ABSTRACT

SCHUG, HAYDEN T. Evaluating the Economic Threshold for *Helicoverpa zea* (Lepidoptera: Noctuidae) in Determinate and Indeterminate Soybeans. (Under the direction of Drs. Dominic Reisig and Anders Huseth).

Helicoverpa zea (Boddie) is one of the most serious pests that impacts soybeans (*Glycine max L*) in the southern US. *Helicoverpa zea* causes millions of dollars of damage annually in soybeans and, in North Carolina, usually accounts for at least 50% of all insect costs of management and losses. The current economic thresholds for *H. zea* are based on determinate growth habit soybeans. However, in recent years more North Carolina farmers have been planting indeterminate soybeans with lower relative maturity groups in order to capitalize on optimal growing conditions and harvest times. The objectives of my study are to investigate whether the economic thresholds for *H. zea* developed with determinate soybeans can be used for indeterminate soybeans and to determine how determinate and indeterminate soybeans compensate to simulated *H. zea* feeding. Due to differences in vegetative growth and reproductive growth, indeterminate soybeans may be better able to compensate to *H. zea* feeding than determinate soybeans.

To investigate if the current economic thresholds developed for determinate soybeans can be used for indeterminate soybeans, complementary trials were sampled across North Carolina and Arkansas. Field plots were manipulated with insecticides to create a check, low, medium, and high infestation level of *H. zea* in varieties of both growth habits. During infestation, weekly samples of larvae were taken along with damaged flowers and pods. At harvest, yield was taken along with yield components. Between two determinate and indeterminate varieties with the same relative maturity groups, there was not a significant difference in yield. I also found that there was not a significant difference in the number of *H. zea* or the number of flowers and pods

damaged between growth habits. The difference in seed weight was significantly different between growth habits, with indeterminate soybeans having the heavier seed weight.

To investigate the differences in compensation further, reproductive tissues were removed by hand to measure the differences in response. Paired determinate and indeterminate soybean varieties were damaged by hand during a single reproductive growth stage. There was no difference in the amount of seeds per pod between the determinate and indeterminate variety in any of the three levels of reportative tissue removal (0, 50%, 100% removal). There was a difference in seed weight, with the indeterminate variety having the heavier seed weight.

While seed weight was heavier for indeterminate soybeans, there was no difference in yield, indicating that the economic threshold used for determinate soybeans can be used for indeterminate soybeans. These experiments will provide useful context to improve our understanding of determinate and indeterminate soybeans response to *H. zea* damage.

Evaluating the Economic Threshold for *Helicoverpa zea* (Lepidoptera: Noctuidae) in Determinate and Indeterminate Soybeans.

by
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DEDICATION

To my significant other Emily: You have supported me though my undergraduate and graduate degree and helped me through all of life’s other adventures.

To my parents and siblings: You have always encouraged my ideas and are always there to support me when needed.

BIOGRAPHY

Hayden Schug grew up in upstate New York and moved to North Carolina in middle school. Upon entering high school, he started taking horticulture classes and worked in a nursery, leading to his interest in agriculture. After graduating high school, he obtained his undergraduate degree in Agricultural Science while minoring in Agricultural Business. Also, during undergrad, he started his own beekeeping business and worked with a local high school to teach the students about beekeeping. This sparked his interest in entomology, and he decided to combine his love for agriculture and entomology by pursuing his master's degree in Entomology at North Carolina State University.

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CHAPTER 1

Effects of *Helicoverpa zea* (Lepidoptera: Noctuidae) damage in determinate and indeterminate soybeans

Abstract

Soybeans (*Glycine max L*) are one of the most economically important row crops in North Carolina with more than a million acres planted annually. *Helicoverpa zea* (Boddie) is often the most serious insect pest in soybeans, causing direct yield loss and costing millions of dollars annually for farmers to manage. To combat these losses, farmers use economic thresholds to determinate the economically optimal time to apply pesticides. Economic thresholds for *H. zea* in North Carolina were developed from soybean varieties with determinate growth habits. Farmers in North Carolina have recently planted more soybeans varieties with indeterminate growth habits. In this study, I looked at both determinate and indeterminate soybeans to determinate if the same economic threshold can be used. To do this, trials were conducted in 2019 and 2020 in North Carolina and 2019 in Arkansas with two determinate and two indeterminate varieties. Insecticides were used to make a low, medium, high, and check infestation level of *H. zea* to see how determinate and indeterminate varieties would compensate to damage at different levels of infestation. My results showed no significant difference in yield between determinate and indeterminate soybeans. There was a significant difference in seed weight between the determinate and indeterminate varieties with the indeterminate having the heavier seed weight. These results show that the economic threshold developed for determinate soybeans can be used for indeterminate soybeans.

Introduction

Helicoverpa zea (Boddie) is a multivoltine polyphagous pest whose larvae feed on economically important crops. In the southern United States, it is a pest of the several row crops, including soybean (*Glycine max* L.), cotton (*Gossypium hirsutum* L.), corn (*Zea mays* L.), and sorghum (*Sorghum bicolor* L.) (Fitt, 1989; Olmstead et al., 2016). In this region, *H. zea* can complete at least four generations in a year before overwintering in the soil as pupae (Kennedy & Storer, 2000). In North Carolina, the first generation that emerges from overwintering oviposits on and the subsequent larval generation develops on wild host plants and whorl stage corn (Neunzig, 1963; Kennedy & Storer, 2000). The second generation develops on its preferred host, corn, during pollination and while kernels are filling (Terry et al., 1987). After this point, corn is not a suitable host, and the third generation typically develops on cotton and soybeans during late July and early August when these crops are flowering (Kogan & Turnipseed, 1987; Terry et al., 1987).

Soybeans are the most economically important row crop in North Carolina generating over 673 million dollars in agricultural revenue for the state in 2020 (USDA, 2011). Soybeans are short day plants, meaning that the photoperiod must be shorter than a specific time in order to induce a reproductive response (McWilliams et al., 1999; Stowe & Dunphy, 2017). Depending on their morphological growth habit, soybeans can be classified as determinate and indeterminate (McWilliams et al., 1999). Soybean varieties with an indeterminate growth habit (hereafter referred to as indeterminate varieties) start reproductive growth several weeks before they terminate vegetative growth (Stowe & Dunphy, 2017). In contrast, soybean varieties with a determinate growth habit (hereafter referred to as determinate varieties) terminate vegetative growth on the main stem when reproductive growth begins (Stowe & Dunphy, 2017). An additional classification for soybean varieties is maturity group (MG); a maturity group assignment is given to a variety based on how it responds to a particular photoperiod, ranging from MG 000 to MG X (D. A. McWilliams et al., 1999; Mourtzinis et al., 2017; Stowe & Dunphy, 2017). Maturity groups MG 000 are short season varieties that are typically grown in the northern United States and in Canada. Varieties with increasing maturity group number tend to be more optimal as latitude decreases, with the southern Gulf states often growing MG X varieties (McWilliams et al., 1999; Mourtzinis et al., 2017). Higher maturity groups historically grown in the southern United States typically have determinate growth habits, while lower maturity groups historically grown in the northern United States have typically have indeterminate growth habits (Parvez et al., 1989). In North Carolina, for example, soybean growers historically grew MG 5-7's with determinate growth habits (Mourtzinis et al., 2017; Stowe & Dunphy, 2017; Vann et al., 2021). However, more North Carolina growers are planting lower maturity group varieties that have an indeterminate growth habit (Vann et al., 2021). Planting maturity groups IV and lower in North Carolina can increase yields by 494 kg/ha and 346 kg/ha when planted earlier in the growing season, capitalizing on optimal growing conditions (Vann et al., 2021).

The length of flowering time typically varies between growth habits. Determinate varieties often flower for a shorter period of time (15-20 days) compared to indeterminate varieties (30-37 days) (Yoshida et al. 1983). However the length of flowering period can vary among varieties, planting dates within a year, and on the same planting date across years depending on annual environmental conditions (Egli, 2005). *Helicoverpa zea* prefers flowering plants for oviposition; thus, a difference in flowering duration could relate to the number of eggs deposited on soybeans with a particular growth habit (Johnson et al., 1975).

Helicoverpa zea larvae cause direct damage by feeding on soybean flowers and pods and can cause indirect damage from feeding on leaves that reduces overall plant health (Eckel et al., 1992b; Reisig et al., 2017). This can lead to yield loss if the number of *H. zea* larvae is high and the soybean plant cannot compensate for the feeding damage (Eckel et al., 1992a). However, in many seasons, soybeans have the ability to compensate substantially to injury caused by insect feeding (McPherson & Moss, 1989; Eckel et al., 1992a, 1992b, 1993). For example, when soybean plants had two thirds of their pods removed at growth stage R6, simulating insect injury, seed size was not affected compared to control plants (Thomas et al., 1976). However, the compensatory ability of the plant is not the same among growth stages. While soybean plants were able to compensate from simulated insect damage at growth stage R6, they were only partially able to compensate for damage by replacing lost pods in growth stages R6-R8 (Thomas et al., 1976). Additionally, flowers or pods damaged by *H. zea* can be replaced while plants are still flowering, but pod set might be delayed (Eckel et al., 1992a).

Both indeterminate and determinant soybeans can compensate for reproductive tissue loss. For example, if *H. zea* population levels decline before determinate varieties stop flowering, they have the ability to initiate additional flowering that results in small pods (Eckel et al., 1992a). Indeterminate soybeans can compensate to flower loss when the flowers are artificially removed at the R3 growth stage (Adams et al., 2015). Indeterminate soybeans can also compensate for 25% removal of flowers and pods with no loss in yield (Coelho et al., 2020). In a study comparing the defoliation response of determinate and indeterminate soybeans, an indeterminate variety was able to increase biomass by growing more leaves, allowing the plant to produce more photosynthate and preventing more yield loss compared to the determinate variety included in the study (Li et al., 2005). Despite several studies documenting the response of the plant to artificial damage, variable insect injury can further complicate the linkage between insect injury and soybean yield. The amount of *H. zea* damage varies greatly with the age of the plant and the instar of the larvae. In one study, a single *H. zea* larvae destroyed, on average, 37.5 seeds during early pod development stages, but only 4.2 seeds in the late pod development stages (McWilliams, 1983). Seed destruction also varies with larval instar. In the aforementioned study, 6th instar *H. zea* were responsible for half of the total number of seeds destroyed and caused more damage than both the penultimate and antepenultimate instars combined (McWilliams, 1983).

The economic thresholds for *H. zea* in North Carolina were established based on studies using later maturity group soybean varieties (MG 5-6) with determinate growth habits (Smith & Bass, 1972; Mueller & Engroff, 1980; McWilliams, 1984; McPherson & Moss, 1989; Eckel et al., 1992b). Because yield damage is likely an interaction between soybean growth habit and *H. zea* feeding intensity, we sought to better define field-relevant economic thresholds across multiple growing environments in North Carolina. This study investigates how determinate and indeterminate soybean varieties compensate to *H. zea* feeding damage, relating plant response capability to potential mechanisms of compensation between growth habits. The goal of this study is to determine if the current *H. zea* economic thresholds are relevant for both determinate and indeterminate soybean varieties. I hypothesized that indeterminate soybean varieties would have an increased ability to compensate for *H. zea* injury when compared to determinate varieties, because indeterminate soybeans are able to continue vegetative growth while starting reproductive growth and typically flower for a longer period of time. To test this hypothesis, experiments were designed to compare determinate and indeterminate varieties to determine if compensation mechanisms are the same when experiencing varying levels or duration of *H. zea* feeding pressure.

Materials and Methods

Experimental Design and Planting

Small plots were planted in a factorial design consisting of two main effects (soybean variety and *H. zea* population density) each with four replications in a randomized complete block design. In 2019, four experiments were planted in North Carolina (35.8488, -76.6574; 35.8937, -77.6725; 35.3007, -77.5774; 35.2357, -78.4320) and one experiment in Arkansas (34.1727, -91.9568). In 2020, and four experiments were planted in North Carolina (35.8488, -76.6573; 36.1356, -77.1790; 35.8966, -77.6729; 35.6629, -78.5048). Each plot was eight rows wide on 0.91 m row spacing, and 12.19 m long, with the exception of one experiment (35.3007, -77.5774) with 0.76 m row spacing and plots 12.19 m long. Four varieties were selected; two varieties had a determinate growth habit, while two varieties had an indeterminate growth habit. These were selected as pairs, with a variety with a determinate and indeterminate growth habit of within each relative maturity. The two pairs were: relative maturity group of 5.2, determinate 5220R2X/S (Bayer Crop Science, St. Louis, MO) and indeterminate AG52X9 (Bayer Crop Science), and relative maturity group of 5.9, determinate AG59X9 (Bayer Crop Science), and indeterminate H59-18R2X (Bayer Crop Science).

Plots were planted with commercial soybean planters at seed depths and seeding rates in accordance with local agronomic practices. Planting dates ranged from mid- to late-May depending on planting conditions at each location. In 2020, two out of the four experiments were omitted, one due to extensive white-tailed deer (*Odocoileus virginianus* Zimmerman) damage (35.8966, -77.6729) and the other due to kudzu bug (*Megacopta cribraria* F.) damage (36.1356,

-77.1790). *Helicoverpa zea* population levels were manipulated with either disruptive or selective insecticides to individual treatments as the second factor in addition to soybean variety. The insecticides were applied with a CO_2-powered backpack sprayer calibrated to deliver 15.32 liters per hectare at 379.21 kPa with two TX-10 hollow cone spraying nozzles (TeeJet, Dillsburg, VA) or mechanical sprayer. Acephate (Orthene 97, AMVAC, Los Angeles, CA, 178.79 g a.i./ha) was applied in mid-July to create a high *H. zea* infestation level by reducing natural enemies prior to *H. zea* oviposition. Chlorantraniliprole (Prevathon, DuPont, Wilmington, DE, 12.33 g a.i./ha) was applied in late-July to create a low *H. zea* infestation level. Asana (Asana XL, DuPont, Wilmington, DE, 2.84 g a.i./ha) was applied in early-August to create a medium infestation level. Finally, a single untreated plot of each variety was included in each replication.

***Helicoverpa zea* Sampling and Harvest**

Weekly surveillance sampling for *H. zea* was conducted in each field using a 0.3 m drop cloth starting in mid-July. Once the first larva was found in each field, two 0.3 m drop cloth samples were taken alternating between rows two and three or six and seven, weekly, until there were no more *H. zea* found in the field, around late-August. The instar of individual *H. zea* larva was recorded and summed to a count. Concurrently, ten randomly selected plants from each plot were inspected from rows four and five to count the number of flowers, pods, damaged flowers, and damaged pods. This was not done in Plymouth in 2019 and Lewison in 2020 due to personnel constraints; however, both field sites had low *H. zea* pressure.

When the plots were physiologically mature, all pods from 10 plants per plot were destructively sampled by hand and pods placed into paper bags. Two hundred seeds were mechanically counted using a seed counter and placed into paper envelopes. These envelopes were dried in an oven at 60 °C for 72 hours and then weighed to determine the average seed weight. Rows four and five where then mechanically harvested and yields were converted to 13% moisture content. The number of pods and number of seeds per pod were then counted.

Statistical Analysis

All trials in North Carolina were infested by *H. zea* larvae, while the Arkansas trial was not. To determine yield potential of varieties in the absence of *H. zea*, an analysis of variance (ANOVA) was conducted using the Arkansas data. Yield (kilograms per hectare) represented the independent variable and variety (separated into the paired determinate and indeterminate 5.2 and 5.9 maturity groups) represented the dependent variable. A linear mixed model approach was taken with variety coded as a fixed factor and replication coded as a random factor.

We assumed that compensation capability might differ when *H. zea* pressure was low when compared to high pressure, based on the findings of a previous study that showed a difference between low and high infestations (Reisig et al. 2017). Furthermore, we observed considerable *H. zea* infestation variation across study locations and years in this study. Finally, due to time constraints (as mentioned earlier), more yield component data were collected from high pressure trials (total flowers, damaged flowers, total pods, damaged pods). Therefore, the trials that were not dropped in North Carolina trials were split into either a high infestation or low infestation groups with the current economic threshold (2.89 *H. zea* larvae per row meter) as the division point. To classify study locations into either group, the number of *H. zea* larvae across the control (unsprayed) plots from the four replications (n=16) on a given sampling date was averaged. If this average reached the economic threshold at any point in the season, then it was placed into the high infestation category (*n* = 2 trials) and if it did not were placed into the low infestation category (*n* = 4 trials).

Grouped data from each category (high or low pressure) were then analyzed using a separate linear mixed effects regression ANOVA. ANOVA models from the high infestation trials included variety, infestation level, the interaction between variety and infestation level, growth habit, maturity group, and the interaction between growth habit and maturity group as fixed effects; yield components (kilograms per hectare, seed weight, total number of *H. zea*, total number of flowers, total number of damaged flowers, total number of pods, total number of damaged pods, total number of pods with one seed, total number of pods with two seeds, total number of pods with three seeds, total number of pods with four seeds) were then analyzed as a response variable in separate ANOVA models. Replication nested within location was included as a random effect in these models. Since less data were collected from low infestation trials, the same model structure was used but ANOVA tests were not conducted for total flower number, total damaged flowers, total pods, and total damaged pods. To satisfy the assumption of normality, yield components were log(x+1) transformed. All ANOVAs were conducted using the base RStudio (version 1.2.5033, R Core Team 2019) and the *lme4* package (v1.1-26; Bates et al., 2015). Means separations were performed with Tukey's honest significant difference test using the *lsmeans* package in R (version 2.30-0; Lenth, 2016).

Results

In the Arkansas trial where *H. zea* was not present, yield was not significantly different for the interaction of variety and infestation level (F = 0.617; df = 9, 48; P = 0.7765) and the main factor of infestation level (F = 2.70; df = 3, 48; P = 0.0565). Yield was higher for the determinate 5.2 variety compared to the indeterminate 5.9 variety (Table 1.1) (F = 3.498; df = 3, 48; P = 0.0224), but was not different between the growth habit pairs within each relative maturity.

In the high infestation category, yield was not significantly different for the interaction of growth habit and maturity group (*F* = 0.389; df = 1, 128; *P* = 0.5328), the main factor of growth habit (*F* = 0.280; df = 1, 128; *P* = 0.5968), and maturity group (*F* = 0.116; df = 1, 128; *P* = 0.734). The total number of *H. zea* was not significantly different for the interaction of variety and infestation level and the main factor of variety (Table 1.2). The total number of *H. zea* was significantly different for the main factor of infestation level (Table 1.2). Generally, the total number of *H. zea* was lower in the low infestation plots when compared to the check and high infestation plots (Table 1.3). However, the total number of *H. zea* in the medium infestation plots was equivalent to all other infestation levels. The total number of flowers was not significantly different for the interaction of variety and infestation level and the main factor of infestation level (Table 1.2). The total number of flowers was significantly different for the main factor of variety (Table 1.2). The number of total flowers was higher in the determinate 5.9 variety compared to determinate 5.2 and indeterminate 5.2 varieties (Table 1.3). However, total number of flowers was equal between the indeterminate 5.2 and determinate 5.9 varieties (Table 1.3). The total number of damaged flowers was not significantly different for the interaction of variety and infestation level and the main factor of infestation level (Table 1.2). The total number of damaged flowers was significantly different for the main factor of variety (Table 1.2). The total number of damaged flowers was higher in the indeterminate 5.9 variety compared to indeterminate 5.2 variety (Table 1.3). However, the total number of damaged flowers for both indeterminate 5.2 and 5.9 varieties was equivalent the determinate 5.2 and 5.9 varieties (Table 1.3). The total number of pods was not significantly different for the interaction of variety and infestation level and the main factor of infestation level (Table 1.2). The total number of pods was significantly different for the main factor of variety (Table 1.2). Generally, the total number of pods was higher in the determinate and indeterminate 5.2 varieties compared to determinate and indeterminate 5.9 varieties, but varieties with the same relative maturity were equivalent to each other (Table 1.3). The total number of damaged pods was not significantly different for the interaction of variety and infestation level and the main factor of infestation level (Table 1.2). The total number of damaged pods was significantly different for the main factor of variety (Table 1.2). The total number of damaged pods was higher in the determinate and indeterminate 5.2 varieties compared to determinate and indeterminate 5.9 varieties, but not among varieties of the same relative maturity (Table 1.3).

Also in the high infestation category, yields (kg/ha) were not significantly different for the interaction of variety and infestation level and the main factor of variety (Table 1.2). Yield was significantly different for the main factor of infestation level (Table 1.2). Low infestation plots had higher yields than medium infestation plots; however, both low and medium infestation plots were not significantly different from the high infestation and the check (Table 1.4). Seed weight was significantly different for the interaction of variety and infestation level (Table 1.2). However, the determinate 5.2 variety had seed weights that were equivalent to the indeterminate varieties in the check, medium infestation, and high infestation treatments, and the indeterminate 5.9 variety had seed weights that were equivalent to all other varieties in all insecticide treatments, except the check (Table 1.5). The number of pods with one seed was not significantly different for the interaction of variety and infestation level and the main factor of variety (Table 1.2). The number of pods with one seed was significantly different for the main factor of infestation level (Table 1.2). The number of pods with one seed was higher in the high infestation treatment compared to the low infestation, but were not different between the check and the medium infestation treatments (Table 1.4). The number of pods with two seeds was not significantly different for the interaction of variety and infestation level and the main factor of infestation level (Table 1.2). The number of pods with two seeds was significantly different for the main factor of variety (Table 1.2). The number of pods with two seeds was higher in the determinate 5.9 variety compared to the determinate 5.2 variety, but not different from the other varieties (Table 1.4). The number of pods with three seeds was not significantly different for the interaction of variety and infestation level and the main factor of infestation level (Table 1.2). The number of pods with three seeds was significantly different for the main factor of variety (Table 1.2). In general, the number of pods with three seeds was higher in the indeterminate 5.2 variety compared to the determinate and indeterminate 5.9 varieties (Table 1.4). However, the indeterminate 5.2 variety had numbers of pods with three seeds that were equivalent to the other varieties (Table 1.4). The number of pods with four seeds was not significantly different for the interaction of variety and infestation level and the main factor of infestation level (Table 1.2). The number of pods with four seeds was significantly different for the main factor of variety (Table 1.2). Generally, the number of pods with four seeds was higher in the indeterminate 5.2 variety compared the other varieties (Table 1.4).

In the low infestation category, yields (kg/ha) were not significantly different for the interaction of variety and infestation level, the main factor of variety, and the main factor of infestation level (Table 1.6). Like in the high infestation category, seed weight was not significantly different for the interaction of variety and infestation level and the main factor of infestation level (Table 1.6). Seed weight was significantly different for the main factor of variety (Table 1.6). In general, seed weight was heavier in the indeterminate 5.2 variety compared to the other varieties and seed weight in the determinate 5.9 variety was lighter compared to the other varieties (Table 1.7). However, seed weights were equivalent between the determinate 5.2 and indeterminate 5.9 varieties (Table 1.7). The total number of *H. zea* was not significantly different for the interaction of variety and infestation level but was significantly different for the main factors of variety and infestation level (Table 1.6). Generally, the total number of *H. zea* was lower in the indeterminate 5.2 variety compared to determinate 5.9 and indeterminate 5.9 varieties (Table 1.8). However, the total number of *H. zea* was equivalent between the determinate 5.2 variety and all other varieties (Table 1.8). The total number of *H. zea* was highest in the high infestation plots compared to all other plots and lowest in the low infestation plots compared to all other plots; numbers in both the check and medium infestation plots were equal to each other (Table 1.8). The number of pods with one seed was not significantly different for the interaction of variety and infestation level and the main factor of infestation level (Table 1.6). Although the main factor of variety was significant (Table 1.6), means failed to separate using the Tukey procedure (Table 1.8). The number of pods with two seeds was not significantly different for the interaction of variety and infestation level and the main factor of infestation level (Table 1.6). The number of pods with two seeds were significantly different for the main factor of variety (Table 1.6). The number of pods with two seeds was higher in the determinate 5.9 variety compared to the indeterminate 5.2 and indeterminate 5.9 varieties (Table 1.8). However, the determinate 5.2 variety had the number of pods with two seeds equivalent to all the other varieties (Table 1.8). The number of pods with three seeds was not significantly different for the interaction of variety and infestation level and the main factor of infestation level (Table 1.6). The number of pods with three seeds was significantly different for the main factor of variety (Table 1.6). In general, the number of pods with three seeds was higher in the determinate, and indeterminate 5.2 varieties compared to determinate, and indeterminate 5.9 varieties, but not between varieties of the same maturity group (Table 1.8). The number of pods with four seeds was not significantly different for the interaction of variety and infestation level and the main factor infestation level (Table 1.6). The number of pods with four seeds was significantly different for the main factor of variety (Table 1.6). Generally, the number of pods with four seeds was higher in the indeterminate 5.2 variety compared to the other varieties (Table 1.8). However, the determinate 5.2, 5.9 varieties and indeterminate 5.9 variety had a similar number of pods with four seeds (Table 1.8).

Discussion

This study evaluated the compensation ability of soybean to *H. zea* feeding among varieties with determinate and indeterminate growth habits. The hypothesis that varieties with an indeterminate growth habit can compensate differently to *H. zea* is true, but this difference in compensation did not lead to a significant difference in yield between varieties with an indeterminate or determinate growth habit within the same relatively maturity. Overall, yields of the determinate and indeterminate varieties that were tested were not significantly different when fed upon by *H. zea* at both low and high infestation levels. However, seed weight was significantly different for factors of variety and infestation level in both low and high infestation categories, indicating that indeterminate varieties compensated for yield loss. Moreover, in the Arkansas trial varieties yielded the same under no *H. zea* pressure; this indicated that the determinate and indeterminate varieties we tested within the same relative maturity did not have inherent differences in yield potential. Finally, total *H. zea* numbers were similar among varieties, implying that they did not prefer one variety over another. Taken together, these results indicate that varieties with determinate and indeterminate growth habits are equally suitable for *H. zea* colonization and that both can compensate for yield loss. Varieties with an indeterminate growth habit compensated differently than those varieties with a determinate growth habit by increasing seed weight.

Although there was no significant difference in yield, in the high infestation level trials the indeterminate 5.2 variety had the least number of total flowers and total damaged flowers, but the most total number of pods and total damaged pods along with the determinate 5.2 variety. The indeterminate 5.2 variety also had the heaviest seed weight and the greatest number of pods with three and four seeds; hence, this variety was able to compensate to *H. zea* feeding by increasing the seed weight and the number of pods with three and four seeds. Average seed weight was also different between determinate and indeterminate varieties at both low and high infestation levels of *H. zea*. In both high and low infestation levels, seed weight was heavier in the indeterminate varieties in both 5.2 and 5.9 relative maturities, indicating that, for this particular yield component, varieties with indeterminate growth habits were better than varieties with determinate growth habits. My results align with a previous study where indeterminate and determinate varieties differed in seed weight depending on defoliation timing (Goli & Weaver, 1986). While defoliation timing was not studied, *H. zea* levels could have had a similar effect on determinate and indeterminate varieties by causing stress to the plant. Although my studies show that seed weight is a potential compensation mechanism to feeding by *H. zea* in indeterminate varieties, higher infestation levels, plants under different environmental stress conditions, or the growth stage when *H. zea* infests the field, could provide more insight on potential compensation mechanisms.

The difference in total flower number and total damaged flowers between growth habits may be explained by flower availability. Varieties with determinate growth habits produce more flowers than varieties with indeterminate growth habits in a shorter amount of time, but varieties with indeterminate growth habits produce flowers for a longer period of time (Kuroda et al., 1998). Furthermore, while varieties with determinate growth habits, on average, flower for shorter periods of time, varieties with determinate growth habits shed flowers at a slower rate than varieties with indeterminate growth habits (Yoshida et al. 1983; Kuroda et al., 1998), potentially leaving more flowers available for consumption by *H. zea* for a longer period of time. This difference in flower shedding could explain why the indeterminate 5.2 variety had the least total flower number and total damaged flowers, but still had a high number of total pods. Along with differences in total flower number and total damaged flowers, there were differences in the total number of pods and damaged pods. The indeterminate and determinate 5.2 varieties had a higher number of total pods and total damaged pods. This is because they were further along in reproductive development than the later maturing 5.9 varieties, meaning that more pods were available to be fed upon by *H. zea*. Although early instar *H. zea* cannot survive solely on developing pods, they are one of their preferred tissue choices (Suits et al., 2017). This suggests that a greater number of pods available to *H. zea* in the earlier maturing varieties could have resulted in the higher number of damaged pods compared to the later maturing varieties.

Due to phenological differences between soybean growth habits, differences in flowering length, number of flowers, and number of pods at any point in time were observed in the field, but no significant difference was found in yield between growth habits. Although growth habits did not yield differently in this trial, further research looking at other phenological differences such as plant height, flower and pod placement in the canopy, and row spacing could show how different growth habits compensate to *H. zea* feeding. Yield component differences were also not consistent across maturity groups and infestation levels. This suggests that different maturity groups that start reproductive growth earlier or later in the season could have different results if there are no flowers or large pods when *H. zea* arrive in the field. Early instar *H. zea* have also been shown to prefer newly emerging trifoliates and can even develop on fully emerged trifoliates (Suits et al., 2017). This suggests that maturity groups that have developing pods and newly emerged trifoliates available for feeding by *H. zea* at the time when the infestation occurs may result in better survivorship or feeding opportunities for larvae, resulting in more damage to the plants.

The results of my study showed no significant difference in yield among varieties with determinate and indeterminate growth habits under both low and high infestations of *H. zea* Therefore, the current economic injury level developed using varieties with determinate growth habits can be used for varieties with indeterminate growth habits. Future studies should include a range of planting dates, maturity dates, and environmental conditions since this experiment focused on soybeans planted within the recommended planting window in a narrow range of maturity groups, and these factors can impact *H. zea* infestation. Differing environmental conditions can also affect how soybeans compensate to feeding. For example, soybeans were less susceptible to yield loss due to pod damage, with as many as two larvae per row-foot due to excellent moisture conditions in the soil (Smith & Bass, 1972), compared to an average of 1.3 per-row foot in my high infestation plots and high pressure trials. Another study found evidence that indeterminate varieties experiencing stress induced yield loss at a lower rate than determinate varieties (Nitami et al., 2013), suggesting that, during environmental stress, indeterminate varieties may be able to compensate more to *H. zea* feeding. Differences in planting dates, maturity groups, and environmental conditions, such as water availability, could affect how soybean growth habits are able to compensate to *H. zea* feeding by having more or less water available to support growth, larger or smaller pods, fewer flowers available for feeding, or no flowers developed when infestation occurs.

Helicoverpa zea larval densities could affect how indeterminate and determinate varieties compensate from feeding. While Eckel et al. (1992b) found that relatively low *H. zea* levels were able to affect yields in soybeans, Mueller and Engroff (1980) found that infestations of *H. zea* had no effect on yield in some years (even at three times the economic threshold), demonstrating a wide range of compensation to *H. zea* feeding on soybeans. Results from this study show that a new economic threshold likely may not need to be developed for varieties with an indeterminate growth habit in North Carolina in soybeans planted within the recommended planting window for full-season soybean. However, this study also shows that there are differences in compensation methods to *H. zea* feeding among varieties with determinate and indeterminate growth habits and that further research is needed understand the impact of planting date and environmental conditions to see if yield responses are consistent between growth habits.

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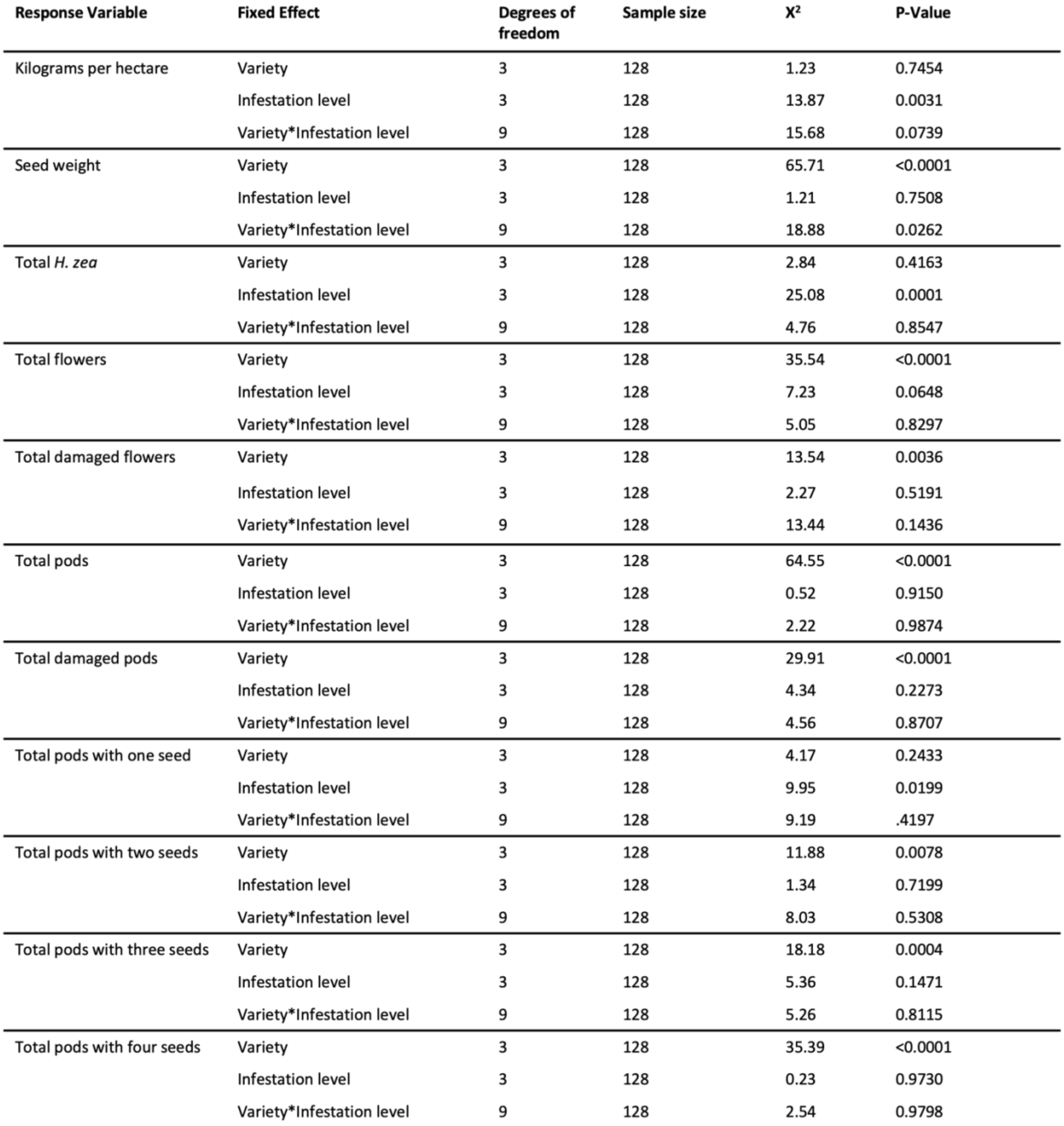
TABLES

Table 1.1. Arkansas mean ± SEM for variety, infestation level, and the interaction of variety and infestation level effect on kilograms per hectare.

		Variety and infestation level	**Kilograms per hectare**
Variety		Determinate 5.2	4380 ± 194a
		Indeterminate 5.2	4250± 150ab
		Determinate 5.9	4150± 150ab
		Indeterminate 5.9	3752± 150b
Infestation level		Check	4254± 150
		High	4182± 141
		Medium	4318± 202
		Low	3783± 150
Interaction of variety and infestation level	**Check**	Determinate 5.2	4767± 299
		Indeterminate 5.2	4367± 299
		Determinate 5.9	4222± 299
		Indeterminate 5.9	3660± 299
	High	Determinate 5.2	4371± 227
		Indeterminate 5.2	4638± 299
		Determinate 5.9	4099± 299
		Indeterminate 5.9	3622± 299
	Medium	Determinate 5.2	4437± 617
		Indeterminate 5.2	4279± 299
		Determinate 5.9	4239± 299
		Indeterminate 5.9	4317± 299
	Low	Determinate 5.2	3948± 299
		Indeterminate 5.2	3734± 299
		Determinate 5.9	4042± 299
		Indeterminate 5.9	3409± 299

[a] SEM (Standard error of the mean), Means in same row and column grouping followed by a different letter are significantly different (Tukey's HSD; $P < 0.05$).

Table 1.2. ANOVA results for the high infestation category with variety (separated into determinate and indeterminate, and 5.2, 5.9 maturity groups), infestation level, and the interaction between variety and infestation level as fixed effects; yield components were analyzed separately as the response variable.



Response Variable	Fixed Effect	Degrees of freedom	Sample size	X^2	P-Value
Kilograms per hectare	Variety	3	128	1.23	0.7454
	Infestation level	3	128	13.87	0.0031
	Variety*Infestation level	9	128	15.68	0.0739
Seed weight	Variety	3	128	65.71	<0.0001
	Infestation level	3	128	1.21	0.7508
	Variety*Infestation level	9	128	18.88	0.0262
Total *H. zea*	Variety	3	128	2.84	0.4163
	Infestation level	3	128	25.08	0.0001
	Variety*Infestation level	9	128	4.76	0.8547
Total flowers	Variety	3	128	35.54	<0.0001
	Infestation level	3	128	7.23	0.0648
	Variety*Infestation level	9	128	5.05	0.8297
Total damaged flowers	Variety	3	128	13.54	0.0036
	Infestation level	3	128	2.27	0.5191
	Variety*Infestation level	9	128	13.44	0.1436
Total pods	Variety	3	128	64.55	<0.0001
	Infestation level	3	128	0.52	0.9150
	Variety*Infestation level	9	128	2.22	0.9874
Total damaged pods	Variety	3	128	29.91	<0.0001
	Infestation level	3	128	4.34	0.2273
	Variety*Infestation level	9	128	4.56	0.8707
Total pods with one seed	Variety	3	128	4.17	0.2433
	Infestation level	3	128	9.95	0.0199
	Variety*Infestation level	9	128	9.19	.4197
Total pods with two seeds	Variety	3	128	11.88	0.0078
	Infestation level	3	128	1.34	0.7199
	Variety*Infestation level	9	128	8.03	0.5308
Total pods with three seeds	Variety	3	128	18.18	0.0004
	Infestation level	3	128	5.36	0.1471
	Variety*Infestation level	9	128	5.26	0.8115
Total pods with four seeds	Variety	3	128	35.39	<0.0001
	Infestation level	3	128	0.23	0.9730
	Variety*Infestation level	9	128	2.54	0.9798

Table 1.3. High infestation means ± SEM for variety, infestation level, and the interaction of variety and infestation level effect on soybean reproductive characteristics and *H. zea* injury.

	Variety and infestation level		Total *H. zea*	Total flowers	Total damaged flowers	Total pods	Total damaged pods
Variety		Determinate 5.2	11.2 ± 1.9	202 ± 27.3ab	7.9 ± 2.7ab	329 ± 38.2a	32.4 ± 9.8a
		Indeterminate 5.2	10.2 ± 1.9	173 ± 27.3a	5.3 ± 2.71b	340 ± 38.2a	36.2 ± 9.8a
		Determinate 5.9	14.0 ± 1.9	310 ± 27.3cb	5.9 ± 2.7ab	178 ± 38.2b	20.3 ± 9.8b
		Indeterminate 5.9	11.4 ± 1.9	378 ± 27.3c	15.6 ± 2.7a	133 ± 38.2b	18.7 ± 9.8b
Infestation level		Check	11.0 ± 1.9a	261 ± 27.3	9.7 ± 2.7	268 ± 38.2	30.4 ± 9.8
		High	20.2 ± 1.9a	217 ± 27.3	9.8 ± 2.7	256 ± 38.2	25.6 ± 9.8
		Medium	9.2 ± 1.9ab	269 ± 27.3	7.6 ± 2.7	232 ± 38.2	32.7 ± 9.8
		Low	6.7 ± 1.9b	315 ± 27.3	7.8 ± 2.7	223 ± 38.2	19.0 ± 9.8
Interaction of variety and infestation level	**Check**	Determinate 5.2	8.9 ± 3.8	178 ± 52.6b	5.3 ± 4.6	351 ± 65.3ab	39.0 ± 14.3
		Indeterminate 5.2	8.8 ± 3.8	152 ± 52.6a	8.6 ± 4.6	380 ± 65.3a	34.4 ± 14.3
		Determinate 5.9	15.6 ± 3.8	303± 52.6ab	5.5 ± 4.6	202 ± 65.3b	22.2 ± 14.3
		Indeterminate 5.9	10.6 ± 3.8	408 ± 52.6a	19.4 ± 4.6	139 ± 65.3b	26.1 ± 14.3
	High	Determinate 5.2	19.9 ± 3.8	175 ± 52.6ab	3.8 ± 4.6	349 ± 65.3a	35.0 ± 14.3ab
		Indeterminate 5.2	20.9 ± 3.8	112 ± 52.6b	4.6 ± 4.6	354 ± 65.3a	35.5 ± 14.3a
		Determinate 5.9	20.0 ± 3.8	264 ± 52.6ab	7.8 ± 4.6	176 ± 65.3b	14.1 ± 14.3b
		Indeterminate 5.9	19.9 ± 3.8	317 ± 52.6a	23.0 ± 4.6	154 ± 65.3b	17.6 ± 14.3ab
	Medium	Determinate 5.2	8.4 ± 3.8	187 ± 52.6	9.1 ± 4.6	314 ± 65.3a	39.5 ± 14.3a
		Indeterminate 5.2	6.3 ± 3.8	187 ± 52.6	2.9 ± 4.6	308 ± 65.3a	42.2 ± 14.3ab
		Determinate 5.9	14.3 ± 3.8	302 ± 52.6	7.3 ± 4.6	185 ± 65.3ab	25.5 ± 14.3ab
		Indeterminate 5.9	7.9 ± 3.8	402 ± 52.6	11.1 ± 4.6	122 ± 65.3b	23.6 ± 14.3b
	Low	Determinate 5.2	7.9 ± 3.8	269 ± 52.6	13.6 ± 4.6	302 ± 65.3	16.0 ± 14.3
		Indeterminate 5.2	5.1 ± 3.8	235 ± 52.6	5.3 ± 4.6	320 ± 65.3	32.9 ± 14.3
		Determinate 5.9	6.3 ± 3.8	372 ± 52.6	3.3 ± 4.6	150 ± 65.3	19.5 ± 14.3
		Indeterminate 5.9	7.4 ± 3.8	386 ± 52.6	9.0 ± 4.6	119 ± 65.3	7.5 ± 14.3

[a] SEM (Standard error of the mean), Means in same row and column grouping followed by a different letter are significantly different (Tukey's HSD; P < 0.05).

Table 1.4. High infestation means ± SEM for soybean yield components. Means in same row and column grouping followed by a different letter are significantly different (Tukey’s HSD; P < 0.05).

Variety and infestation level			Kilograms per hectare	Total pods with one seed	Total pods with two seeds	Total pods with three seeds	Total pods with four seeds
Variety		Determinate 5.2	3495 ± 129	16.2 ± 2.0	185 ± 13.1b	230 ± 15.3ab	1.7 ± 0.9b
		Indeterminate 5.2	3479 ± 129	18.1 ± 2.0	213 ± 13.1ab	242 ± 15.3a	6.3 ± 0.9a
		Determinate 5.9	3573 ± 129	20.2 ± 2.0	216 ± 13.1a	187 ± 15.3b	1.7 ± 0.9b
		Indeterminate 5.9	3502 ± 129	19.7 ± 2.0	201 ± 13.1ab	204 ± 15.3b	1.3 ± 0.9b
Infestation level		Check	3484 ± 129ab	16.7 ± 2.0ab	208 ± 13.1	221 ± 15.3	2.4 ± 0.9
		High	3438 ± 129ab	23.6 ± 2.0a	206 ± 13.1	197 ± 15.3	2.6 ± 0.9
		Medium	3372 ± 129b	16.4 ± 2.0ab	195 ± 13.1	215 ± 15.3	3.1 ± 0.9
		Low	3755 ± 129a	17.4 ± 2.0b	205 ± 13.1	231 ± 15.3	2.9 ± 0.9
Interaction of variety and infestation level	**Check**	Determinate 5.2	3400 ± 185	11.8 ± 3.8	180 ± 18.3	242 ± 22.9	1.1 ± 1.3b
		Indeterminate 5.2	3547 ± 185	13.8 ± 3.8	215 ± 18.3	255 ± 22.9	5.4 ± 1.3a
		Determinate 5.9	3475 ± 185	22.4 ± 3.8	235 ± 18.3	192 ± 22.9	1.9 ± 1.3b
		Indeterminate 5.9	3515 ± 185	18.8 ± 3.8	203 ± 18.3	194 ± 22.9	1.1 ± 1.3b
	High	Determinate 5.2	3324 ± 185	21.8 ± 3.8	200 ± 18.3	211 ± 22.9	1.6 ± 1.3ab
		Indeterminate 5.2	3161 ± 185	28.1 ± 3.8	209 ± 18.3	213 ± 22.9	6.5 ± 1.3a
		Determinate 5.9	3626 ± 185	20.2 ± 3.8	218 ± 18.3	172 ± 22.9	0.9 ± 1.3b
		Indeterminate 5.9	3643 ± 185	24.4 ± 3.8	198 ± 18.3	192 ± 22.9	1.3 ± 1.3b
	Medium	Determinate 5.2	3431 ± 185	16.1 ± 3.8	184 ± 18.3	234 ± 22.9	2.3 ± 1.3
		Indeterminate 5.2	3202 ± 185	15.5 ± 3.8	216 ± 18.3	250 ± 22.9	6.5 ± 1.3
		Determinate 5.9	3468 ± 185	21.0 ± 3.8	206 ± 18.3	188 ± 22.9	1.1 ± 1.3
		Indeterminate 5.9	3386 ± 185	13.0 ± 3.8	176 ± 18.3	185 ± 22.9	1.4 ± 1.3
	Low	Determinate 5.2	3824 ± 185	15.2 ± 3.8	174 ± 18.3	234 ± 22.9	1.8 ± 1.3
		Indeterminate 5.2	4008 ± 185	14.9 ± 3.8	211 ± 18.3	251 ± 22.9	6.6 ± 1.3
		Determinate 5.9	3722 ± 185	17.0 ± 3.8	208 ± 18.3	194 ± 22.9	1.9 ± 1.3
		Indeterminate 5.9	3466 ± 185	22.6 ± 3.8	226 ± 18.3	244 ± 22.9	1.3 ± 1.3

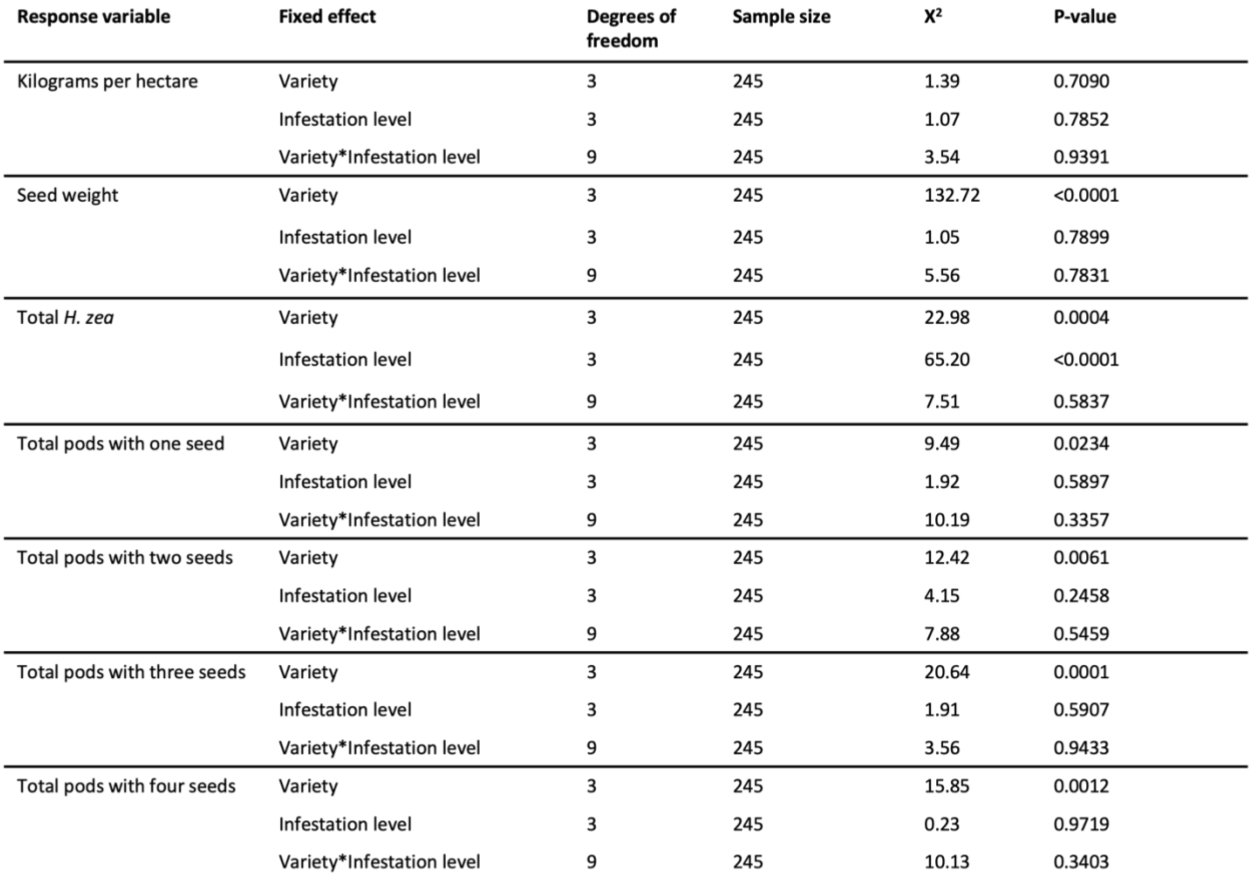
[a] SEM (Standard error of the mean), Means in same row and column grouping followed by a different letter are significantly different (Tukey’s HSD; P < 0.05).

Table 1.5. High infestation means +/- SEM for variety, infestation level, and the interaction of variety and infestation level effect seed weight.

		Variety and infestation level	**Seed weight**
Variety		Determinate 5.2	30.9 ± 0.6b
		Indeterminate 5.2	32.6 ± 0.6a
		Determinate 5.9	28.3 ± 0.6c
		Indeterminate 5.9	31.6 ± 0.6ab
Infestation level		Check	30.7 ± 0.6
		High	31.0 ± 0.6
		Medium	30.5 ± 0.6
		Low	31.1 ± 0.6
Interaction of variety and infestation level	**Check**	Determinate 5.2	30.4 ± 1.0ab
		Indeterminate 5.2	31.7 ± 1.0a
		Determinate 5.9	28.2 ± 1.0b
		Indeterminate 5.9	32.4 ± 1.0a
	High	Determinate 5.2	32.9 ± 1.0a
		Indeterminate 5.2	32.3 ± 1.0a
		Determinate 5.9	27.9 ± 1.0b
		Indeterminate 5.9	30.8 ± 1.0ab
	Medium	Determinate 5.2	31.0 ± 1.0a
		Indeterminate 5.2	32.8 ± 1.0a
		Determinate 5.9	28.1 ± 1.0b
		Indeterminate 5.9	30.3 ± 1.0ab
	Low	Determinate 5.2	29.4 ± 1.0b
		Indeterminate 5.2	29.4 ± 1.0a
		Determinate 5.9	33.5 ± 1.0b
		Indeterminate 5.9	32.7 ± 1.0ab

[a] SEM (Standard error of the mean), Means in same row and column grouping followed by a different letter are significantly different (Tukey's HSD; $P < 0.05$).

Table 1.6. Low infestation category with variety (separated into determinate and indeterminate, and 5.2, 5.9 maturity groups), infestation level, and the interaction between variety and infestation as fixed effects; yield components were separately analyzed as the response variable.



Response variable	**Fixed effect**	**Degrees of freedom**	**Sample size**	**X^2**	**P-value**
Kilograms per hectare	Variety	3	245	1.39	0.7090
	Infestation level	3	245	1.07	0.7852
	Variety*Infestation level	9	245	3.54	0.9391
Seed weight	Variety	3	245	132.72	<0.0001
	Infestation level	3	245	1.05	0.7899
	Variety*Infestation level	9	245	5.56	0.7831
Total *H. zea*	Variety	3	245	22.98	0.0004
	Infestation level	3	245	65.20	<0.0001
	Variety*Infestation level	9	245	7.51	0.5837
Total pods with one seed	Variety	3	245	9.49	0.0234
	Infestation level	3	245	1.92	0.5897
	Variety*Infestation level	9	245	10.19	0.3357
Total pods with two seeds	Variety	3	245	12.42	0.0061
	Infestation level	3	245	4.15	0.2458
	Variety*Infestation level	9	245	7.88	0.5459
Total pods with three seeds	Variety	3	245	20.64	0.0001
	Infestation level	3	245	1.91	0.5907
	Variety*Infestation level	9	245	3.56	0.9433
Total pods with four seeds	Variety	3	245	15.85	0.0012
	Infestation level	3	245	0.23	0.9719
	Variety*Infestation level	9	245	10.13	0.3403

Table 1.7. Low infestation means +/- SEM for variety, infestation level, and the interaction of variety and infestation level effect seed weight.

		Variety and infestation level	**Seed weight**
Variety		Determinate 5.2	26.2 ± 0.5b
		Indeterminate 5.2	28.4 ± 0.5a
		Determinate 5.9	24.7 ± 0.5c
		Indeterminate 5.9	25.8 ± 0.5b
Infestation level		Check	26.2 ± 0.5
		High	26.2 ± 0.5
		Medium	26.3 ± 0.5
		Low	26.4 ± 0.5
Interaction of variety and infestation level	**Check**	Determinate 5.2	25.7 ± 0.6b
		Indeterminate 5.2	28.1 ± 0.6a
		Determinate 5.9	25.1 ± 0.6b
		Indeterminate 5.9	25.7 ± 0.6b
	High	Determinate 5.2	26.4 ± 0.6ac
		Indeterminate 5.2	25.0 ± 0.6ac
		Determinate 5.9	24.5 ± 0.6b
		Indeterminate 5.9	25.9 ± 0.6c
	Medium	Determinate 5.2	26.0 ± 0.6a
		Indeterminate 5.2	28.7 ± 0.6c
		Determinate 5.9	24.7 ± 0.6ab
		Indeterminate 5.9	25.8 ± 0.6b
	Low	Determinate 5.2	26.7 ± 0.6a
		Indeterminate 5.2	28.7 ± 0.6c
		Determinate 5.9	24.4 ± 0.6b
		Indeterminate 5.9	25.9 ± 0.6ab

[a] SEM (Standard error of the mean), Means in same row and column grouping followed by a different letter are significantly different (Tukey's HSD; $P < 0.05$).

Table 1.8. Low infestation means +/- SEM for variety, infestation level, and the interaction of variety and infestation level effect on kilograms per hectare, total number of pods with one seed, total number of pods with two seeds, total number of pods with three seeds, total number of *H. zea* sampled throughout the season.

Variety and infestation level			Total *H. zea*	Kilograms per hectare	Total pods with one seed	Total pods with two seeds	Total pods with three seeds	Total pods with four seeds
Variety		Determinate 5.2	1.5 ± 0.4ab	2637 ± 268	17.0 ± 1.7a	164 ± 15.8ab	194 ± 16.7a	0.98 ± 0.24b
		Indeterminate 5.2	0.8 ± 0.4b	2741 ± 268	13.2 ± 1.7a	156 ± 15.9a	193 ± 16.8a	2.03 ± 0.25a
		Determinate 5.9	2.1 ± 0.4a	2781 ± 268	17.2 ± 1.7a	177 ± 15.9b	166 ± 16.8b	0.95 ± 0.26b
		Indeterminate 5.9	2.2 ± 0.4a	2636 ± 268	14.6 ± 1.7a	157 ± 15.8a	166 ± 16.7b	0.75 ± 0.25b
Infestation level		Check	1.2 ± 0.4b	2734 ± 268	15.1 ± 1.7	161 ± 15.8	176 ± 16.7	1.25 ± 0.25
		High	3.2 ± 0.4a	2693 ± 268	15.8 ± 1.7	162 ± 15.8	180 ± 16.7	1.19 ± 0.25
		Medium	1.6 ± 0.4b	2644 ± 268	16.0 ± 1.7	161 ± 15.8	179 ± 16.7	1.16 ± 0.25
		Low	0.5 ± 0.4c	2724 ± 268	15.2 ± 1.7	170 ± 15.8	183 ± 16.7	1.11 ± 0.25
Interaction of variety and infestation level	**Check**	Determinate 5.2	0.8 ± 0.6	2536 ± 286	17.3 ± 2.4	164 ± 17.3	195 ± 19.0	1.50 ± 0.45ab
		Indeterminate 5.2	0.8 ± 0.6	2759± 288	13.1 ± 2.4	153 ± 17.4	193 ± 19.2	2.59 ± 0.46a
		Determinate 5.9	1.4 ± 0.6	2869 ± 288	17.5 ± 2.4	169 ± 17.4	162 ± 19.2	0.59 ± 0.46ab
		Indeterminate 5.9	2.0 ± 0.6	2773 ± 286	12.3 ± 2.4	157 ± 17.3	172 ± 19.0	0.31 ± 0.45b
	High	Determinate 5.2	3.2 ± 0.6ab	2604 ± 286	19.1 ± 2.4	162 ± 17.3	198 ± 19.0	0.63 ± 0.45
		Indeterminate 5.2	1.5 ± 0.6a	2727 ± 288	12.2 ± 2.4	152 ± 17.4	192 ± 19.2	1.73 ± 0.47
		Determinate 5.9	3.9 ± 0.6b	2814 ± 290	14.1 ± 2.5	176 ± 17.6	165 ± 19.5	1.28 ± 0.48
		Indeterminate 5.9	4.3 ± 0.6b	2629 ± 286	17.9 ± 2.4	159 ± 17.3	161 ± 19.0	1.13 ± 0.45
	Medium	Determinate 5.2	1.6 ± 0.6	2650 ± 286	17.2 ± 2.4	158 ± 17.3	179 ± 19.0	1.19 ± 0.45
		Indeterminate 5.2	0.8 ± 0.6	2645 ± 288	14.5 ± 2.4	157 ± 17.4	196 ± 19.2	1.66 ± 0.47
		Determinate 5.9	2.2 ± 0.6	2709 ± 288	17.2 ± 2.4	173 ± 17.4	165 ± 19.2	0.99 ± 0.47
		Indeterminate 5.9	1.9 ± 0.6	2573 ± 286	15.1 ± 2.4	158 ± 17.3	166 ± 19.2	0.81 ± 0.45
	Low	Determinate 5.2	0.3 ± 0.6	2758 ± 286	14.5 ± 2.4	173 ± 17.3ab	203 ± 19.0	0.63 ± 0.45
		Indeterminate 5.2	0.1 ± 0.6	2833 ± 288	13.1 ± 2.4	161 ± 17.4a	192 ± 19.2	2.13 ± 0.47
		Determinate 5.9	0.8 ± 0.6	2734 ± 290	20.2 ± 2.5	192 ± 17.6a	173 ± 19.5	0.93 ± 0.48
		Indeterminate 5.9	0.7 ± 0.6	2572 ± 288	13.0 ± 2.4	154 ± 17.4b	164 ± 19.2	0.76 ± 0.47

[a] SEM (Standard error of the mean), Means in same row and column grouping followed by a different letter are significantly different (Tukey's HSD; $P < 0.05$).

CHAPTER 2

Effects of simulated *Helicoverpa zea* (Lepidoptera: Noctuidae) damage in determinate and indeterminate soybeans

Abstract

Determining how determinate and indeterminate soybeans compensate to *Helicoverpa zea* (Boddie) damage is essential to understand how to control these pests. To examine this, a determinate soybean variety and an indeterminate soybean variety with the same maturity group were compared. Each variety was subjected to 50%, 100%, or 0% reproductive tissue removal between the R1 and R3 growth stage to simulate *H. zea* feeding damage. Yield components were collected to look for differences between the determinate and indeterminate variety. We found no significant difference between the determinate and indeterminate soybeans in the number of seeds per pod. There was a significant difference in seed weight between the determinate and indeterminate varieties with the indeterminate variety having heavier seed weight. Our study suggests that there may not be a difference in yield components other than seed weight between determinate and indeterminate soybeans, even under high artificial reproductive tissue damage.

Introduction

Soybean (*Glycine max* L.) is the most widely planted crop in North Carolina with 1.6 million acres planted in an average year and valued at $800 million (Piggott, 2017). Soybean acreage in the United States has been steadily increasing since 1980, and has become an important component of profitable crop production (Piggott, 2017).

Soybeans are placed into categories based on the timing of reproductive growth stage onset and the morphological growth habit of the plant (Stowe & Dunphy, 2017). Soybean growth habits are split into two categories, determinate and indeterminate. Soybean varieties with a determinate growth habit (determinate varieties) terminate vegetative growth after the onset of reproductive growth (Stowe & Dunphy, 2017). In contrast, soybeans with an indeterminate growth habit (indeterminate varieties) continue vegetative growth for several weeks after the initiation of reproductive growth (Stowe & Dunphy, 2017). Varieties are divided further by the period from planting to initiation of the flowering growth stage. Pre-reproductive periods are used to organize soybean varieties into maturity groups; these group numbers represent a straightforward phenology classification system (Mourtzinis & Conley, 2017). Varieties with higher maturity numbers are common starting in Virginia, Tennessee and Arkansas and moving south, typically have determinate growth habits, and take longer to reach flowering stages compared to varieties with lower maturity groups grown in the same environment (Parvez et al., 1989; S. Mourtzinis et al., 2015). Varieties with lower maturity group numbers are typically grown in the northern United States, have indeterminate growth habits, and reach flowering stages in a shorter period of time (Parvez et al., 1989). In North Carolina, determinate varieties of soybeans have been historically grown in maturity groups 5-7 (Stowe & Dunphy, 2017). However, an increasing number of North Carolina farmers are currently experimenting with indeterminate varieties in lower maturity groups, hoping to capitalize the longer day length in June when they are flowering and with humidity that is conducive to optimal growth (Spyridon Mourtzinis et al., 2017; Vann et al., 2020). Beyond direct yield benefits, there is interest in producing earlier maturing soybean varieties for price premiums associated with early delivery and ability to harvest prior to hurricanes in the fall.

Helicoverpa zea (Boddie) is a multivoltine polyphagous pest whose larvae cause direct feeding damage to soybeans and can cause economic loss (Eckel et al., 1992a, 1992b). *Helicoverpa zea* is the most destructive pest soybeans in the Southern US and costs farmers millions of dollars annually across the region (Musser et al., 2020). For example, *H. zea* was responsible for 22.3% of all insect costs and losses during 2019 across 17 states that were surveyed and accounted for 52% of all insect costs and losses in North Carolina (Musser et al., 2020); it continues to be a key pest for annual scouting and management across many Southern states (Huseth et al., 2021). *Helicoverpa zea* can feed and develop on multiple parts of the soybean plant, including the leaves, flowers, and pods (Suits et al., 2017).

Soybeans possess the ability to compensate to *H. zea* feeding depending on the timing and intensity of feeding (McPherson & Moss, 1989; Eckel et al., 1992a, 1992b, 1993). However, studies have found mixed results between *H. zea* feeding and soybean yield. For example, one study found that three to five *H. zea* larvae per row foot reduced yields by 3.7-4.9 bushels per acre (Smith & Bass, 1972b); in contrast, another study found no significant yield impact with *H. zea* densities of 14 larvae per row foot, (Mueller & Engroff, 1980). The difference in response to *H. zea* feeding suggests that final yield may be influenced differently among varieties or across varying environmental conditions. This response may also differ between determinate and indeterminate growth habits based on compensation capabilities. Indeterminate varieties flower, on average, for 10 days longer than determinate varieties and this difference in flowering duration can change from year to year (Yoshida et al. 1983; Egli, 2005). In addition, this flowering period can be shortened further if the plants are stressed (Yoshida et al. 1983; Egli, 2005). *Helicoverpa zea* prefers to oviposit on flowering plants and, thus, a difference in flowering duration could directly affect oviposition intensity and subsequent larval injury to vegetative and reproductive tissues (Johnson et al., 1975).

Helicoverpa zea feeding has been simulated in previous studies to link yield loss to larval feeding (i.e., vegetative or reproductive tissues), feeding timing relative to soybean phenology, and plant compensation (McAlister & Krober, 1958; Thomas et al., 1974; Li et al., 2005; Adams et al., 2016; Coelho et al., 2020). These studies have shown that indeterminate varieties with simulated defoliation and reduction in stand numbers increased the number of pods per plant to compensate for potential yield loss (Teigen & Vorst, 1975). In a similar study with determinant soybeans, researchers found that yield was not affected by 33% defoliation at R6 or 100% depodding at R6 (Thomas et al., 1974). However, these studies did not directly compare determinate to indeterminate soybean yield response compensation outcomes when plants were exposed to *H. zea* feeding.

Soybean plants abort the majority of flowers prior to pod development. Depending on field conditions, determinate variety soybeans abort 67-82% of their flowers, while indeterminate varieties abort 69-90% of their flowers. As a result, direct flower herbivory by *H. zea* larvae may not affect final yield (Heitholt et al., 1986). Moreover, there is not an economic injury level for *H. zea* during the flowering period. Soybeans can compensate to florivory by *H. zea* without a yield loss, even at larval densities two to three times above the pod-stage economic injury levels (Reisig et al., 2017). Indeterminate varieties can compensate for 100% pod removal at R2 and 50% at R3 with no loss in yield (Adams et al., 2015). In a similar study, three indeterminate varieties were defoliated with no yield loss in a year with heavy rain, and at low levels of defoliation, yields increased compared to check plots, demonstrating that indeterminate varieties were be able to compensate substantially to damage (Haile et al., 1998). However, some other types of damage can result in yield loss. For example, when 50% of the plant was defoliated and the plant was cut in half, the yield was 8% and 4% lower for determinate and indeterminate varieties when compared to undamaged checks, respectively (Pickle & Caviness, 1984). When 100% of the plant was defoliated and the plant was cut in half, yield of the determinate variety was higher than the indeterminate variety, suggesting that determinate and indeterminate varieties may compensate differently depending on the extent of foliar injury (Pickle & Caviness, 1984).

Indeterminate varieties may be more tolerant of defoliation compared to determinate varieties, presumably because they continue vegetative growth after they start flowering. Indeterminate varieties can allocate biomass to leaf growth after simulated defoliation due to the continued vegetative growth (Li et al., 2005). Furthermore, indeterminate varieties are able to compensate to water stress induced yield loss more successfully than determinate varieties (Nitami et al., 2013); as a result, indeterminate varieties may be able to compensate to *H. zea* feeding better under water stress conditions. Reisig et al. (2017) evaluated the relationship of florivory by *H. zea* and yield using a determinate variety across multiple locations in North Carolina. This study found a significant negative relationship in only one out of four locations, suggesting the impact of *H. zea* feeding on yield was minimal. Further exploration of the single location revealed that the study was moisture deficient and had low numbers of *H. zea* larvae. The researchers surmised that this moisture deficiency inhibited plant compensation for *H. zea* feeding. In a different study, soybean plants were artificially defoliated in one year with wet conditions and no loss in yield was detected; however, when plants were defoliated in two other years with drought conditions, yield was reduced (Hammond & Pedigo, 1982). Although the interaction of moisture stress on soybean and *H. zea* has not been tested directly for determinate or indeterminate varieties, such a study would be helpful.

The purpose of this study was not to help elucidate complex these relationships between moisture deficiency and *H. zea* feeding. The goal of this study was to generate new field-based information about this relationship using contemporary soybean varieties. Here, I used simulated *H. zea* flower and pod feeding to investigate compensation differences between growth habits. I hypothesized that indeterminate soybeans would be able to compensate more to damage then determinate varieties because they are able to continue vegetative growth throughout the reproductive stages.

Materials and Methods

Experimental Design and Plot Establishment

To document differences in compensation potential between growth habits, I used determinate and indeterminate soybean varieties and simulated *H. zea* feeding on reproductive tissue in the field. Small plots were planted in North Carolina on 26 May 2020 (35.8983, -77.6714) with a commercial soybean planter in a randomized complete block design. There were two factors (soybean growth habit and percentage removal of reproductive tissue removed- 0%, 50%, 100%) with ten replications. Each plot consisted of four rows planted on a 0.91 m row spacing and was 12.19 m long. Two varieties were selected, one with a determinate growth habit and one an indeterminate growth habit, 5220R2X/S (determinate) (Bayer Crop Science, St. Louis, MO) and AG52X9 (indeterminate) (Bayer Crop Science). Both varieties were a maturity group 5.2. Seed depths, number of seed per meter, and plot maintenance was done in accordance with local agronomic practices. Foliar insecticide was used to eliminate natural *H. zea* herbivory on plots. The insecticide chlorantraniliprole (Prevathon, DuPont, Wilmington, DE, 12.33 g a.i./ha) was applied with a CO_2-powered backpack sprayer calibrated to deliver 15.32 L per hectare at 379.21 kPa with two TX-10 hollow cone spraying nozzles (TeeJet, Dillsburg, VA) in late-July to prevent any feeding damage from *H. zea*. In early August, 71 days after planting, during growth stage R1-R3, ten plants were selected at random for removal of flowers and pods and were then marked with flagging tape tied onto the stem base near the soil. Ten plants were randomly selected from each plot and marked with pink flagging tape. If randomly selected plants were extremely irregular in size or previously damaged, another plant was chosen at random. In one treatment, 100% of the reproductive tissue (flowers and small pods) were carefully trimmed by hand using a small pair of scissors. The trimming was performed evenly throughout the canopy by hand, equally divided between small pods and flowers, and care was taken to not harm the racemes. In a second simulated herbivory treatment, 50% of the reproductive tissue (flowers and small pods) was carefully trimmed. Finally, one plot of each variety was left untreated within each replication for a check.

Harvest

When the plots were physiologically mature, each of the ten plants that were previously marked were cut at the base near the soil, stripped of pods, and the pods were placed in a paper bag. The number of pods per plant and number of seeds per pod were counted on the plant-level. The seeds from all plants within each plot were then mixed and a sample of two hundred seeds from each plot were mechanically counted using a seed counter and placed into paper envelopes.

Envelopes were dried in an oven at 60°C for 72 hours and then weighed to determine the average seed weight.

Statistical Analysis

To determine if soybeans with determinate and indeterminate growth habits compensated differently to simulated *H. zea* feeding a linear mixed model was used to conduct an analysis of variance (ANOVA). Independent variables included growth habit, percentage removal of reproductive tissue, and the interaction between growth habit and percentage removal of reproductive tissue as fixed effects. Dependent variables were yield components (seed weight, total number of pods with one seed, total number of pods with two seeds, total number of pods with three seeds, total number of pods with four seeds) tested in independent models. Replication was included as a random effect in each model. To satisfy the assumption of normality, yield components were log(x+1) transformed. All ANOVAs were conducted using RStudio version 1.2.5033, using the *stats* package (R Core Team 2019) and the *lme4* package (v1.1-26; Bates et al., 2015). Post-hoc means separations were performed with Tukey's honest significant difference test using the *lsmeans* package in R (v2.30-0; Lenth, 2016).

Results

Seed weight was not significantly different for the interaction of growth habit and percent removal of reproductive tissue ($\chi^2 = 3.45$; d.f. = 2, 60; $P = 0.1785$). Seed weight was significantly different between determinant and indeterminate growth habits ($\chi^2 = 72.92$; d.f. = 1,60; $P < 0.0001$). Seed weight was heavier for the indeterminate variety when compared to the determinate variety (Table 2.1). Seed weight was also significantly different for the main factor of percentage removal of reproductive tissue ($\chi^2 = 39.05$; d.f. = 2,60; $P < 0.0001$). Seed weight when 100% of the reproductive tissue was removed was heavier than the check, but seed weight when 50% of the reproductive tissue was removed was not different than the 100% treatment or the check (Table 2.1).

Total number of number of pods with one seed was not significantly different for the interaction of growth habit and percent removal of reproductive tissue ($\chi^2 = 2.21$; d.f. = 2,60; $P = 0.3316$) or growth habit ($\chi^2 = 0.60$; d.f. = 1,60; $P = 0.4382$). The main factor of percentage removal of reproductive tissue, however, was significantly different ($\chi^2 = 9.41$; d.f. = 2,60; $P = 0.0091$), but means failed to separate using the Tukey procedure (Table 2.2). The number of pods with two seeds was not significantly different for the interaction between growth habit and percent removal of reproductive tissue ($\chi^2 = 2.25$; d.f. = 2,60; $P = 0.1971$), the main factor of growth habit ($\chi^2= 0.13$; d.f. = 1,60; $P = 0.7158$), and the main factor of percentage removal of reproductive tissue ($\chi^2 = 2.55$; d.f. = 2,60; $P = 0.2758$). Also, the number of pods with three seeds was not significantly different for the interaction of growth habit and percent removal of reproductive tissue ($\chi^2 = 0.08$; d.f. = 2,60; $P = 0.9619$), the main factor of growth habit ($\chi^2 = 0.63$; d.f. = 1,60; $P = 0.4273$), and the main factor of percentage removal of reproductive tissue ($\chi^2 = 0.40$; d.f. = 2,60; $P = 0.8207$). The number of pods with four seeds was not significantly different for the interaction of growth habit and percent removal of reproductive tissue ($X^2 = 0.07$; d.f. = 2,60; $P = 0.9675$) and the main factor of growth habit ($X^2 = 1.61$; d.f. = 2,60; $P = 0.2046$). Although the main factor of percentage removal of reproductive tissue was significant ($X^2 = 7.62$; d.f. = 2,60; $P =0.9675$), means were not significantly different (Table 2.2).

Discussion

In this study, determinate and indeterminate plots were evaluated for yield response to simulated *H. zea* feeding. Seed weight was the only significant difference for the main effects of variety and percent removal of reproductive tissue. Soybean seed weight was heavier in the indeterminate variety compared to the determinate variety. Seed weight was significantly heavier when 100% of reproductive tissue was removed when compared to the undamaged treatment; however, there was not a significant interaction between growth habit and percent removal of reproductive tissue. These results indicate that indeterminate varieties had a higher seed weight regardless of tissue removal. This outcome aligns with the previous study that documented similar a relationship in indeterminate varieties (Schug, Chapter 1).

Although the variety with an indeterminate soybean variety had heavier seed weight than the determinate, both varieties did compensate similarly by increasing seed weight, because the interaction term was not significant. When 100% of the reproductive tissue was removed, we observed heavier seed weight compared to the undamaged check. When 50% of the reproductive tissue was removed, seed weight was intermediate. These results align with a previous study where soybeans were able to compensate by increasing seed weight when pods were removed at the R3/R4 growth stage (McAlister & Krober, 1958). Unfortunately, whole plot yield was not collected for my study and the effects of a heavier seed weight may not correspond to a yield increase across the plant population; furthermore, soybeans can also compensate for yield loss from reproductive tissue removal by increasing vegetative growth, delaying leaf senescence, producing more pods, and producing more flowers (McPherson & Moss, 1989; Haile et al., 1998). In the previous study with natural *H. zea* infestations, yield was not significantly different between growth habits, and plots with *H.* zea damage compensated by increasing seed weight (Schug, Chapter 1). However, the levels of reproductive tissue removal in the present study were much higher relative to natural infestations used in Chapter 1. Further research using higher levels of reproductive tissue removal or damage should also include plot-level yield to understand the impact of seed weight compensation between populations of soybeans with different growth habits.

Simulated insect feeding is a common experimental method to demonstrate the effects of insect feeding on soybean yield (Todd & Morgan, 1972; McPherson & Moss, 1989; Singer et al., 2004; Coelho et al., 2020). Defoliation has been the most common type of simulated feeding studied in the soybean-insect herbivore literature (Todd & Morgan, 1972; Poston et al., 1976; Goli & Weaver, 1986; Ostlie & Pedigo, 1984; Haile et al., 1998; Li et al., 2005), with only a limited number of studies conducted with depodding or flower removal (McAlister & Krober, 1958; McPherson & Moss, 1989; Adams et al., 2015). While simulated reproductive tissue removal introduces a level of artificiality compared to natural tissue removal by *H. zea*, soybeans have been shown to compensate similarly to *H. zea* damage and simulated damage (McPherson & Moss, 1989). In my previous study, I observed that *H. zea* feeding was not limited to flowers and pods and that often only part of the pod was damaged from feeding, likely because pods lack some of the nutrients required for complete larval development (Suits et al., 2017; Schug, Chapter 1). Moreover, *H. zea* feeding was distributed over the reproductive period and the damage extent differed depending on the infestation timing in relation to growth stage of the plant, instar of *H. zea* that was feeding, and density of *H. zea* on the plants (Schug, Chapter 1). Because the present study reproductive tissue removal treatments were conducted at a single time point, additional studies with tissue removal at different time points and partial tissue removal would be useful to mimic natural feeding by *H. zea*.

Although seed weight was significantly different between varieties, the number of seeds per pod was not significantly different between the main factors of variety or the amount of reproductive tissue removed. This aligns with the study where the number of pods with one, two, and three seeds was not significantly different between 100% pod removal and the undamaged check across multiple planting dates (McPherson & Moss, 1989). The same study also found that 100 seed weight (dry weigh of 100 seeds) was higher in deppoded plants than the check in five out of six planting dates (McPherson & Moss, 1989). The difference in seed weight between the determinate and indeterminate variety in this study suggests that indeterminate varieties may compensate more than determinate varieties following reproductive tissue removal. However, seed weight can be influenced by other factors, such as timing of damage and other environmental factors, such as weather (Smith & Bass, 1972a). In a similar study, in one year, a determinate variety produced heavier seeds than an indeterminate variety, while in the second year, an indeterminate variety produced heavier seeds (Beaver et al., 1985). Furthermore, the number of pods and seed weight on branches off the main stem varied more for the determinate variety in this study compared to the indeterminate variety between years (Beaver et al., 1985). These differences between years could have been exacerbated by stress on the plant from loss of reproductive parts or leaves from insect feeding, implying that multiple year or location studies across a wide range of environmental conditions may be needed in order to show a true difference between growth habits. One environmental condition associated with stress is drought. For example, seed weight and seed number for determinate varieties tend to decrease under water stress conditions, but seed weight and number tend to stay the same for indeterminate varieties (Nitami et al., 2013). While our study did not test water stress conditions, the impact of complex interactions between soybean physiology and environmental factors could explain some variation in compensatory response observed between growth habits tested in this experiment. This study was also limited in that only one year and location of data was collected, this limitation did not encompass the range of environmental conditions tested in other multi-year studies.

Timing of reproductive tissue removal can also result in differences in compensation. For example, the more a soybean plant advances in reproductive growth development, the more influential depodding will be on overall yield (Thomas et al., 1974). Soybean pod removal after R5 can reduce yield when 100% of the pods are removed (Coelho et al., 2020). In this study, reproductive tissue was removed during early reproductive stages (R1-R3), and, while final yield in kg/ha was not measured, there were seeds present at harvest, indicating that 100% removal of reproductive tissue at these stages did not necessarily mean that this would result in total yield loss. However, this could change if plants were stressed by other environmental factors. Future studies should investigate percent removal of reproductive tissue during different growth stages in stressed and non-stressed conditions. For example, studies under irrigated, or high rainfall, and water stressed conditions compounded with infestations of *H. zea* could be used as a predictor on how the different growth habits might react to feeding under different environmental conditions.

Helicoverpa zea prefers to oviposit on plants while flowering compared to all other growth stages (Hillhouse & Pitre, 1975). While both determinate and indeterminate soybeans flower over multiple weeks, indeterminate soybeans flower, on average, for longer than determinate soybeans and develop pods while continuing to flower (Yoshida et al., 1983; Foley et al., 1986). Furthermore, given that soybeans flower for many weeks, the level of harm caused by *H. zea* could vary depending on when oviposition occurs when flowers are present. Therefore, using a range of growth stages may reveal the effects of larvae feeding earlier or later in the flowering cycle. A more comprehensive study examining the impact of *H. zea* feeding on different stages of reproductive tissue would be useful in determining how feeding may impact the difference in compensation between growth habits.

My study showed a difference in seed weight, but not a difference in seeds per pod between the determinate and indeterminate variety. Furthermore, my study using one determinate and one indeterminate variety suggests that indeterminate soybeans may compensate differently to simulated *H. zea* feeding by having a heavier seed weight. These results support my previous study with natural infestations of *H. zea*, where varieties with an indeterminate growth habit had heavier seeds than varieties with a determinate growth habit (Schug, Chapter 1). While yield was unaffected by seed weight in my previous study, this could have been due to insufficient levels of damage. This present study has high levels of damage; therefore, future studies should incorporate yield to see if higher levels of damage result in increased seed weight and subsequently yield differences between growth habits.

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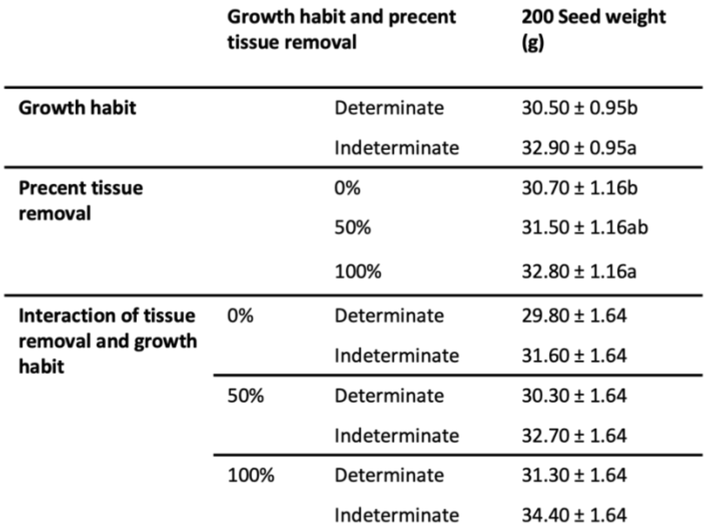
TABLES

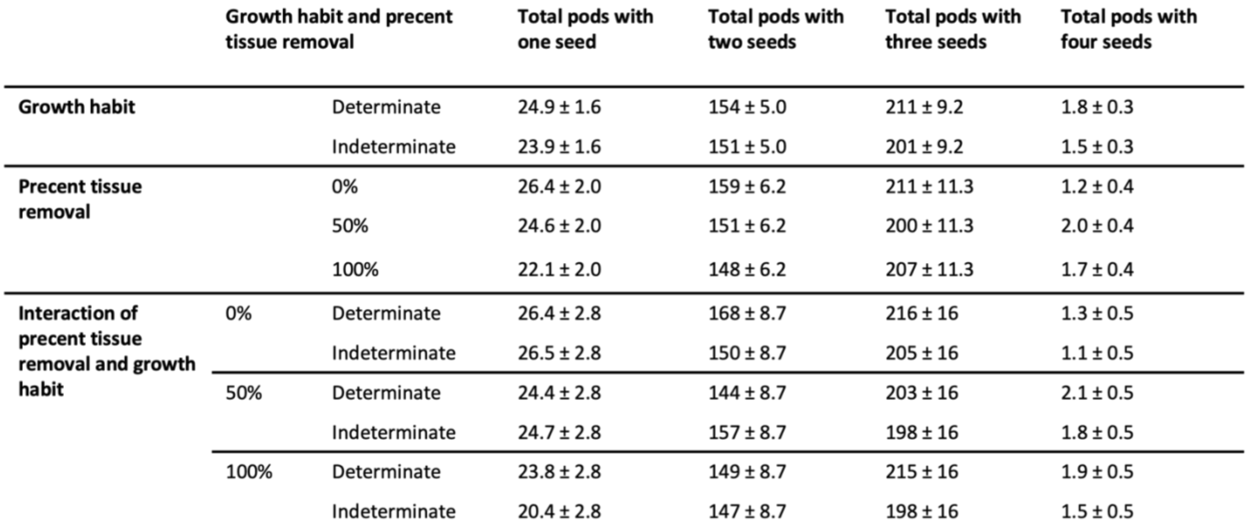
Table 2.1. Mean grams per 200 seeds (± SEM) for growth habit, tissue removal from R1-R3, and their interaction.



	Growth habit and precent tissue removal		200 Seed weight (g)
Growth habit		Determinate	30.50 ± 0.95b
		Indeterminate	32.90 ± 0.95a
Precent tissue removal		0%	30.70 ± 1.16b
		50%	31.50 ± 1.16ab
		100%	32.80 ± 1.16a
Interaction of tissue removal and growth habit	0%	Determinate	29.80 ± 1.64
		Indeterminate	31.60 ± 1.64
	50%	Determinate	30.30 ± 1.64
		Indeterminate	32.70 ± 1.64
	100%	Determinate	31.30 ± 1.64
		Indeterminate	34.40 ± 1.64

[a] SEM (Standard error of the mean), Means in same row and column grouping followed by a different letter are significantly different (Tukey's HSD; $P < 0.05$).

Table 2.2. Mean ± SEM for growth habit, tissue removal, and the interaction of growth habit and tissue removal total number of pods with one seed, total number of pods with two seeds, total number of pods with three seeds, total number of pods with four seeds.



	Growth habit and precent tissue removal		**Total pods with one seed**	**Total pods with two seeds**	**Total pods with three seeds**	**Total pods with four seeds**
Growth habit		Determinate	24.9 ± 1.6	154 ± 5.0	211 ± 9.2	1.8 ± 0.3
		Indeterminate	23.9 ± 1.6	151 ± 5.0	201 ± 9.2	1.5 ± 0.3
Precent tissue removal		0%	26.4 ± 2.0	159 ± 6.2	211 ± 11.3	1.2 ± 0.4
		50%	24.6 ± 2.0	151 ± 6.2	200 ± 11.3	2.0 ± 0.4
		100%	22.1 ± 2.0	148 ± 6.2	207 ± 11.3	1.7 ± 0.4
Interaction of precent tissue removal and growth habit	0%	Determinate	26.4 ± 2.8	168 ± 8.7	216 ± 16	1.3 ± 0.5
		Indeterminate	26.5 ± 2.8	150 ± 8.7	205 ± 16	1.1 ± 0.5
	50%	Determinate	24.4 ± 2.8	144 ± 8.7	203 ± 16	2.1 ± 0.5
		Indeterminate	24.7 ± 2.8	157 ± 8.7	198 ± 16	1.8 ± 0.5
	100%	Determinate	23.8 ± 2.8	149 ± 8.7	215 ± 16	1.9 ± 0.5
		Indeterminate	20.4 ± 2.8	147 ± 8.7	198 ± 16	1.5 ± 0.5

[a] SEM (Standard error of the mean), Means in same row and column grouping followed by a different letter are significantly different (Tukey's HSD; P < 0.05).