–18 April 2013, 15 May 2013, and 17–20 June 2013. For both locations and both years, Roundup Ready soybean seeds (Asgrow, Monsanto Company, St. Louis, MO) with no insecticide coating were planted with MG IV (variety AG4531), V (AG5503), VI (AG6132), and VII (AG7502).

Scouting for *M. cribraria* adults and egg masses per whole-plant was conducted at 14 and 28 d after planting by visual inspection of plants in 0.61-m row samples. During these visual inspections, six samples per plot were taken where total number of *M. cribraria* adults and eggs were counted. In 2012, visual inspections were not performed in soybeans planted in April. Once plants reached vegetative stage five (V5, Fehr et al. 1971), sweep-net samples were taken every other week, from ~42 d after planting until plants reached reproductive stage seven (R7; Fehr et al. 1971). Twenty sweeps, using a 0.38-m-diameter standard sweep net, were taken on each sampling date. The net was plunged into the canopy so that the entire diameter of the net was submerged in the canopy just below the top of a single soybean row. Numbers of *M. cribraria* adults and nymphs were recorded during sweeping, as well as other insect pests such as defoliators and stink bugs. Newly unfolded top soybean trifoliates were randomly selected from 25 plants in each plot and inspected for *M. cribraria* eggs. Adult and nymph densities on a per plant basis were recorded from the previous 25 selected plants. Sweep-net and trifoliate samples were taken initially from rows two and three, respectively. At the following sampling date, sample locations were switched, where sweep-nets were taken from row three and trifoliates from row two. Sample locations were kept alternating in this manner during each visit until soybean plants reached R7.

Insecticide treatment regimens were either protected (sprayed every two weeks with insecticide after the first application) or unsprayed. Bifenthrin (Discipline 2EC, AMVAC Chemical Corp., Los Angeles, CA) was applied at 0.11 kg/ha of active ingredient, in a volume of 93.5 liter/ha, using a two-row CO_2 backpack sprayer with TX-10 hollow-cone nozzles (Teejet, Wheaton, IL). Insecticide application was triggered when 10 or more adults per plant (from V1–V4) or 0.5–1.0 adult per sweep (from V5–R4) of *M. cribraria* were found across maturity groups in one planting date. A total of four and five insecticide applications were made during 2012 and 2013, respectively. During 2013, larvae of a heliothine species reached economic threshold at both locations in late July. To minimize yield losses associated with either corn earworm or tobacco budworm, *Heliothis virescens* (F.) (Lepidoptera: Noctuidae), flubendiamide (Belt, Bayer CropScience LP, Research Triangle Park, NC) was applied once to the entire experiment at 0.11 kg/ha of active ingredient, using the same backpack sprayer and volume/ha previously mentioned. Flubendiamide was chosen because the rate used in these applications had little to no impact on *M. cribraria* (Seiter et al. 2015b).

Soybean maturity was reached at different dates, depending on the maturity group and planting date. To make the harvest operation feasible, one harvesting date per site was selected during 2012 and 2013. Soybeans were harvested using a two-row mechanical plot combine harvester (Gleaner model K2, AGCO Corporation, Duluth, GA). The middle two rows of each plot were harvested to calculate yield/ha. Seed shattering was measured immediately after the combine harvested the plots. Since seed shattering was not different among planting dates nor maturity groups at any given year or location (data not shown), seed weight was not corrected. Soybean yield per plot and moisture content were measured to determine yield/ha with 13% moisture content.

South Carolina

Trials were established in 2012 and 2013 at the Clemson University Edisto Research and Education Center in Barnwell County, SC. Soybeans were planted using a four-row planter (John Deere MaxEmerge II model 7300, Deere and Co., Moline, IL) with a row spacing of 0.97 m at a seeding rate of 25 seeds per row meter. Plots were eight rows (7.7 m) wide by 12.2 m long. Planting dates were 20 April 2012, 18 May 2012, 5 July 2012 (the 5 July planting was originally planted on 22 June, but dry conditions resulted in poor germination and emergence therefore those plots were replanted), 18 April 2013, 20 May 2013, and 26 June 2013. For both years, Roundup Ready soybean seeds (Asgrow, Monsanto Company) were planted with MG IV (variety: AG4730), V (AG5732), VI (AG6732), and VII (AG7532). Seed was treated with 0.13 mg clothianidin per seed (Poncho/Votivo, Bayer CropScience LP). Although the evidence was mixed, previous field observations indicated that *M. cribraria* might be attracted to soybeans planted following a neonicotinoid seed treatment. Hence, seeds were treated to increase chances of *M. cribraria* infestation.

Insecticide treatment regime was either unsprayed or protected from populations of *M. cribraria* with a foliar insecticide spray. In the protected treatments, applications of 0.035 kg/ha of λ-cyhalothrin and 0.046 kg/ha of thiamethoxam (Endigo ZC, Syngenta Crop Protection LLC, Greensboro, NC) were made in a volume of 93.5 liter/ha using a high-clearance self-propelled sprayer. Insecticide applications were triggered when presence of *M. cribraria* nymphs was observed across maturity groups in one planting date. A total of three applications were made during each year of this experiment. Because of the presence of soybean looper and heliothine species during 2013, spinosad (Tracer Naturalyte, Dow AgroSciences, Indianapolis, IN) was applied to the entire experiment on 24 July and 27 August at a rate of 0.077 kg/ha. Spinosad was chosen because the rate used in these applications had little to no impact on *M. cribraria* (Seiter et al. 2015b).

The experimental design differed between 2012 and 2013. In 2012, unsprayed and insecticide protected treatments were applied to separate, adjacent experiments, which were each deployed as a randomized complete block design with four replications. All combinations of planting date and maturity group were randomly assigned within each block. In 2013, a single experiment was conducted as in NC as a split-split plot with four replications, where the main plot was insecticide treatment regime (protected or unsprayed), the split-plot was MG (four groups), and the split-split-plot was planting date (three dates).

The methodology for monitoring *M. cribraria* was similar to the one followed in NC. In 2012, visual inspections recorded from each sample on the 14th and the 28th day after planting included only egg masses. In 2013, total number of adults per sample was also determined during visual inspections, along with egg masses. Sweep-net samples were taken every other week, starting from ~42 d after planting and ended when plants reached reproductive stages six to eight (R6 to R8, Fehr et al. 1971) in 2012. Ten sweeps were taken on each sampling date. The net was placed into the canopy so that at least half of the diameter of the net was submerged in the canopy. Sweep-net samples were taken at 180° across two soybean rows, and then alternated between the second and third and the sixth and seventh rows at each plot. Number of *M. cribraria* adults and nymphs were counted and recorded from sweep-net samples. From reproductive stage seven (R7) to eight (R8), sweep-net samples were taken from rows one and two or seven and eight (outside rows) to avoid damaging internal rows. In 2013, sweep-net sampling ended at R7 to avoid damaging the outside rows at each plot. To monitor *M. cribraria* eggs, 25 randomly selected, newly unfolded top soybean trifoliates were inspected for presence of egg masses.

Soybeans were harvested from the four center rows in each plot using a two-row plot combine (model 8-XP, Kincaid Equipment Manufacturing, Haven, KS). Harvest was triggered based on when different planting date and maturity group combinations reached maturity; therefore, different planting date and maturity group combinations were selectively harvested at different times as soon as they reached R8. Soybean yield per plot and moisture content were measured in order to determine yield/ha with 13% moisture content.

Data Analysis

Insect evaluations on *M. cribraria* and soybean yield from NC were pooled together based on similar experimental design and methodologies, creating a single data set that included a new variable named "trial." The variable trial accounted for the interaction of both years (2012 and 2013) and location (Montgomery and Scotland Counties). Since NC and SC differed in the experimental design and how sweeping (post-V5) was performed, data from SC were analyzed separately from NC. For both NC and SC, data from the first two insect evaluations on *M. cribraria* were combined into one data set for NC and two data sets for SC (one for each year); all three data sets were analyzed using a generalized linear mixed model (PROC GLIMMIX, SAS Institute 2010, Cary, NC) approach. Individual analysis of variance (ANOVA) tests were conducted where response variables were egg masses per 0.61-m row and adults per 0.61-m row. These analyses incorporated early season data (V5 and earlier). Because insecticide treatment had not begun at this time, treatments were organized as a randomized complete block design for SC 2012, and split-plot for NC and SC 2013. Fixed effects included planting date, maturity group, and the interaction between planting date and maturity group. Data distribution was selected as log-normal for egg masses and adults, based on model selection criteria (Littell et al. 2006). Degrees of freedom were calculated using the procedure of Kenward and Roger (1997). The effect of replication nested with trial, trial alone, and replication nested with trial by planting date interaction were included in the random statement for analyzing NC data. Replication was considered nested to account for the new hierarchy of this class after the variable "trial" was originated when NC data were pooled together. The random statement in the SC analyses included effects of replication in 2012 and replication and the planting date by replication interaction in 2013.

Total numbers of *M. cribraria* egg masses per 25 trifoliates, and *M. cribraria* adults and nymphs per plant were calculated from visual counts (V6 and older). Using the sweep-net data (V6 and older), cumulative insect days were also calculated to measure the magnitude and duration of infestation of *M. cribraria* by following the equation from Ruppel (1983):

$$\mathrm{Insect-days} = (X_{i+1} - X_i) \times [(Y_i + Y_{i+1})/2]$$

where X_i and X_{i+1} were adjacent sampling dates, and Y_i and Y_{i+1} were *M. cribraria* densities for those adjacent sampling dates. Insect density per plant and cumulative insect days per sweep were log-transformed $[\log_{10}(X+1)]$ to comply with the assumptions of the ANOVA.

Soybean yield and post-V5 sampling data from NC and SC were analyzed using individual mixed-model ANOVAs (PROC MIXED, SAS Institute 2010). The response variables were soybean yield, $\log_{10}$-transformed *M. cribraria* adults per plant, $\log_{10}$-transformed *M. cribraria* nymphs per plant, $\log_{10}$-transformed cumulative *M. cribraria* egg masses per 25 trifoliates, $\log_{10}$-transformed cumulative *M. cribraria* days per sweep for nymphs, and $\log_{10}$-transformed cumulative *M. cribraria* days per sweep for adults. In the NC statistical model, fixed effects were planting date, maturity group, insecticide regime, and their interactions. Random effects were replication nested with trial, trial alone, the interaction between replication nested with trial by planting date, and the interaction of maturity group by replication nested with trial by planting date. In the SC 2012 model, unsprayed and sprayed experiments were analyzed separately with planting date, maturity group, and the interaction between planting date and maturity group as fixed effects, and replication alone as a random effect. In the SC 2013 model, the fixed effects were insecticide, maturity group, planting date, and their interactions; random effects were replication alone, replication by insecticide regime interaction, and the replication by insecticide regime by maturity group interaction. Degrees of freedom from all models were also calculated using the Kenward–Roger's procedure. Mean separation post-ANOVA of the transformed data was performed using the Tukey's test at $\alpha \leq 0.05$. Means and standard errors are reported from the back-transformed data.

A regression analysis was performed between soybean yield (response variable) and *M. cribraria* densities (independent variable) using PROC REG (SAS Institute 2010). Transformed insect data were used to comply with assumptions of the regression analysis. Data from each location and year were analyzed separately. Significance of the linear relationship and coefficients of correlation (R^2) were calculated.

Results

Planting Date Effect on *M. cribraria* Densities

Planting date alone influenced the number of egg masses of *M. cribraria* during 2012 and 2013 in SC, when plants were V5 or younger (Table 1). More egg masses per 0.61-m row were found on soybeans planted during April compared with June- or July-planted soybeans (Table 2). Planting date had an effect on the number of egg masses found on the uppermost fully expanded soybean trifoliates in both untreated and insecticide-treated soybeans in 2012 in SC, when plants were V6 or older (Table 3). The highest numbers of egg masses per 25 trifoliates were observed on soybeans planted in April compared with July-planted soybeans (Fig. 1). Additionally, egg masses were influenced by planting date during 2013 in SC (Table 4). April-planted soybeans had more egg masses than May- or June-planted soybeans (Table 2).

Planting date also affected cumulative insect days for nymphs per sweep in both untreated and insecticide-treated soybeans in

Table 1. Analysis of variance results for influence of planting date and maturity group on presence of *M. cribraria* egg masses and adult abundance in soybean plants at V5 growth stage or younger

Location / year	Response variable	Source of variation	df	*F*	*P*
North Carolina 2012 & 2013	Egg masses/0.61-m row	Planting date	2, 192	4.33	0.0145
		Maturity group	3, 189	8.98	<0.0001
		Planting date × maturity group	3, 189	7.51	<0.0001
	Adults/0.61-m row	Planting date	2, 207	0.05	0.9509
		Maturity group	3, 193.20	9.01	<0.0001
		Planting date × maturity group	6, 193.90	10.15	<0.0001
South Carolina 2012[a]	Egg masses/0.61-m row	Planting date	2, 77	226.31	<0.0001
		Maturity group	3, 77	1.81	0.1518
		Planting date × maturity group	6, 77	0.64	0.6991
South Carolina 2013	Egg masses/0.61-m row	Planting date	2, 1	214.15	0.0483
		Maturity group	3, 22.13	2.22	0.1138
		Planting date × maturity group	6, 1	10.84	0.2284
	Adults/0.61-m row	Planting date	2, 72	39.71	<0.0001
		Maturity group	3, 72	4.78	0.0205
		Planting date × maturity group	6, 72	2.33	0.0411

[a] Adult data are not included in this table because densities were not collected at this trial.

Table 2. Effect of planting date on significant response variables in South Carolina during 2012 and 2013

Year	Location	Response variable	Planting date (mean ± SE)		
			April	May	June / July
2012	South Carolina	Egg masses/0.61-m row	92.38 ± 5.57A	25.41 ± 4.71B	0.03 ± 0.03C
2012	SC Untreated[a]	Yield (kg/ha)	1,244.40 ± 98.61b	1,609.25 ± 89.62a	1,674.76 ± 73.71a
2013	South Carolina	Egg masses/0.61-m row	122.50 ± 14.26A	79.88 ± 14.08A	0.31 ± 0.16B
2013	South Carolina	Cumulative egg masses/25 trifoliates	28.31 ± 2.06a	10.94 ± 1.03b	4.56 ± 0.46c

Each row in the table represents a separate statistical analysis. Means ± standard error (SE) sharing the same letters are not statistically different ($\alpha > 0.05$).
[a] In 2012, there were two separated tests where one field was sprayed with insecticide and the adjacent field was left untreated.

Table 3. Analysis of variance for planting date and maturity group effects on *M. cribraria* for insecticide-treated and untreated 2012 South Carolina trials

Trial	Response variable	Source of variation	df	*F*	*P*
Untreated	Cumulative egg masses/25 trifoliates	Planting date	2, 33	481.44	<0.0001
		Maturity group	3, 33	2.86	0.0519
		Planting date × maturity group	6, 33	0.99	0.4511
	Cumulative insect days for nymphs/sweep	Planting date	2, 36	178.96	<0.0001
		Maturity group	3, 36	1.31	0.2874
		Planting date × maturity group	6, 36	1.15	0.3517
	Cumulative insect days for adults/sweep	Planting date	2, 33	61.18	<0.0001
		Maturity group	3, 33	2.03	0.1288
		Planting date × maturity group	6, 33	2.17	0.0709
	Yield (kg/ha)	Planting date	2, 33	11.10	0.0002
		Maturity group	3, 33	5.76	0.0028
		Planting date × maturity group	6, 33	1.82	0.1258
Insecticide treated	Cumulative egg masses/25 trifoliates	Planting date	2, 33	113.97	<0.0001
		Maturity group	3, 33	2.43	0.0825
		Planting date × maturity group	6, 33	0.99	0.4488
	Cumulative insect days for nymphs/sweep	Planting date	2, 33	22.97	<0.0001
		Maturity group	3, 33	1.53	0.2239
		Planting date × maturity group	6, 33	1.10	0.3839
	Cumulative insect days for adults/sweep	Planting date	2, 33	37.92	<0.0001
		Maturity group	3, 33	2.23	0.1034
		Planting date × maturity group	6, 33	4.37	0.0024
	Yield (kg/ha)	Planting date	2, 36	162.48	<0.0001
		Maturity group	3, 36	22.66	<0.0001
		Planting date × maturity group	6, 36	10.01	<0.0001

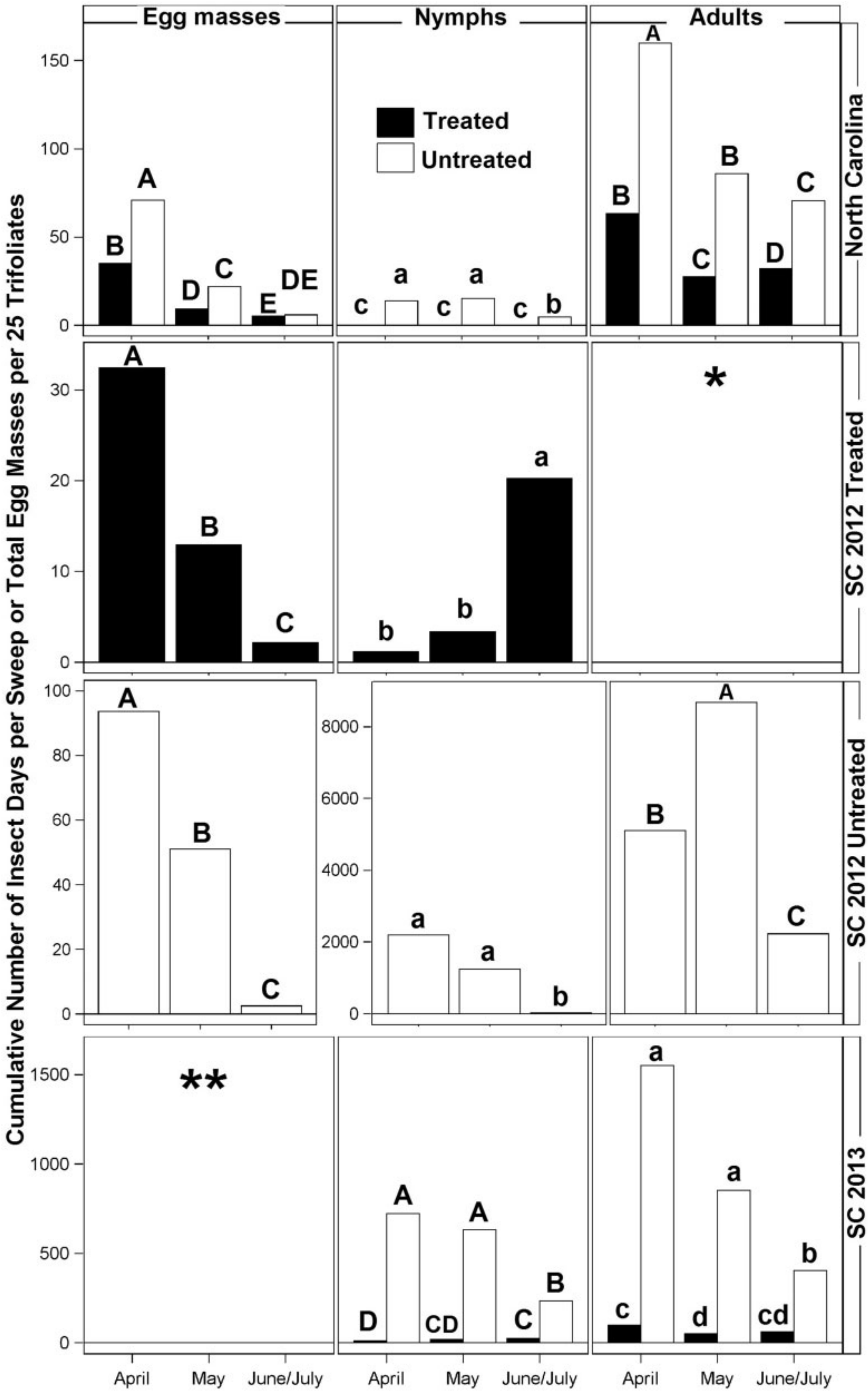

Fig. 1. Significant effect of the interaction between planting date (X-axis) and insecticide use (treated plots—black bars, untreated plots—white bars) on *M. cribraria* egg masses (panels on the left column), on cumulative insect days for nymphs per sweep (panels on the center column), and cumulative insect days for adults per sweep (panels on the right column) from soybean plants older than V5 growth stage in North and South Carolina during 2012 and 2013. Means sharing the same letters are not statistically different ($\alpha > 0.05$). Separate analyses are presented at each cell level. Asterisk indicates that mean separation was not performed during the analysis because the interaction between planting date and maturity group (single asterisk), and the effect of maturity group (double asterisk) had an effect on the analyzed variables, rather than the effect of planting date alone. The mean separation for the interaction and the single effect are presented in-text and in Table 4, respectively.

Table 4. Analysis of variance for planting date, maturity group, and insecticide effects on *M. cribraria* in South Carolina in 2013

Response variable	Source of variation	df	*F*	*P*
Cumulative egg masses/25 trifoliates	Insecticide	1, 66	2.19	0.1894
	Maturity group	3, 66	14.31	<0.0001
	Insecticide × maturity group	3, 66	0.73	0.5389
	Planting date	2, 66	152.32	<0.0001
	Planting date × insecticide	2, 66	1.84	0.1666
	Planting date × maturity group	6, 66	1.89	0.0961
	Planting date × insecticide × maturity group	6, 66	0.15	0.9893
Cumulative insect days for nymphs/sweep	Insecticide	1, 72	501.45	<0.0001
	Maturity group	3, 72	0.17	0.9156
	Insecticide × maturity group	3, 72	1.38	0.2549
	Planting date	2, 72	2.67	0.0764
	Planting date × insecticide	2, 72	15.87	<0.0001
	Planting date × maturity group	6, 72	0.27	0.9470
	Planting date × insecticide × maturity group	6, 72	0.23	0.9674
Cumulative insect days for adults/sweep	Insecticide	1, 6	444.55	<0.0001
	Maturity group	3, 66	5.10	0.0031
	Insecticide × maturity group	3, 66	1.01	0.3941
	Planting date	2, 66	25.33	<0.0001
	Planting date × insecticide	2, 66	8.06	0.0007
	Planting date × maturity group	6, 66	0.41	0.8667
	Planting date × insecticide × maturity group	6, 66	0.46	0.8323
Yield (kg/ha)	Insecticide	1, 3	96.28	0.0022
	Maturity group	3, 66	23.30	<0.0001
	Insecticide × maturity group	3, 66	3.88	0.0129
	Planting date	2, 66	26.25	<0.0001
	Planting date × insecticide	2, 66	8.07	0.0007
	Planting date × maturity group	6, 66	9.09	<0.0001
	Planting date × insecticide × maturity group	6, 66	1.74	0.1264

2012 in SC when plants were V6 or older (Table 3). There were more cumulative nymph days per sweep in April- and May-planted soybeans in the 2012 untreated trial compared with July (Fig. 1). In contrast, more cumulative insect days for nymphs per sweep were experienced from treated plots planted in July, compared with soybeans planted in April and May (Fig. 1). During the same year in the 2012 untreated trial, soybeans planted in May had more cumulative insect days for adults per sweep compared with soybeans planted in April and July (Table 3, Fig. 1).

Densities of *M. cribraria* egg masses and adults per 0.61-m row were influenced by the interaction of planting date and maturity group in NC during 2012 and 2013, and SC during 2013 (Table 1). When planted during April, MG V and VI soybeans had more egg masses than the MG IV and VII varieties in NC. Also, the MG V and VI varieties planted during April had more egg masses than MG IV, V, and VII varieties planted during June in NC (Fig. 2). More adults were observed on MG V and VI soybeans planted in April than MG IV and VII soybeans planted in the same month in NC (Fig. 2). On the contrary, more adults were observed on MG IV soybean plants planted during April in SC, compared with MG V and VII soybeans planted during May or with all MG of soybeans planted during June (Fig. 2). Cumulative insect days for adults per sweep were also affected by the interaction between planting date and maturity group in the insecticide-treated trial in 2012 in SC (Table 3). Maturity groups V and VII soybeans planted in July, and MG IV planted in May had more cumulative insect days for adults per sweep, compared with soybeans planted with MGs V, VI, and VII planted in May or any MG planted in April (Supp Table 1 [online only]).

The interaction between planting date and insecticide regime consistently influence *M. cribraria* densities when plants were V6 or older in both NC and SC (Tables 4 and 5). Cumulative number of egg masses deposited by *M. cribraria* on soybean trifoliates was influenced by this interaction in NC during 2012 and 2013 (Table 5). More egg masses were found in both insecticide-treated and untreated soybeans planted in April and May compared with soybeans planted in June, and more eggs were found in April plantings than May plantings (Fig. 1). There were more egg masses in untreated soybeans than insecticide-treated soybeans, except for the June plantings (Fig. 1).

Cumulative insect days for both *M. cribraria* nymphs per sweep and adults per sweep were influenced by the interaction of planting date and insecticide regime during 2012 and 2013 in NC (Table 5), and in SC during 2013 (Table 4). More insect days for nymphs were calculated for untreated soybeans planted during April or May compared with untreated soybeans planted during June in both NC and SC (Fig. 1). Fewer insect days for nymph per sweep were calculated from any insecticide-treated soybean planted on any date in NC, or from soybeans treated with insecticide and planted in April than insecticide-treated soybeans planted in June in SC (Fig. 1). Higher insect days for adults accrued on untreated soybeans planted in April compared with untreated soybeans planted during June in both NC and SC (Fig. 1). Fewer insect days for adults per sweep were calculated from untreated soybeans planted in June than May plantings in NC, and from any of the other insecticide-treated soybean planted on any date in SC (Fig. 1). Similar insect days for adults accrued for insecticide-treated soybeans planted in April compared with untreated soybeans planted during May in NC, insecticide-treated soybeans planted during May compared with untreated soybeans planted during June in NC, and untreated soybeans planted during April compared with untreated soybeans planted during May in SC (Fig. 1).

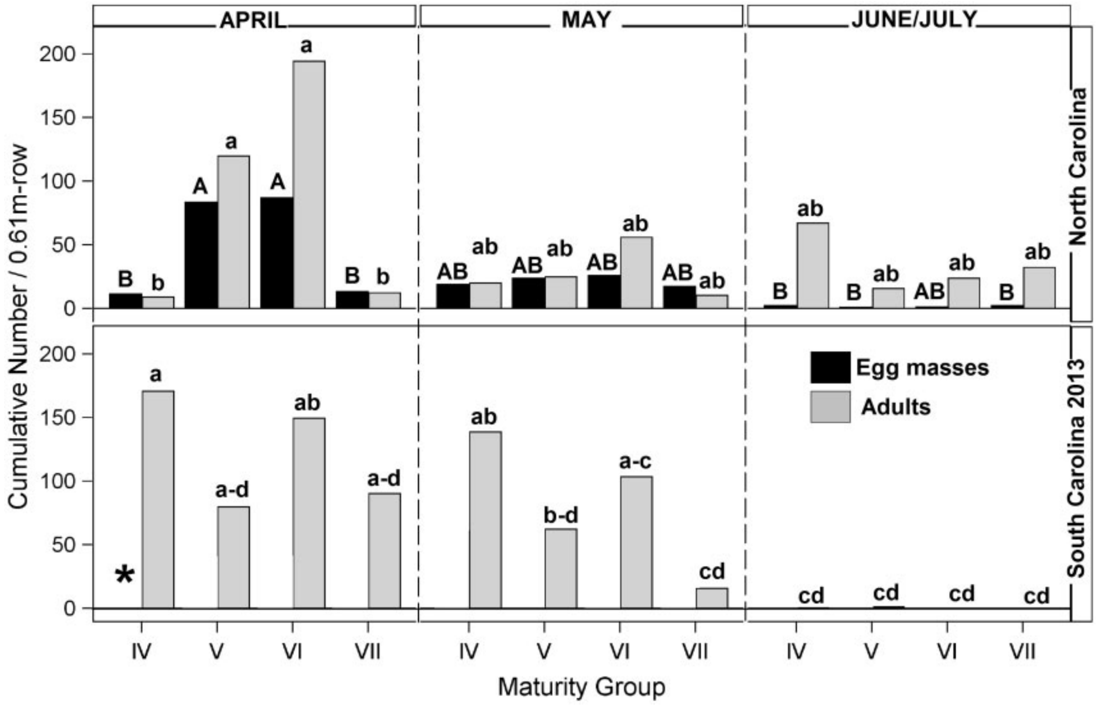

Fig. 2. Significant effects of the interaction between planting date and maturity group on *M. cribraria* egg masses laid in soybean at V5 growth stage or younger (black bars, upper case letters) and adults (gray bars, lower case letters) in North Carolina during 2012 and 2013 and South Carolina in 2013. Means sharing the same letters are not statistically different ($\alpha > 0.05$). Separate analyses are presented at each row level. The asterisk at the lower panel indicates that separation of means was not performed for egg masses during the analysis of the interaction because the effect of planting date, rather than maturity group, was significant on *M. cribraria* egg mass abundance. Mean separations for this effect are presented in Table 2.

The interaction between planting date and insecticide regime also consistently influenced nymph and adult presence in soybeans in NC during 2012 and 2013 when plants were V6 or older (Table 5). There were more nymphs per plant in untreated soybeans planted in April or May, compared with insecticide-treated and untreated soybeans planted in June, or insecticide-treated soybeans planted in either April or May (Fig. 3). Additionally, untreated soybeans planted in April had the highest densities of adult per plant, compared with treated soybeans planted during April or insecticide-treated or untreated soybeans planted in May and June (Fig. 3). More adults per plant were also observed on insecticide-treated soybeans planted in April than insecticide-treated soybeans planted in May or June and untreated soybeans planted in June (Fig. 3).

The Effect of Maturity Group on *M. cribraria* Densities

Maturity group alone influenced the cumulative number of egg masses deposited by *M. cribraria* on the uppermost fully expanded soybean trifoliates when plants were V6 growth stage or older in NC (Table 5) and SC in 2013 (Table 4). There were more egg masses per 25 trifoliates on MG IV soybeans compared with MG V soybeans in NC, and more eggs on MG V soybeans than on MG VI soybeans in SC (Table 6). Cumulative insect days for adults per sweep were also affected by maturity group alone in SC during 2013 (Table 4). More insect days for adults were accrued on MG IV and V soybeans compared with MG VII soybeans. Additionally, densities of nymphs per plant were also influenced by maturity group when soybeans were V6 or older in NC during 2012 and 2013 (Table 5). More nymphs per plant were found in soybeans planted with MG IV compared with MGs V and VI, where MG VII soybeans had the same nymph density compared with the rest of MGs (Table 6).

Soybean Yield

The interaction between planting date and maturity group influenced soybean yield in NC (Table 5), the SC insecticide-treated trial in 2012 (Table 3), and the SC 2013 (Table 4). Yields (ranging from 3,300–3,700 kg/ha) were higher for MG IV, V, and VI soybeans planted in May compared with MG IV soybeans planted in either April or June (Fig. 4). There were relatively high yields for MG VI and VII soybeans planted in April (Fig. 4). Yields were relatively lower for MG V and VI soybeans planted in June (SC 2012 insecticide-treated trial), for MG VII soybeans planted during June (SC 2012 insecticide-treated trial and SC 2013), and for MG V soybeans planted during April (SC 2012 insecticide-treated trial; Fig. 4). Planting date and maturity group alone (Table 3) affected yield in the SC untreated trial in 2012. Soybeans planted in May and July usually had higher yields than April-planted soybeans (Table 2). Yields were higher in MG V soybeans, compared with MG IV and VI soybeans (Table 6).

Soybean yields were influenced by both the interaction between planting date and insecticide regime in SC in 2013 (Table 4), and the interaction between MG and insecticide regime in NC (Table 5) and SC in 2013 (Table 4). Plots yielded more when treated with insecticide and planted either in April or May, compared with the untreated plots planted during April, May, or June, and insecticide-treated plots planted in June (Supp Table 2 [online only]). In addition, insecticide-treated soybeans planted with MG V yielded more, compared with insecticide-treated soybean planted with MG IV or untreated soybeans planted with either MG IV or V in NC (Fig. 5). In SC during 2013, insecticide-treated soybeans planted with MG V and VI soybeans had higher yields compared with insecticide-treated soybean planted with MG IV or untreated soybeans planted with either MG IV or V, and untreated soybeans planted with MG IV (Fig. 5).

Table 5. Analysis of variance results for planting date, maturity group, and insecticide effects on *M. cribraria* egg mass numbers, cumulative insect days for nymphs and adults per sweep, and cumulative nymphs and adults per plant in North Carolina using combined data from 2012 and 2013

Response variable	Source of variation	df	*F*	*P*
Cumulative egg masses/25 trifoliates	Planting date	2, 177	207.36	<0.0001
	Maturity group	3, 177	4.15	0.0071
	Planting date × maturity group	6, 177	0.63	0.7036
	Insecticide	1, 180	131.84	<0.0001
	Insecticide × planting date	2, 180	15.37	<0.0001
	Insecticide × maturity group	3, 180	0.11	0.9526
	Insecticide × planting date × maturity group	6, 180	0.29	0.9425
Cumulative insect days for nymphs/sweep	Planting date	2, 345	3.09	0.0469
	Maturity group	3, 345	0.66	0.5796
	Planting date × maturity group	6, 345	1.02	0.4130
	Insecticide	1, 345	98.62	<0.0001
	Insecticide × planting date	2, 345	5.21	0.0059
	Insecticide × maturity group	3, 345	0.69	0.5560
	Insecticide × planting date × maturity group	6, 345	0.96	0.4492
Cumulative insect days for adults/sweep	Planting date	2, 165	102.44	<0.0001
	Maturity group	3, 165	1.98	0.1183
	Planting date × maturity group	6, 165	1.82	0.0990
	Insecticide	1, 180	302.41	<0.0001
	Insecticide × planting date	2, 180	4.94	0.0081
	Insecticide × maturity group	3, 180	2.16	0.0939
	Insecticide × planting date × maturity group	6, 180	1.19	0.3160
Cumulative nymphs/plant	Planting date	2, 345	13.60	<0.0001
	Maturity group	3, 345	4.90	0.0024
	Planting date × maturity group	6, 345	1.26	0.2772
	Insecticide	1, 345	141.13	<0.0001
	Insecticide × planting date	2, 345	47.67	<0.0001
	Insecticide × maturity group	3, 345	0.88	0.4538
	Insecticide × planting date × maturity group	6, 345	0.69	0.6583
Cumulative adults/plant	Planting date	2, 165	104.29	<0.0001
	Maturity group	3, 165	0.87	0.4597
	Planting date × maturity group	6, 165	0.72	0.6324
	Insecticide	1, 180	168.11	<0.0001
	Insecticide × planting date	2, 180	7.06	0.0011
	Insecticide × maturity group	3, 180	0.22	0.8790
	Insecticide × planting date × maturity group	6, 180	0.42	0.8660
Yield (kg/ha)	Planting date	2, 165	18.93	<0.0001
	Maturity group	3, 165	3.22	0.0241
	Planting date × maturity group	6, 165	3.20	0.0054
	Insecticide	1, 180	20.19	<0.0001
	Insecticide × planting date	2, 180	0.57	0.5650
	Insecticide × maturity group	3, 180	4.60	0.0040
	Insecticide × planting date × maturity group	6, 180	1.61	0.1463

There was a negative relationship between soybean yield (sometimes $\log_{10}$-transformed) and $\log_{10}$-transformed abundance of *M. cribraria* in a majority of locations in NC and SC (Table 7). Higher-yielding trials in NC (average yield above 3,344.64 kg/ha), including Montgomery County during 2012 and Scotland County during 2013, with relatively low pressure from *M. cribraria* (below 2.40 and 10.78 cumulative adults and nymphs per sweep in 2012 and 2013, respectively) failed to show a relationship between soybean yield and insect abundance. Coefficients of determination (R^2) were 0.23 or higher when insect levels were 27.59 cumulative adults and nymphs per sweep or higher, and soybean yield ranged from 2,585.73 to 3,050.16 kg/ha.

Discussion

The present study showed that in the early season, when plants were at V5 growth stage or younger, both planting date and maturity group influenced *M. cribraria* egg masses and adult densities in soybeans. This study also showed that in soybeans at the V6 growth stage and older, *M. cribraria* densities, as measured by both cumulative insects per sweep and number of insects per plant, were consistently influenced by the interaction between soybean planting date and insecticide treatment regime.

Adults in the early season, when plants were at V5 growth stage or younger, were assumed to be from the F_0 generation (coming directly from overwintering sites), although this study did not address the origin of the adult population. There was not a clear preference of dispersing adults for any MG of soybeans planted during May or June in NC nor any MG of soybean planted during April in SC. Adult densities were more abundant in MG V and VI soybeans planted during April, compared with MGs IV and VII planted during the same month in NC. In addition, more adults were found on soybeans of all maturity groups planted during April in SC, compared with soybeans of all maturity groups planted in June. Fewer adults emigrating from overwintering sites and the existence of an early planted host in the field could have reduced adult densities in June-planted soybeans when plants were at the V5 growth stage or younger. We can infer that fewer egg masses were found in June-planted soybeans because there were fewer adults in those late planted soybean plots. For instance, fewer eggs were found in MG V soybeans planted during June in NC, compared with MG V soybeans planted in April. Fewer egg masses were also found in SC soybeans planted in May than April, and fewer were found in soybeans planted in June than May. However, we cannot explain the fact that there were fewer egg masses on MG IV, an indeterminate soybean variety, and MG VII, a determinate soybean variety, planted in April in NC, when compared with MG V and MG VI (both determinate varieties). Since a single variety was used as a proxy for MG effects, one possible explanation could be a varietal effect. Different varieties were planted in SC and adult densities were not assessed in the early season during 2012. Moreover, the effect was only observed in a single year in NC. So it is not possible to test this hypothesis with data we collected in this study.

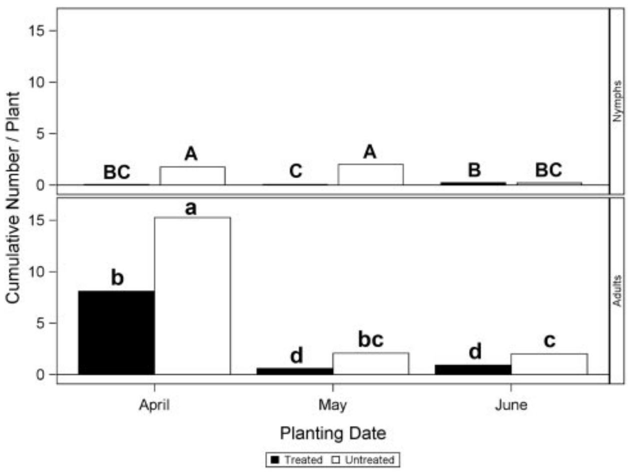

Fig. 3. Significant effects of the interaction between planting date (X-axis) and insecticide use (treated plots—black bars, untreated plots—white bars) on *M. cribraria* nymphs (upper panel) and adults (lower panel) per soybean plant older than V5 growth stage in North Carolina during 2012 and 2013. Means sharing the same letters are not statistically different ($\alpha > 0.05$). Separate analyses are presented at each row level.

In soybeans at the V6 growth stage and older, *M. cribraria* densities were consistently influenced by the interaction between soybean planting date and insecticide treatment regime. Although the assignment of the sub-sub-plot for NC (insecticide treatment regime) and SC (planting date) varied in 2013, the overall findings were similar, despite the different precision levels for each factor. *Megacopta cribraria* was most prevalent in untreated soybeans planted in April compared with soybeans planted in June and left untreated, corroborating a previous finding from Georgia (Blount et al. 2015). However, our findings were not as pronounced in NC, as those observed in the GA study. Whereas they observed 73% fewer adults in June-planted soybeans, we observed only 55% fewer in NC (data from both years combined). Early planted soybeans are one of the first hosts available for overwintering adults of *M. cribraria* (Ruberson et al. 2013), which could explain this phenomenon. Hence, more *M. cribraria* egg masses were laid on these early planted soybeans (April planted) when they were at, or before, the V5 growth, compared with June- or July-planted soybeans. Furthermore, there could be an interaction of geography with planting date and infestation rate. One possible factor influencing dispersal might be that *M. cribraria* breaks overwintering diapause earlier in southern latitudes than northern ones due to changes in temperature or impacts of photoperiodism. Yet another possibility is a density-dependent effect, as densities were higher in the GA study and in SC trials, compared with those in NC.

Planting date alone influenced *M. cribraria* densities when it was not possible to incorporate the insecticide treatment in the statistical analysis (SC experiment from 2012). More *M. cribraria* eggs masses were always found in April-planted soybeans compared with July-planted soybeans at either of the separate insecticide-treated or untreated trials during SC 2012. Insecticide application to an entire field drastically reduced *M. cribraria* densities in this trial where ~10 times fewer cumulative insect days for adults per sweep accrued, compared with the untreated trial during SC 2012. Densities of nymphs and adults of *M. cribraria* were affected by planting date when insecticide was sprayed as a whole-field application, compared with the adjacent field left untreated during SC 2012. Planting date also affected where egg masses of *M. cribraria* were laid in the SC 2013 trial, as attractive host for oviposition was available at different times during the season. However, planting date alone did not influence subsequent life stages of *M. cribraria*. Higher mobility and interplot movement of adults might have impacted the in-field distribution of *M. cribraria* in plots with different planting dates and insecticide regimes in the SC 2013 trial.

Table 6. Significant effect of maturity group (Roman numerals) on significant response variables in North and South Carolina during 2012 and 2013, using *M. cribraria* and soybean yield data

Year	Location	Response variable	Maturity group (mean ± SE)			
			IV	V	VI	VII
2012 & 2013	North Carolina	Cumulative egg masses/25 trifoliates	29.90 ± 3.99 A	21.24 ± 3.32B	24.91 ± 3.01AB	22.95 ± 2.70AB
2012 & 2013	North Carolina	Cumulative nymphs/plant	0.95 ± 0.19 a	0.60 ± 0.19b	0.66 ± 0.20b	0.70 ± 0.14ab
2012	SC Untreated[a]	Yield (kg/ha)	1,303.39 ± 107.47 B	1,746.74 ± 138.99A	1,415.11 ± 55.82B	1,572.64 ± 105.17AB
2013	South Carolina	Cumulative egg masses/25 trifoliates	13.42 ± 1.78 b	22.13 ± 3.59a	11.46 ± 2.19c	11.42 ± 1.78bc
2013	South Carolina	Cumulative insect days/sweep for adults	570.88 ± 129.23 A	661.03 ± 184.08A	513.36 ± 141.53AB	265.75 ± 53.91B

Each row in the table represents a separate statistical analysis. Means ± standard error (SE) sharing the same letters are not statistically different ($\alpha > 0.05$).
[a] In 2012, there were two separated tests where one field was sprayed with insecticide and the adjacent field was left untreated.

Rapid oviposition of eggs during early growth stages (VC to V2) might have been one of the reasons why early planted soybeans accumulated higher populations of *M. cribraria* throughout the season; it is also possible that presence of *M. cribraria* adults early in the season might have attracted later emigrating adults into these experimental fields. Adults already established in the crop might have produced semiochemicals that influenced movement patterns by directly or indirectly attracting subsequent emigrant adults in the field. The existence of an aggregation pheromone in *M. cribraria* has not been proven; however, research and field observations have shown that adults cluster while feeding on host plants (Seiter et al. 2013a) and that they aggregate for mating (Hibino and Itô 1983). There was only one instance where relatively high numbers of *M. cribraria* adults were recorded in July (SC in 2012 insecticide-treated trial). There were fewer *M. cribraria* adults in the beginning of the sampling period in late planted soybeans (5–13 adults per 10 sweeps), compared with the last sampling dates at the same plots (170–280 adults per 10 sweeps). Possibly the increase in *M. cribraria* adult abundance in late planted soybeans at this trial originated from a late infestation of F_1 generation of immigrant *M. cribraria* adults.

Maturity group alone did not consistently have an effect on densities of *M. cribraria* when plants were at V6 growth stage and older; our studies included both indeterminate varieties (MG IV) and determinate varieties (MGs V-VII). Maturity group did have a significant effect in SC during 2013, where more *M. cribraria* adults were found in MG V soybeans compared with MG VII. Because *M. cribraria* is thought to feed on phloem components (Zhang et al. 2012), the presence or absence of reproductive plant tissue would not likely be a major driving force to attract *M. cribraria* to soybeans. However, soluble nutrient content in soybeans can vary in the phloem (Walter and DiFonzio 2007) and xylem (Krishnan et al. 2011), and this is dependent on plant developmental stage. This, in turn, can influence densities of insects, such as aphids (Walter and DiFonzio 2007). In SC, the peak of *M. cribraria* oviposition (9.81 egg masses per 25 trifoliates) was recorded on 19 June 2013. At that time, MG V soybeans were at fully flowering (R2), while MG VII soybeans were under vegetative stage (V8–V9). Higher number of egg masses were recorded from MG V soybeans (15.50 egg masses per 25 trifoliates), compared with MG VII soybeans (8.25 egg masses per 25 trifoliates). Having more egg masses during crop establishment or during early growth stages could have led to a larger first in-field generation (F_1 generation) of *M. cribraria* in MG V plants in SC during 2013.

The interaction between planting date and maturity group consistently influenced soybean yield in NC and SC. In contrast to a related study that did not find an interaction (Blount et al. 2015), soybeans in our study usually yielded more when planted in May or April using MGs V or VII variety, respectively. Optimum yield can be achieved when the ideal planting date and maturity group are selected for a specific environment or location (Hu 2013). Environmental conditions, such as average daily temperatures,

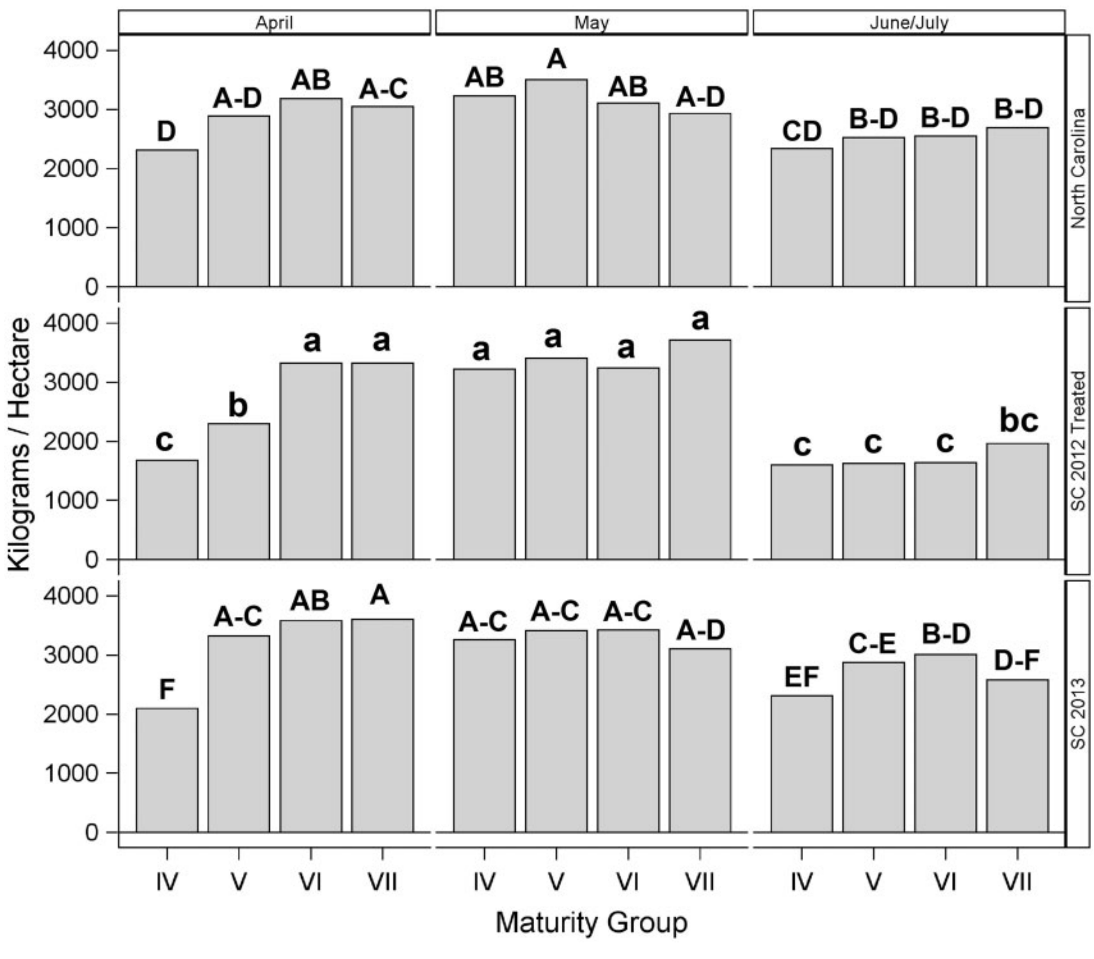

Fig. 4. Significant effect of the interaction between planting date and maturity group (roman numerals on X-axis) on soybean yield in North and South Carolina during 2012 and 2013. Means sharing the same letters are not statistically different ($\alpha > 0.05$). Separate analyses are presented at each row level.

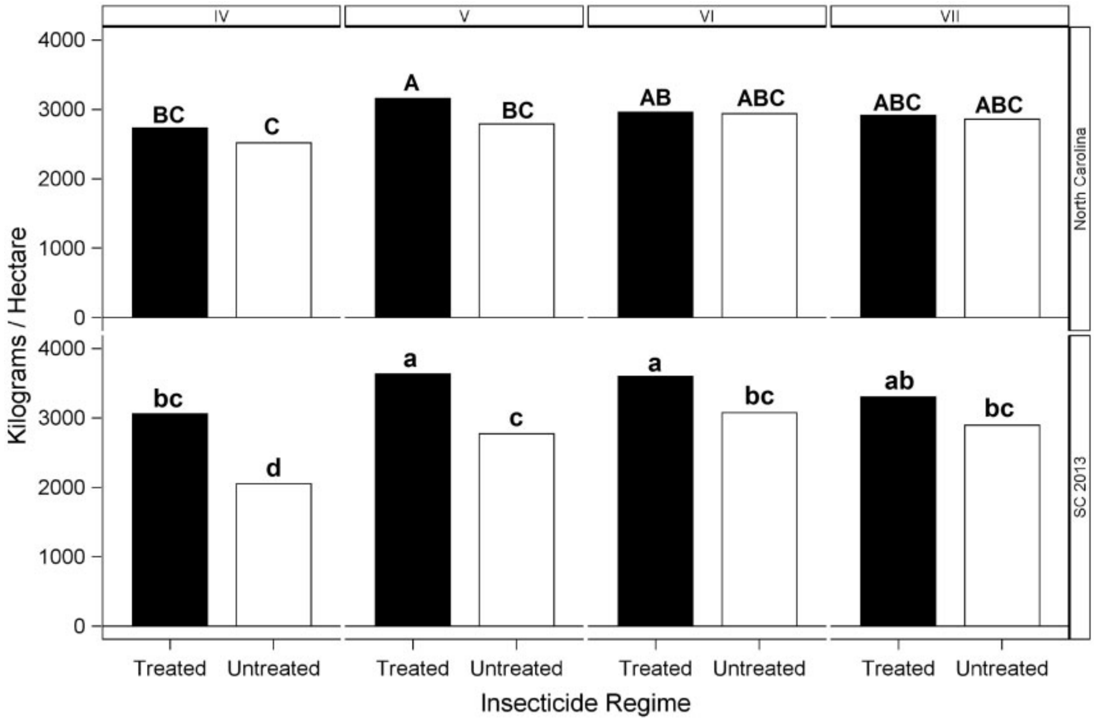

Fig. 5. Significant effect of the interaction between maturity group (Roman numerals) and insecticide regime (X-axis) on soybean yield in North Carolina during 2012 and 2013 and South Carolina in 2013. Means sharing the same letters are not statistically different ($\alpha > 0.05$). Separate analyses are presented at each row level.

drought periods, and the length of the day directly impact plant physiology and, ultimately, yield. In this study, soybeans planted in June or April using a MG IV variety usually yielded the least. Soybean yield was also impacted by the interaction of insecticide treatment (which reduced densities of *M. cribraria*) and planting date in SC in 2013, similar to a previous related study (Blount et al. 2015). For example, soybean yield was reduced by 20.6% in SC in 2013 when May planted untreated plots were compared with insecticide-treated plots. Blount et al. (2015) found a 28.18% reduction when untreated soybeans were compared with insecticide-treated soybeans planted in May.

In our study, soybean yield was also influenced by the interaction of insecticide treatment and maturity group in NC (data from both years combined) and SC in 2013, an effect not observed by Blount et al. (2015). Generally, in our study, early maturing soybeans (MGs IV and V) treated with insecticide had higher yields compared with untreated soybeans with the same MGs. This effect was not as consistent with later maturity groups. Earlier maturing soybeans, by definition, reach reproductive status sooner, leaving less time for compensation. This, combined with the stress of *M. cribraria* feeding throughout the season might have affected plant performance, and ultimately yield, in untreated plots.

There was a positive correlation between soybean yield loss and high numbers of *M. cribraria* (adults and nymphs) in five of the seven locations in this study. Even when we combined data from all trials in a single analysis (data not shown), the correlation between these two factors was still positive and with a R^2 of 0.14. There was no relationship between soybean yield and insect densities in experiments where relatively lower numbers of *M. cribraria* occurred with relatively high-yielding soybean plots (Montgomery County, NC, 2012 and Scotland County, NC, 2013). Plants can compensate for insect herbivory (Trumble et al. 1993), and soybeans have the capacity to compensate for yield under stressed conditions, including injury caused by insects (Ball et al. 2014). Furthermore, there is likely an interaction among yield potential of the soybean crop, *M. cribraria* density, and duration of the infestation. In the NC experiments with relatively high yields (ranging from 3,334.64 to 3,601.15 kg/ha), densities of *M. cribraria* recorded in two locations of this study were very low and always under the proposed action threshold by Seiter et al. (2015a) of one nymph per sweep. Finally, we use the term "relatively high yielding," because yields were compared to our lower yielding trials (from 1,509.47 to 3,050.16 kg/ha). The average soybean yield in NC and SC during 2012 and 2013 was 2,471 and 2,084 kg/ha, respectively (USDA 2015). Hence, most fields in these areas will likely not exhibit good yield compensation under *M. cribraria* infestations at or near threshold.

This study clearly demonstrates that early planted soybeans are at high risk of having infestations of *M. cribraria*, a principle corroborated with another study (Blount et al. 2015). Historically, southeastern U.S. soybeans planted early in the planting window resulted in reduced susceptibility to late-season defoliators. However, early planting now will put soybeans at a higher risk for infestation and yield loss due to *M. cribraria* if the species continues to be a prominent pest early in the season. Manipulating planting date to manage *M. cribraria* could be an important cultural control for this pest in soybeans. Planting soybeans during the middle of May or later will ensure lower *M. cribraria* infestations, compared with an earlier planting. Lowering the risk of higher infestation of *M. cribraria* in soybeans will aid to reduce insecticide applications in this crop. Reducing insecticide active ingredient per hectare will decrease the negative effects of whole-field applications on natural enemies (Higley and Boethel 1994). Reducing insecticide applications will also alleviate the cost of labor, equipment, and supplies during the growing season, ultimately increasing farmer's profits. Modifying

Table 7. Regression analyses between soybean yield (kg/ha) [response variable] and *M. cribraria* (cumulative adults and nymphs per sweep) [independent variable] in NC and SC locations for 2012 and 2013

Year	Location	Variable	Min	Max	Mean	SE	Regression analysis			
							F	P	R^2	Equation
2012	Montgomery Co., NC	Yield (kg/ha)	1,626.81	4,864.26	3,344.64	70.73	0.001	0.9722	0.001	$Yield = 3{,}350.04 - 11.09 \times \log_{10}(adults + nymphs/sweep)$
		Adults + nymphs/sweep	0.10	11.30	2.40	0.19				
	Scotland Co., NC	Yield (kg/ha)	675.53	4,084.26	2,576.67	83.61	15.250	0.0002	0.14	$Yield = 3{,}080.87 - 1{,}261.10 \times \log_{10}(adults + nymphs/sweep)$
		Adults + nymphs/sweep	0.05	6.70	1.83	0.16				
	Barnwell Co., SC (untreated)	Yield (kg/ha)	613.02	2,357.76	1,509.47	56.83	7.310	0.0096	0.14	$Yield = 2{,}072.50 - 141.83 \times \log_{10}(adults + nymphs/sweep)$
		Adults + nymphs/sweep	47.80	1007.90	453.36	38.48				
	Barnwell Co., SC (insecticide treated)	Yield (kg/ha)	1270.83	3830.36	2585.73	122.32	13.350	0.0007	0.23	$\log_{10}(Yield) = 3.57 - 0.13 \times \log_{10}(adults + nymphs/sweep)$
		Adults + nymphs/sweep	3.30	220.10	27.59	6.06				
2013	Montgomery Co., NC	Yield (kg/ha)	226.49	3,224.21	1,909.70	63.71	11.840	0.0009	0.11	$Yield = 2{,}440.73 - 412.55 \times \log_{10}(adults + nymphs/sweep)$
		Adults + nymphs/sweep	1.80	80.50	18.37	1.55				
	Scotland Co., NC	Yield (kg/ha)	1,692.49	5,973.46	3,601.15	87.19	0.004	0.9522	0.001	$\log_{10}(Yield) = 3.54 + 0.001 \times \log_{10}(adults + nymphs/sweep)$
		Adults + nymphs/sweep	0.60	86.05	10.78	1.39				
	Barnwell Co., SC	Yield (kg/ha)	111.49	4,412.48	3,050.16	72.10	29.970	<0.0001	0.24	$Yield = 3{,}700.79 - 286.48 \times \log_{10}(adults + nymphs/sweep)$
		Adults + nymphs/sweep	2.00	380.70	69.18	8.64				

Minimum (Min), maximum (Max), mean, and standard error (SE) values are also presented for each variable.

the planting date of soybeans aiming to control *M. cribraria* might impact yields, if the planting happens outside the proposed and recommended planting window by each region. Selection of different maturity groups might help to compensate any loss of heat units (Heatherly and Hodges 1999), if planting date would be modified to manage *M. cribraria* in soybeans.

The mechanisms behind how *M. cribraria* is attracted to early planted soybeans are not fully understood. Future research should investigate dispersal patterns of this insect (from overwintering sites to soybean fields and movement within soybean fields) in order to elucidate the mechanism(s) for large populations of *M. cribraria* in early planted soybeans. Quality of host plant might be another factor influencing infestation levels of *M. cribraria* in soybeans. A complementary choice-test could be conducted in the field, where *M. cribraria* coming from overwintering sites would be concurrently exposed to soybean plants at different developmental stages, ranging from late-vegetative to early reproductive stages. Furthermore, it is also possible that endosymbionts of *M. cribraria* play an important role in this insect's "ability" to obtain essential nutrients for survival from a soybean plant. How these endosymbiont bacteria support *M. cribraria* growth is still unknown; however, Hosokawa et al. (2006) hypothesized that the endosymbionts might provide essential amino acids and vitamins to the insect.

This study also indicates that planting date and insecticide protection can be manipulated to influence populations of *M. cribraria* in soybeans. Changing planting date to manage an insect pest in a crop should be examined cautiously. For example, manipulation of planting date and maturity group in soybean may impact yield, independent of *M. cribraria* densities, as soybean yield potential is influenced by environmental factors such as temperature, rainfall, and day length. The only formal recommendation to alter planting date for insect management in soybean has been proposed under trap-cropping programs to use early planted soybeans for managing stink bugs (McPherson and Newsom 1984). Hence, ideal planting date and maturity group should be selected considering the geographical region and other factors that aimed for the best plant performance. When planting soybeans earlier in the Southeast, it is important to consider that those fields may be at higher risk of having economically damaging infestations of *M. cribraria*.

Supplementary Data

Supplementary data are available at *Journal of Economic Entomology* online.

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