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Fire ant response to management of native grass field buffers

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FIRE ANT RESPONSE TO MANAGEMENT OF NATIVE GRASS FIELD
BUFFERS

By

Sarah Lucinda Hale

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Submitted to the Faculty of
Mississippi State University
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BUFFERS

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Imported fire ants are invasive and cause injury to people, crops, livestock and wildlife. Disturbance may increase abundance and activity of fire ants. However, native grass field buffers established for grassland birds require periodic disturbance. I experimentally tested if fire ant mound density and foraging activity changed after burning and disking in native grass buffers and examined relationships among fire ants, vegetation, and grassland bird and butterfly metrics in undisturbed buffers. In 2008, disking increased mound density and foraging activity, but burning did not. In 2009, disking had no effect, but effects of disking the previous season persisted. Fire ant metrics were not related generally to bird or butterfly metrics. Mound density and foraging activity were related negatively to grass cover and related positively to forbs. Burning had less influence on abundance and activity of fire ants, and may better conserve grassland habitats in areas with fire ants.

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CHAPTER I

INTRODUCTION

Imported Fire Ants

Black imported fire ants (*Solenopsis richteri Forel*) were first introduced to the United States in 1918 in coconut shipped from South America to Mobile, Alabama (Vinson and Sorensen 1986). The more aggressive and prolific red imported fire ant (*Solenopsis invicta Buren*) arrived in the 1930s in infested ship ballast from South America which was unloaded along with cargo in Mobile, Alabama (Vinson and Sorensen 1986). I will refer to both species and hybrids collectively as fire ants.

Fire ants spread from Alabama to the rest of the southeastern United States via transport of infested sod and nursery root stock, movement of construction equipment, and landfills (Vinson 1997). Fire ants also spread by natural mating flights (when winged males and females mate in the air above the mound), vehicle transportation (e.g., truck beds), and floating rafts for queens and larva formed by worker ants after floods (Vinson and Sorensen 1986, Vinson 1997). It takes only a single mated female to start a new colony, and 2,000 - 3,000 winged females are produced per mature colony per year for mating flights (Vinson 1997).

Fire ants invaded eight southern states before the spread was recognized and shipment regulations were imposed in the 1950s (Vinson and Sorensen 1986). Fire ants were restricted to the southern US because they thrive in warm areas that vary between

wet and dry (Vinson 1997), but now have been reported in California and as far north as Maryland (Wojcik et al. 2001). Also contributing to fire ant range expansion is the lack of any natural predators or effective competitors (Allen et al. 2004).

Negative effects of fire ants are numerous and varied. They feed on beneficial insects/pest predators (e.g., ladybugs); protect aphids (plant disease vectors), and out compete native ants and insects (Porter and Savignano 1990). Fire ants infest agricultural fields with 50 - 75 colonies/hectare and mounds between 1.0 and 1.5 feet tall which can damage farm equipment (especially in dry seasons; destroy crops by girdling, eating buds, and burrowing through roots; sting livestock, pets and humans (which may result in anaphylactic shock); and increase use of pesticides for fire ant control (Vinson and Sorensen 1986, Vinson 1997). Fire ants also prey on avian nests (Allen et al. 1995, Campomizzi 2009, Conner 2010), destabilize community structure, and cause extinction of native species (Allen et al. 2004).

Fire ants have limited positive effects. They feed on crop pests such as boll weevils, sugar cane borers, and corn ear worms, and other insect pests like chiggers, ticks, and cockroaches (Vinson and Sorensen 1986, Vinson 1997), but these positives do not outweigh the negatives. Because eradication of fire ants is no longer realistic, the main concern is control (Vinson and Sorensen 1986).

CP33-Habitat Buffers for Upland Birds

To ameliorate declines of northern bobwhite (*Colinus virginianus*) and other grassland birds, the Southeast Quail Study Group promoted establishment of grassland habitat buffer practices under the Conservation Reserve Program through Conservation

Practice 33 (CP33) – Habitat Buffers for Upland Birds (Burger et al. 2006).

Conservation Practice 33 was the first continuous CRP practice established specifically to meet the goals of a national species recovery plan and to require monitoring wildlife response on state, regional, and national levels (Burger et al. 2006).

In Mississippi, nearly 900,000 acres have been enrolled in the Conservation Reserve Program (USDA 2008), 2,000 acres of these being CP33 habitat buffers (USDA 2004). CP33 buffers replace low-yielding cropland around field margins while monetarily compensating landowners for establishment, maintenance, and lost opportunity costs (Hamrick et al. 2006). Buffers provide wildlife habitat, catch pollutants, control soil-erosion, retain sediment, and improve water quality (Burger et al. 2006). Located around crop field margins, they are established with native grass and forb cover and must be disturbed periodically during the 10-yr contract period to keep them in early successional stages (Hamrick et al. 2006). Buffers in early stages of succession have a vegetative structure that provides adequate open space at ground level for the movement and feeding of target species (Harper et al. 2007). The only way to maintain this structure is to keep buffers in early stages of succession and eliminate the buildup of dead vegetative material using some form of planned disturbance like prescribed fire and/or light-strip disking (Harper et al. 2007, USDA 2004).

Prescribed fire reduces woody cover and dead plant material on the ground, and boosts nutrient availability in the soil, seed germination, sprouting and herbaceous growth (Jones et al. 2007). Burning in the spring leaves overwinter cover for grassland wildlife and stimulates rapid growth of native warm season grasses (Harper et al. 2007). Soil fertility can be increased for 1 - 2 years because nutrients (nitrogen, potassium,

magnesium) from the ash are leached into the upper layer of soil (Harper et al. 2007). Burning must be implemented under several specific conditions to disperse smoke buildup and to ensure litter and vegetation are burned while leaving a layer of ash containing available nutrients (20 - 60% humidity, 1 - 3 mph windspeed at eye level, length of time the wind blows from one direction, specific fuel and soil moistures, etc.; Wade and Lunsford 1988, Harper et al. 2007). Burning also requires a permit.

Disking is useful in areas where burning is not possible because it has some of the same effects as burning (Harper et al. 2007), less restrictive weather conditions for implementation, and farmers have the technology and expertise to implement disking themselves. Disking retards succession, promotes decomposition of dead plant material, opens space at ground level, creates bare soil for seed germination, and improves wildlife food plant coverage (Harper et al. 2007, Jones et al. 2007). Fall disking encourages desirable grass species, whereas spring disking encourages agronomic weeds and invasives like Johnsongrass (*Sorghum halepense*; Harper et al. 2007). A rotational schedule for burning and disking is recommended because this creates a mosaic of successional stages (Harper et al. 2007). This can provide a variety of habitats for different species of wildlife throughout the season (Harper et al. 2007).

How Disturbance Affects Fire Ants

Although disturbance of grass buffers benefit grassland birds, fire ants often increase when grasslands are disturbed (Stiles and Jones 1998, Williamson et al 2002) which could potentially decrease grassland bird nest success due to fire ant depredation.

Fire ants are invasive species with similar traits to invasive “weedy” plant species that invade cleared or disturbed land (Hobbs and Huenneke 1992; Tschinkel 1993). Weedy species have high dispersal rates, are effective colonizers, and have rapid reproduction which leads to high population growth rates (Tschinkel 1993). Disturbance also opens canopy, allows light to penetrate, and eliminates other native ant competitors (Williamson et al. 2002). Fire ant abundance increased with disturbance intensity (unharvested, partially thinned, clearcut with woody debris retained, clearcut with woody debris removed; Todd et al. 2008) and clearcutting in South Carolina forests (Zettler et al. 2004).

Disturbance may affect fire ants both directly, through mechanical processes, like destruction of mounds during disking and exposure to high levels of heat during burning, or indirectly through alteration of the vegetative community. Disking destroys mounds, which could be especially detrimental to fire ants on spring and fall mornings when the brood (larvae and pupae) is moved near the surface of the mound for warmth from the sun (Penick and Tschinkel 2008). Burning does not destroy mounds, but does expose them to high levels of heat which could be detrimental if the brood is exposed. Although burning and disking may cause direct mortality to fire ants, the subsequent changes in vegetative community may facilitate recolonization, and provide better foraging resources for fire ants (Williamson et al. 2002).

Several aspects of fire ants in managed CP33 buffers have not been explored. Two unknown areas are comparison of mound density and foraging activity between treatments after different time periods and relationships among fire ants and other grassland taxa (birds and butterflies).

How Fire Ants Affect Biodiversity

Fire ants reduce animal diversity in infested areas directly by preying on ground nesting animals (Allen et al. 2004, Vinson and Sorensen 1986, Vinson 1997) and immature butterflies (Forys et al. 2001), and indirectly by competition for resources (Allen et al. 1995, Vinson and Sorensen 1986). Fire ants are a threat to many different taxa including insects (Vinson and Sorensen 1986), mammals, reptiles, amphibians, and birds (Allen et al. 2004).

Between 1966 and 2006, 54% of grassland bird species declined significantly in the U.S. compared to only 14% that significantly increased (Sauer and Hines 2006). The degree to which fire ants contributed to the decline of grassland bird populations is unknown, but several studies indicate that fire ants may lower reproduction of grassland birds (the most widely investigated being northern bobwhite).

Negative relationships between fire ants and northern bobwhite have been well documented (Allen et al. 1995, Lochmiller et al. 1993, Pedersen et al. 1996, Williamson et al. 2002). In Texas, abundance of bobwhite decreased after fire ant infestation, increased in areas treated to reduce fire ants, and was correlated negatively to years of fire ant infestation (Allen et al. 1995). Similarly, fire ant treatment increased the proportion of northern bobwhite chicks surviving 21 days (Mueller et al. 1999).

Several other studies have investigated physiological and behavioral consequences of fire ant and northern bobwhite chick interactions. Fire ants are attracted to mucous membranes (Vinson and Sorensen 1986), making bobwhite especially susceptible to mortality while hatching (Allen et al. 1995). If not fatal, exposure to fire ant venom can decrease growth rate of young northern bobwhite (Allen et al. 1995) and

cause blindness from stings in the eyes (Vinson 1997). Fire ants also may decrease availability of food insects for grassland birds (Allen et al. 1995), thus decreasing protein availability and resulting in reduced cell-mediated immunity of the birds (Lochmiller et al. 1993). Young bobwhite exposed to fire ants spent more time avoiding fire ants than foraging and sleeping (Pedersen et al. 1996).

CP33 buffers provide nesting habitat for a suite of common grassland birds including dickcissel (*Spiza americana*), red-winged blackbird (*Agelaius phoeniceus*), mourning dove (*Zenaida macroura*), eastern meadowlark (*Sturnella magna*), field sparrow (*Spizella pusilla*), and indigo bunting (*Passerina cyanea*) (Hamrick et al. 2006), but relationships between fire ants and other nesting grassland birds have not been as widely investigated. In longleaf pine (*Pinus palustris*) forests, fire ants were responsible for 28% of total nest depredation of shrub-nesting songbirds (Conner et al. 2010). In Texas, fire ants were responsible for 31% of black-capped vireo (*Vireo atricapilla*) nest depredation (Stake and Cimprich 2003) and nest success of white-eyed vireos (*Vireo griseus*) was 10% greater in areas treated for fire ants (Campomizzi et al. 2009).

To provide information about how fire ants respond to planned disturbance, I measured fire ant mound density and foraging activity in burned, disked and undisturbed controls in CP33 native grass buffers in northeastern Mississippi. To provide information about how fire ants may influence diversity of other taxa, I also measured relationships among fire ant foraging activity, mound density, bird metrics, butterfly metrics, and vegetation metrics in undisturbed buffers.

I tested the following hypotheses:

- 1) Foraging activity and mound density would be greater in disturbed buffers than in undisturbed controls, and that foraging activity and mound density would be greatest in disked buffers because it is a more intensive disturbance than burning.
- 2) Richness and abundance of birds and butterflies would be related negatively to fire ant mound density and foraging activity.
- 3) Fire ant metrics would be related positively to vegetation characteristics of an early successional community (e.g., more open space, greater forb density, etc.).

CHAPTER II

METHODS

Study Area

B. Bryan Farms (West Point, MS) has approximately 2000 hectares of row crops and cattle pasture. In spring 2004, 78.5 hectares of cropland were enrolled in CP33 buffers, which were planted with native warm season grasses like big bluestem (*Andropogon gerardii*), little bluestem (*Schizachyrium scoparium*), broomsedge bluestem (*Andropogon virginicus*), indiagrass (*Sorghastrum nutans*), switchgrass (*Panicum virgatum*), eastern gamagrass (*Tripsacum dactyloides*), and sideoats grama (*Bouteloua curtipendula*), forbs like partridge pea (*Chamaecrista fasciculata*), black-eyed susan (*Rudbeckia hirta*), and maximilian sunflower (*Helianthus maximiliani*), and shrubs like blackberry (*Rubus spp.*; Burger et al. 2006, Harper et al. 2007). B. Bryan Farms is located in the upper coastal plain (Hamrick et al. 2006) and blackland prairie region of Mississippi (Moran et al. 1997).

Treatments

Fields in similar locations with similar soils were put into blocks, and treatments were assigned randomly to fields within each block. Beginning in Fall 2007, one buffer edge per treatment field per year (assigned randomly) was either burned (5 fields) or

disked (5 fields). Control fields were left undisturbed (4 fields; Figure 1). This created a successional sequence allowing me to observe fire ants at different post-disturbance time periods. Buffers were disked in fall (September-October) prior to the growing season (2007 and 2008) and burned in spring (March-April) of each growing season (2008 and 2009). Untreated buffers attached to treated buffers will be referred to as in-field controls. Entirely untreated fields will be referred to as whole-field controls.

Fire Ant Species Identification

I collected two samples of fire ants from a single mound at each study field in 2008 ($n = 28$). I chose mounds that were close to buffers (5 – 25 m), but not actually in buffers, so that I did not cause unnecessary disturbance in my study area. I extracted venom alkaloids and cuticular hydrocarbons from ants with hexane and sent these samples to the USDA-ARS, National Biological Control Laboratory in Stoneville, MS to be tested using gas chromatography/mass spectrometry (GC/MS) tests (David C. Cross, Department of Entomology and Plant Pathology, Mississippi State University, personal communication; J. Chen performed tests). Species, and hybrids, were distinguished using venom alkaloid and cuticular hydrocarbon profiles (Menzel et al. 2008). From GC and MS, a combined alkaloid and hydrocarbon index (hereafter I) was calculated. If I was < 0.06 , the colony was determined to be *S. richteri*. If I was between 0.06 and 0.85, the colony was determined to be hybrid, if I was > 0.85 the colony was determined to be *S. invicta* (Menzel et al. 2008).

Molecular tests also were performed to determine fire ant species by looking at genetic markers. Tests showed genetic markers characteristic to *S. richteri*, *S. invicta*, or

both. When markers of both species were present, the colony was determined to be hybrid. Molecular tests used were random amplified polymorphic DNA (RAPD) marker test (detailed in Shoemaker et al. 1994) and a restrictive fragment analysis of mitochondrial DNA (detailed in Goodisman et al. 1998).

To determine social form of a colony, polymerase chain reaction (PCR) was used to determine if the allele (Gp-9^b) associated with polygyny (multiple queens) was present in each sample (Menzel et al. 2008). If it were present, the mound the sample was taken from was determined to be polygynous.

Fire Ant Sampling

I collected data in buffers around all 14 fields in May and August of 2008 and 2009. My sampling schedule bracketed grassland bird nesting season and allowed comparisons of measurements not only among treatments, but also after different periods of succession (e.g., disking 2007: 7, 10, 19, and 22 months after treatment).

In 2008, I sampled the newly disturbed buffer and two in-field controls (untreated buffers attached to the treated buffer) in each field. I also sampled three buffers in whole field controls (untreated fields). In 2009, I re-sampled the same buffers as in 2008, except that in treatment fields only one buffer remained as an in-field control (the other was now disturbed). I used whole-field controls in addition to in-field controls because in-field controls may have been potentially influenced by dispersal of fire ants from treated buffers that were connected to in-field controls. This way, I tested for field-level effects in addition to buffer-level effects of disturbance.

To measure mound density, I positioned three 50 x 10 m transects along a 200 m section of each buffer (Figure 2). I counted all active fire ant mounds (determined by light disturbance of each mound) found within 5 m on each side of the 50 m transect centerline.

I measured foraging activity on mornings (0630 – 1200 CST) of dry days by placing three consecutive lines of 10 bait cups (50 ml test tubes with small, Oscar Meyer, hot dog pieces inside; Williamson et al. 2002) on the ground in each 50 x 10 m transect. I used the same transects used to estimate mound densities. Bait cup lines were 50 m long, and bait cups were spaced 5 m apart (Figure 2). I exposed cups for 30 minutes, capped them with small pieces of cotton, then froze and counted captured fire ants.

Bird and Butterfly Sampling

Breeding bird abundance and richness were estimated along the same line transects used for fire ant data collection, as part of a separate, but related, project (Figure 2). An observer walked each transect at a rate of 10 m/minute and recorded all birds seen or heard within the grass buffer. Transects were surveyed six times during each breeding season on mornings (0530 - 1000 CST) with no precipitation and wind speeds < 15 mph (Smith et al. 2005). Nest density was estimated by systematically searching buffers to locate nests, then using ArcGIS to estimate area of each buffer and calculate approximate nesting density of dickcissel and red-winged blackbird, the most common species detected (H. Puckett, personal communication).

Butterfly abundance and richness were estimated along the same line transects used for fire ant data collection (Figure 2). Transects were surveyed six times each study

year (during June-August), and number of individuals (of each species) detected within a 10 m band were recorded (J. Goldenetz-Dollar, personal communication). Butterfly counts were conducted from 8 am to 1 pm CST (peak activity times, S. K. Riffell, unpublished data) during favorable weather conditions (Ries et al. 2002).

Vegetation Sampling

I used a modified point-intercept technique to estimate grass density and height. A 2-m metal rod was passed vertically through the vegetation, and number of times different types of vegetation touched the pole was recorded (Riffell et al. 2001). This served as an estimate of vegetation density and a way to measure vegetation height. I also used 0.25-m² sampling frames (0.5 x 0.5 m) to estimate percent coverage of grasses, native-warm season grasses, Johnsongrass, forbs and litter (Reeder et al. 2005). In each buffer, I sampled 30 0.25-m² sampling frames.

Statistical Analysis

To test for differences in mound density and foraging activity among disturbance treatments, I used general linear mixed models (Littell et al. 2006). I included field as a random effect to account for sampling multiple, connected buffers in the same fields. Connected buffers may not have been totally independent because ants (and birds and butterflies) might disperse from treated buffers into attached, undisturbed controls. For each buffer, response variables were mound density (mounds/1500 m²) and foraging activity (average ants/vial). For 2008 analysis, treatment levels were: no treatment (control/whole-field control), disked fall 2007 (disk 2007), in-field controls of disked

fields (disk control), burned spring 2008 (burn 2008), and in-field controls of burned fields (burn control). For 2009 analysis, treatment levels were the same as 2008 plus disked fall 2008 (disk 2008) and burned spring 2009 (burn 2009). I used an *F*-test to test the null hypothesis that treatments did not differ. If there was a difference, I used least squared means for multiple comparisons among treatment (2008 $n = 5$, 2009 $n = 7$). I used a *priori* $\alpha = 0.10$ for all tests.

To test for relations between fire ants, birds and butterflies, I also used general linear mixed models (Littell et al. 2006) using bird and butterfly metrics as dependent variables and fire ant metrics as predictors (Tables 1 & 2). Field was included as a random effect to account for multiple, connected buffers in the same field, and treatment was a fixed effect. I used only control buffers to test for relationships because disturbance also altered vegetation structure and composition. Had I tested for and detected relationships in treated buffers, I could not have determined whether birds and butterflies were responding to fire ants or changes in vegetation. I used Proc Mixed in SAS for density and abundance metrics. Because richness variables were count data, and not normally distributed, I used Proc Glimmix to model these variables as Poisson distributed (Littell et al. 2006).

I classified birds in one of two guilds. Grassland birds were obligate or facultative grassland species according to Vickery et al (1999), and other species were classified as upland species (Appendix A). I calculated avian nest density as total number of nests per hectare of buffer. I calculated nest density for all species (total avian nest density), dickcissel, and red-winged blackbird. I calculated total avian richness, grassland bird richness and upland bird richness as total number of species detected

across the 6 sampling visits. I calculated total avian abundance, grassland bird abundance and upland bird abundance as mean number of birds per hectare per visit (\bar{x} #/ha/visit).

Similarly, I classified all butterfly species into one of three guilds. Grassland specialist butterflies were species that used primarily grassland or prairie species for either larval or adult food sources, whereas disturbance –tolerant species are generalists that favor open habitats highly altered by human activity (Reeder et al. 2005, Davros et al. 2006, Vogel et al. 2007). Forest species use primarily forest plants for host and floral resources and used the native grass buffers for additional foraging resources or were detected incidentally as they moved throughout the farm’s habitats (Appendix B). I calculated total butterfly richness, specialist butterfly richness, disturbance-tolerant butterfly richness, and forest butterfly richness as total number of species detected across the 6 sampling visits. I calculated total butterfly abundance, specialist butterfly abundance, disturbance-tolerant butterfly abundance, and forest butterfly abundance as mean number of butterflies per hectare per visit (\bar{x} #/ha/visit).

To test for relationships between fire ants and vegetation characteristics, I again used general linear mixed models (Littell et al. 2006) using fire ant metrics as dependent variables and vegetation metrics as predictors (Table 3). Field was included as a random effect to account for multiple, connected buffers in the same field, and treatment was a fixed effect. Grass density was mean number of contacts on the 2.0-m point intercept pole (\bar{x} # hits on 2 m pole), and grass height was mean height in cm at the pole (\bar{x} grass height). Total grass cover was mean percent coverage of all grasses (\bar{x} % cover of all grasses), native warm season grass cover was percent coverage of only planted native

warm season grass species (\bar{x} % cover of native warm season grasses), Johnsongrass cover was percent coverage of Johnsongrass only (\bar{x} % cover of Johnsongrass). I also calculated mean percent coverage of forbs (\bar{x} % cover) and litter (\bar{x} % cover; Table 3). I used a *priori* $\alpha = 0.10$ for all tests.

CHAPTER III

RESULTS

Fire Ant Species Identification

Gas chromatography (GC) and mass spectrometer (MS) tests indicated that 11 of 14 mounds had *I* values between 0.06 and 0.85 (hybrid). One mound sample was misplaced, so I did not have GC or MS tests performed on it. One mound had an *I* value < 0.06 (*S. richteri*), and one had an *I* value = 0.06. Twelve of 14 mounds had molecular markers characteristic of both species, and 2 mounds had markers characteristic of *S. richteri*. Polymerase chain reaction indicated that 2 mounds had the allele (Gp-9b) associated with polygyny. When considering all of the tests, 13 of 14 mounds were hybrid fire ants. One was borderline between hybrid and black fire ant ($I = 0.06$ and molecular marker characteristic of *S. richteri*). Two of 14 mounds were polygyne, having multiple queens. Fire ants at my study site were primarily monogyne hybrid with the possibility of a small population of black imported fire ants.

Mound Density

In May 2008, mound density was greatest in buffers disked fall 2007 ($t = -5.44 - -6.43$, $P < 0.0001$), but all differences among treatments had diminished by August ($F_{4,37} = 1.75$, $P = 0.160$). In May 2009, mound density was again greatest in buffers disked fall 2007 ($t = -1.93 - -2.99$, $P = 0.005 - 0.066$) and buffers burned spring 2009 ($t_{24.2} = -2.47$, P

= 0.018), but unlike the previous year, mound density was not greater in recently disked buffers ($t = -0.25 - -1.28$, $P = 0.207 - 0.802$). In August 2009, buffers disked in 2007 continued to have the greatest mound density ($t = -1.86 - -3.11$, $P = 0.004 - 0.071$; Figure 3).

For buffers disked fall 2007, mound density increased 7 months post-disturbance, decreased 10 months post-disturbance, increased again 19 months post-disturbance, and decreased again 22 months post-disturbance. For buffers burned spring 2008, mound densities remained low and relatively constant 2, 5, 14, and 17 months post-disturbance. For buffers disked fall 2008, mound density remained low and constant 7 and 10 months post-disturbance. For buffers burned spring 2009, mound density increased 2 months post-disturbance, but decreased 5 months post-disturbance.

Foraging Activity

In May 2008 there were no differences in foraging activity ($F_{4,15.7} = 1.71$, $P = 0.197$) In August 2008, foraging activity was greatest in buffers disked fall 2007 ($t = -2.72 - -3.09$, $P = 0.004 - 0.010$) and associated infield controls ($t = -3.17 - -3.64$, $P = 0.001 - 0.003$; Figure 4). In May 2009, foraging activity was greatest in buffers disked fall 2007 ($t = 0.73 - 3.42$, $P = 0.002 - 0.06$) and buffers burned spring 2009 ($t = 1.88 - 2.32$, $P = 0.030 - 0.068$), but unlike the previous year, fire ant foraging activity was not greater in recently disked buffers ($t = -0.25 - -1.23$, $P = 0.232 - 0.806$). In August 2009 there were no differences ($F_{6,24.3} = 0.71$, $P = 0.644$) in foraging activity (Figure 4).

For buffers disked fall 2007, foraging activity was greater than controls 7, 10, 19, and 22 months post-disturbance. For buffers burned spring 2008, foraging activity

remained consistently low 2, 5, 14, and 17 months post-disturbance. For buffers disked fall 2008, foraging activity was low 7 months post-disturbance, but showed an increasing trend 10 months post-disturbance (although not significantly greater than other treatments). For buffers burned spring 2009, foraging activity remained low 2 and 5 months post-disturbance.

Relationships among Fire Ants and Other Grassland Taxa

In May 2008, total avian nest density ($F_{1,26} = 4.60$, $P = 0.042$), red-winged blackbird nest density ($F_{1,26} = 4.72$, $P = 0.039$), total avian abundance ($F_{1,26} = 8.76$, $P = 0.007$), grassland bird abundance ($F_{1,25.1} = 7.66$, $P = 0.011$), and total butterfly abundance ($F_{1,25} = 3.32$, $P = 0.081$) were related positively to mound density (Tables 1 & 2). Disturbance-tolerant butterfly abundance was related positively to foraging activity ($F_{1,25.8} = 8.54$, $P = 0.007$). In August 2008, total avian nest density ($F_{1,25.6} = 10.67$, $P = 0.003$), red-winged blackbird nest density ($F_{1,26} = 9.98$, $P = 0.004$), and total avian abundance ($F_{1,26} = 3.14$, $P = 0.088$) were related positively to mound density. Total avian abundance ($F_{1,26} = 4.83$, $P = 0.037$), grassland bird abundance ($F_{1,26} = 5.14$, $P = 0.032$), and disturbance-tolerant butterfly abundance ($F_{1,26} = 6.77$, $P = 0.015$) were related positively to foraging activity. In May 2009, there were no relationships among mound density and bird and butterfly metrics. Total avian abundance ($F_{1,18} = 12.04$, $P = 0.003$) and grassland bird abundance ($F_{1,18} = 11.07$, $P = 0.004$) were related positively to foraging activity. In August 2009, there were no relationships among mound density and bird and butterfly metrics, but total avian abundance was positively related to foraging

activity ($F_{1,18} = 4.34$, $P = 0.052$; Tables 1 & 2). I detected no negative relationships between fire ant metrics and bird and butterfly metrics.

Fifteen out of 136 statistical tests involving bird and butterfly metrics were statistically significant. This is close to the 13.6 significant relationships expected by chance alone at $\alpha = 0.10$, so it is possible these results were simply spurious effects. Overall, there were no widespread or significant relationships among fire ants and density, abundance, or richness of grassland butterflies and birds in undisturbed buffers. The relatively few positive relationships with bird nest density and abundance (and with disturbance-tolerant butterflies) may reflect common responses to similar habitat conditions.

Relationships between Fire Ants and Vegetation

In May 2008, mound density was related negatively to grass height ($F_{1,18} = 9.25$, $P = 0.007$), total grass coverage ($F_{1,18} = 10.10$, $P = 0.005$), native warm season grass coverage ($F_{1,18} = 3.75$, $P = 0.069$), and Johnsongrass coverage ($F_{1,17.9} = 5.71$, $P = 0.028$), and related positively to forb cover ($F_{1,18} = 7.86$, $P = 0.012$). Foraging activity was related negatively to Johnsongrass cover ($F_{1,18} = 7.08$, $P = 0.016$). In August 2008, foraging activity was related negatively to total grass cover ($F_{1,18} = 3.10$, $P = 0.095$), and related positively to forb cover ($F_{1,18} = 4.77$, $P = .042$). In May 2009, foraging activity was related negatively to grass density ($F_{1,18} = 7.25$, $P = 0.015$), grass height ($F_{1,18} = 8.47$, $P = 0.009$), and total grass cover ($F_{1,18} = 3.53$, $P = 0.077$). In August 2009, mound density was related positively to forb cover ($F_{1,18} = 3.98$, $P = 0.061$). Foraging activity was related positively to forb cover ($F_{1,18} = 7.34$, $P = 0.014$), and related negatively to

grass density ($F_{1,18} = 4.80$, $P = 0.042$), grass height ($F_{1,18} = 8.37$, $P = 0.010$),
Johnsongrass cover ($F_{1,18} = 6.03$, $P = 0.025$), and litter cover ($F_{1,18} = 3.15$, $P = 0.093$;
Table 3).

Out of 56 tests, 16 were significant, which is approximately 3 times the 5.6 significant tests expected by chance alone at $\alpha = 0.10$. It is unlikely that these are spurious relationships. Cumulatively, these significant results indicate a positive relationship between fire ants and more open, heterogeneous grassland structure, with abundant forbs above ground.

CHAPTER IV

DISCUSSION

Response to Planned Disturbance

Disking increased fire ant mound density and foraging activity the first year of my study, but burning did not. The next year, fire ants were not affected by disking; but, increased fire ant mound density and foraging activity persisted in buffers that had been disked 2 years earlier. Burning increased fire ant mound densities during the second season only (2009), but this increase diminished by August. The decrease in mound densities could be due to hotter temperatures in August driving ants underground, where the temperature is lower, hence causing the above ground portion of the mound to be less visible (Vinson and Sorensen 1986).

Burning promotes success of species that are adapted to frequent burning, whereas soil disturbance, like that caused by disking, creates openings for establishment, often of weedy, or ruderal species (Hobbs and Huenneke 1992). Because fire ants have similar characteristics of invasive species (high dispersal, rapid reproduction, rapid growth), they may have been able to colonize newly disked buffers before native species were able to, but did not colonize burned buffers as effectively.

It is possible that buffers disked in 2007 had greater pre-treatment fire ant mound density and foraging activity. Thus, these persistent effects could have been due to pre-treatment differences rather than a response to disturbance. I did not collect pretreatment

data for fire ants so I cannot test this directly, but pretreatment data for vegetation and butterflies were collected in 2007 prior to implementing disturbances as part of a related project. Pre-treatment vegetation characteristics did not differ among treatment groups (Goldenetz-Dollar, unpublished data). Additionally, abundance and richness of butterflies (another arthropod taxon) similarly did not differ pre-treatment (Goldenetz-Dollar, unpublished data). Furthermore, abundance of disturbance-tolerant butterflies increased significantly in buffers disked fall 2007 (and this difference persisted throughout the second study season), but disking the second season had no effect (Goldenetz-Dollar, unpublished data), just like what I observed for fire ants. Thus, it is unlikely that my results for fire ants represent pre-treatment artifacts.

Persistent effects of disking from the first season could have affected negatively grassland birds because increased mound density and foraging activity of fire ants increases potential for nest failure due to fire ant depredation. Birds tended to avoid nesting in disked buffers the first season post-treatment (zero attempts; H. Puckett, unpublished data), so disking did not likely affect bird nest success via increased fire ants that first year in my study area. However, birds did begin to nest in disked buffers the second growing season post-disturbance (three attempts; H. Puckett, unpublished data) when fire ant mound density and foraging activity were still elevated, thus increasing potential for nest losses.

Fire ants responded positively to burning in the second study year, and so may have possibly increased nest losses in those buffers because nesting birds did not avoid recently burned buffers (H. Puckett, unpublished data). The extent of this increase is

uncertain because fire ant response had diminished by the end of nesting season, but response to burning spring 2009 was less than response to disking fall 2007.

In May and August 2008, foraging activity was greatest (although not statistically in May) in buffers disked in 2007 and connected in-field controls. This suggests that disturbance may cause an increased response in adjacent buffers due to elevated dispersal of fire ants from treated buffers to connected untreated buffers, and this justifies my separation of in-field controls for analysis.

Persistence of first season disking effects without second season disking effects suggests that temporal variation in environmental variables may mediate arthropod response to disturbances. My study site received more rain the second year (May-July rainfall = 16.53 inches; Mississippi State Department of GeoSciences) than the first year (8.74 inches). Fire ants are less active during rain events (Porter and Tschinkel 1987), so this could explain why there was not a response to disking the second year. However, this still does not explain why effects of disking the first year persisted. Increased rainfall could have possibly influenced vegetation response and recovery and affected indirectly fire ant populations. Persistence of effects in buffers disked the first season also could have been due to fire ants already having colonized those buffers; whereas the second season, they simply may have been unable to colonize newly disked buffers because rain decreased ant activity

Environmental stochasticity may influence fire ant response to disturbance, and disturbance may have varied outcomes under different conditions. Decisions about efficacy of planned disturbance should not be based on only a one or a few years'

response. Future research should examine the influences of environmental stochasticity on fire ant response to disturbance over several years.

Relationships among Fire Ants and Birds and Butterflies

Arthropod biomass, diversity and richness can be related negatively to fire ant abundance (Epperson and Allen 2010), and negative relationships between birds and fire ants have been documented (Allen et al. 1995, Campomizzi 2008, Mueller et al. 1999). However, I observed no strong evidence of this (abundance, richness, and density) in undisturbed buffers at my study site.

Absence of relationships could possibly be because fire ant populations in my control buffers may have been too small to impact bird and butterfly density, abundance, and richness. Fire ant mound density was nearly 10 times greater in control plots in a similar study in Mississippi (Williamson et al. 2002) and plots untreated for fire ants in Texas (Forbes et al. 2002; Table 4). Foraging activity also was consistently greater in other studies (Williamson et al. 2002, Epperson and Allen 2010) than at my study site, so perhaps fire ant populations were not large enough to elicit a deleterious response in bird and butterfly metrics at my study site.

Fire ants at my study site were mainly hybrid with a small population of black imported fire ants. Absence of the more aggressive red imported fire ant could possibly explain the lack of relationships between bird and butterfly metrics and fire ants at my study site. Because black imported and hybrid fire ants are less aggressive than the red imported fire ant (Vinson and Sorensen 1986), they may have been less active foragers or foraged over shorter distances from mounds. Additionally, most colonies I tested were

monogyne colonies which do not achieve the extremely high densities characteristic of polygyne colonies (Porter and Tschinkel 1987, Allen et al. 1995). Thus, ants at my study site may be less detrimental to birds and butterflies than red imported fire ants in other areas.

Relationships between Fire Ants and Vegetation

Mound density and foraging activity were related negatively to extent of grass cover (grass height, density, total cover) and related positively to forbs. Many grassland bird species prefer open space at ground level which is unavailable when grass is too dense (Harper et al. 2007), hence the requirement for periodic disturbance in CP33 buffers. Forbs provide a variety of seeds for grassland bird foraging and are common in CP33 buffers (Jones et al. 2007). My results demonstrated a general relationship between fire ant mound density and foraging activity with native grass buffers that were more open and more rich in forb species. This suggests that management of CP33 buffers may increase fire ants, and consequently, potentially sabotage efforts to provide habitat for birds.

CHAPTER V

CONCLUSION

Burning may be a preferred method for disturbing native grass buffers because it had small or no effects on fire ants compared to disking. I only observed an increased response of fire ants to burning at one time interval. In contrast, response to disking in 2007 persisted throughout two growing seasons, increasing potential for nest losses to fire ants. It is unlikely that fire ants can be completely eliminated in CP33 buffers, so control is the only realistic option for management. Unfortunately, vegetation management like disking and burning for birds (and other early successional species) also may make buffers more favorable to fire ants. Because burning appeared to have less effect on fire ants, using strictly burning as a disturbance tool could potentially increase nest success of grassland birds relative to other modes of disturbance, but further evaluation is needed to monitor long term responses of fire ants.

Although I observed little to no relationships among bird metrics and fire ants, fire ants were a frequent cause of grassland bird nest failure at my study site. In 2008, fire ants were responsible for 27% of grassland bird nest losses. In 2009, fire ants were responsible for 11.5% of grassland bird nest losses (H. Puckett, unpublished data). Management practices minimizing fire ant presence could potentially increase future nest success.

Because my study and other studies of fire ant response to disturbance have been short term (Williamson et al. 2002, Forbes et al. 2002), long term studies would greatly benefit the body of scientific knowledge via monitoring consistency of treatment response over long time frames to determine how environmental stochasticity causes year to year variation in treatment responses. If response to treatments remains constant, burning should replace disking as the preferred disturbance method.

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APPENDIX A

DETECTED BIRD SPECIES AND GUILD CLASSIFICATION

Guild	Common Name	Scientific Name
Grassland	Brown-headed Cowbird	<i>Molothrus ater</i>
Grassland	Common Yellowthroat	<i>Geothlypis trichas</i>
Grassland	Dickcissel	<i>Spiza americana</i>
Grassland	Eastern Kingbird	<i>Tyrannus tyrannus</i>
Grassland	Eastern Meadowlark	<i>Sturnella magna</i>
Grassland	Grasshopper Sparrow	<i>Ammodramus savannarum</i>
Grassland	Loggerhead Shrike	<i>Lanius ludovicianus</i>
Grassland	Mourning Dove	<i>Zenaida macroura</i>
Grassland	Northern Bobwhite	<i>Colinus virginianus</i>
Grassland	Red-winged Blackbird	<i>Agelaius phoeniceus</i>
Grassland	Sedge Wren	<i>Cistothorus platensis</i>
Upland	Blue Grosbeak	<i>Guiraca caerulea</i>
Upland	Blue-gray Gnatcatcher	<i>Polioptila caerulea</i>
Upland	Carolina Chickadee	<i>Poecile carolinensis</i>
Upland	Eastern Towhee	<i>Pipilo erythrophthalmus</i>
Upland	Field Sparrow	<i>Spizella pusilla</i>
Upland	Indigo Bunting	<i>Passerina cyanea</i>
Upland	Northern Cardinal	<i>Cardinalis cardinalis</i>
Upland	Northern Mockingbird	<i>Mimus polyglottos</i>
Upland	Orchard Oriole	<i>Icterus spurius</i>
Upland	Ruby-throated Hummingbird	<i>Archilochus colubris</i>
Upland	Tree Swallow	<i>Tachycineta bicolor</i>
Upland	Yellow-breasted Chat	<i>Icteria virens</i>

APPENDIX B
DETECTED BUTTERFLY SPECIES AND GUILD CLASSIFICATION

Guild	Common Name	Scientific Name
Disturbance-tolerant	American Snout	<i>Libytheana carinenta</i>
Disturbance-tolerant	American Lady	<i>Vanessa virginiensis</i>
Disturbance-tolerant	Black Swallowtail	<i>Papilio polyxenes</i>
Disturbance-tolerant	Common Buckeye	<i>Junonia coenia</i>
Disturbance-tolerant	Common Checkered Skipper	<i>Pyrgus communis</i>
Disturbance-tolerant	Cloudless Sulphur	<i>Phoebis sennae</i>
Disturbance-tolerant	Eastern Tailed Blue	<i>Cupido comyntas</i>
Disturbance-tolerant	Gray Hairstreak	<i>Strymon melinus</i>
Disturbance-tolerant	Gulf Fritillary	<i>Agraulis vanillae</i>
Disturbance-tolerant	Little Yellow	<i>Pyrisitia lisa</i>
Disturbance-tolerant	Long-tailed Skipper	<i>Urbanus proteus</i>
Disturbance-tolerant	Monarch	<i>Danaus plexippus</i>
Disturbance-tolerant	Pearl Crescent	<i>Phyciodes tharos</i>
Disturbance-tolerant	Sleepy Orange	<i>Abaeis nicippe</i>
Disturbance-tolerant	Clouded Sulphur	<i>Colias philodice</i>
Disturbance-tolerant	Orange Sulphur	<i>Colias eurytheme</i>
Disturbance-tolerant	Variiegated Fritillary	<i>Euptoieta claudia</i>
Forest	Eastern Tiger Swallowtail	<i>Papilio glaucus</i>
Forest	Great Purple Hairstreak	<i>Atlides halesus</i>
Forest	Hackberry Emperor	<i>Asterocampa celtis</i>
Forest	Horace's Duskywing	<i>Erynnis horatius</i>
Forest	Red-banded Hairstreak	<i>Calycopis cecrops</i>
Forest	Red-spotted Purple	<i>Limenitis arthemis</i>
Forest	Tawny Emperor	<i>Asterocampa clyton</i>
Forest	Viceroy	<i>Limenitis archippus</i>
Forest	Giant Swallowtail	<i>Papilio cresphontes</i>
Forest	Pipevine Swallowtail	<i>Battus philenor</i>
Forest	Spicebush Swallowtail	<i>Papilio troilus</i>
Grassland	Clouded Skipper	<i>Lerema accius</i>
Grassland	Delaware Skipper	<i>Anatrytone logan</i>
Grassland	Dun Skipper	<i>Euphyes vestris</i>
Grassland	Eufala Skipper	<i>Lerodea eufala</i>
Grassland	Fiery Skipper	<i>Hylephila phyleus</i>
Grassland	Sachem	<i>Atalopedes campestris</i>
Grassland	Southern Skipperling	<i>Copaeodes minima</i>
Grassland	Swarthy Skipper	<i>Nastra lherminier</i>
Grassland	Tawny-Edged Skipper	<i>Polites themistocles</i>
Grassland	Southern Cloudywing	<i>Thorybes bathyllus</i>
Grassland	Silver-spotted Skipper	<i>Epargyreus clarus</i>
Grassland	Silvery Checkerspot	<i>Chlosyne nycteis</i>
Grassland	Whirlabout	<i>Polites vibex</i>

Table 1 Relationships (coefficients)¹ between bird and butterfly metrics and fire ant mound density in undisturbed buffers during 2008 (n = 28) and 2009 (n = 20) at B. Bryan Farms, Clay County, Mississippi. *P*-values in parentheses. Significant relationships in boldface.

	May 2008	Aug 2008	May 2009	Aug 2009
<i>Mound Density (#/1500m²)</i>				
Avian Nest Density	0.61 (0.042)	1.22 (0.003)	-0.31 (0.467)	-0.27 (0.593)
Dickcissel Nest Density	0.14 (0.184)	0.13 (0.383)	-0.15 (0.502)	-0.05 (0.859)
Red-winged Blackbird Nest Density	0.54 (0.039)	1.01 (0.004)	-0.23 (0.439)	-0.18 (0.616)
Total Avian Richness ²	0.10 (0.355)	0.07 (0.577)	-0.05 (0.679)	0.12 (0.473)
Total Avian Abundance	0.52 (0.007)	0.47 (0.088)	-0.12 (0.721)	0.50 (0.221)
Grassland Bird Richness	0.14 (0.345)	0.10 (0.553)	-0.16 (0.471)	0.03 (0.899)
Grassland Bird Abundance	0.53 (0.011)	0.49 (0.117)	-0.12 (0.768)	0.52 (0.286)
Upland Bird Richness	0.05 (0.665)	0.03 (0.846)	0.03 (0.847)	0.19 (0.413)
Upland Bird Abundance	-0.02 (0.753)	-0.01 (0.874)	-0.00 (0.987)	-0.02 (0.901)
Total Butterfly Richness	0.02 (0.678)	0.02 (0.712)	0.01 (0.875)	0.00 (0.962)
Total Butterfly Abundance	0.62 (0.081)	0.17 (0.745)	-0.43 (0.678)	-0.21 (0.867)
Habitat-Specialist Butterfly Richness	0.06 (0.509)	0.05 (0.654)	0.04 (0.814)	-0.17 (0.480)
Habitat-Specialist Butterfly Abundance	0.31 (0.133)	0.26 (0.395)	0.01 (0.950)	-0.34 (0.158)
Disturbance-tolerant Butterfly Richness	0.01 (0.773)	0.01 (0.862)	0.01 (0.896)	0.05 (0.602)
Disturbance-tolerant Butterfly Abundance	0.29 (0.245)	-0.11 (0.750)	-0.44 (0.643)	0.15 (0.897)
Forest Butterfly Richness	-0.04 (0.684)	0.01 (0.967)	-0.03 (0.874)	-0.11 (0.675)
Forest Butterfly Abundance	0.02 (0.624)	0.00 (0.925)	-0.00 (0.857)	-0.01 (0.612)

¹ Coefficients are beta coefficients associated with each bird or butterfly metric from a general linear mixed model.

² I used Poisson regression for richness variables

Table 2 Relationships (coefficients)¹ between bird and butterfly metrics and fire ant foraging activity in undisturbed buffers during 2008 (n = 28) and 2009 (n = 20) at B. Bryan Farms, Clay County, Mississippi in untreated buffers. *P*-values in parentheses. Significant relationships in boldface.

	May 2008	Aug 2008	May 2009	Aug 2009
<i>Foraging Activity</i> (\bar{x} ants/vial)				
Avian Nest Density	1.16 (0.696)	3.15 (0.344)	11.04 (0.119)	-1.48 (0.683)
Dickcissel Nest Density	1.53 (0.145)	1.46 (0.190)	4.72 (0.193)	-0.86 (0.638)
Red-winged Blackbird Nest Density	0.55 (0.831)	2.28 (0.433)	6.89 (0.176)	-0.11 (0.965)
Total Avian Richness ²	0.48 (0.561)	0.60 (0.517)	1.04 (0.615)	1.17 (0.350)
Total Avian Abundance	1.80 (0.348)	4.37 (0.037)	16.03 (0.003)	5.55 (0.052)
Grassland Bird Richness	0.87 (0.466)	1.90 (0.236)	4.36 (0.288)	0.22 (0.878)
Grassland Bird Abundance	1.71 (0.468)	4.89 (0.032)	18.57 (0.004)	4.40 (0.209)
Upland Bird Richness	0.03 (0.982)	-1.55 (0.408)	-2.06 (0.520)	1.86 (0.295)
Upland Bird Abundance	0.11 (0.864)	-0.44 (0.513)	-2.54 (0.275)	1.15 (0.320)
Total Butterfly Richness	-0.55 (0.319)	-0.09 (0.831)	1.21 (0.386)	0.52 (0.426)
Total Butterfly Abundance	4.49 (0.218)	4.25 (0.307)	21.17 (0.226)	5.41 (0.540)
Habitat-specialist Butterfly Richness	-0.23 (0.771)	-1.07 (0.397)	2.41 (0.463)	0.32 (0.822)
Habitat-specialist Butterfly Abundance	-1.86 (0.414)	-2.08 (0.380)	-0.24 (0.946)	-1.65 (0.343)
Disturbance-tolerant Butterfly Richness	-0.45 (0.450)	0.25 (0.648)	0.72 (0.592)	0.61 (0.416)
Disturbance-tolerant Butterfly Abundance	6.27 (0.007)	6.15 (0.015)	20.94 (0.188)	7.06 (0.379)
Forest Butterfly Richness	-1.61 (0.310)	-0.20 (0.854)	3.24 (0.441)	0.06 (0.975)
Forest Butterfly Abundance	-0.30 (0.367)	0.09 (0.808)	0.47 (0.265)	0.01 (0.971)

¹ Coefficients are beta coefficients associated with each bird or butterfly metric from a general linear mixed model.

² I used Poisson regression for richness variables.

Table 3 Relationships (coefficients)¹ between vegetation metrics and fire ant mound density and foraging activity in undisturbed buffers during 2008 (n = 20) and 2009 (n = 20) at B. Bryan Farms, Clay County, Mississippi. *P*-values in parentheses. Significant relationships in boldface.

	May 2008	Aug 2008	May 2009	Aug 2009
<i>Mound Density (#/1500m²)</i>				
Grass Density	-0.56 (0.313)	-0.49 (0.164)	0.11 (0.761)	-0.30 (0.304)
Grass Height	-0.06 (0.007)	-0.01 (0.370)	0.00 (0.760)	-0.01 (0.214)
Total Grass Cover	-0.07 (0.005)	-0.01 (0.394)	-0.00 (0.920)	-0.03 (0.226)
Native Warm Season Grass Cover	-0.05 (0.069)	-0.01 (0.386)	-0.03 (0.415)	-0.03 (0.343)
Johnsongrass Cover	-0.18 (0.028)	0.00 (0.936)	0.03 (0.404)	-0.03 (0.239)
Forb Cover	0.07 (0.012)	0.03 (0.195)	0.01 (0.828)	0.04 (0.061)
Litter Cover	-0.06 (0.461)	-0.04 (0.470)	-0.04 (0.411)	-0.05 (0.140)
<i>Foraging Activity(\bar{x} ants/vial)</i>				
Grass Density	2.36 (0.617)	-0.97 (0.845)	-4.58 (0.015)	-7.88 (0.042)
Grass Height	-0.25 (0.237)	-0.32 (0.138)	-0.19 (0.009)	-0.39 (0.010)
Total Grass Cover	-0.13 (0.556)	-0.38 (0.095)	-0.30 (0.077)	-0.55 (0.111)
Native Warm Season Grass Cover	0.08 (0.710)	-0.29 (0.208)	-0.35 (0.119)	-0.22 (0.640)
Johnsongrass Cover	-1.45 (0.016)	-0.90 (0.292)	-0.23 (0.233)	-0.81 (0.025)
Forb Cover	0.11 (0.677)	0.52 (0.042)	0.22 (0.115)	0.66 (0.014)
Litter Cover	-0.44 (0.516)	-0.45 (0.520)	-0.38 (0.140)	-0.86 (0.093)

¹ Coefficients are beta coefficients associated with each vegetation metric from a general linear mixed model.

Table 4 Comparisons of imported fire ant mound density¹ and foraging activity² across similar studies.

Location	Month/Year	Mound Density	Foraging Activity	Reference
Mississippi	May 2008	3.42	28.78	Hale 2010
Mississippi	August 2008	1.50	31.14	Hale 2010
Mississippi	May 2009	3.58	14.19	Hale 2010
Mississippi	August 2009	2.25	32.49	Hale 2010
Mississippi	May 1999	30.30	39.40	Williamson et al. 2002
Mississippi	October 1999	37.50	46.50	Williamson et al. 2002
Texas	Jan/Feb 1998	~31.50	N/A	Forbes et al. 2002
Mississippi	May 1997	N/A	52.50	Epperson and Allen 2010
Mississippi	May 1998	N/A	40.95	Epperson and Allen 2010
Mississippi	October 1998	N/A	51.45	Epperson and Allen 2010
Mississippi	May 1999	N/A	19.45	Epperson and Allen 2010
Mississippi	October 1999	N/A	150.20	Epperson and Allen 2010
Mississippi	May 2000	N/A	36.50	Epperson and Allen 2010
Mississippi	October 2000	N/A	51.40	Epperson and Allen 2010

¹ Mound density measured as mounds/1500m²

² Foraging activity measured as average ants/vial or trap

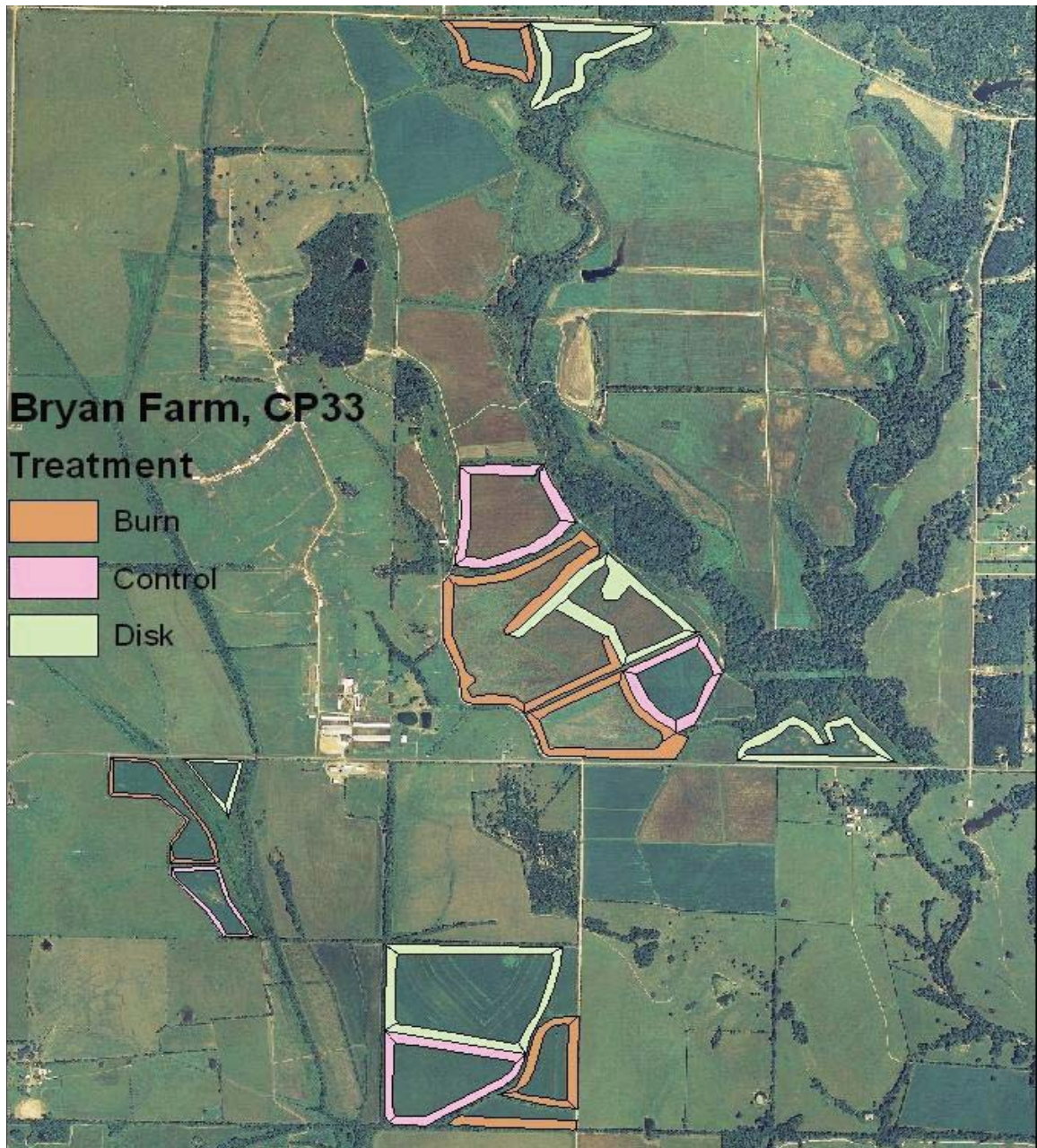


Figure 1 Aerial view of study area (B. Bryan Farms, Clay County, Mississippi) and experimental design. Native grass buffers are outlined in green (disked), orange (burned) and pink (untreated).

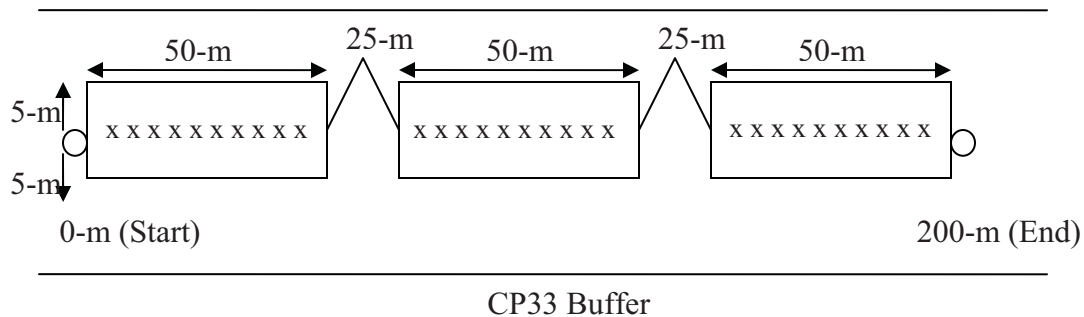


Figure 2 Layout of transects in buffers at B. Bryan Farms (Clay County, Mississippi) during 2008 and 2009. Total length was 200-m divided into three 50x10-m transects with 25-m in between each. Ten bait cups (x's) were set in a straight line 5-m apart in each 50x10-m transect.

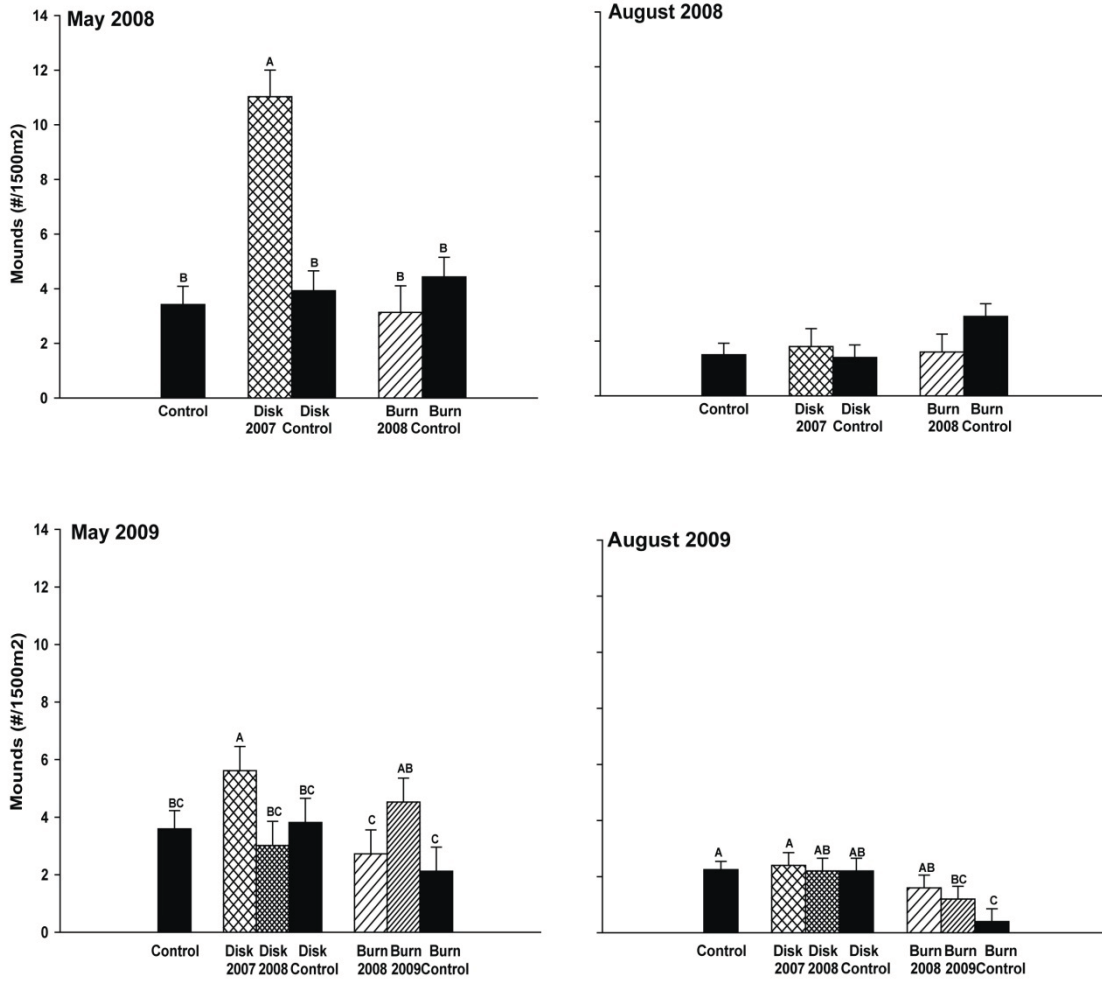


Figure 3 Imported fire ant mound densities at B. Bryan Farms (Clay County, Mississippi) during 2008 and 2009. In each season, means with the same letter do not differ significantly ($\alpha = 0.10$). Letters are absent where no significant differences occurred.

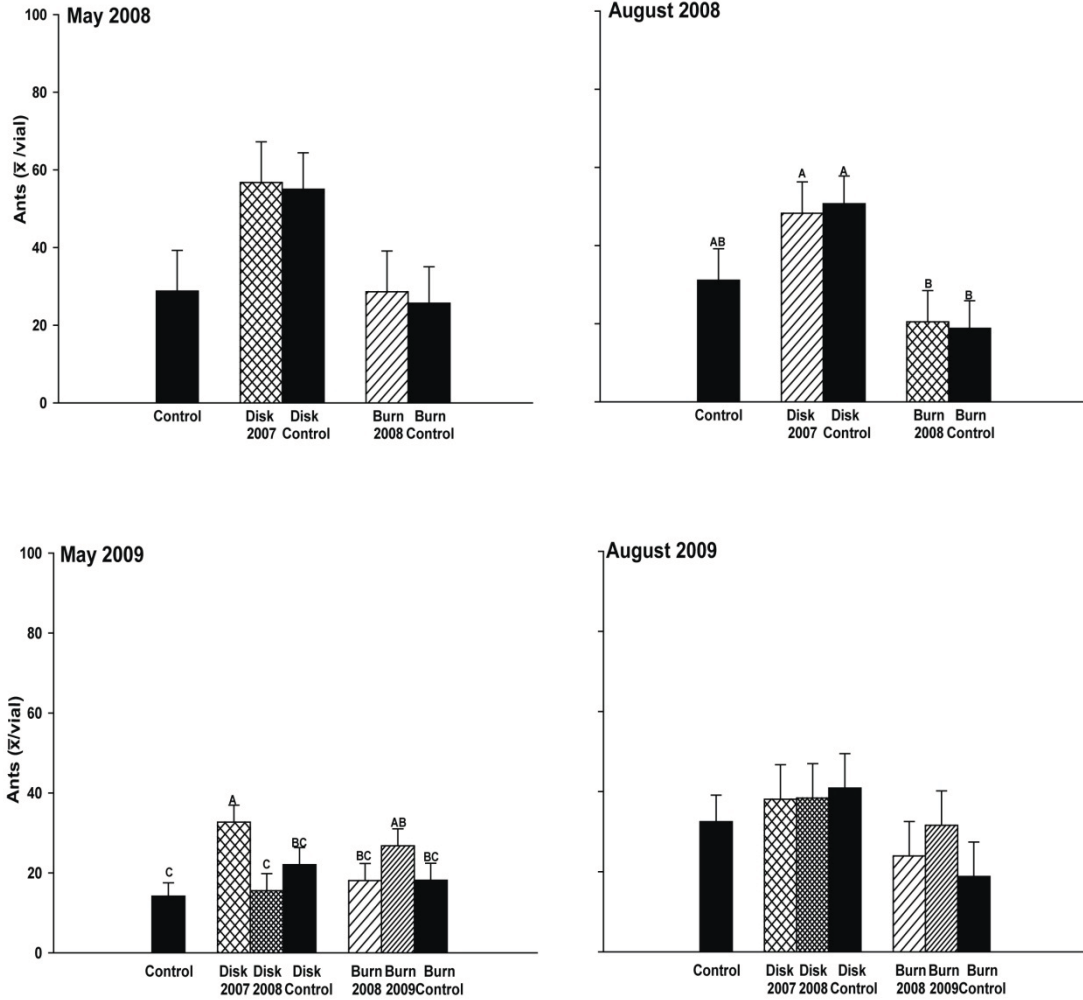


Figure 4 Imported fire ant foraging activity at B. Bryan Farms (Clay County, Mississippi) during 2008 and 2009. In each season, means with the same letter do not differ significantly ($\alpha = 0.10$). Letters are absent where no significant differences occurred.