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Estimation of Deer Damage to Soybean Production in Mississippi: A Spatial and Temporal Context

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By

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Soybean (*Glycine max* (L.) Merr.) are one of Mississippi's most profitable agricultural crops. White-tailed deer (*Odocoileus virginiaus*) damage soybean every year due to the plant's high palatability, digestibility and nutritional content. I estimated the amount of damage (browsing and loss of yield) caused by deer within 5 soybean fields in eastern Mississippi and compared damage to the number of deer using each field during the 2012 and 2013 growing seasons. I assessed the effectiveness of the chemical repellent Hinder on soybean. While deer did affect soybean height, soybean yield remained unaffected during both years of my study. Given the results of this study, the perception of deer damage may be greater than the physical damage and other environmental factors such as field margin effects may be the reason for spatial variations in soybean yield throughout fields. Hinder also improved soybean height and decreased deer damage but soybean yield remained unchanged.

DEDICATION

I dedicate this thesis to my family, friends, and numerous other people who have supported me along the way. I thank my wife April and my Mom and Dad for their unwavering support both emotionally and physically as well as their enduring patience. Words cannot describe the debt of gratitude I owe. Finally I would like to dedicate this thesis to my Grandmother, Ethel Sanford. You always had faith in me and your guidance and wisdom will never be forgotten.

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CHAPTER I

INTRODUCTION

Soybean are one of the nation's top agricultural crops in regard to land area planted and gross income, and are Mississippi's second largest agricultural commodity only behind poultry with a production value of over $1 billion (USDA 2013). Damage to these crops from wildlife, including white-tailed deer, can be inevitable. However, with an economic impact of $1 billion to Mississippi alone (Grado et al. 2007), localized eradication of white-tailed deer is not an ecologically or economically viable or responsible option. Alternative methods must be employed to reduce depredation to crops and to allow both of these critical resources to continue to thrive and coexist.

White-tailed deer feeding patterns vary spatially throughout agricultural fields with most damage occurring within 50-m of an edge (Lyon and Scanlon 1987, Rogerson 2005) and along edges of fields with forested borders (Lyon and Scanlon 1987, Rogerson 2005, DeVault et al. 2007). The growth stage in which browsing of soybean by white-tailed deer occurs is critical in relation to long-term damage. Colligan (2007) found deer browsing remains constant throughout soybean growth stages and growing season. Therefore, early browse pressure affects yield the greatest due to limited plant foliage, possibly killing the plant. Constant browsing pressure during increasing plant biomass also leads to the notion that the perception of deer damage may exceed the actual economic damage due to deer damage being historically estimated visually.

Furthermore, yield of an agricultural crop can vary spatially throughout the field due to environmental influences known as field margin effects. While multiple methods exist to repel white-tailed deer from agricultural crops, the repellent Hinder® is currently the only chemical based repellent approved by the USDA for use on soybean. Tanner and Dimmick (1983) found that Hinder reduced browsing by as much as 72% in soybean fields. However, Hinder® may require multiple applications due to rainfall and new plant growth (El Hani and Conover 1995), making application costly.

I assessed how soybean height, plant count, and yield varied spatially throughout fields due to deer damage in Chapter II. Deer-proof enclosures were constructed and strategically placed throughout fields to control for damage. In Chapter III, I tested the effectiveness of the chemical repellent Hinder® preventing deer browsing. Understanding the impacts and how to control deer damage in agricultural fields is important in order to allow optimum agricultural production as well as maintain a healthy deer herd.

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CHAPTER II

VARIATION IN SOYBEAN ((*Glycine max* (L.) Merr.) HEIGHT AND YIELD SPATIALLY WITHIN FIELDS AND TEMPORALLY THROUGHOUT THE GROWING SEASON

The world's human population now exceeds 7 billion and is projected to be over 9 billion by the year 2050. As such, optimizing the earth's agricultural resources is imperative to feed the growing population. Over 130 million hectares were planted in agricultural crops in the United States in 2013 (USDA 2013) and producers are seeking ways to improve crop yield on arable lands. Furthermore, the amount of farmland is decreasing due to housing development and general suburban expansion (EPA 2012). Regrettably, damage to agricultural crops by wildlife is inevitable because wildlife inhabit these rural areas. Conover (1994) reported U.S. farmers suffered losses ≥$1000 dollars annually due to wildlife and 56% of farmers thought these losses were intolerable. Conversely, wildlife have many economic benefits to the U.S. which include hunting and wildlife watching. For example, Conover (1997) estimated that deer alone had a positive net economic value of $14 billion. Compromises must be found to simultaneously provide food for the world and maintain a healthy ecosystem.

Soybean are one of the nation's top agricultural crops in regard to land area planted and gross income. Approximately 32 million hectares were planted in soybean during 2013 in the United States including 810,000 hectares in Mississippi (USDA 2013).

Soybean are Mississippi's second largest agricultural commodity only behind poultry with a production value of over $1 billion (USDA 2013). With uses that range from livestock feed to vegetable oil, the value of soybean to US economy is significant and optimizing production is imperative to producers. Unfortunately, numerous species of wildlife depredate soybean, most notably, white-tailed deer.

White-tailed deer populations have increased substantially in recent decades due to successful restocking efforts, abundant habitat, and regulatory management strategies by the Mississippi Department of Wildlife, Fisheries & Parks. Over the last 60 years, Mississippi's deer population has expanded from a few thousand to about 1.75 million and hunters harvest ≥ 250,000 deer annually in Mississippi. Soybean are premium forage for white-tailed deer due to their palatability, digestibility and nutritional value. Although white-tailed deer cause approximately $100 million in damage to agricultural crops annually in the U.S. (Conover 1997), their recreational value (i.e., hunting) had an economic impact of $1 billion to Mississippi alone in 2007 (Grado et al. 2007). Because localized eradication is not an ecologically or economically viable or responsible option, alternative methods must be employed to reduce depredation to crops and allow both of these critical resources to continue to thrive and coexist.

Yield of an agricultural crop can vary spatially throughout the field due to environmental influences. Typically, yield in cereal crops is reduced at the field edge compared to the center (Kuemmel 2003) because shading, soil compaction, weed pressure, and competition for sunlight, water, and nutrients (Stamps et al. 2008) limit plant growth. Conversely, windbreak effects may improve plant growth at field edges and into the field (Marshall 2004); thus, margin effects on crop yields vary considerably from site to site, reflecting differences in crop-margin composition, soil type, management practices, and field history (Stamps et al. 2008). The importance of spatially quantifying deer damage is evident because field margin effects could easily be misinterpreted as deer damage.

White-tailed deer feeding patterns vary spatially throughout agricultural fields. Numerous studies have shown the majority of damage occurs within 50-m of an edge due to white-tailed deer's tendency to remain relatively close to escape cover (Lyon and Scanlon 1987, Rogerson 2005). Studies have further shown fields with ≥ one forested borders are more likely to receive damage because the forested areas provide hiding cover and serve as a travel corridor to the field (Lyon and Scanlon 1987, Rogerson 2005, DeVault et al. 2007). However, the amount and extent of deer damage in a field is related to the number of deer occupying the area (i.e., deer population size), which historically has been difficult to document.

The growth stage in which browsing of soybean by white-tailed deer occurs is critical in relation to long-term damage. Colligan (2007) found deer browsing remains constant throughout soybean growth stages and growing season. Therefore, early browse pressure affects yield the greatest due to limited plant foliage, possibly killing the plant. If the plant were to lose all trifoliates and terminal bud, the plant could no longer collect necessary nutrients for survival and would die. DeCalesta and Schwendeman (1978) simulated deer damage to soybean by removing trifoliate leaves of test plants. Results showed damage during the first week of growth could affect yield by as much as 80%, but up to 75% of leaves could be removed during weeks 2 through 5 with little effect on yield. Singer (2001) found soybean that were continuously clipped, to simulate deer damage, throughout each growth stage had a higher yield than soybean clipped during various stages. Deer damage both spatially and temporally needs to be quantified to provide producers with knowledge of when and where to apply repellents, thus conserving money spent on chemicals.

Perception of deer damage may exceed the actual economic damage caused by white-tailed deer. Determining the extent of deer damage has historically relied on visual estimation (Singer 2001). Flyger and Thoerig (1962) reported soybean producers often exaggerated their losses or underestimated the degree of damage (Singer 2001). Garrison and Lewis (1987) determined deer browsing which resulted in ≤33% of leaf removal actually improved yield and plants could receive up to 67% defoliation with no change in yield. They also reported yields differed significantly only after 100% defoliation and approximately 2.1% of sampled plants received 100% defoliation. Rogerson (2005) found deer browsing within 60-m of a forested edge increased yield by 2.4 bushels per hectare in Delaware. Rogerson (2005) also found prices for Hinder® application ranged from $198 to $396 per hectare and deer damage ranged from $63 to $111 per hectare. However, these findings are relative to the area studied and depend on deer population numbers.

A relatively new method of assessing vegetation quality is the Normalized Difference Vegetation Index (NDVI). Chlorophyll in plants absorbs both visible and infrared light which plants use as energy for photosynthesis. Healthy plants absorb more visible light than non-healthy plants or sparse vegetation. The NDVI calculates these absorption levels, thus assessing overall plant vigor. NDVI values can be obtained using a hand-held unit which emits photons of light and registers results. Values can also be derived from satellite imagery and aerial photos. Recent studies have shown NDVI values can be correlated to animal use of forage (Duffy and Pettorelli 2012, Ryan et al. 2012). Ryan et al. (2012) also found that NDVI values correlated with nitrogen content and relative body size of African Buffalo. Bardsen and Tveraa (2012) found Enhanced Vegetation Index values, which can be used analogous to the NDVI, positively correlated with female and offspring body masses of caribou in Finland.

Traditional methods for obtaining deer densities consist primarily of spotlight surveys and trail camera surveys (Roberts et al. 2006, Collier et al. 2013). Although widely used, spotlight surveys can be biased and unreliable. Collier et al. (2013) found while comparing thermal imaging and spotlight surveys that spotlight surveys were unrepresentative of the deer population, with detection probabilities averaging 0.41. In recent years the trail camera survey has become a popular technique and has been shown to provide reliable estimates of deer population characteristics (McKinley et al. 2006). The shortcoming of these techniques lies with the level of inference they provide. Although deer population size should be correlated to soybean field damage, population size provides no information regarding how many deer are actually foraging in each field. What is needed is a direct count of deer impacting soybean fields. Thermal imaging allows the user to observe deer day or night, unlike other studies where researchers were limited to daylight hours for observations (Lyon and Scanlon 1987, Tardiff et al. 1999, Beringer et al. 2003). A direct field-specific deer count should provide the most reliable information to relate to deer damage at each site.

Research Hypotheses

I hypothesized (1) most deer damage would be greatest at field margins and would remain relatively constant throughout the growing season (Lyon and Scanlon 1987, Rogerson 2005, Colligan 2007), (2) the extent of intra-field damage would be related to mean deer observations (ha/deer; DeVault et al. 2007) and (3) areas of soybean fields with adjacent vegetation types that provide cover for deer (e.g., forest) would experience the greatest damage (Lyon and Scanlon 1987, Rogerson 2005, DeVault et al. 2007).

Objectives

My objectives were to 1) quantify variation in soybean height, plant count, and yield spatially within fields and temporally throughout the growing season, 2) relate white-tailed deer abundance to soybean damage and yield, and 3) relate landscape characteristics surrounding soybean fields to spatial patterns of deer utilization of soybean plants.

Materials and Methods

Study area

During the 2012 field season soybean were sampled in five fields throughout eastern Mississippi. Three fields were located on a farm in the Interior Flat Woods region of Northwest Noxubee County (NRCS 2012) and received an average rainfall of 145-cm per year. Field 1 was 8.7 hectares with soils consisting of Falkner silt loam and Mantachie loam and was completely surrounded by forest. One side consisted of an 18-year-old pine plantation and the other sides were mature, mixed-pine and hardwood forests. Field 2 was 9.0 hectares with Urbo silty clay loam and Mooreville loam soils. The forest adjacent to one side of the field was recently harvested (i.e., clear cut) and the other sides consisted of mature, mixed-pine and hardwood forests. Field 3 was 25.7 hectares and consisted mainly of Freest fine sandy loam and Falkner silt loam soils. The field was partially bordered by another agricultural field and the remaining borders consisted of a 5-year-old pine plantation, an 18-year-old pine plantation, and mature mixed-pine and hardwood forests. Field 4 was located in the Black Prairie region of northeastern Noxubee County (NRCS 2012) and was 13.4 hectares. Annual rainfall averages 145-cm per year and this region has silt and sandy loam soil types. Two sides of the field had mature, mixed hardwoods timberlines with fields containing catfish ponds and soybean beyond the border. The remaining two sides were mature, mixed hardwoods forest. Field 5 was located in the Upper Coastal Plain region of southeastern Monroe County and was 7.3 hectares. Soils types ranged from clay to sandy loams and rainfall averaged approximately 142-cm per year. A residential house bordered one side of the field along with a grass field partially occupying the opposing side. The remaining borders were mature mixed-pine and hardwood forests. During the 2013 field season, fields 1-4 were sampled again. A field in Clay County was added. This field was 10.3 hectares and contains Griffith and Okolona silty clay soil types. Annual rainfall averaged 146-cm per year and the field was surrounded by agricultural fields. The study field and surrounding fields have borders that consist of various hardwoods and native grasses for wildlife habitat.

Plant Sampling

The following methods were implemented during the 2012 field season. Fields were selected based on adjacent forest and vegetation types as well as relative size. I constructed between 12 and 16 5 x 5-m deer-proof enclosures per field depending upon size of the field. The deer-proof enclosures were protected from deer browsing and allowed me to compare the effect of deer browsing on soybean height and yield. Enclosure construction followed the methodology reported by Rosenberry et al. (2001). I constructed four rows of enclosures per field. Each row had three to four enclosures based on field size. When the distance from the adjacent side of the field to the enclosure was ≤ the distance from the enclosure's originating side to the enclosure, the enclosure was not constructed. The enclosure rows were placed in random locations; however, the row had to be spaced far enough from a corner to allow at least three enclosures to be constructed. Enclosures within each row were constructed at distances of 10-m, 40-m, 70-m, and 100-m from the field border.

To construct these enclosures, I first used a Stihl® earth auger to excavate holes located at the four corners of an enclosure using a 5.08-cm auger bit. I then inserted 5.08-cm diameter PVC pipe into each hole at depths of 0.76-m. Next, I inserted a 3.2-m x 3.81-cm PVC pipe into the 5.08-cm buried pipe. The 0.76-m of pipe in the ground creates stability within the structure as well as allowing easy removal of enclosures. The 3.81-cm pipes were the posts which supported the fence. I used 2.28-m tall Deer Busters© heavy-duty plastic mesh deer fence with 3.81-cm x 3.81-cm mesh dimensions to exclude deer. This fence was wrapped around the 4 corner posts and then secured on all four corners by 25.4-cm zip ties.

After plant emergence and throughout the growing season, I measured and recorded plant height, plant count, soybean growth and reproductive stage, and deer damage once a week. Soybean growth stages include VE which is first emergence, VC which is the first unrolled, unifoliate leaves, and V1-Vn with n being the number of nodes on the plant (Rogerson 2005). A node is the location on the stem of the plant where a branch originates. Nodes occur above the unifoliate leaves. The reproductive stages include R1-R6 which begin with the first flower and continue with pods developing as well as the size of the beans in the pod, ending when beans are fully mature.

I sampled each field once per week. Inside enclosures, I measured 3 1-m rows of soybean located at the center of the plot, and 5-m outside the enclosures I sampled 3 1-m rows of soybean adjacent to the enclosure plot (called "check plots"). I also sampled points within the field at distances of 10-m, 40-m, 70-m and 100-m from the field border to measure spatial variation in soybean growth and damage within the field. As with the enclosures, size of the field determined the number of sample points. The origin of those sampling rows was determined by measuring 150-m from each corner of the field along the border. While walking along the border of the field, a point to start a row was placed every 100-m until a corner of the field was reached. On each of these sample points I sampled 1-m of 1 row of soybean.

I followed the same process when sampling the enclosures and the random points. First, I measured a 1-m transect along the row I was sampling. Next, I counted the number of plants growing along the 1-m transect and then measured the height and assessed the vegetative state of 3 plants which included the closest plants to the ends of the transect as well as one in the middle. The height measurement was from the tallest leaf of the plant to the ground. On the random sample points, I assessed the number of plants damaged by deer occurring in the 1-m transect and then randomly chose ≤ two of the damaged plants and counted the total nodes as well as the nodes which have been browsed by deer.

At the midpoint of the growing season, plant sampling intensity was reduced to once per two weeks. Once soybean were mature (approximately October), I collected samples to determine soybean yield. I used plant shears to remove all plants along the 1-m sampling area at previously sampled plots, including inside and outside of the enclosures and random points throughout the field. The entire plants were placed into woven plastic, breathable sacks and tagged to differentiate each sample. An Agriculex® SPT-1A: Single Plant Threshing Machine was then used to shell the beans. Beans were collected and weighed to compare yield between protected and unprotected plots as well as the random points.

During the 2013 season methodology was the same with a few exceptions. We added an additional enclosure and random sample point to each row in all fields on the border of the field to better enumerate deer damage adjacent to field borders. After weighing beans for yield data, beans were placed in paper bags and labeled. Each sample was then measured for moisture content and all samples were measured on the same day because moisture content values can vary daily due to humidity.

Different soybean varieties were also planted at different fields. At the Taylor fields, Pioneer 50t64 was planted both years. At Bigbee, Asgrow 5332 were planted in

2012 and in 2013 Asgrow 5606 were planted. Asgrow 5332 were also planted at Hamilton. Morsoy 47X12 were planted at West Point.

Deer Counts

The number of deer feeding in the study fields was counted once per week. I used a 3.7-m tripod-style elevated stand for deer observations. A Raytheon® Palm IR 250 thermal imaging camera was used to observe deer. The device has a lens which captures infrared light, which comes from heat, emitted from objects in view. I observed deer for a total of 3 hours, 1 hour before sundown and 2 hours after. I recorded the greatest number of deer observed in the field during a viewing session. This may be a conservative estimate but should be more representative of deer usage than counting the total number of deer observed during the session because deer may leave a field, return later, and be double counted. Deer counts continued until soybean were harvested.

Imagery

During the field season, GPS coordinates were obtained using a hand-held GPS device. Coordinates for the protected and unprotected sample points were then used to create spatial interpolation maps in ArcGIS. I used soybean height, yield, and deer damage as response variables in these maps. Satellite imagery showing NDVI values of certain fields were also obtained.

Data Analysis

I compared plant count, height, and weight each year within and among fields using analysis of covariance (ANCOVA) in the MIXED procedure in SAS (SAS version 9.2; SAS Institute, Cary, North Carolina; Littell et al. 2006). Samples from the enclosures and the check plots were combined into one category ("protected") and compared to the random points ("unprotected") to better assess intra-field variation. Borders or field edges were classified as either "cover" (a vegetation type that provided cover for deer; e.g., forest) or "open" depending on vegetation types (e.g., crops, pasture, etc.). I used ANCOVA with year and field ID as random effects to account for variation between years and inter-field variation. Height or weight was the response variable with border type (cover, open), and deer protection (protected, unprotected) as fixed effects and distance from border (m), and deer count (hectares/deer) as covariates.

The distribution of deer damage data did not follow a normal distribution so I used the GLIMMIX procedure in SAS (SAS version 9.2; SAS Institute, Cary, North Carolina; Littell et al. 2006) to model deer damage using a binomial distribution. Plant count for each sample was totaled for the entire growing season along with the number of plants that had been browsed. The proportion of plants browsed to the entire plant count was my response variable (i.e., deer damage). I assigned year and field ID as random effects with border type as a fixed effect, and distance from border, and deer count as covariates.

Results

I conducted 8 site visits per field in 2012 and 6 visits per field in 2013. Site visits were fewer in 2013 because farmers planted later than the previous year due to the amount of rain received prior to planting. Approximately 120 points were sampled per field each visit within and adjacent to the enclosures, and approximately 60 points were sampled in the unprotected areas throughout the fields. I conducted 11 site visits per field in 2012 for deer counts and 14 site visits per field in 2013 (Table 2.1). Monthly rain totals for field regions were also collected (Table 2.2).

Height differed with border (P = <0.001, $F_{1,680}$ = 36.70; Table 2.3), protection (P = <0.001, $F_{1,680}$ = 19.31; Table 2.3), distance (P = <0.001, $F_{1,680}$ = 55.64; Table 2.3, Figure 2.8), deer count (P = <0.001, $F_{1,680}$ = 102.18; Table 2.3), and the combined effects of distance*protection (P = 0.072, $F_{1,680}$ = 3.26; Table 2.3) and deer count*border (P = <0.001, $F_{1,680}$ = 14.12; Table 2.3). Soybean height was greater for the open border type and in the protected areas (Table 2.4). Soybean height also increased as distance into the field increased.

Soybean yield differed by border type (P = <0.001, $F_{1,643}$ = 33.17; Table 2.5), distance (P = <0.001, $F_{1,643}$ = 16.61; Table 2.5), distance*border (P = 0.001, $F_{1,643}$ = 10.81; Table 2.5, Figure 2.8), and deer count*border (P = <0.001, $F_{1,643}$ = 12.35; Table 2.5). Soybean yield was greater in the open border type and in the unprotected areas (Table 2.6). Yield also increased as distance into the field increased. Fewer yield samples were collected in 2013 compared to height samples due to farmer harvesting complications. Deer damage was affected by border (P = 0.027, $F_{1,369}$ = 4.97; Table 2.7), distance (P = <0.001, $F_{1,369}$ = 124.90; Table 2.7, Figure 2.9), deer count (P = <0.001, $F_{1,25.5}$ = 17.50; Table 2.7), distance*border (P = 0.063, $F_{1,369}$ = 3.48; Table 2.7), and deer count*border (P = 0.005, $F_{1,143.6}$ = 8.35; Table 2.7).

Figures 2.11-2.14 are spatial interpolation maps created using ArcGIS. Certain trends involving variation in soybean height and yield were evident, particularly along field borders and near edges of fields with forested borders. However, differences in soybean height and yield spatially throughout fields did not appear to be entirely related to deer damage. Apparently, other environmental factors are the cause of these differences. Although not included in the results, I ran models for each individual field and year and those findings with associated figures are provided in the Appendix.

Discussion

My research was conducted during the 2012 and 2013 growing season, which was the two best years in Mississippi's history of soybean production, a result likely influenced by timing and amounts of rainfall. This increased soybean production is noteworthy when forming conclusions from my research. That is, during less productive years, deer damage may be more extensive and stressful on soybean, and growth may not as easily compensate from damage. My study fields averaged 12.4 ha, much smaller than the Mississippi average of 106 ha. The larger statewide average field size is likely due to large-scale farming operations in the Delta region of Mississippi. However, I believe the field sizes I studied are representative of the east Mississippi region and much of the southeastern US.

Optimal foraging theory suggests crops like soybean are ideal for herbivores like white-tailed deer. Animals strive to maximize food intake while minimizing time spent foraging to reduce predation risk. Soybean are highly palatable and digestible while providing essential nutrients deer require for both growth and reproduction. Agricultural practices make these plants easily attainable which allow deer to spend relatively small amounts of time consuming very nutritious food. In a sense, ecological theory conflicts with efficient agricultural practices leaving producers and wildlife biologists always searching for solutions to mitigate crop damage.

Reduction in soybean height is one of the first indicators of deer damage. However, height reductions may or may not affect yield which is the most economically important issue soybean producers. A strong relationship was found between soybean height and protection. Deer browsing reduced soybean height significantly when compared to my protected areas that had been free from deer damage the entire growing season. However, no relationship was found between protection and soybean yield. These findings support previous research by Garrison and Lewis (1987), Rogerson (2005) and Meats et al. (2015) and suggest that deer damage does not necessarily impact soybean yield negatively. DeCalesta and Schwendeman (1978) reported soybean could lose ≤ 75% of leaf mass after the second week of growth with no effect on yield, and Garrison and Lewis (1987) reported soybean plants could lose ≤ 67% defoliation with no effect on yield. Thus, soybean compensate for moderate browsing and produce the same amount of pods as plants that have not been browsed. I observed that browsed plants typically responded by producing more stems. Therefore, while height was reduced, the additional stems provide extra biomass per plant for pods to form.

The relationship between distance and soybean height is consistent with the results of Lyon and Scanlon (1987) and Rogerson (2005) where they documented most deer browsing occurred near the edge of a field. Deer browse is the most evident at the edge of the field due to their tendency to remain relatively close to escape cover. A relationship also existed between soybean yield and distance. Because no relationship existed in either year for protection and yield, I assume field margins were the cause of this relationship. Many natural factors have been shown to cause reductions in the yield of agricultural crops near the boundary of a field including shading, soil compaction, weed pressure, and competition for sunlight, water, and nutrients (Stamps et al. 2008) along with windbreak effects (Marshall 2004). As distance into the field increases, the field margin effects are reduced. These effects could easily be misinterpreted as deer damage.

The relationship between border and soybean height supports the results of Lyon and Scanlon (1987), Rogerson (2005) and DeVault et al. (2007) where they found fields with one or more forested borders are more likely to receive deer damage. Deer browse, and subsequent reduction of soybean height, is more prevalent near these forested border types because they are more conducive to deer usage. Forested areas provide both escape cover and travel corridors for deer. A relationship was also found between soybean yield and border type. As stated previously when referring to the relationship between soybean yield and distance, protection did not influence yield so factors other than deer must have caused this relationship. The same effects related to field margins are likely the cause. Root competition, shading, and soil compaction are all conditions that exist adjacent to forested borders. Forested edges likely compete with soybean nearby for nutrients and sunlight. Field to field variation could also be a factor.

A significant relationship existed between deer count and soybean height. The relationship between deer count and soybean height is readily explained- more deer will consume more soybean biomass and reduce soybean height. Another possible explanation for this relationship could be field size. The effects of border types and field margins are more pronounced in some smaller fields. The overreaching effects of border types and field margins are not compensated for because small fields lack a large "interior" area of protected soybean as found in larger fields.

I measured deer damage as the number of plants that had been browsed upon by deer in a sample row compared to the total number of plants in each row. The relationship between border type and deer damage supports my hypothesis and previous research of Lyon and Scanlon (1987), Rogerson (2005) and DeVault et al. (2007) that found fields with one or more forested borders are more likely to receive deer damage. These forested borders or borders that are conducive to deer usage provide escape cover and travel corridors for deer. The more forested borders a field possess, the greater the probability of receiving deer damage.

The relationship between distance and deer damage also supports my hypothesis and previous research of Lyon and Scanlon (1987) and Rogerson (2005) that most deer browse occurred near the edge of a field. As distance into the field increases, deer damage decreases. The majority of deer utilizing an agricultural field will tend to remain relatively close to the edge of a field so they can retreat into escape cover as quickly as possible.

The relationship between deer damage and deer count also supports my hypothesis that extent of intra-field damage would be related to deer density. The more deer that are utilizing an agricultural field, the more damage that field will receive. A relationship was also found between the interaction of deer count and border type to deer damage which also suggests, as mentioned earlier, that fields with one of more forested borders are more likely to receive damage. However, while deer browsing rate was related to border type, distance from border, and deer density, deer browsing (i.e., deer damage) did not affect soybean yield.

Conclusions

Deer damage was heterogeneous in soybean fields but followed similar trends reported in previous research. Under normal conditions with typical deer populations, fields with one or more forested borders will receive more damage than fields with open border types. The majority of deer damage will also remain on the perimeter of each field. If a producer believes his losses to deer damage each year are intolerable, planting soybean in areas without adjacent deer habitat would be advised. Also, applying a repellent or temporary fence to protect soybean during the first few weeks of growth could prove beneficial in high deer density areas. However, in my study areas I found that deer will reduce soybean height, but not yield. I believe that perception of deer damage exceeds actual damage and other environmental conditions, such as border type and field margins, are responsible for much of the spatial variation in yield. I suggest producers reduce funds spent on repelling deer throughout the entire growing season and only protect plants during the early growth stages if protection is absolutely necessary.

Table 2.1 County, size, border type, and deer counts from fields sampled to determine the impact of deer browsing on soybean height and yield during 2012 and 2013 in eastern Mississippi

Year	Field	County	Size (ha)	Border types[a]	Deer count (ha/deer)[b]
2012	Taylor 1	Noxubee	25.7	AF, MPH, PF	4.28
	Taylor 2	Noxubee	9.0	AF, ESP, MPH	1.02
	Taylor 3	Noxubee	8.7	MPH, PF	1.02
	Bigbee	Noxubee	13.4	AF, HF	2.68
	Hamilton	Monroe	7.3	AF, MPH	1.49
2013	Taylor 1	Noxubee	25.7	AF, MPH, PF	1.14
	Taylor 2	Noxubee	9.0	AF, ESP, MPH	0.59
	Taylor 3	Noxubee	8.7	MPH, PF	0.86
	Bigbee	Noxubee	13.4	AF, HF	3.83
	West Point	Clay	10.3	AF	10.3

a = Description of field border types followed by the classification used for statistical models (i.e., open or cover): AF = Agricultural field (open), PF = Pine forest (cover), MPH = Mixed pine-hardwood forest (cover), ESP = Early successional plants (open), HF = Hardwood forest (cover).

b = Mean of weekly counts of maximum number of deer observed in each field.

Table 2.2 Monthly rain totals during the soybean growing season for 2012 and 2013 for each field sampled in eastern Mississippi

Year	Field	May	June	July	August	September	October
2012	Taylor 1	13.28	7.77	15.32	20.73	22.99	8.15
	Taylor 2	13.28	7.77	15.32	20.73	22.99	8.15
	Taylor 3	13.28	7.77	15.32	20.73	22.99	8.15
	Bigbee	11.18	9.80	18.59	7.24	20.70	4.32
	Hamilton	8.69	8.41	19.00	7.85	12.14	6.20
2013	Taylor 1	10.46	8.92	17.91	15.57	12.93	1.37
	Taylor 2	10.46	8.92	17.91	15.57	12.93	1.37
	Taylor 3	10.46	8.92	17.91	15.57	12.93	1.37
	Bigbee	5.11	20.93	16.15	11.71	9.53	1.52
	West Point	9.86	8.13	13.08	10.31	15.39	2.06

(National Climatic Data Center 2012 and 2013)

Table 2.3 Effects of border type, protection from deer browsing, distance from field border, and deer count on soybean height[a] from 6 fields in eastern Mississippi during 2012 and 2013.

Effect	*df*	*F*	*P*
Border	1,680	36.70	<0.001
Protection	1,680	19.31	<0.001
Distance	1,680	55.64	<0.001
Deer Count	1,680	102.18	<0.001
Distance*Border	1,680	0.73	0.393
Border*Protection	1,680	0.10	0.747
Distance*Protection	1,680	3.26	0.072
Deer Count*Protection	1,680	2.65	0.104
Deer Count*Border	1,680	14.12	<0.001

a = Soybean height data was analyzed using a mixed-model analysis of covariance with year and field ID as random effects and deer count as a covariate.

Table 2.4 Least-squares means[a] of border and protection types for soybean height from 6 fields in eastern Mississippi during 2012 and 2013.

Effect	Border	Protection	Estimate(cm)	SE
Border	Cover		72.55	28.55
Border	Open		79.95	28.52
Protection		Protected	78.88	28.53
Protection		Unprotected	73.62	28.53

a = Means were derived from a mixed-model analysis of covariance using year and field ID as random effects and deer count as a covariate to measure the effect of border type, protection from deer browsing, distance from field border, and deer count on soybean height.

Table 2.5 Effects of border type, protection from deer browsing, distance from field border, and deer count on soybean yield[a] from 6 fields in eastern Mississippi during 2012 and 2013.

Effect	*df*	*F*	*P*
Border	1,643	33.17	<0.001
Protection	1,643	2.18	0.140
Distance	1,643	16.61	<0.001
Deer Count	1,643	0.13	0.719
Distance*Border	1,643	10.81	0.001
Border*Protection	1,643	0.60	0.438
Distance*Protection	1,643	0.95	0.331
Deer Count*Protection	1,643	2.02	0.156
Deer Count*Border	1,643	12.35	<0.001

a = Soybean yield data was analyzed using a mixed-model analysis of covariance with year and field ID as random effects and deer count as a covariate.

Table 2.6 Least-squares means[a] of soybean yield related to border types from 6 fields in eastern Mississippi during 2012 and 2013.

Border	Estimate(g)	SE
Cover	164.73	35.671
Open	170.24	35.475

a = Means were derived from a mixed-model analysis of covariance using year and field ID as random effects and deer count as a covariate to measure the effect of border type, protection from deer browsing, distance from field border, and deer count on soybean yield.

Table 2.7 Effects of border type, distance from field border, and deer count on deer damage[a] to soybean from 6 fields in eastern Mississippi during 2012 and 2013.

Effect	*df*	*F*	*P*
Border	1,369	4.97	0.027
Distance	1,369	124.90	<0.001
Deer Count	1,25.5	17.50	<0.001
Distance*Border	1,369	3.48	0.063
Deer Count*Border	1,143.6	8.35	0.005

a = Deer damage data was analyzed using a GLIMMIX model and binomial probability distribution. Deer damage was calculated by counting the total number of plants in a 1-m row and total number of plants browsed.

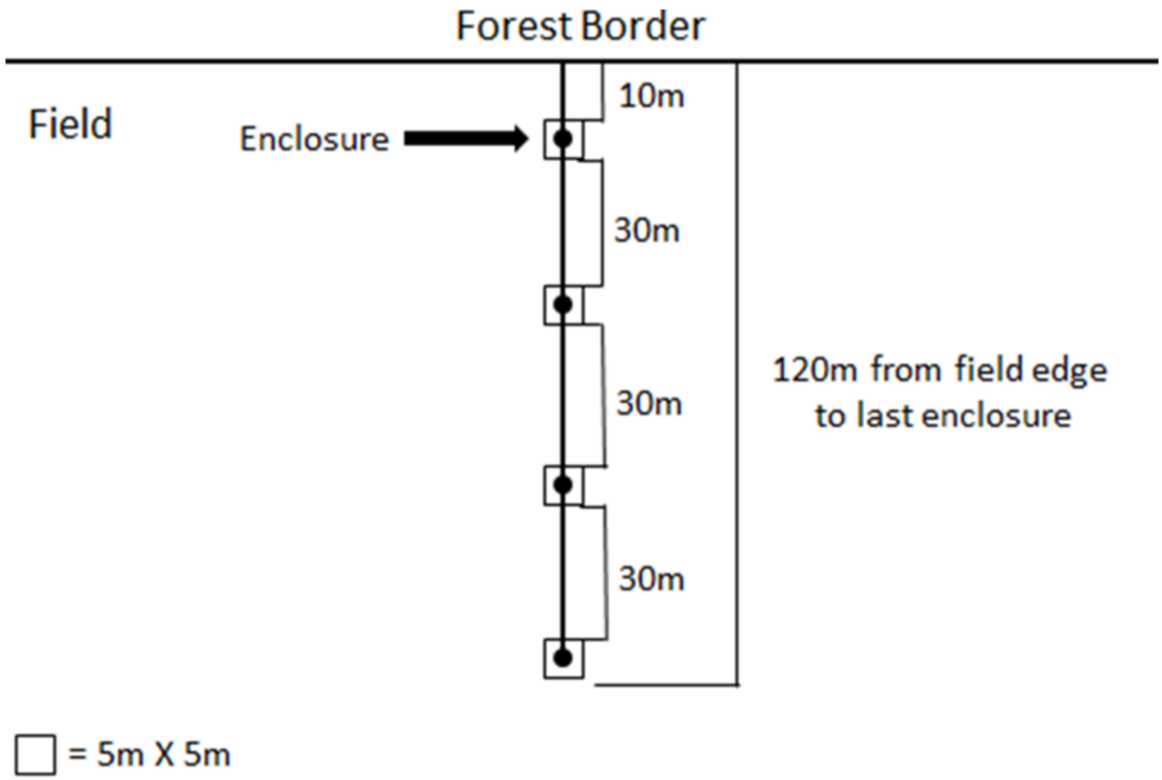

Figure 2.1 Diagram showing how each row of enclosures was placed entering the field from the border

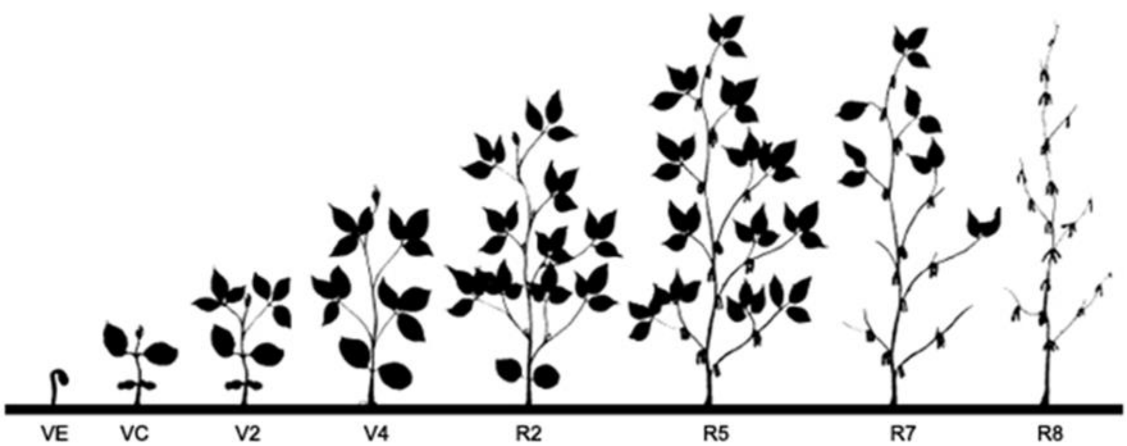

Figure 2.2 Diagram showing the various vegetative and reproductive stages of soybean growth.

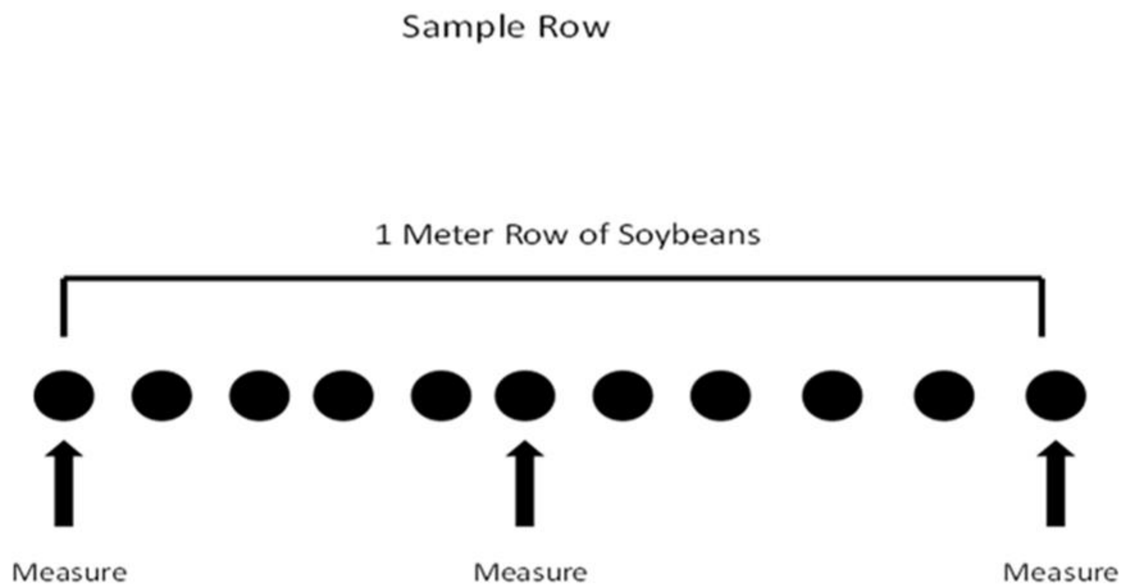

Figure 2.3 Diagram depicting process used to select soybean plants for sampling.

Endpoint and midpoint plants were measured along a 1-meter sample plot.

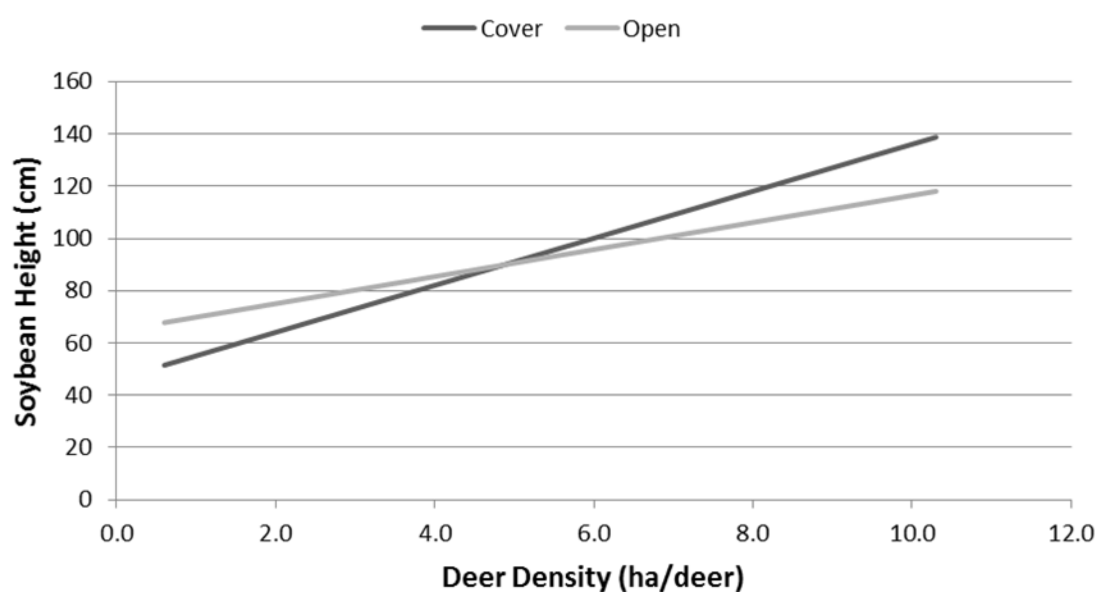

Figure 2.4 Interaction of border type and deer density on soybean height[a] for 6 fields in eastern Mississippi during 2012 and 2013.

a = Soybean height estimates were derived from a mixed ANCOVA model using deer protection and border type as fixed effects, field and year as random effects, and deer density and distance from border as covariates.

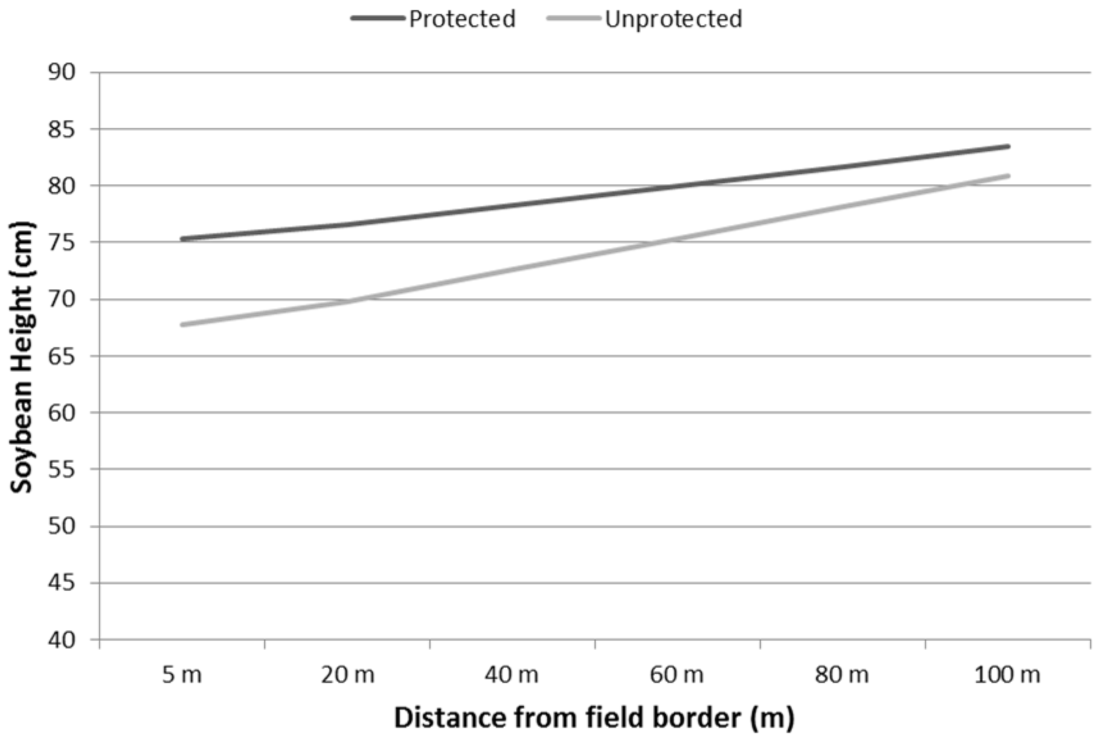

Figure 2.5 Interaction of deer protection and distance from field border on soybean height[a] for 6 fields in eastern Mississippi during 2012 and 2013.

a = Soybean height estimates were derived from a mixed ANCOVA model using deer protection and border type as fixed effects, field and year as random effects, and deer density and distance from border as covariates.

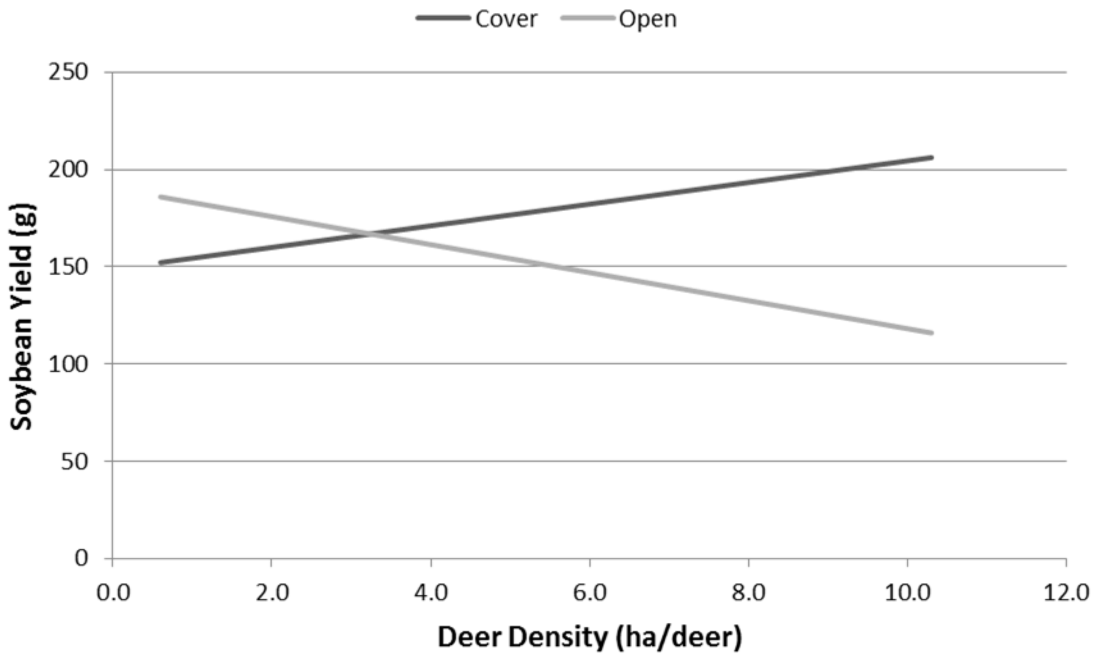

Figure 2.6 Interaction of border type and deer density on soybean yield[a] for 6 fields in eastern Mississippi during 2012 and 2013.

a = Soybean yield estimates were derived from a mixed ANCOVA model using deer protection and border type as fixed effects, field and year as random effects, and deer density and distance from border as covariates.

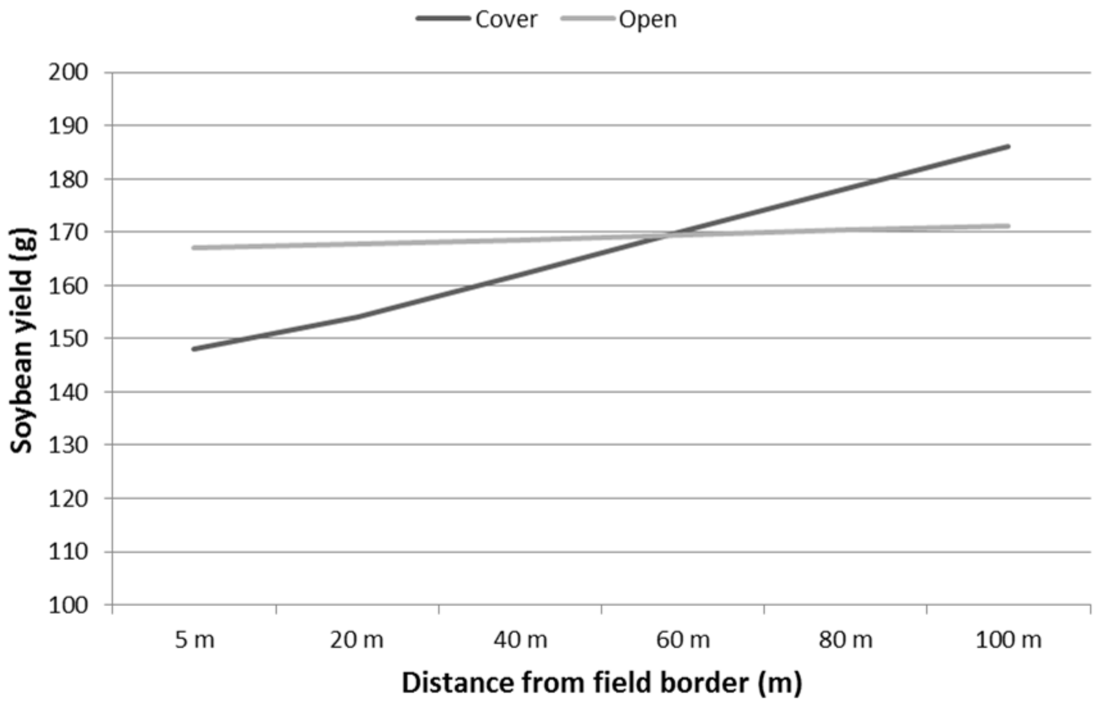

Figure 2.7 Interaction of border type and distance from field border on soybean yield[a] for 6 fields in eastern Mississippi during 2012 and 2013.

a = Soybean yield estimates were derived from a mixed ANCOVA model using deer protection and border type as fixed effects, field and year as random effects, and deer density and distance from border as covariates.

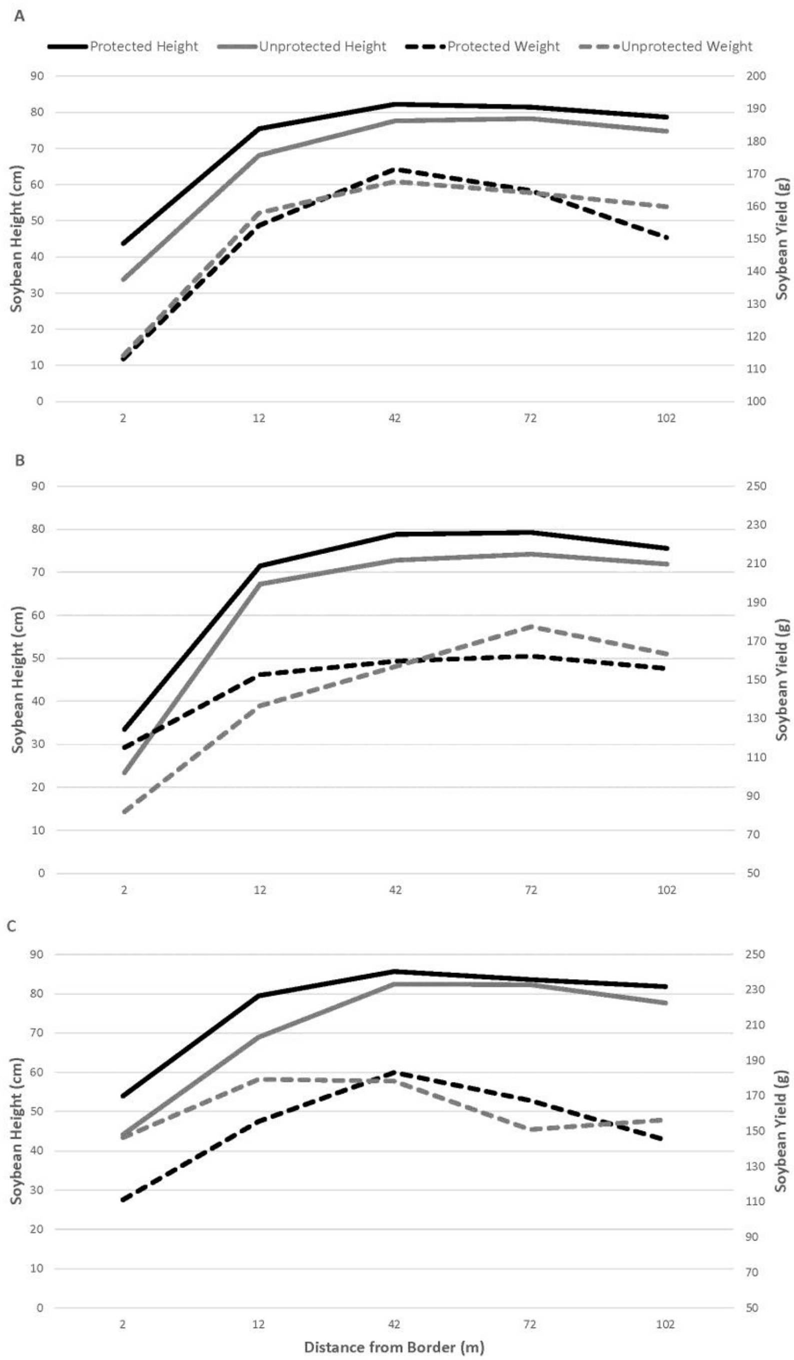

Figure 2.8 Variation in soybean height and yield[a] in eastern Mississippi in 2012 and 2013.

Related to deer protection and distance from field border (A), the cover border type (B), and the open border type (C)
a = Soybean height and yield estimates were derived from a mixed ANCOVA model using deer protection and border type as fixed effects, field and year as random effects, and deer density and distance from border as covariates.

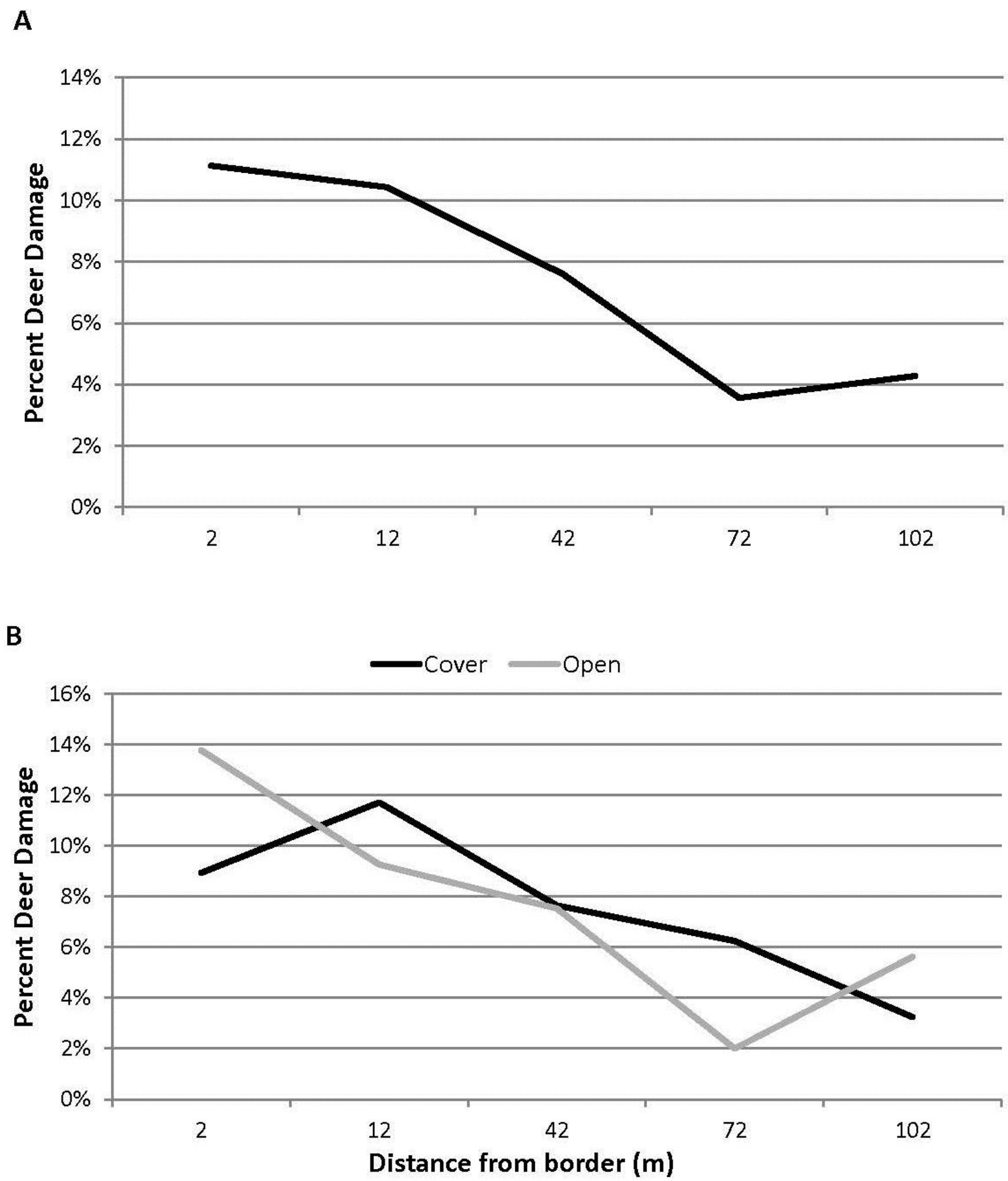

Figure 2.9 Variation in deer damage[a] in eastern Mississippi in 2012 and 2013.

Related to distance from field border (A) and the cover and open border types (B)
a = Deer damage estimates were derived from a GLIMMIX model using border type as a fixed effect, year and field ID as random effects, and distance from border and deer count as covariates.

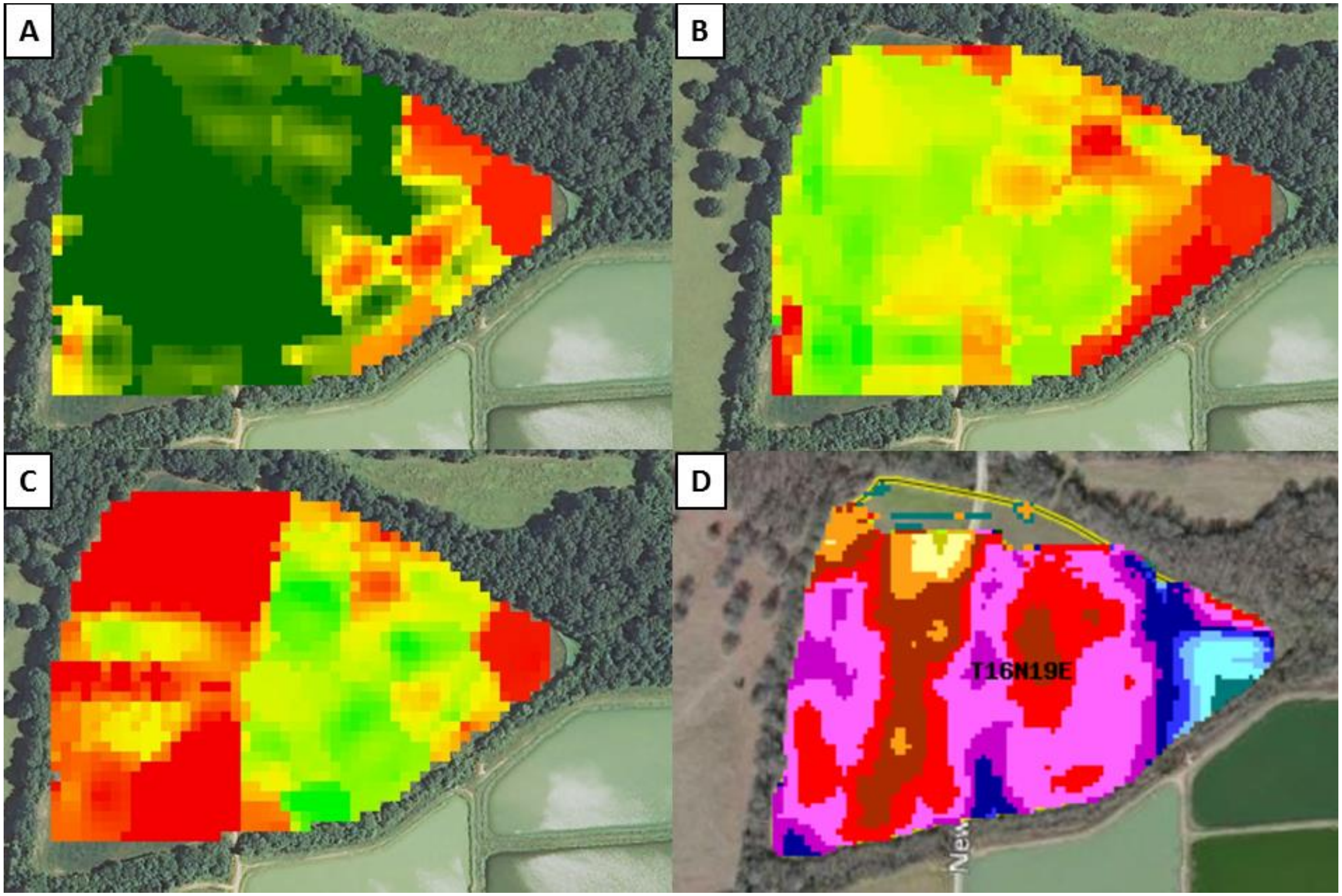

Figure 2.10 Spatial interpolation of soybean measurements from the Bigbee study site in 2013.

Depicting deer damage (A), soybean height (B), and soybean yield (C) as well as an NDVI satellite image (D)

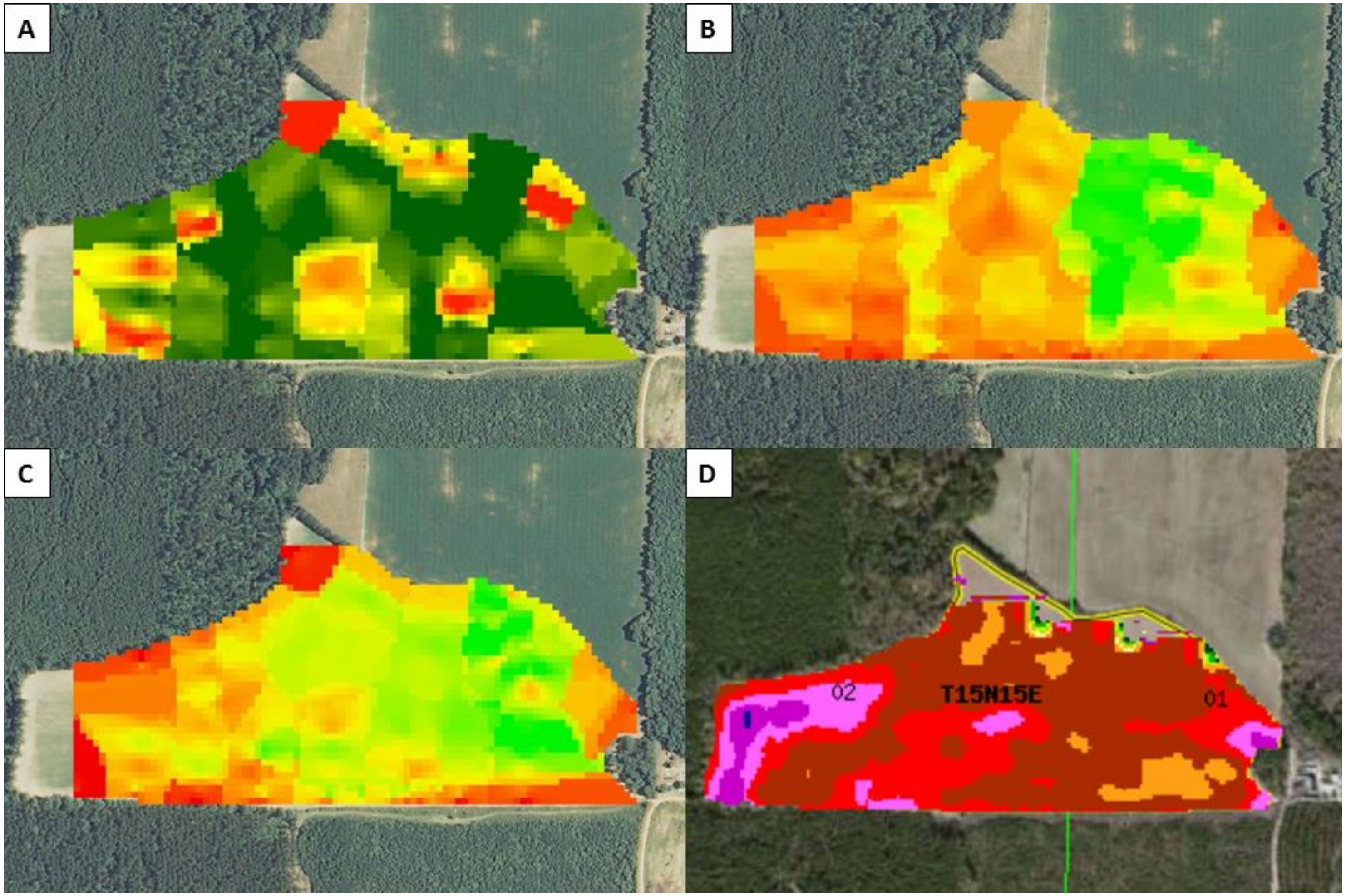

Figure 2.11 Spatial interpolation of soybean measurements from the T1 study site in 2013.

Depicting deer damage (A), soybean height (B), and soybean yield (C) as well as an NDVI satellite image (D)

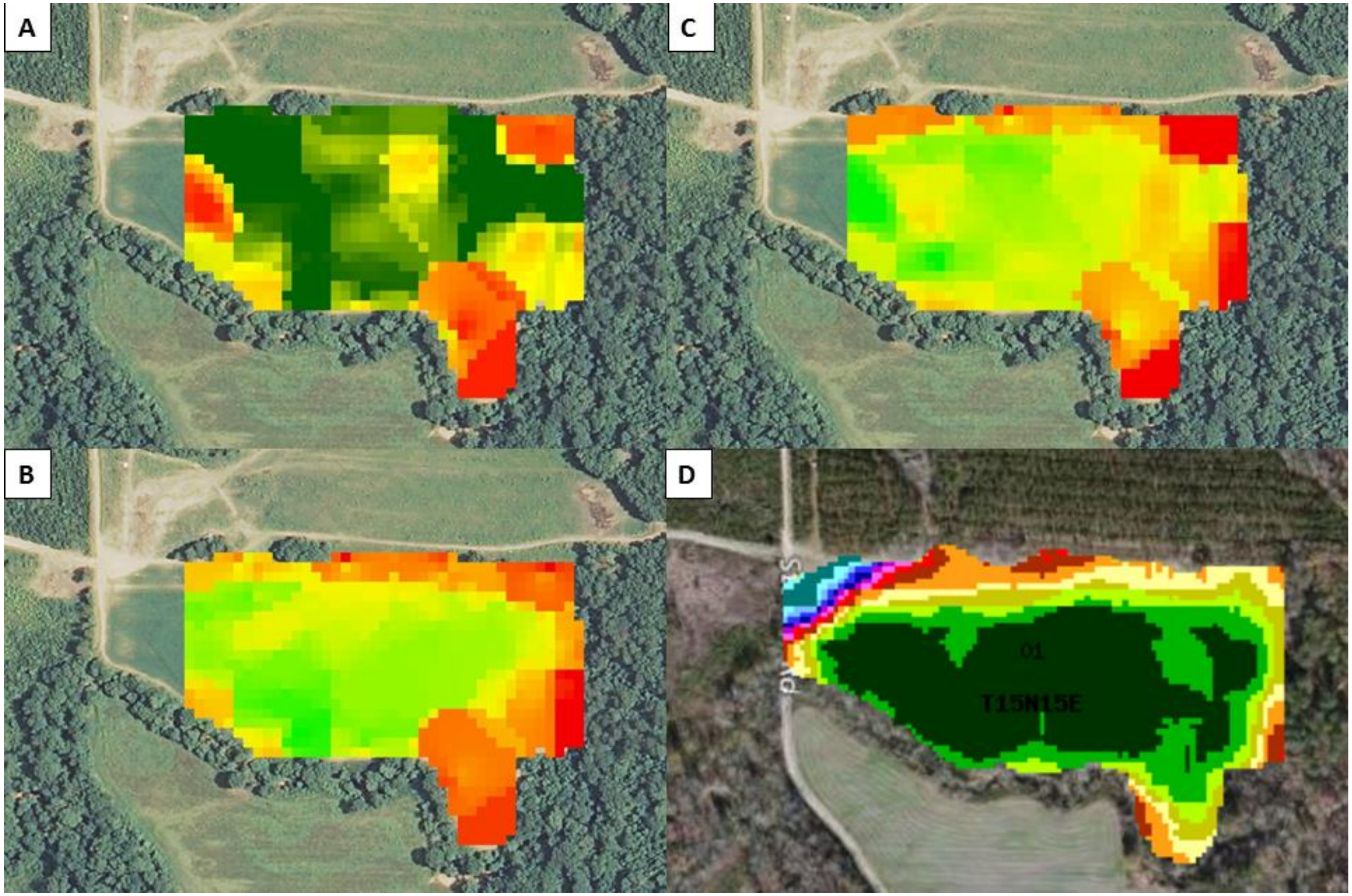

Figure 2.12 Spatial interpolation of soybean measurements from the T2 study site in 2013.

Depicting deer damage (A), soybean height (B), and soybean yield (C) as well as an NDVI satellite image (D)

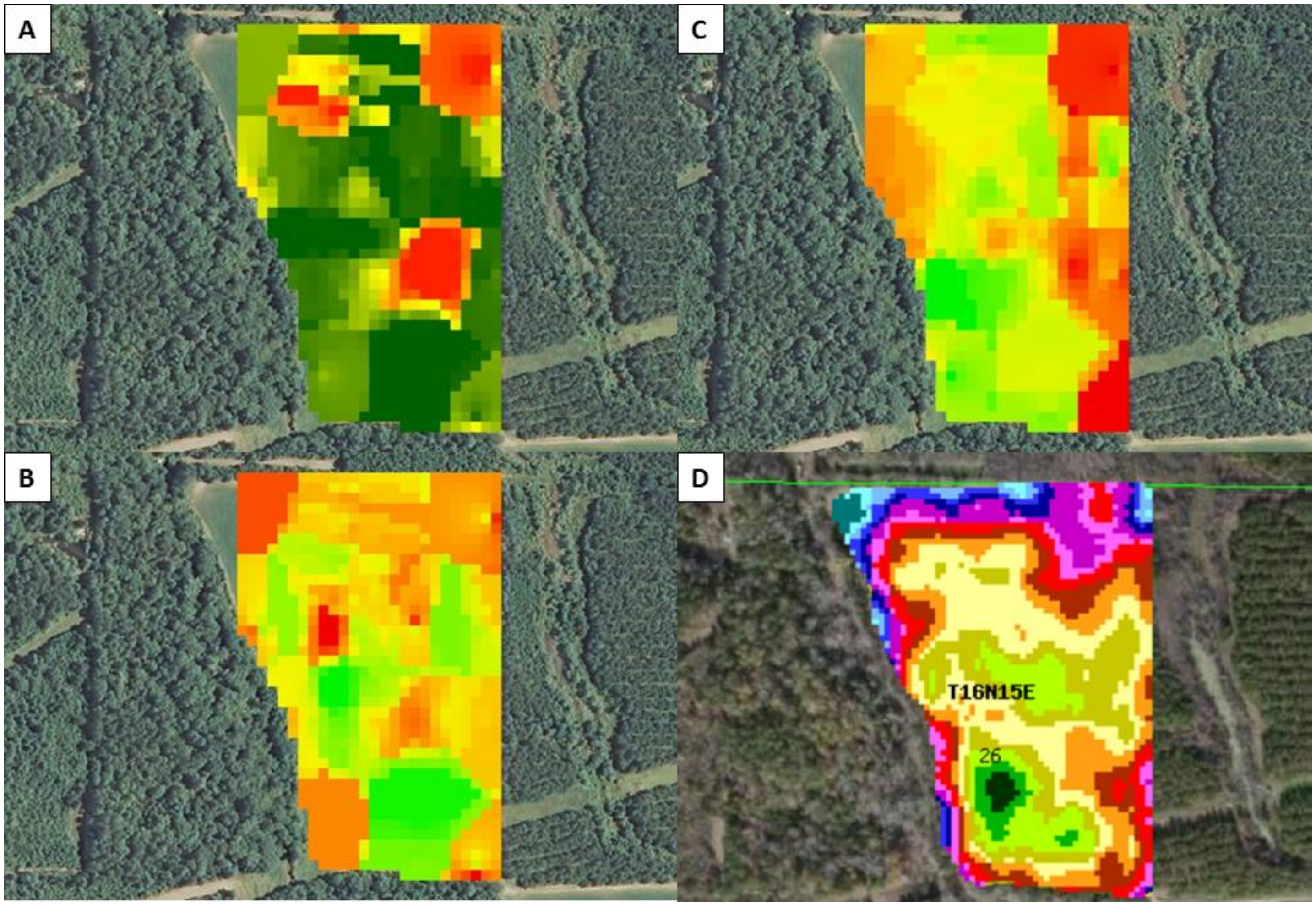

Figure 2.13 Spatial interpolation of soybean measurements from the T3 study site in 2013.

depicting deer damage (A), soybean height (B), and soybean yield (C) as well as an NDVI satellite image (D)

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CHAPTER III

EFFECTIVENESS OF THE REPELLENT HINDER TO REDUCE DEER DEPREDATION OF SOYBEAN

The total land area of the United States totals approximately 930 million hectares with about half of this area in agricultural land. The need for efficient, cost-effective strategies to feed the growing human population in the United States and the world is paramount. One of the major challenges agricultural producers face is crop damage from wildlife species. In 2001, wildlife damage to agricultural producers was estimated to reach $4.5 billion including both damage caused to property and money and time spent to prevent or reduce the problem (Conover 2001). However, many wildlife species have positive economic impacts to the U.S. and their value must be considered when selecting effective damage control methods.

As long as humans have been planting crops, they have faced the challenge of controlling wildlife damage. One of the most effective methods of damage control is exclusion by fences (Hillock et al. 1991). However, due to the current trend in large-scale agriculture, the construction of fences around hundreds to thousands of hectares is not be economically feasible to many producers. Population reduction is another effective method of controlling damage, but these reductions may also negate certain wildlife species' positive benefits. Planting alternative crops is another method to manage wildlife damage (Hillock et al. 1991) by planting less desirable agriculture crops in areas with high wildlife populations.

One species of wildlife that causes damage to agricultural crops annually throughout the Southeastern U.S. is white-tailed deer (*Odocoileus Virginianus*). Multiple methods exist to repel white-tailed deer from agricultural crops. These methods include propane cannons, scarecrows, fencing and several forms of natural and chemical applications (Hani and Conover 1995). A common problem with methods such as cannons and scarecrows is deer eventually habituate to such events rendering the devices ineffective after a short period of time. Studies have shown white-tailed deer will even become aware of laser triggers for "scarecrows" and will simply feed around the area (Beringer et al. 2003). Repellents are categorized as either contact or area types. Contact repellents, or taste-based, are applied directly to plants and repel deer due to their foul or painful taste (Trent et al. 2001). Area repellents, or odor-based, are applied near the surrounding area and repel deer by invoking fear (Trent et al. 2001). Repellent effectiveness varies and depends upon several variables such as amount of rainfall, field distance from forested edges, and quality and abundance of surrounding natural forage (Hani and Conover 1995).

The chemical repellent Hinder® contains ammonium soaps which repel deer from applied vegetation and is currently the only chemical repellent currently approved by the USDA for use on soybean. Tanner and Dimmick (1983) found that Hinder® reduced browsing by as much as 72% in soybean fields. However, Hinder® may require multiple applications due to rainfall and new plant growth (Hani and Conover 1995), making application costly. Rogerson (2005) found prices for Hinder® application ranged from

$198 to $396 per hectare and deer damage ranged from $63 to $111 per hectare. However, these findings are relative to the area studied and depend on deer population numbers.

Research Hypotheses

I hypothesized that the application of the chemical repellent Hinder® would not improve soybean yield.

Objectives

My objective was to determine effectiveness of a chemical deer repellent on soybean height, growth stage, and yield.

Materials and Methods

Study area

During the 2013 field season soybean were sampled in three fields in eastern Mississippi. The fields were located on a farm in the Interior Flatwoods region of Northwest Noxubee County (NRCS 2012) and received an average rainfall of 145-cm per year. Field 1 was 8.7 hectares with soils consisting of Falkner silt loam and Mantachie loam and was completely surrounded by forest. One side consisted of an 18-year-old pine plantation and the other sides were mature, mixed-pine and hardwood forests. Field 2 was 9.0 hectares with Urbo silty clay loam and Mooreville loam soils. The forest adjacent to one side of the field was recently harvested (i.e., clear cut) and the other sides consisted of mature, mixed-pine and hardwood forests. Field 3 was 25.7 hectares and consisted mainly of Freest fine sandy loam and Falkner silt loam soils. The field was partially bordered by another agricultural field and the remaining borders consisted of a

5-year-old pine plantation, an 18-year-old pine plantation, and mature, mixed-pine and hardwood forests.

Hinder® Application

Three fields were selected to test the effectiveness of the chemical repellent Hinder® during the 2013 season. Hinder® recommends the repellent should be applied every two weeks and additionally after precipitation events. Hinder® was applied manually to soybean using a carbon dioxide-pressurized, back-pack chemical sprayer with a fan nozzle. Hinder® was mixed with water before application and I used the recommended concentration rate of 6.4 ounces of Hinder® per 1 gallon of water. I also used the recommended application rate of 10-20 gallons of solution per acre.

Four plots approximately 15m x 45m in size were established in each field along the field borders. Each plot was divided into three equal 15m x 15m sections and repellent was applied to each section at different intervals of time. The entire plot was sprayed with repellent immediately after soybean emergence. The second and third sections were then sprayed two weeks later and the third section was sprayed after an additional two weeks. I also reapplied Hinder® after each rain event.

Plant Sampling

I sampled 5 points per section of each plot. A random number generator was used to create pairs of numbers between 1 and 15. Five number pairs were created for each section of each Hinder® plot. The first number would determine the distance in meters I would walk down the section border and the second number would determine the distance I would walk into the section perpendicular to the border I previously walked. I would then sample the nearest row of soybean. For plant sampling, I used the same methods described in the previous chapter to determine soybean height, plant count, deer damage, and yield. Sampling intensity was also the same as mentioned in the previous chapter.

Data Analysis

I compared plant count, height, growth stage, and weight within and among fields for the Hinder® plots using analysis of variance (ANOVA) in the MIXED procedure in SAS (SAS version 9.2; SAS Institute, Cary, North Carolina; Littell et al. 2006). I combined data from protected and unprotected samples from each field into the Hinder® data set to assess intra-field variation. I selected a row of enclosures closest to each Hinder® plot (protected) and used the first two enclosures since they were a similar distance into the field as the Hinder® plots. I also selected the nearest line transect on either side of each Hinder® plot (unprotected) and used the first two points from these as well. For the ANOVA I used the interaction of field*plot as a random effect. Height or weight was the response variable and fixed effects were field, border type (cover or open), plot, and treatment (section 1, section 2, section 3, protected, or unprotected).

The distribution of deer damage data did not follow a normal distribution so I used the GLIMMIX procedure in SAS (SAS version 9.2; SAS Institute, Cary, North Carolina; Littell et al. 2006) to model deer damage using a binomial distribution. For the damage analyses Hinder® plots and unprotected samples were used but the protected samples were deleted since deer damage was not recorded in these areas. Plant count for each sample was totaled for the entire growing season along with the number of plants that had been browsed. This proportion of plants browsed to entire plant count was my response variable. For my model I assigned the interaction of field*plot as a random effect with field, border type (cover or open), plot, and treatment (section 1, section 2, section 3, or unprotected).

Results

I conducted 6 site visits per field in 2013 (Table 3.1). Approximately 60 points were sampled per field for the Hinder® plots. Monthly rain totals for field regions averaged ranged from 17.91 cm to 1.37 cm with an average of 11.19 cm and standard deviation of 5.82 cm (Table 3.2).

Differences in soybean height were found between treatments (P = <0.001, $F_{4,232}$ = 10.89; Table 3.3) and with the interaction of border type*treatment (P = 0.001, $F_{4,232}$ = 4.89; Table 3.3) with soybean height being greater in the areas where Hinder® was sprayed multiple times. For soybean yield, no differences were found among the treatments or between treatments and the control (Table 3.4). Differences in deer damage were found among the treatments (P = <0.001, $F_{3,220}$ = 27.86; Table 3.5) and border type*treatment (P = <0.001, $F_{3,220}$ = 25.84; Table 3.5). Deer damage was greater at the unprotected areas compared to the hinder plots. Deer damage was also lower in the section of the Hinder® plots that had been sprayed twice compared to the sections that had been sprayed once and three times.

Discussion

While many methods exist to repel deer from agricultural fields, Hinder® is the only chemical based repellent that is approved by the USDA for use on soybean. In 2013, differences in soybean height were found between soybean sprayed with Hinder®

and unprotected samples. Height differences were also found between plots that had been sprayed once and plots that had been sprayed multiple times with Hinder®. Corresponding patterns were apparent with deer damage with treated plots experiencing lesser deer damage than control plots. My results support previous research by Tanner and Dimmick (1983) and suggest the chemical repellent Hinder® did reduce deer damage and may require multiple applications to achieve maximum effectiveness. Plots near forested borders also had lower soybean height and higher deer damage because these areas provide travel corridors for deer to soybean.

However, no differences were found in soybean yield suggesting, as found in the previous chapter, that while deer damage does reduce soybean height, soybean yield may be unaffected. Since multiple applications may be required to achieve maximum effectiveness, the cost of Hinder® should be considered. As also stated earlier, Rogerson (2005) found prices for Hinder® application ranged from $198 to $396 per hectare and deer damage ranged from $63 to $111 per hectare.

Conclusions

The chemical repellent Hinder® was found to increase soybean height and decrease deer damage. Multiple applications were required to achieve the most protection. However, soybean yield remained the same between Hinder® plots and unprotected areas of the field. Under normal conditions and deer populations, the cost of Hinder® application may exceed losses due to deer damage. However, in areas with extremely high deer populations, Hinder® applied during the first few weeks of soybean growth and particularly along field edges and forested borders, could prevent excessive deer damage particularly along areas of fields with forested borders.

Table 3.1 County, size, and border type from fields sampled to determine the impact of deer browsing on soybean height and yield during 2013 in eastern Mississippi.

Year	Field	County	Size (ha)	Border types[a]
2013	Taylor 1	Noxubee	25.7	AF, MPH, PF
	Taylor 2	Noxubee	9.0	AF, ESP, MPH
	Taylor 3	Noxubee	8.7	MPH, PF

[a] = Description of field border types followed by the classification used for statistical models (i.e., open or cover): AF = Agricultural field (open), PF = Pine forest (cover), MPH = Mixed pine-hardwood forest (cover), ESP = Early successional plants (open), HF = Hardwood forest (cover).
[b] = Mean of weekly counts of maximum number of deer observed in each field.

Table 3.2 Monthly rain totals during the soybean growing season for 2013 for each field sampled in eastern Mississippi (National Climatic Data Center 2013).

May	June	July	August	September	October
10.46	8.92	17.91	15.57	12.93	1.37

Table 3.3 Effects of treatment and border type between Hinder® plots, protected, and unprotected samples on soybean height[a] from 3 fields in eastern Mississippi during 2013.

Effect	*df*	*F*	*P*
Treatment	4,232	10.89	<0.001
Border Type	1,10	1	0.340
Border Type*Treatment	4,232	4.89	0.001

a = Soybean height data was analyzed using a mixed-model analysis of variance with field*plot as a random effect.

Table 3.4 Least-squares means[a] of treatment types for soybean height from 3 fields in eastern Mississippi during 2013.

Treatment	Estimate(cm)	SE
Sprayed 1	63.57	2.53
Sprayed 2	68.34	2.53
Sprayed 3	67.08	2.53
Protected	62.75	2.83
Unprotected	45.22	2.58

a = Means were derived from a mixed-model analysis of variance using field*plot as a random effect of border type and treatment on soybean height.

Table 3.5 Effects of treatment and border type between Hinder® plots, protected, and unprotected samples on soybean yield[a] from 3 fields in eastern Mississippi during 2013.

Effect	*df*	*F*	*P*
Treatment	4,195	0.15	0.965
Border Type	1,10	0.17	0.688
Border Type*Treatment	4,195	1.73	0.146

a = Soybean yield data was analyzed using a mixed-model analysis of variance with field*plot as a random effect.

Table 3.6 Least-squares means[a] of treatment types for soybean yield from 3 fields in eastern Mississippi during 2013.

Treatment	Estimate(g)	SE
Sprayed 1	98.02	0.03
Sprayed 2	102.24	0.03
Sprayed 3	105.64	0.03
Protected	97.79	0.04
Unprotected	104.19	0.03

a = Means were derived from a mixed-model analysis of variance using field*plot as a random effect to measure the effect of border type and treatment on soybean yield.

Table 3.7 Effects of treatment and border type on deer damage[a] to soybean at 3 study fields in eastern Mississippi during the 2013 season.

Effect	*df*	*F*	*P*
Treatment	3,220	27.86	<0.001
Border Type	1,10	0.40	0.543
Border Type*Treatment	3,220	25.84	<0.001

a = Deer damage data was analyzed using a GLIMMIX model and binomial probability distribution. Deer damage was calculated by counting the total number of plants in a 1-m row and total number of plants browsed for Hinder® plots and unprotected samples.

Table 3.8 Least-squares means[a] of treatment types for deer damage at 3 fields in eastern Mississippi during the 2013 season.

Treatment	Mean	SE
Sprayed 1	0.11	0.21
Sprayed 2	0.07	0.22
Sprayed 3	0.11	0.21
Unprotected	0.16	0.21

a = Means were derived from a GLIMMIX model and binomial probability distribution of deer damage to soybean based on total number of plants in a 1-m row and total number of plants browsed for Hinder® plots and unprotected samples.

Figure 3.1 Diagram showing the placement of Hinder® plots in a soybean field.

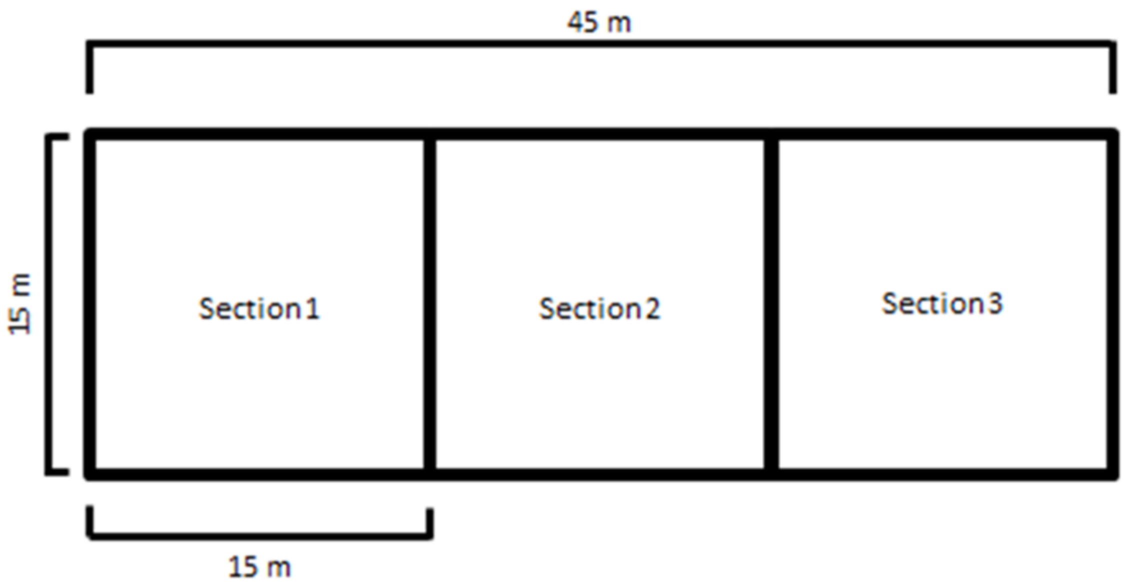

Figure 3.2 Diagram showing the size and division of Hinder® plots.

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CHAPTER IV

SYNTHESIS AND CONCLUSIONS

Deer damage was heterogeneous in soybean fields but followed similar trends reported in previous research. Under normal conditions with typical deer populations, fields with one or more forested borders will receive more damage than fields with open border types. The majority of deer damage will also remain on the perimeter of each field. If a producer believes his losses to deer damage each year are intolerable, planting soybean in areas without adjacent deer habitat would be advised. Also, applying a repellent or temporary fence to protect soybean during the first few weeks of growth could prove beneficial in high deer density areas. However, in my study areas I found that deer will reduce soybean height, but not yield. I believe that perception of deer damage exceeds actual damage and other environmental conditions, such as border type and field margins, are responsible for much of the spatial variation in yield. I suggest producers reduce funds spent on repelling deer throughout the entire growing season and only protect plants during the early growth stages if protection is absolutely necessary.

The chemical repellent Hinder® was found to increase soybean height and decrease deer damage. Multiple applications were required to achieve the most protection. However, soybean yield remained the same between Hinder® plots and unprotected areas of the field. Under normal conditions and deer populations, the cost of Hinder® application may exceed losses due to deer damage. However, in areas with extremely high deer populations, Hinder® applied during the first few weeks of soybean growth could prevent excessive deer damage particularly along areas of fields with forested borders.

APPENDIX A

YEAR- AND FIELD-SPECIFIC EFFECTS OF DEER DAMAGE ON SOYBEAN HEIGHT AND YIELD IN EASTERN MISSISSIPPI

Table A.1 Effects of border type, protection from deer browsing and distance from field border on soybean height[a] and yield from 5 fields in eastern Mississippi during 2012.

Variable	Field	Effect	*df*	*F*	*P*
Height	T1	Border	1,76	3.89	0.052
		Protection	1,76	0.83	0.365
		Distance	1,76	0.94	0.335
		Distance*Border	1,76	1.01	0.320
		Border*Protection	1,76	1.83	0.180
		Protection*Distance	1,76	2.94	0.091
	T2	Border	1,38	13.39	0.001
		Protection	1,38	14.68	0.001
		Distance	1,38	14.76	<0.001
		Distance*Border	1,38	8.84	0.005
		Border*Protection	1,38	3.14	0.085
		Protection*Distance	1,38	6.79	0.013
	T3	Protected	1,46	0.88	0.354

Table A.1 (Continued)

		Distance	1,46	0.77	0.384
		Protected*Distance	1,46	0.82	0.369
	Bigbee	Border	1,59	0.43	0.515
		Protection	1,59	2.26	0.138
		Distance	1,59	0.24	0.624
		Distance*Border	1,59	0.43	0.512
		Border*Protection	1,59	0.33	0.569
		Protection*Distance	1,59	1.03	0.314
	Hamilton	Border	1,36	3.85	0.058
		Protection	1,36	0.03	0.866
		Distance	1,36	0.00	0.959
		Distance*Border	1,36	1.84	0.184
		Border*Protection	1,36	3.14	0.085
		Protection*Distance	1,36	0.30	0.589
Yield	T1	Border	1,76	0.03	0.863
		Protection	1,76	0.14	0.709

Table A.1 (Continued)

	Distance	1,76	0.60	0.443
	Distance*Border	1,76	1.09	0.299
	Border*Protection	1,76	9.43	0.003
	Protection*Distance	1,76	0.18	0.671
T2	Border	1,38	2.06	0.160
	Protection	1,38	3.11	0.086
	Distance	1,38	2.42	0.130
	Distance*Border	1,38	1.52	0.225
	Border*Protection	1,38	0.50	0.485
	Protection*Distance	1,38	1.56	0.219
T3	Protection	1,46	1.63	0.208
	Distance	1,46	4.41	0.041
	Protection*Distance	1,46	0.30	0.586
Bigbee	Border	1,59	0.05	0.830
	Protection	1,59	0.28	0.600
	Distance	1,59	3.57	0.064

Table A.1 (Continued)

	Distance*Border	1,59	0.75	0.390
	Border*Protection	1,59	1.46	0.232
	Protection*Distance	1,59	0.01	0.929
Hamilton	Border	1,36	6.72	0.014
	Protection	1,36	0.13	0.721
	Distance	1,36	2.38	0.132
	Distance*Border	1,36	9.69	0.004
	Border*Protection	1,36	0.71	0.404
	Protection*Distance	1,36	1.20	0.280

a = Soybean height data was analyzed using a mixed-model analysis of covariance with field as a random effect and deer count as a covariate.

Table A.2 Effects of border type, protection from deer browsing and distance from field border on soybean height[a] and yield from 5 fields in eastern Mississippi during 2013.

Variable	Field	Effect	*df*	*F*	*P*
Height	T1	Border	1,110	29.02	<0.001
		Protection	1,110	4.01	0.048
		Distance	1,110	20.68	<0.001
		Distance*Border	1,110	0.39	0.534
		Border*Protection	1,110	3.29	0.073
		Protection*Distance	1,110	3.50	0.064
	T2	Border	1,57	20.91	<0.001
		Protection	1,57	12.89	0.001
		Distance	1,57	33.80	<0.001
		Distance*Border	1,57	0.38	0.539
		Border*Protection	1,57	1.32	0.256
		Protection*Distance	1,57	4.37	0.041
	T3	Protection	1,63	9.03	0.004

Table A.2 (Continued)

		Distance	1,63	0.14	0.713
		Protection*Distance	1,63	0.34	0.561
	Bigbee	Border	1,76	7.57	0.007
		Protection	1,76	0.65	0.422
		Distance	1,76	9.00	0.004
		Distance*Border	1,76	1.14	0.289
		Border*Protection	1,76	0.22	0.637
		Protection*Distance	1,76	0.43	0.515
	West Point	Protection	1,74	1.36	0.247
		Distance	1,74	27.85	<0.001
		Protection*Distance	1,74	0.97	0.327
Yield	T1	Border	1,110	23.48	<0.001
		Protection	1,110	5.63	0.019
		Distance	1,110	18.93	<0.001
		Distance*Border	1,110	0.88	0.349
		Border*Protection	1,110	6.52	0.012

Table A.2 (Continued)

	Protection*Distance	1,110	2.94	0.089
T2	Border	1,57	12.54	0.001
	Protection	1,57	1.61	0.209
	Distance	1,57	23.47	<0.001
	Distance*Border	1,57	1.32	0.256
	Border*Protection	1,57	0.51	0.479
	Protection*Distance	1,57	3.78	0.057
T3	Protection	1,58	0.27	0.606
	Distance	1,58	0.73	0.395
	Protection*Distance	1,58	2.01	0.162
Bigbee	Border	1,56	0.41	0.523
	Protection	1,56	2.20	0.143
	Distance	1,56	14.60	0.001
	Distance*Border	1,56	1.14	0.290
	Border*Protection	1,56	2.27	0.138
	Protection*Distance	1,56	0.07	0.794

Table A.2 (Continued)

West Point	Protection	1,61	2.74	0.103
	Distance	1,61	3.34	0.073
	Protection*Distance	1,61	1.18	0.282

a = Soybean height data was analyzed using a mixed-model analysis of covariance with field as a random effect and deer count as a covariate.

Table A.3 Effects of border type, distance from field border, and deer count on deer damage[a] to soybean in eastern Mississippi during 2012 and 2013.

Year	Field	Effect	*df*	*F*	*P*
2012	T1	Border	1,47	0.00	0.970
		Distance	1,47	0.00	0.971
		Distance*Border	1,47	0.00	0.968
	T2	Border	1,17	11.19	0.004
		Distance	1,17	13.57	0.002
		Distance*Border	1,17	1.77	0.201
	T3	Distance	1,20	45.96	<0.001
	Bigbee	Border	1,30	0.64	0.431
		Distance	1,30	10.35	0.003
		Distance*Border	1,30	3.02	0.092
	Hamilton	Border	1,15	8.12	0.012
		Distance	1,15	19.02	0.001
		Distance*Border	1,15	0.76	0.398

Table A.3 (Continued)

2013	T1	Border	1,73	0.95	0.332
		Distance	1,73	6.58	0.012
		Distance*Border	1,73	4.18	0.045
	T2	Border	1,28	4.10	0.052
		Distance	1,28	18.59	<0.001
		Distance*Border	1,28	0.03	0.856
	T3	Distance	1,29	2.68	0.113
	Bigbee	Border	1,43	9.74	0.003
		Distance	1,43	19.30	<0.001
		Distance*Border	1,43	2.61	0.114
	West Point	Distance	1,39	31.32	<0.001

a = Deer damage data was analyzed using a GLIMMIX model and binomial probability distribution. Deer damage was calculated by counting the total number of plants in a 1-m row and total number of plants browsed for each field.

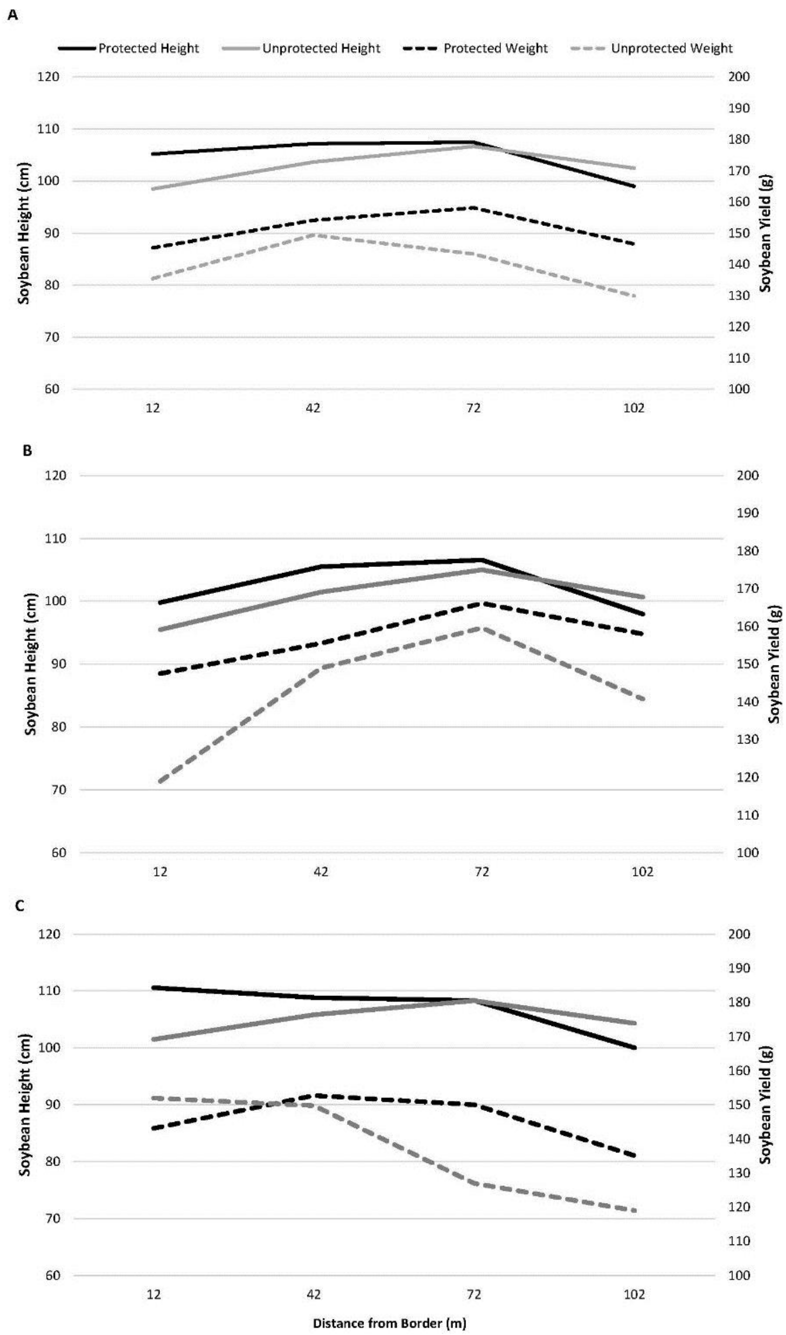

Figure A.1 Variation in soybean height and yield[a] in eastern Mississippi in 2012.

Related to deer protection and distance from field border (A), the cover border type (B), and the open border type (C)

a = Soybean height and yield estimates were derived from a mixed ANCOVA model using deer protection and border type as fixed effects, field as a random effect, and deer density and distance from border as covariates.

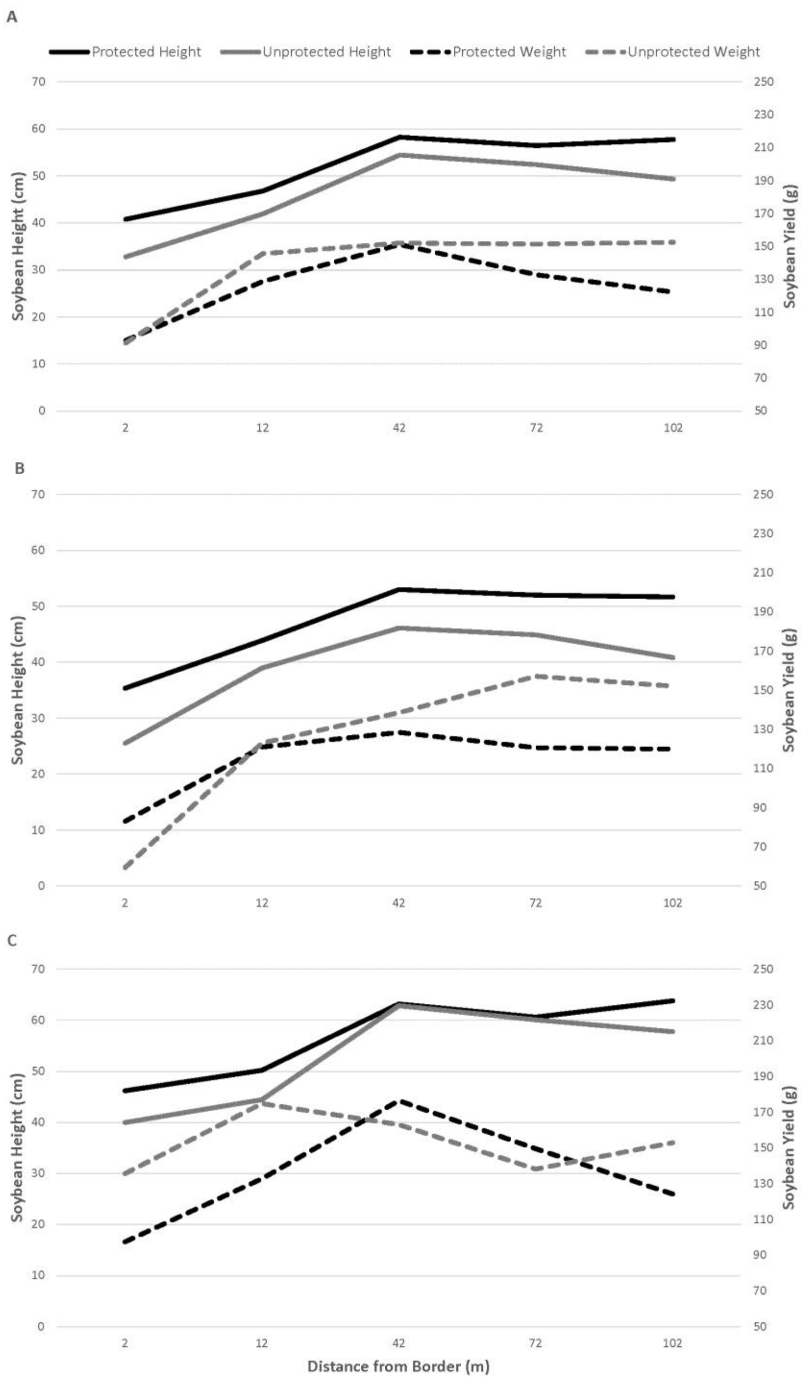

Figure A.2 Variation in soybean height and yield[a] in eastern Mississippi in 2013.

Related to deer protection and distance from field border (A), the cover border type (B), and the open border type (C)
a = Soybean height and yield estimates were derived from a mixed ANCOVA model using deer protection and border type as fixed effects, field as a random effect, and deer density and distance from border as covariates.

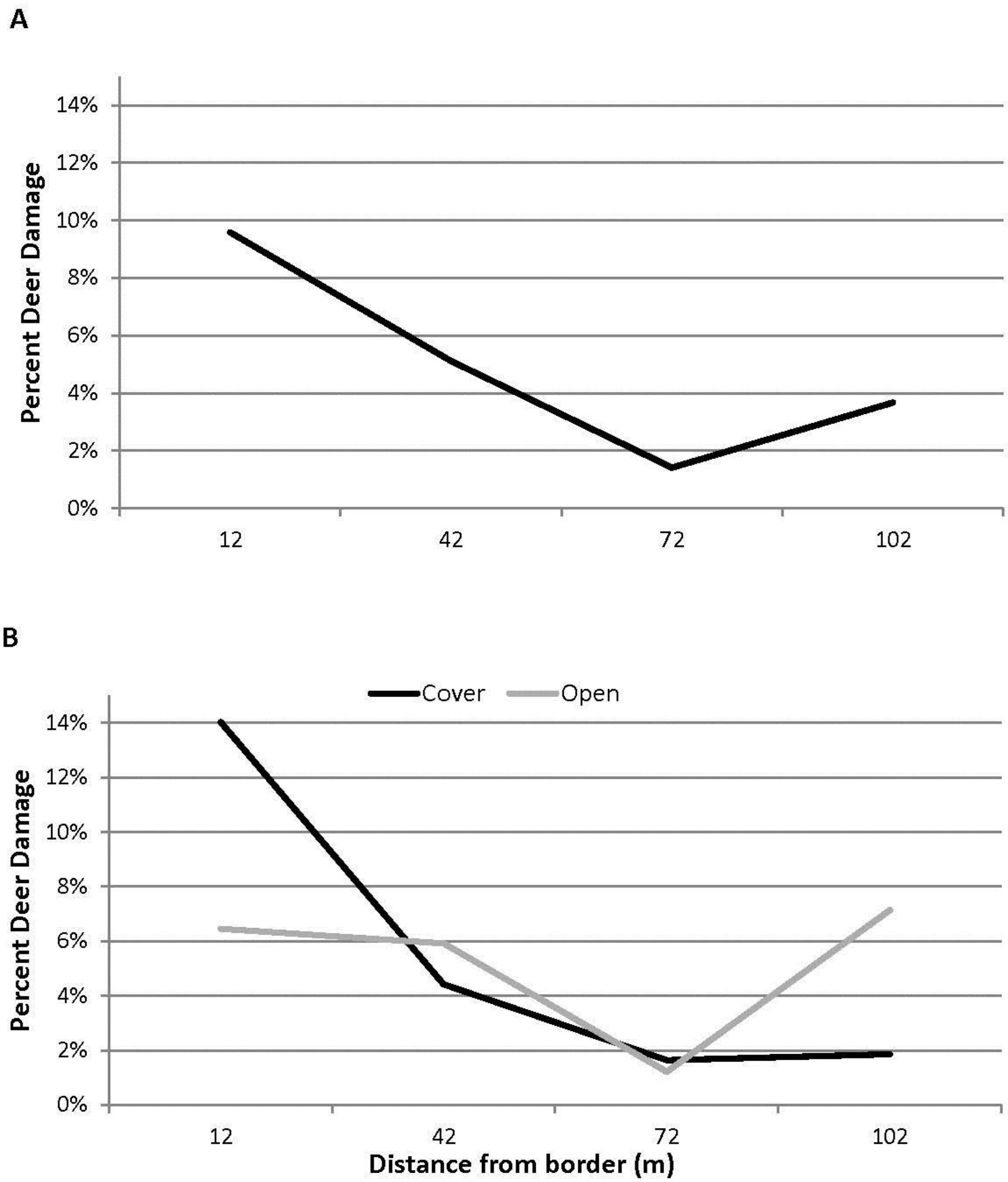

Figure A.3 Variation in deer damage[a]) in eastern Mississippi in 2012.

Related to distance from field border (A) and the cover and open border types (B
a = Deer damage estimates were derived from a GLIMMIX model using border type as a fixed effect, field ID as a random effect, and distance from border and deer count as covariates.

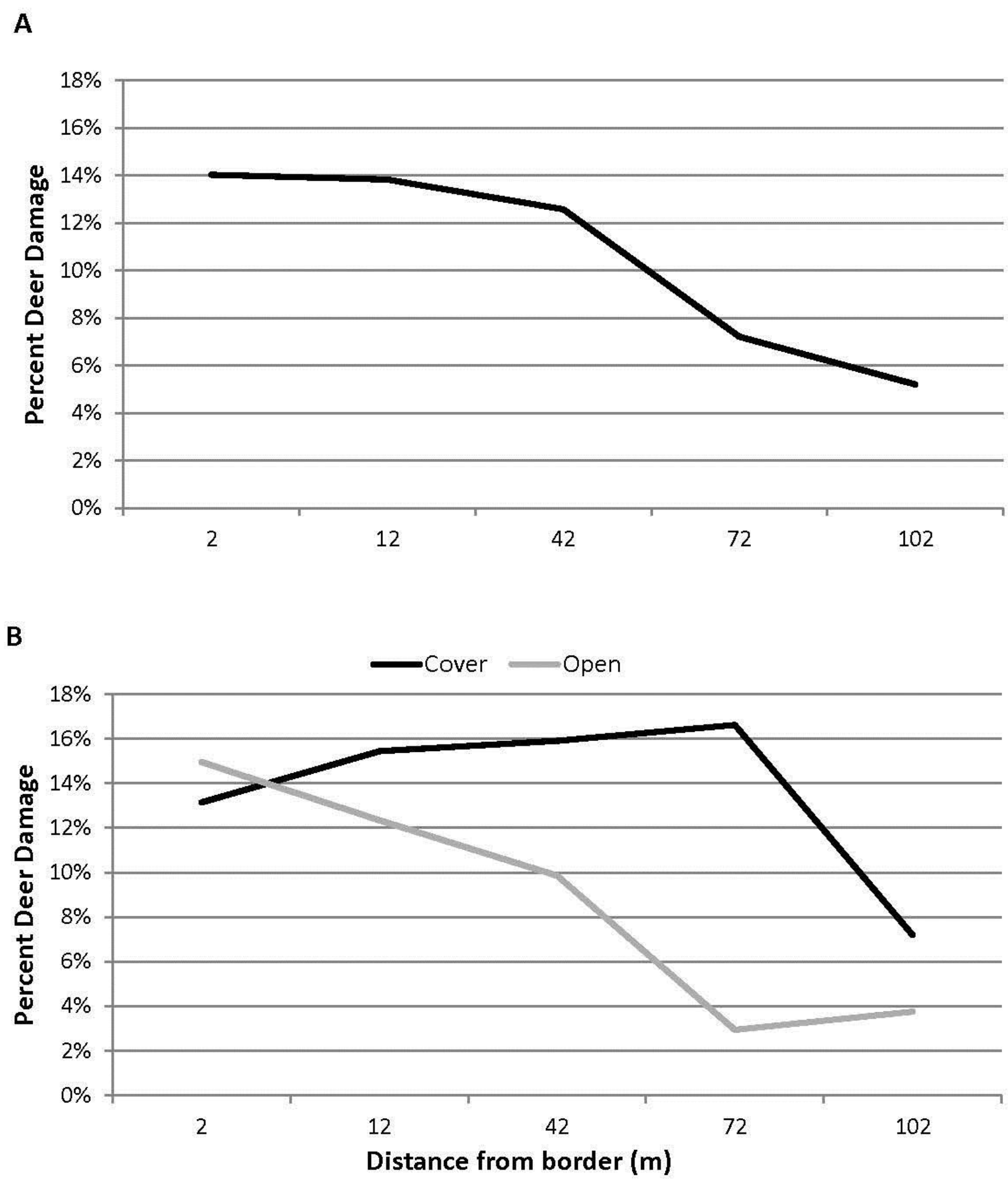

Figure A.4 Variation in deer damage[a] in eastern Mississippi in 2013.

Related to distance from field border (A) and the cover and open border types (B)
a = Deer damage estimates were derived from a GLIMMIX model using border type as a fixed effect, field ID as a random effect, and distance from border and deer count as covariates.