EFFECTS OF PATCH MOSAIC BURNING ON TICK BURDEN ON CATTLE, TICK SURVIVAL, AND TICK ABUNDANCE

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CHAPTER I

INTRODUCTION

Interactions between a patch mosaic burning (PMB) regimen with difference burn intervals and the grazing of ruminants create a shifting mosaic of grassland patches in pastures. This management strategy produces heterogeneous patterns in the plant community structure and composition (Fuhlendorf and Engle, 2004). Aside from creating diversity in vegetation, fire also may control tick populations (Jacobson and Hurst, 1979; Warren et al., 1987; Scifres et al., 1988; Davidson et al., 1994; Cully, 1999). Fire reduces tick populations in two different ways: direct mortality and longer lasting microhabitat changes. Fire removes leaf litter and vegetation and causes a general increase in temperature and decrease in relative humidity of the environment (Warren et al., 1987; Scifres et al., 1988). Ticks are sensitive to these changes in temperature and vegetation structure (Davidson et al., 1994). This type of habitat associated mortality plays a role in the regulation of the tick population size and species range (Bertrand and Wilson, 1997).

Patch mosaic burning entails dividing one pasture into multiple, smaller subplots. These subplots are burned at various times to increase the structure and diversity of plant communities. Fire and focal grazing by cattle interact through a series of positive and negative feedback loops to drive this variation in structure and composition of the vegetation. Recently burned subplots have high quality, nutritious re-growth which is selectively grazed by cattle. Cattle spent over 75% of their time grazing within the area of the pasture that was most recently burned (Fuhlendorf and Engle, 2004; Vermeire et al., 2004). Recently burned areas have minimal leaf litter and are unlikely to support another fire. A thinner layer of leaf litter is also less favorable for ticks since it reduces protective cover. Heat and low relative humidity associated with direct sunlight, wind, and bare ground cause water stress in ticks and increase risk for desiccation. Water stress is a main factor governing tick survival and behavior (Cully, 1999).

Water stress incurred from unsuccessful questing attempts is reversed by ticks returning to the leaf litter for rehydration which prevents the breakdown of the exocuticle and desiccation (Scrifres et al., 1988). Most ixodid ticks begin to experience water loss when relative humidity falls below 80% (Burks et al., 1996). Returning to microhabitats with relative humidity above this point allows ticks to reabsorb moisture via their water up-take system (Semnter et al., 1971). Less recently burned patches in a PMB pasture accumulate more leaf litter and biomass making them more susceptible to fire and providing a more suitable microhabitat for ticks. Although older vegetation patches are more conducive to tick survival, the cattle spend minimal time grazing in them and may potentially limit their exposure to ticks (Fuhlendorf and Engle, 2004; Vermeire et al., 2004).

Ticks are an important pest of cattle and a constraint to the livestock industry (de Castro and Newson, 1993). They are obligate blood feeding parasites that in high densities can impair growth and productivity of cattle (Barnard and Morrison, 1985; Scifres et al., 1988; Byford et al., 1992; Tolleson et al., 2010). Worldwide, losses from ticks have been estimated at $7 billion USD (de Castro and Newson, 1993) which corrected for inflation is equal to more than $11 billion in 2012. Drummond (1987) estimated that the US cattle industry losses from *Amblyomma americanum* alone are around $82 million USD. In current USD, this is equal to more than $165 million.

This production loss led to various control methods and one of increasing interest is the use of fire. Part of this interest in prescribed burning is fueled by its increasing use to restore prairie ecosystems and control brush and part of it is due to the increasing development of acaricide resistance, risk for environmental contamination with acaricides, high cost of research and development for vaccines, and difficulties with application and use of biocontrol agents (de Castro and Newson, 1993; Pegram et al., 1993; Graf et al., 2004; Willadsen, 2006; de la Fuente et al., 2007).

Ticks burden their hosts through their feeding resulting in blood loss, irritation, and increased susceptibility to secondary infections (Scifres et al., 1988). Tick populations also play an important role in the ecology of various disease agents (Paddock and Yabsley, 2007). They can serve as vectors of bacterial, rickettsial, viral, and protozoal disease agents to livestock, humans, and other animals (Cully, 1999). Incorporation of fire into an integrated tick management plan may benefit cattle producers by reducing tick populations and ultimately reducing dependency on acaricides. My hypothesis was that the PMB regimen will reduce tick populations by creating microhabitats less conducive to supporting ticks which will lead to fewer ticks parasitizing cattle.

Objectives of my thesis were:

1. Determine if levels of infestation were reduced in cattle maintained on PMB treated pastures compared to cattle on control pastures burned entirely once every three years.
2. Determine if PMB regimen altered microhabitats in subplots with different burn intervals by monitoring relative humidity and temperature 10 cm above the ground.
3. Determine if PMB regimen reduced survival of *A. americanum* and *D. variabilis* compared to control pastures burned entirely once every three years.
4. Determine if PMB affects the abundance of ticks in cattle pastures compared to control pastures burned entirely once every three years by performing drags with flannel cloth panels.

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CHAPTER II

REVIEW OF LITERATURE

PATCH MOSAIC BURNING

Fire is a key driver of ecosystems. Fire promotes biodiversity and when used for pastoralist purposes can exploit fire-survival traits that increase nutritious re-growth for grazing animals (Parr and Andersen, 2006; Allen, 2008). Fire-dependent ecosystems can be found in various regions of the world including North America. In these ecosystems, vegetation is not killed by the fire even though it provides the fuel for fire. The vegetation survives and re-growth is promoted (Allen, 2008). After decades of fire-suppression on agricultural landscapes in the Great Plains and western United States, use of active fire management is increasing (Parr and Andersen, 2006). One of the fire management burning regimens now being implemented on pastures used for grazing ruminants is a patch mosaic burning (PMB).

Patch mosaic burning originated in Australia and is most widely implemented there and South Africa (Parr and Andersen, 2006). In a PMB regimen, one pasture is divided into separate subplots that are burned at different time intervals to create variability in the vegetation across space and time. Patch mosaic burning has been linked to traditional burnings by indigenous people across a global range of ecosystems and to the natural burning patterns that aided in the evolution of grassland ecosystems without anthropogenic influences (Fuhlendorf and Engle, 2004; Parr and Andersen, 2006). Patch mosaic burning produces heterogeneous patterns in the plant community structure and composition (Fuhlendorf and Engle, 2004; Vermeire et al., 2004). In the tall-grass prairies of Oklahoma, a series of feedback loops governed by the interactions between the burning regimen and the grazing of ruminants (Figure 1) create a shifting mosaic of grassland patches in pastures.

A positive feedback loop begins after a recent fire event. The recently burned area is unlikely to support another fire event and tender re-growth attracts grazing animals which further adds to the disturbance and further reduces the probability of fire. Fuhlendorf and Engle (2004) showed that on pastures where a PMB regimen was implemented, cattle devoted 75% of their grazing time to the one-third of the pasture that was most recently burned. This is a disproportionally high amount of time in a limited area when compared with cattle on pastures that were managed with more a traditional burning regimen. This study showed that PMB is able to provide nutritious re-growth that attracts grazing animals (Allen, 2008).

As fire is rotationally applied to other patches across the landscape, focal grazing shifts and helps create heterogeneity in the vegetation structure (Figure 2). One to two years after a fire event, the tall graminoid plant species recover dominance. This decreases the grazing focus of cattle and allows more leaf litter to accumulate. About 3 years after the last fire event, the probability of another fire event increases due to biomass accumulation (Fuhlendorf and Engle, 2004). The possibility of a fire occurring is strongly tied to the type of vegetation present and other ecosystem attributes such as biomass (Allen, 2008).

TICKS IN OKLAHOMA

According to Jongejan and Uilenberg (2004), there are currently 867 named species of ticks. Ticks are blood-feeding parasites whose distribution in nature is largely determined by activities of their vertebrate hosts and climatic influences (Goddard, 1997). In Oklahoma, there are 6 common ixodid species: *Amblyomma americanum* (L.), *Amblyomma maculatum* (Koch), *Dermacentor albipictus* (Pacard), *Dermacentor variabilis* (Say), *Ixodes scapularis* (Say), and *Rhipicephalus sanguineus* (Latreille) (Clymer et al., 1970; Wright and Barker, 2006; CDC website, 2011; Table 1). Except for *D. albipictus*, all of these are three host ticks that are most active early spring through late fall in Oklahoma.

Dermacentor albipictus is a one-host tick. After larvae hatch from eggs, they attach to a host and take a blood meal. They then molt into nymphs while on the same host and take another blood meal before molting again into adults. All three of the motile stages remain on the same host. In contrast, the other five tick species common in Oklahoma are three-host ticks that feed on a different host for each separate motile stage. In general, larvae and nymphs typically feed on smaller animals or birds whereas adults typically feed on larger mammals such as white-tailed deer and cattle. A notable exception to this is *A. americanum*. Larvae and nymphs of *A. americanum* regularly feed on medium and large-sized mammals, particularly white-tailed deer.

The typical three-host tick life cycle includes a male and female adult tick mating, the female feeding to repletion and dropping off the host to lay eggs in leaf litter. Larvae hatch from eggs in June through October, peaking in September. Larvae, or “seed ticks”, crawl out of leaf litter and climb to a suitable position on vegetation to quest for a host. Larvae will latch onto a suitable host as it passes and move to an acceptable location on the host before taking a blood meal. After larvae have engorged with blood, they drop off the host and crawl into leaf litter where they molt to nymphs. Nymphs then repeat this cycle of questing, obtaining a blood meal, dropping off the host, and molting into an adult. Adults once again quest for a host from which they take a blood meal. Once on a host, adults take 1 to 3 days to begin feeding. Females take an initial blood meal about days 4 to 7 before mating. Mating stimulates female ticks to take a final meal and completely engorge by feeding intensely from days 7 to 10 before dropping off to lay eggs around day 14. Males feed quickly after infesting a host, typically days 1 to 4 before detaching to breed. Males may remain on the host for longer periods of time to mate with more females (Wright and Barker, 2006; Tolleson et al., 2010).

EFFECTS OF FIRE ON TICKS

Management strategies for various North American wildlife species including grouse (*Tympanuchus* spp.), turkey (*Meleagris gallopavo*), quail (*Colinus* spp.), song birds, white-tailed deer (*Odocoileus virginianus*), elk (*Cervus canadensis*), moose (*Alces alces*), and waterfowl have used prescribed burning to improve habitat quality and also, rarely, to control transmission of wildlife disease agents. This has led to prescribed burning being proposed as a means of control for ticks (Jacobson and Hurst, 1979). Fire both kills ticks directly and alters microhabitats critical to tick survival (Jacobson and Hurst, 1979; Warren et al., 1987; Scifres et al., 1988; Davidson et al., 1994; Cully, 1999; Allan, 2009).

Warren et al. (1987) categorized the sequence of impacts of prescribed burning into a four-phase event: fuel development, combustion, shock, and ecosystem recovery. These four phases partition the short-term and long-term effects of fire on tick populations. All four of these phases can be seen in a single pasture at any one time when a PMB regimen is used. This is unlike the previously mentioned studies of prescribed burning effects on ticks (Jacobson and Hurst, 1979; Warren et al., 1987; Scifres et al., 1988; Davidson et al., 1994; Cully, 1999; Allan, 2009), where entire pastures were burned with one burn interval, typically either annually, biannually, or had long-term fire suppression. To the author's knowledge, the effects of the PMB regimen on ticks have not previously been reported.

Fuel development, the first phase, is the accumulation of plant biomass that occurs as the time since burn of the pasture / subplot increases. The longer the burning interval, the greater the amount of fuel (biomass) that accumulates. Combustion is the actual burning of the pasture / subplot. This phase is responsible for directly killing ticks in the environment. Combustion is most likely to occur in pastures / subplots where there has been sufficient fuel development. It is unlikely to occur in recently burned pastures / subplots because there is not sufficient fuel present to sustain a fire. Shock, the third phase, occurs directly after combustion. Here re-growth is beginning but the environment is still quite inhospitable to ticks. In a PMB pasture, this phase lasts for a few months following the occurrence of a prescribed burn. Ecosystem recovery is the final phase and occurs about a year after the fire disturbance. This sequence then loops back and enters into the fuel development stage again, about two to three years after the burn. The difference in vegetation induced by varying burn intervals within a PMB pasture can be quite dramatic as shown in Figure 2. Throughout this sequence, the microhabitats critical to tick survival are in a state of flux.

In previous burn regimen studies, microhabitat differences have been shown to have a strong influence over tick populations. For instance, Davidson et al. (1994) showed that in central Georgia ticks were sensitive to temperature, desiccation, and changes in vegetation structure, such as those modifications generated by different burning intervals. In their study, two different burning regimens (annual and biennial) were applied to plots and tick abundance was monitored with cloth drags and CO_2 baited traps. They observed reductions in ticks on the most recently burned plots which they associated with reduced litter depths. This removed the moist, cool microhabitat that reduced the risk of desiccation to ticks. The most consistent reductions were associated with larvae which were thought to be correlated with impaired survival and oviposition of replete females. These females could not find favorable oviposition sites which led to decreased egg survival and hatchability.

Cully (1999) also noted reduced tick abundance using an annual burning regimen on tall-grass prairies but did not see similar results when using a 4 or 20 year burn interval. Both of these burn intervals were long enough to allow reestablishment of the leaf litter layer and re-growth of larger, protective vegetation. The microhabitats only remain inhospitable until ecosystem recovery, which begins about 1 to 2 years following a prescribed burn.

Allan (2009) also conducted a study to monitor the effects of prescribed burning on tick populations. In his study, prescribed burning was deemed to have considerable potential to alter the abundance of *A. americanum* ticks. Allan (2009) did, however, note a larger amount of *A. americanum* larvae in areas two years post burn compared to unburned control areas. He reported this was likely due to a higher abundance of white-tailed deer, a main host of *A. americanum*, foraging in the recently burned areas. Allan's (2009) study was conducted in an oak-hickory forest managed by the Missouri Department of Conservation and was treated with low-intensity burns whereas the habitat of interest in the present study was tall-grass prairie which may not illicit the same response from white-tailed deer.

EFFECTS OF MICROHABITATS ON TICKS

Microhabitats are in a state a flux after a prescribed fire. Microhabitats are critical to tick survival and influence the amount of time taken to complete phases of their life cycle including molting, questing behavior, oviposition, and egg development. Two of the main factors that influence ixodid tick survival in the environment are relative humidity (RH) and temperature (Harlan and Foster, 1986; Harlan and Foster, 1990; Chilton and Bull, 1994; Bertrand and Wilson, 1997; Schulze and Jordan, 2003). These two factors are heavily influenced by the vegetation community and biomass accumulated on the surface of the soil. It is in these microhabitats between the upper soil and litter layer that three-host ticks spend the majority of their lives (Needham and Teel, 1991; Harlan and Foster, 1990). Both vegetation and accumulated biomass provide protective cover from desiccating winds which pose a major threat to tick survival. Tick survival and behavior is largely governed by their level of water stress (Cully, 1999).

All three motile stages of ticks must climb out of protective microhabitats and quest for a passing-by host. If ticks are unsuccessful at questing, they will return to the leaf litter for rehydration to prevent breakdown of the exocuticle and desiccation (Scrifres et al., 1988). Ticks will quest until they lose approximately 4-5% of their body weight to evaporation (Harlan and Foster, 1990). After this point, they return to the leaf litter. Burning pastures alters microhabitats by reducing the leaf litter and protective vegetation which leads to a general drying in the environment (Warren at al., 1987; Scifres et al., 1988).

Drying affects all free-living stages of ticks but some of the most susceptible stages are replete females immediately preoviposition and during ovipostion itself. Preoviposition is the time period between females detaching from their host to the start of egg deposition (Campbell and Harris, 1979; Chilton and Bull, 1994). Campbell and Harris (1979) found an inverse relationship between the preoviposition period and temperature. They determined the average preoviposition period for *D. variabilis* engorged females was 4.3 days when held at 35°C and 27.2 days at 15°C. Temperatures between 15°C and 30°C were best for laying eggs, with the highest average number of eggs laid at 25°C. Prolonged exposure to temperatures above 35.6°C was detrimental to oviposition. Both 35.6°C and 15°C serve as ‘pivot points’ where survival was significantly different above or below that point.

Similar results were published by Chilton and Bull (1994). The authors also noted that the preoviposition period for engorged female *A. limbatum* and *Aponomma hydrosauri* decreased when temperatures increased, a relationship that has been seen in most ixodid tick species studied. A second key point in the Chilton and Bull (1994) study was the effect of RH on hatching success. Eggs suffered reduced hatching success at low RH, suggesting desiccation is a risk for egg clutches.

Ixodid eggs are susceptible to desiccation because, like other arthropod eggs, they are unable to replenish their water supply by drinking or feeding. Tick eggs also have a large surface to volume ratio which further exacerbates desiccation. Since eggs are not able to rehydrate themselves, water is retained through low respiratory rates and an impermeable chorion. However, eggs are not able to counter long term water loss (Yoder et al., 2004).

Yoder et al. (2004) found that *A. americanum* eggs, which have low water content (58%) compared to other arthropod eggs, were able to survive a ten hour exposure to 0% RH. However, prolonged exposures to RH below 93% at temperature optima of 22-24°C significantly reduced hatchability. Only at 99% RH did the eggs achieve a state of water balance (gain = loss, equilibrium in water content). Eggs kept at 93% RH had a 60% reduction in hatchability (only 30% of eggs hatched) compared to eggs kept at 99% RH. Eggs failed to hatch at 85% RH. It is crucial for development and hatching that adequate levels of water be maintained inside the egg clutch.

According to Campbell and Harris (1979), Chilton and Bull (1994), and Yoder et al. (2004), the optimal conditions for oviposition and egg survival for *A. americanum*, the species of particular interest in this region of Oklahoma, were typically around 25°C and >93% RH. Larval ticks, like egg clutches, are sensitive to environmental factors. These factors directly influence their survival by potentially causing desiccation, but also alter host seeking activity (Harlan and Foster, 1986).

Harlan and Foster (1986) noted a positive linear correlation between larval *D. variabilis* host seeking activity and evening ambient temperatures. High temperatures (>21.5°C) recorded at 1900 h yielded the highest numbers of unengorged larval *D. variabilis* ticks (n = 423). Lower temperature yielded fewer larval *D. variabilis* ticks (at 18.5°C, n = 205 and at 15.5°C, n = 62). However, Atwood and Soneshine (1967) showed that ambient evening temperature did not have a significant influence on larval *D. variabilis* host seeking. Instead, the most important factor correlated with behavior was average daily solar radiation received at ground level.

Nymphs also modify their behavior to avoid adverse climatic conditions. In a comparison of questing behavior of *I. scapularis* and *A. americanum* nymphs by Schulze and Jordan (2003), *A. americanum* nymphs quested at times of the day when RH was lower. This was explained in part by their small surface to volume ratio and aggressive feeding behavior. *A. americanum* may quest during the day to seek out resting white-tailed deer, their preferred host. In general, *A. americanum* has been shown to be more tolerant of desiccating conditions than other species of ticks because of these habits. *Ixodes scapularis* nymphs may show a predisposition for more nocturnal questing to match the nocturnal behavioral pattern of its preferred small mammal hosts. Ambient temperatures and litter conditions contributed to mediating nymphal questing in both species. All stages of questing ticks typically seek out microhabitats with the lowest temperature fluctuations and most favorable ambient humidity (Schulze and Jordan, 2003).

Bertrand and Wilson (1997) demonstrated that the influences of microenvironments on nymphal *I. scapularis* showed an inverse relationship between average daily survival and soil temperature but not to air temperature, humidity or any other climatic variable. Although some of these studies present conflicting 'most important' factors, the overall influence of the microenvironment is evident.

Unlike eggs, motile stages of ticks can uptake water. However, this water uptake system is not active at lower temperatures. McEnroe (1975) proposed that this lower temperature limit for water uptake plays a major role in limiting the range of *A. americanum*. The minimum temperature for water uptake for *A. americanum* is 5°C, whereas *D. variabilis* is 3°C. Below these respective points, ticks need a near saturated environment to prevent water loss (McEnroe, 1982). Without this water uptake system working, ticks are susceptible to desiccation while overwintering. Ticks are not able to survive for one month without this pump (McEnroe, 1975). This type of habitat associated mortality plays a role in the regulation of the tick population size and species range (Bertrand and Wilson, 1997). Spontaneous freezing and direct chilling are not a significant source of mortality for either *D. variabilis* or *A. americanum* since half of them can survive exposure to -12.5°C for two hours (Burks et al., 1996).

Ticks quest until they either come into contact with a host or until they lose approximately 4-5% of their body weight to evaporation (Harlan and Foster, 1990). Ticks then move back down the vegetation to rehydrate. After rehydration, ticks return to questing. Their internal water state can trigger or curb their host seeking behavior (Harlan and Foster, 1990). For instance, *D. variabilis* remained active as long as the mean temperature remained above 18°C but when temperature averaged 10°C, closer to its lower limit, outdoor activity terminated. Low and high temperature extremes along with other closely related climatic factors such as RH and mean winter temperature are important when explaining variability of questing ticks (McEnroe, 1975). Low temperatures prevent the tick's water up-take system from working properly, but at high temperatures this system is not able to keep up with demands (Semnter et al., 1973).

High temperatures cause a depression in the host seeking behavior of ticks (Harlan and Foster, 1990). In general, high temperatures and low RH have been shown to decrease longevity in all life stages of ticks. Most ixodid ticks experience water loss at RH lower than 80% (Burks et al., 1996); Scifres et al. (1988) found that unfed *A. maculatum* adults started to lose body water to their environment when the RH was less than 92%. The importance of a humid microhabitat is crucial for long term survival of ticks while off-host (Burks et al., 1996).

EFFECTS OF TICKS ON CATTLE

In 1992 infestation by ectoparasites was estimated to cause more than $2.26 billion in losses annually to livestock production (Byford et al., 1992). In 2012 dollars these losses equate to more than $3.7 billion USD. While this takes into account all ectoparasites and livestock, *A. americanum* alone was estimated to cost the cattle industry $82 million in the United States (Drummond, 1987), roughly equivalent to over $165 million in current USD. These estimates show the profound impact ticks have on the cattle industry. Infestation by ticks on cattle can result in exsanguinations, toxicosis, transmission of vector-borne disease agents, and reduced animal production and performance (Byford et al., 1992). These various effects make ticks an important constraint to the livestock industry (de Castro and Newson, 1993).

Ticks feeding on cattle results in reduced fitness. This reduced fitness is due to the altered energy distribution of an infested cow (Tolleson et al., 2010). A cow's energy balance is negatively affected when a tick takes a blood meal which forces cattle to expend energy regenerating this lost blood. In addition, cattle heavily infested with ticks have been shown to have decreased productivity and impaired growth as a result of energy loss (Scifres et al., 1988; Byford et al., 1992).

Barnard and Morrison (1985) estimated that for each engorged *A. americanum* female tick, cattle lost 16-29g of body weight. For each engorged *A. maculatum* female, Williams et al. (1978) estimated a loss of 33g of body weight for cattle. This loss may not seem large when overall weight of an individual animal is considered, but, in a heavy infestation with hundreds of female ticks, the cumulative loss can cause significant reductions in body weight. Byford et al. (1992) showed that *A. maculatum* caused the greatest reduction in average daily gain (ADG) of all the ectoparasites, not just ticks, considered.

Other studies have found additional negative effects solely from the feeding of ticks. Tolleson et al. (2010) examined the effects of ticks on growing beef steers. They used 13 steers randomly assigned to either a non-treated control group or to a group infested with 300 pairs of *A. americanum* adults per animal and monitored weight gain, dry matter intake, cortisol, and glucose concentration and found that *A. americanum* feeding caused acute stress to animals on a moderate plane of nutrition, mainly inducing stress on the cattle's livers. Liver IGF1 gene expression, which has an inverse relationship with nutritional state, was significantly lower in tick-infested steers. Infestation by ticks did not affect steer body weight gain or feed intake. However, Tolleson et al. (2010) did show that tick infested animals had higher blood protein and platelet concentrations than uninfested controls. Other studies (Seebeck et al., 1971; Williams et al., 1978; Barnard and Morrison, 1985; Byford et al., 1992; Jonsson et al., 1998) reported lowered body weight gains in tick-infested compared to non-infested animals.

Another noticeable difference observed by Tolleson et al. (2010) was the decreased expression of the liver IGF1 gene. In infested animals, this expression was significantly lower than in animals without ticks. Additionally, animals with fewer replete ticks and more non-replete ticks exhibited greater visual signs of stress including head tossing, vocalization and grooming (Tolleson et al., 2010). The reason for the difference in stress level varying was not clear but the authors proposed this could be due to non-replete females less effectively modulating the immune system causing them to be more irritable to the host. Feeding of ticks also induces irritation and pruritus resulting in cattle rubbing on trees, fence posts or other objects and causing hide damage and loss of production (Scifres et al., 1988).

Stacey et al. (1978) observed Hereford steers infested with *A. maculatum* and noted reduced weight gains and altered blood composition due to tick feeding. These changes were caused by ticks either directly influencing host metabolism or by ticks causing a depression in feed intake. The reduced fitness incurred from replacing blood lost to ticks' feeding was further exacerbated by the depression of feed intake. Animals infested with ticks may have an increased metabolic rate, which reduces the amount of metabolizable energy available for growth. Parasitized animals may also digest feed less efficiently than non-parasitized animals. (Byford et al., 1992).

Secondary effects of ticks on cattle are typically more dramatic and can vary depending on the species of tick. For instance, *Amblyomma* spp. have large hypostomes and are more likely to create lesions that allow bacteria to establish leading to secondary infection and / or abscesses. Depending on the site of attachment, abscess formation could cause the loss of teats or lameness (Jongejan and Uilenberg, 2004). *Amblyomma maculatum* adults primarily attach to the outer ears of cattle and cause swelling and deformity of the ear producing a condition called gotch ear (Stacey et al., 1978). Adults of *D. variabilis*, another tick common in Oklahoma, contain toxins in their saliva that can result in tick paralysis (Jongejan and Uilenberg, 2004).

DISEASE AGENTS VECTORED BY TICKS

Ticks can serve as vectors of bacterial, rickettsial, viral, and protozoal disease agents for livestock, humans, and other animals (Cully, 1999). In Oklahoma, two of the most abundant ticks are *A. americanum* and *D. variabilis*. Both of these tick species play an important role in the ecology of several disease agents of humans and animals. *Amblyomma americanum* has been specifically cited for its role in disease agent transmission due to its aggressive and non-specific feeding habits that cause it to be one of the most economically important ticks in the United States (Paddock and Yabsley, 2007).

Barker et al. (1973) showed that white-tailed deer fawns were debilitated by heavy infestations of *A. americanum*. These infestations can be severe enough to cause mortality in eastern Oklahoma. *Amblyomma americanum* typically infest ground-dwelling birds or medium to large sized mammals, like white-tailed deer and cattle. The non-specificity and the aggressive feeding of *A. americanum* aids in the transmission of pathogens including *Ehrlichia chaffeensis, E. ewingii, Rickettsia rickettsii, Francisella tularensis,* and *Theirleria cervi* (Mixson et al., 2006; Goddard, 2009). Paddock and Yabsley (2007) discussed the relationship of some of these tick-borne pathogens associated with *A. americanum* and white-tailed deer. *Dermacentor variabilis* is also an important vector for pathogens such as *A. marginale, R. rickettsii,* and *F. tularensis*.

Other ticks species in Oklahoma may be less populous but can also serve as vectors for disease agents. *Amblyomma maculatum*, the Gulf Coast tick, can transmit *R. parkeri* to humans (CDC Tickborne Diseases of the U.S., 2012). *Ixodes scapularis,* best known for its role in the ecology of *Borrelia burgdorferi* in the northeastern United States, is also a vector for *A. phagocytophilum* and *Babesia microti* (CDC Tickborne Diseases of the U.S., 2012).

Reports of tick-borne zoonoses have increased exponentially over the last few decades (Childs et al., 1998; Chapman, 2006). Approximately 1%-3% of vector ticks have been found to be infected with spotted fever group rickettsiase. Though not all spotted fever group rickettsiae are pathogenic, this statistic shows the risk ticks present as vectors for disease agents (Chapman, 2006).

TRADITIONAL TREATMENTS FOR CONTROLLING TICKS

The effects of ticks on cattle production have been long established and control is critical to curbing detrimental effects and preventing transmission of tick-borne disease agents (Willadsen, 2006). Various treatments have been developed to control ticks on cattle including spraying or dipping cattle in chemical acaricides, using biological control agents, and vaccines. The most common method to date has been applications of acaricides (de Castro and Newson, 2003; Graf et al., 2004; Willadsen, 2006; de la Fuente et al., 2007).

Acaricides can be applied to cattle in the form of an aqueous suspension of chemicals by spraying or dipping, as acaricide impregnated ear tags, or through the use of slow-release rumen boluses, intramuscular injections, and pour-ons (de Castro and Newson, 1993, Pegram et al., 1993). Acaricides can be efficient and cost effective if they are applied correctly but improper use has led to the selection of acaricide-resistant ticks (Willadsen, 2006; de la Fuente et al., 2007). Most often acaricides are applied to cattle in conjunction with other routine management procedures without regard to the level of infestation or the current status of the tick life cycle. This irresponsible use of acaricides has only driven selection for resistant ticks and is less efficient for producers (Tolleson et al., 2010).

The development of acaricide resistant ticks is concerning because of the increasingly expensive cost of drug development (Graf et al., 2004; de la Fuente et al., 2007). Graf et al. (2004) estimated the cost of developing and registering a new anti-parasitic drug to exceed $100 million USD, equal to more than $121 million current USD. A second concern with the application of acaricides is potential environmental contamination and chemical residues in meat and milk (de Castro and Newson, 1993; Graf et al., 2004; Willadsen, 2006; de la Fuente et al., 2007).

Other control methods, such as biological control agents, have been studied for tick control but their efficacy and stability have been a challenge so far. Researchers have not been able to completely utilize fungi like *Beauveria* spp. and *Metarhizium* spp. to control ticks in the field. Researchers have used these fungi in the laboratory to kill ticks, but have not yet developed a practical way of applying them (Willadsen, 2006).

Anti-tick vaccines have shown promise, but have so far lacked efficacy to be a stand-alone control method (Willadsen, 2006). The effects of vaccines are not seen instantly which can be a problem when dealing with cattle producers. Vaccines have been shown to reduce the number of engorging female ticks and their reproductive capabilities which lowers the number of larvae in the subsequent generation (Willadsen, 2006). Anti-tick vaccines may be helpful to some producers in reducing their dependence on acaricides, but not all producers will be willing to use an anti-tick vaccine or acaricides so other alternatives should be explored.

Prescribed burning could help supplement acaricides, vaccines, and biocontrol agents by offering a natural method for controlling ticks. The advantages of fire as a means of control for arthropods include (Warren et al., 1987): (1) it is relatively inexpensive, (2) arthropods are not likely to develop resistance to fire as they have chemical acaricides, (3) no residue problems, (4) fuel for fire is renewable, (5) fire suppresses woody vegetation and enhances vigor and seed production of desirable perennial grasses, and (6) fire aids in recycling the nutrients from dead and senescent plant matter.

SUMMARY OF RESEARCH

Ticks are an important constraint to the livestock industry and cause significant economic losses to producers (Drummond, 1987; Byford et al., 1992). In Oklahoma, three-host ixodid ticks are the most common (Wright and Barker, 2006). These ticks spend roughly 94-97% of their lives off-host (Needham and Teel, 1991). During this time in the microenvironments, ticks use protective layers of leaf litter to prevent desiccation. Many aspects of the tick life cycle are heavily influenced by the temperature and relative humidity of the microenvironment (Harlan and Foster, 1986; Harlan and Foster, 1990; Chilton and Bull, 1994; Bertrand and Wilson, 1997; Schulze and Jordan, 2003).

In a prescribed burning regimen, the microenvironment is altered. This change has led to the implication of prescribed burning as a method of tick control (Jacobson and Hurst, 1979; Warren et al., 1987). As the cost of development and resistance to acaricides continues to grow, fire may aid in the control of ticks (Graf et al., 2004). One burning regimen, patch mosaic burning (PMB), may regulate tick populations and tick-cattle interactions. Due to the rotational use of fire, a constant source of fresh, nutritious plant re-growth is provided which attracts grazing ruminants (Fuhlendorf and Engle, 2004; Vermeire et al., 2004). Recently burned areas in a PMB regimen are inhospitable microenvironments for ticks due to the removal of leaf litter and biomass and are where cattle spend the majority of their time. Patch mosaic burning may be able to reduce tick populations and also reduce cattle-tick interactions.

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Table 1. Ixodid ticks common in Oklahoma.

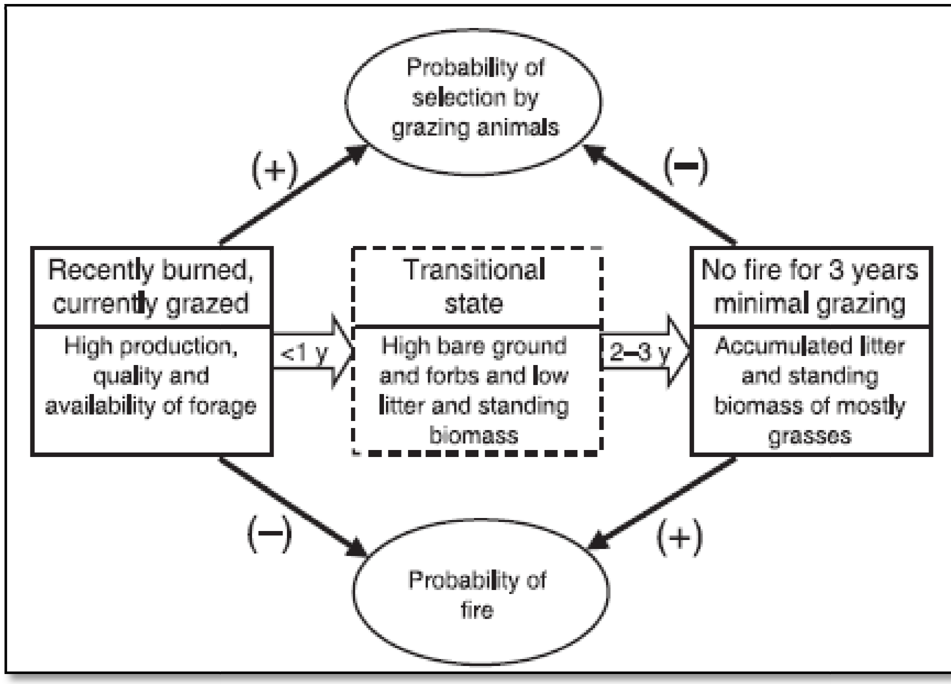
Tick Species	Common Name	Notes
Ixodes scapularis (Say)	Black-legged tick, Deer tick	Immature stages feed on reptiles in OK, not rodents like in other parts of the country Adults feed on large animals Found throughout the fall and winter, not as commonly in OK as in Northeastern U.S.
Dermacentor albipictus (Pacard)	Winter tick	Only one host tick in OK, found on cattle, horses and deer Larvae active in early October, nymphs and adults in late fall, winter and early spring
Dermacentor variabilis (Say)	American dog tick	Larvae and nymphs feed on small mammals, adults feed on large mammals Found early spring until early winter

Rhipicephalus sanguinesus (Latreille)	Brown dog tick	All stages prefer to feed on dogs (not found on cattle) Can infest homes and kennels and remain active year round
Amblyomma americanum (L.)	Lone star tick	Aggressive feeder with a wide host range, important pest of livestock Immature stages feed on turkeys, white-tailed deer, and raccoons commonly while adults prefer white-tailed deer, coyotes and cattle Active early spring to late fall
Amblyomma maculatum (Koch)	Gulf Coast tick	Larvae and nymphs feed on ground-inhabitating birds and small rodents Adults primarily infest ears of cattle and other large hosts, can cause “gotch ear” Adults most abundant in early April to mid-June

Figure Captions

Figure 1. Positive and negative feedback loops associated with PMB in pastures used for grazing animals. Taken from Fuhlendorf and Engle (2004).

Figure 2. Appearance of the heterogeneous vegetation within a PMB treated pasture. The left side of the picture shows a subplot that has not been recently burned whereas the patch on the right has. This picture demonstrates the large difference between the amount of biomass and bare ground between subplots in a single pasture.


Probability of
selection by
grazing animals
(+)
(−)
Recently burned,
currently grazed
High production,
quality and
availability of forage
<1 y
Transitional
state
High bare ground
and forbs and low
litter and standing
biomass
2–3 y
No fire for 3 years
minimal grazing
Accumulated litter
and standing
biomass of mostly
grasses
(−)
(+)
Probability of
fire

CHAPTER III

PATCH MOSAIC BURNING EFFECTS ON TICK BURDEN ON CATTLE

ABSTRACT

Amblyomma americanum is a significant pest of cattle in the south-central and southeastern United States. Application of prescribed burns in cattle pastures has been proposed as a natural means of tick control. We monitored the effects of a patch mosaic burning (PMB) regimen on tick burdens on cattle. Level of infestation was measured on cattle housed on three PMB treated pastures and on cattle housed on three control pastures. PMB treated pastures were divided into 6 subplots with one burned rotationally each spring (March-May) and summer (July-September) and control pastures were burned entirely once every three years. Infestation levels and weight for 5 calves and 3 cows per pasture were recorded once a month from April to October in 2009, 2010, and 2011. A total of 13,609 ticks were observed on cattle. Animals on PMB treated pastures had 4,028 (29.6%) ticks whereas 9,581 (70.4%) ticks were on animals from control pastures. Level of infestation was significantly reduced on animals in PMB treated pastures compared to animals in control pastures in 4 out of the 6 months observed. On adult cows, overall number of ticks was reduced in April, May, June, and September.

Overall number of ticks on calves was reduced in May, June, July, and September in PMB treated pastures. There was no significant difference in average daily weight gain of calves in PMB treatment and control pastures detected. However, application of the PMB regimen significantly reduced the intensity of tick infestation on cattle.

INTRODUCTION

Ticks are obligate blood feeding parasites that can induce a variety of negative effects on cattle. *Amblyomma americanum*, the most abundant tick in Oklahoma, was estimated to cost the cattle industry $82 million in the United States in 1987; in 2012, this is equal to more than $165 million USD (Clymer et al., 1973; Drummond, 1987). Severe infestations by ticks on cattle can cause reduced weight gains, irritation, pruritus, gotch ear, and stress (Seebeck et al., 1971; Stacy et al., 1978; Williams et al., 1978; Barnard and Morrison, 1985; Scrifres et al., 1988; Byford et al., 1992; Jonsson et al., 1998; Cully, 1999; Tolleson et al., 2010). Ticks can also vector bacterial, rickettsial, viral, and protozoal disease agents (de Castro and Newson, 1993; Jongejan and Uilenberg, 2004).

Due to the threat ticks and tick-borne disease agents pose to cattle, various control methods have been implemented. The most commonly used, acaricides, has had problems with resistance and the cost to develop a new anti-parasitic drug has been estimated to exceed $100 million USD in 2004, which would now be equal to more than $121 million USD (Graf et al., 2004; Willadsen, 2006; de la Fuente et al., 2007). Because of these issues, interest in the use of prescribed burning as a means of natural tick control has been growing (Jacobson and Hurst, 1979; Warren et al., 1987; Scifres et al., 1988; Davidson et al., 1994; Cully, 1999).

Ticks can be directly killed when a prescribed burn occurs, but longer lasting effects are on the microhabitats. Burning removes protective leaf litter layers and changes the vegetation structure in these microhabitats (Scifres et al., 1988; Davidson et al., 1994; Cully, 1999; Fuhlendorf and Engle, 2004). Ticks are sensitive to fluctuations in temperature and relative humidity within microhabitats and are at risk for desiccation when exposed to unfavorable conditions for extended periods of time (Harlan and Foster, 1986; Harlan and Foster, 1990; Chilton and Bull, 1994; Bertrand and Wilson, 1997; Schulze and Jordan, 2003).

One burning strategy that has not been studied for its effects on tick populations is patch mosaic burning (PMB). PMB entails dividing one pasture into smaller subplots to which spatially discrete fires are rotationally applied with different times since burn. Along with focal grazing of ruminants, these disturbances create a shifting mosaic of vegetation in pastures. In previous PMB work, cattle spent 75% of their time in the recently burned subplots (Fuhlendorf and Engle, 2004; Vermeire et al., 2004). In these recently burned subplots, the plant community structure and composition may not be suitable tick habitat. These areas have less leaf litter and ticks are more exposed to direct sunlight, wind, and bare ground. These conditions will cause water stress in ticks which affects tick survival and behavior (Cully, 1999).

I hypothesized that PMB would alter the vegetation structure to negatively affect tick populations and reduce the number of ticks on cattle. To test this hypothesis, we compared the level of infestation of cattle housed on three PMB treated and three control pastures.

MATERIALS AND METHODS

Research was performed at the Oklahoma State University (OSU) Research Range located 21km southwest of Stillwater, Oklahoma in north-central Oklahoma. The OSU Research Range in Stillwater is predominantly a tall-grass prairie and contains six pastures varying in size from 45 to 65 ha (Figure 3). Three of these pastures were PMB treated pastures, which were divided into six subplots each measuring approximately 200 m by 400 m. One subplot was burned each spring (March to May) and one subplot was burned each summer (July to September). This created an overall burn return time of three years for the entire pasture as shown in Figure 4. Control pastures were burned entirely once every three years. This three-year burn regimen was chosen as a control because it had the same burn return time as an individual PMB subplot. Unburned pastures were not used as controls because fire suppression would not have the same effects of plant growth regeneration and woody vegetation suppression (Warren et al., 1987). Pastures were grazed moderately year round by mixed cow / calf and yearling herds. Cattle were treated twice yearly with 10 cc of 1% w/v injectable doramectin (10 mg/mL) (Dectomax® Injectable Solution, Pfizer Animal Health, Exton, Pennsylvania). One treatment was given in the spring and one treatment in the fall. Fall treatments occurred after the final tick count on cattle and spring treatments of doramectin occurred directly after the first tick count.

The present study was conducted over three years (2009, 2010, and 2011) and cattle used for sampling were randomly chosen at the first observation of the year. Individuals were only sampled for a single year. Within a year, the same three adult cows and five calves were sampled from each pasture once a month starting in the spring

(April) through the fall (October). Cattle were permanently identified by ear tags and were randomly assigned to a treatment or control plot with free access around their assigned pastures.

Cattle were held in holding pens for no more than 24 hours before tick burden. Cattle were individually run through a squeeze chute, which had panels that could be opened to provide easy access to the entire body of the cattle (Figure 5). Only ticks on the right side of the body were counted and identified due to time constraints. In the first year of the present study, all ticks were removed from cattle and placed in labeled vials with 70% ethanol and later identified. In the following two years, ticks were left on cattle. Life stage and species of each tick were identified by visual inspection to the nymphal stage and all larvae were placed into the "unidentified" category since they could not be reliably identified while still attached to cattle. A magnifying glass was used to help determine species of nymphal ticks. Tick identification keys were used to identify species (Clifford et al., 1960; Diamant and Strickland, 1965; Strickland et al., 1976; Keirans and Litwak, 1988; Keirans and Durden, 1998).

Cattle weights were recorded using a weigh tape (Dupont, Wilmington, Delaware) read by the same individual within a given year. A weigh tape was used to estimate cattle weights because livestock weigh scales were not available over the course of the study. Although it did not provide the most accurate measurement, using a weigh tape allowed for comparisons to be made between animals on control and PMB treatment pastures.

Tick counts on cattle were typically performed over a two day period: 3 pastures per day except on the last count of the season when all cattle were brought to OSU research range headquarters to wean calves from adult cows. Data were analyzed with SAS Version 9.2 (SAS Institute, Cary, NC). Repeated measures analysis of variance (ANOVA) with an autoregressive covariance structure was performed on the number of ticks to compare PMB treated pasture animals and control pasture animals. Years were used as replicates, and month was the repeated measures factor. Average daily weight gain was also compared using repeated measures ANOVA with an unstructured covariance structure. Simple effects of treatment given month (or time) were assessed. Statistical significance was determined at the 0.05 level.

RESULTS

A total of 13,609 ticks were observed on cows and calves. The most commonly observed ticks (Table 2) were *A. americanum* (73.6%), *A. maculatum* (7.3%), and unidentified species (17.2%). Few *D. albipictus* (>1%) and *I. scapularis* (>1%) were recovered. Ticks categorized as "unidentified" species were mainly larval ticks. Larvae were small and difficult to identify to the genus level without the use of a dissecting microscope. However in the first year (i.e., 2009) of the current study all ticks were removed and identified to species in the laboratory. Almost all larvae removed from cattle in 2009 were *A. americanum* larvae (Table 2). Adult ticks were the most common life stage observed on cattle with 7,959 of 13,609 (58.5%) ticks recovered being adults. Nymphs were the second most common with 3261 of 13,609 (24%) ticks recovered being nymphs, followed by larvae with 2389 of 13,609 (17.5%) tick recovered being larvae.

More than twice as many ticks were found on cows and calves from control pastures than on animals from PMB treated pastures (Table 2). On average, adult cows on PMB treatment pastures were infested by 242.9 ticks whereas adult cows on control pastures were infested with 598.6 ticks (Table 3.). Calves in control pastures also had more than twice the amount of ticks. PMB treated calves had on average 122.8 ticks and control calves had 279.6 ticks (Table 3).

Of the 13,609 ticks counted, 9,581 (70.4%) were observed on animals from control pastures. Only 4,028 (29.6%) were observed on animals from PMB treated pastures. This trend of 70% to 30% control versus PMB treatment of ticks on cattle was observed regardless of the time since burn in the control pastures.

Significant reductions in overall number of ticks recovered from calves in PMB treated pastures compared to calves in control pastures occurred in May, June, July, and September (F = 5.93, df = 1, P = 0.018; F = 13.28, df = 1, P = 0.0005; F = 4.77, df = 1, P = 0.037; and F = 6.84, df = 1, P = 0.011, respectively) (Table 4). Infestation by adult ticks on calves in PMB treated pastures was significantly lowered in May and June (F = 7.21, df = 1, P = 0.009; and F = 25.57, df = 1, P = <0.0001, respectively) than on calves in control pastures (Table 6). Level of infestation by nymphs on calves in PMB treated pastures was reduced in May, June, and September (F = 7.53, df = 1, P = 0.009; F = 11.11, df = 1, P = 0.002; and F = 4.07, df = 1, P = 0.051, respectively) compared to calves in control pastures and level of larvae was significantly lowered in July and September (F = 7.17, df = 1, P = 0.010; and F = 7.47, df = 1, P = 0.009) (Table 6) on calves in PMB treated pastures compared to on calves in control pastures.

Number of overall ticks infesting adult cattle in PMB treatment pastures was significantly reduced in 4 out of the 6 months observed compared to adult cattle in control pastures. Differences occurred in April, May, June, and September (F = 4.42, df = 1, P = 0.037; F = 14.55, df = 1, P = 0.001; F = 16.89, df = 1, P = 0.0001; and F = 16.89, df = 1, P = 0.033, respectively) for adult cows (Table 5). Lower numbers of adult ticks on adult cows in PMB treated pastures than on adult cattle in control pastures occurred in April, May, and June (F = 6.86, df = 1, P = 0.009; F = 23.31, df = 1, P = <0.0001; and F = 25.14, df = 1, P = <0.0001, respectively) (Table 7). Level of infestation by nymphs on adult cattle in PMB treatment pastures was significantly lowered from level of infestation of nymphs on adult cattle in control pastures in May, June and September (F = 6.40, df = 1, P = 0.012; F = 20.56, df = 1, P = <0.0001; and F = 4.98, df = 1, P = 0.028, respectively). Fewer larvae were detected in September (F = 3.80, df = 1, P = 0.056) for adult cows in treatment pastures compared to adult cows on control pastures (Table 7).

Average daily gain for calves housed on PMB treatment pastures was 0.59 kg/day and 0.60 kg/day for control calves (Table 6). This difference was not significant (F = 0.40, df = 1, P = 0.528).

DISCUSSION

Amblyomma americanum is the most abundant tick found on cattle in Oklahoma (Clymer et al., 1970; Sterett Robertson et al., 1975). Clymer et al. (1970) found that 92% (31,095 of 34,550) of ticks collected in their study in east-central Oklahoma were *A. americanum*. *Amblyomma americanum* was also the most common species on cattle in the present study. The majority of ticks, 89.0% (10,119 of 11,364) of the ticks identified to species in the current study, were *A. americanum* (Table 2).

Adults were the most commonly found (58.5%) life stage. Nymphs were the second most common (24%), followed by larvae (17.5%). The high portion of adult ticks could be due in part to predilection of some species' juvenile stages to feed on smaller mammals (Clymer et al., 1970; Semtner and Hair, 1973; Zimmerman et al., 1987; Wright and Barker, 2006). Preferred hosts for *A. maculatum* larvae and nymphs in Oklahoma are bobwhite quail (*Colinus virginianus*), grasshopper sparrow (*Ammodramus savannarum*), meadow lark (*Sturnella* sp.), cotton rat (*Sigmodon* sp.), and deer mouse (*Peromyscus* sp.) (Semtner and Hair, 1973; Barker et al., 2004). *Dermacentor variabilis* immature stages prefer to feed on small rodents (Zimmerman et al., 1987). Although *D. albipictus* is a one-host tick that preferentially feeds on cattle, horses, and deer, it is most common in Oklahoma from late fall to early spring (Clymer et al., 1970). This time span was not sampled in the present study. *Ixodes scapularis* immature stages typically feed on lizards, birds, and small mammals in Oklahoma and are also more active late fall (Clymer et al., 1970). A second explanation for adults being the most commonly found life stage could be due to their size. Adults are easier to detect on cattle whereas immature stages can be more difficult to find on cattle.

Since only cattle were sampled in the present study, a complete view of the tick population within PMB treated and control pastures was not achieved. Juvenile ticks may have been present on other hosts (listed above) and adult ticks may have also used other hosts. *Amblyomma americanum*, the most commonly recovered tick, also feeds on white tailed deer (*Odocoileus virginianus*) and coyotes (*Canis latrans*) as an adult and on turkeys (*Meleagris* sp.), white-tailed deer, and raccoons (*Procyon lotor*) in immature stages (Kollars et al., 2000). Preferred hosts for adult *A. maculatum* are also white-tailed deer, raccoons, and coyotes (Barker et al., 2004). *Dermacentor variabilis* is known for having little host specificity as an adult but was the most commonly recovered tick from raccoons by Clymer et al. (1970). *Dermacentor albipictus* and *I. scapularis* adults also feed on white-tailed deer and raccoons (Clymer et al., 1970). The species listed above are likely present in pastures at the OSU Research Range. Other hosts for ticks are important to consider since they responsible for re-establishing tick populations into cattle pastures after a prescribed burn occurs.

Aside from only sampling cattle in the present study, only ticks on the right side of cattle were counted. This type of sampling may have also biased results. Bloemer et al. (1988) observed that adult ticks of *A. americanum* more often attached to the left side of the body of white-tailed deer. However, *A. americanum* larvae more commonly attached to the right side while *A. americanum* nymphs showed no significant preference for the right or left side of deer. This side preference has not been shown in cattle but by sampling the right side of each animal consistency in the results was maintained. This allowed for comparisons between PMB treatment and control animals to be made.

Significant differences in tick infestation were observed in months of peak tick burden for both adult cattle and calves. Adults ticks were significantly reduced on PMB treated animals in April, May, and June. This corresponds to the time when adult ticks are most active in Oklahoma (Clymer et al., 1970; Barker et al., 2004). Nymphs, which are most active spring and early summer, were significantly reduced May, June, and September (Zimmerman et al., 1987). Larvae were reduced on PMB pastures in July and

September, which is also when they are most common in Oklahoma (Semtner and Hair, 1973; Zimmerman et al., 1987).

Time since burn did not seem to play a major role when comparing PMB treated pastures to control pastures. The first year of observations (2009) occurred just following a prescribed burn on the control pastures, which are burned entirely once every three years. In this year, 2,975 of 4,332 (68.7%) ticks were on animals in control pastures and only 1,357 (31.3%) ticks were on animals in PMB treated pastures. In 2010, one year after a prescribed burn, animals in control pastures had 3,998 of 5,703 (70.1%) ticks infesting them whereas animals in PMB treated pastures had only 1,705 (29.9%) of ticks. In the final year of observation, animals in control pastures were infested by 2,608 of 3,574 (73.0%) ticks and animals in PMB treated pastures only had 966 (27.0%) ticks. This slight increase in margin each year between PMB treatment and control pastures was expected. As time progressed from the last prescribed fire application, control pastures accumulated more leaf litter and biomass that may have provided protection to ticks from desiccating sunlight and wind (Davidson et al., 1994). This additional protection which creates more suitable microhabitats could have supported larger tick populations. Leaf litter accumulation in PMB treated pastures should be constant since subplots are burned on a rotating schedule.

The yearly changes in tick populations in control pastures were similar to findings in other burn regimen studies (Jacobson and Hurst, 1979; Warren et al., 1987; Scifres et al., 1988; Davidson et al., 1994; Cully, 1999; Allan, 2009). Davidson et al. (1994) compared annual and biennial burn intervals on tick populations using cloth panel drags and CO_2 baited traps. He found fewer free-living ticks on pastures burned annually than in pastures burned biennially. Cully (1999) also noted reduced tick abundance on annually burned plots but not on plots burned using a 4 or 20 year burn interval. Longer burn intervals allow the reestablishment of the leaf litter layer and re-growth of larger, protective vegetation. This trend of pastures with longer burn intervals supporting larger tick populations was observed in relation to the number of ticks parasitizing cattle as the control pastures aged in the present study.

In the first year after a prescribed burn (2009), the vegetation structure and composition in control pastures was similar to vegetation in annually burned pastures. In this year, there were fewer ticks parasitizing cattle than in 2010. Vegetation in control pastures in 2010 was more like that in a biennially burned pasture since it had not burned in over a year at this point. In 2011, the lowest number of ticks was found on cattle even though vegetation in control pastures had not been burned since 2009. This decrease in ticks is thought to be due in part to the high heat of the late summer and early fall of 2011. The National Oceanic and Atmospheric Administration (NOAA) identified two of these months as the hottest on record in Oklahoma. These temperature extremes could have caused a seasonal depression in the tick population.

One difference observed in the present study compared to other work done with prescribed burning is the lack of an increase in *A. americanum* larvae. Allan (2009) noted an increase in *A. americanum* larvae two years after a fire event in Missouri. This increase was attributed to increased white-tailed deer browsing in burned areas. In the present study, larvae remained lower in PMB treated plots than in control pastures each year. Differences between Allan (2009) and the current study are likely due to the variation in ecoregions. The present study was conducted in tall-grass prairies whereas

Allan's (2009) study was conducted in an oak-hickory forest. Comparisons of these two ecotypes have shown prairie habitat to have much lower success rates for oviposition and hatching (Koch, 1984). Koch (1984) found *A. americanum* ticks had a 100% oviposition success rate and a 95% hatch success in upland oak-hickory habitat whereas meadow habitat had an oviposition success rate of 60% and a 0% hatch success during the same time period. This difference was driven by the dense leaf litter and overstory vegetation preventing direct sunlight from reaching the forest floor in oak-hickory forests. Leaf litter is able to accumulate more quickly due to leaves falling from trees. This added protection is not found in prairie habitats.

PMB pastures offered significant reductions in tick populations compared to other burning regimens that utilize one burn interval for an entire pasture. Aside from this reduction, PMB is a more sustainable practice. Applying fires too often can lead to detrimental changes in the soil chemistry (Duncan, 2003). In a PMB treated pasture, vegetation receives a 3 year rest period between applications of prescribed burning. While one subplot is rested, another is burned. This regimen continually provides cattle with a freshly burned patch. Even though the older subplots in a PMB pasture have re-established leaf litter and biomass which creates favorable tick habitat, cattle do not spend much time in them. Cattle devote the majority of their time to the most recently burned subplots (Fuhlendorf and Engle, 2004; Vermeire et al., 2004).

Other studies have shown reduced weight gain caused by infestations with ticks (Scifres et al., 1988; Byford et al., 1992). Byford et al. (1992) showed that *A. maculatum* caused the greatest reduction in average daily gain (ADG) of all the ectoparasites in their review. Williams et al. (1978) estimated that each engorged *A. maculatum* female caused a loss of 33 g of body weight for cattle, and Barnard and Morrison (1985) estimated that each engorged *A. americanum* female tick caused a loss of 16-29 g of body weight to cattle. In the present study, a weigh tape was used to estimate weights of calves. Although weigh tapes are notoriously inaccurate, a livestock scale was not available for use throughout the study and the weigh tape was the best option. Because of the inaccuracy of weigh tapes, it is likely that we were not able to detect a difference in ADG of calves in PMB treated versus control plot if one truly existed. The relatively low stocking density and overall high plane of nutrition in our cattle may have also masked any adverse effects from tick feeding in the present study. Fuhlendorf and Engle (2004) also measured ADG of cattle on PMB treated pastures using electronic livestock weigh scales. Using the same PMB treated / control pasture design as the present study, differences between PMB treated pasture animals and control pasture animals were not detected (Fuhlendorf and Engle, 2004).

Throughout the duration of this study cattle were treated each spring and each fall with 10 cc per head of 1% w/v injectable doramectin (10 mg/mL) (Dectomax® Injectable Solution, Pfizer Animal Health, Exton, Pennsylvania). Doramectin is not labeled for use in tick control programs but has been shown to be effective in controlling arthropods (George et al., 2004; Lohmeyer et al., 2009). Fall treatments were given after the final cattle infestation observation and therefore did not affect level of infestation seen in fall counts in the present study. Spring treatments were administered immediately after the first tick count on cattle while cattle were still in the squeeze chutes in April. This probably suppressed the number of ticks seen on cattle in the following observation. Although use of doramectin probably lowered the number of ticks present on cattle in

May, number of overall ticks on adult cows increased from April. Doramectin is labeled for 28 days of effectiveness against arthropods (Pfizer Animal Health, Exton, Pennsylvania), after this point number of ticks on cattle would recover. Since doramectin was administered to both animals in PMB treated pastures and animals in control pastures, comparisons could be made and in May there were significant reductions in overall number of ticks for both adult cows and calves on PMB pastures compared to adult cows and calves on control pastures. This difference showed that the PMB regimen is responsible for reductions in infestation level of ticks regardless of dewormer usage.

Application of PMB to pastures significantly reduced the number of ticks on cattle. Although an increase in ADG in calves on PMB treated pastures was not observed, application of PMB can be a useful tool for cattle producers to lower their dependence on chemical acaricides. Additionally, application of PMB over a regimen of annual burns will not compromise soil chemistry yet will still reduce the number of ticks on cattle.

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Table 2. Number and species of ticks recovered from PMB treated and control pasture cows and calves by species and life stage.

Tick	Adult		Nymph		Larva[1]		Total	Percentage
	PMB Treated	Control	PMB Treated	Control	PMB Treated	Control		
A. americanum	2172	5144	807	1838	57	101	10119	73.6%
A. maculatum	171	299	72	426	2	3	973	7.3%
D. variabilis	46	68	4	87	3	0	208	1.5%
D. albipictus	33	13	2	4	0	0	52	0.4%
I. scapularis	8	4	0	0	0	0	12	>0.1%
Unidentified	0	1	3	18	648	1575	2245	17.2%
Total	2430	5529	888	2373	710	1679	13609	
Percentage	17.9%	40.6%	6.5%	17.5%	5.2%	12.3%		

[1] Larvae identified by species were from Year 1 of the study, larvae found in Year 2 and 3 of the study were placed in the unidentified category.

Table 3. Total number of ticks recovered on animals on PMB treated and control pastures by year. Number in parentheses represents average burden on a single animal in that year of the study.

	2009		2010		2011		
	PMB Treated	Control	PMB Treated	Control	PMB Treated	Control	Total
Cows	860 (286.7)	1769 (589.7)	704 (234.7)	1937 (645.7)	622 (207.3)	1681 (560.3)	7573
Calves	497 (99.4)	1206 (241.2)	1001 (200.2)	2061 (412.2)	344 (68.8)	927 (185.4)	6036
Total	1357	2975	1705	3998	966	2608	13609

Table 4. Overall tick burden on calves in PMB treated and control pastures by month.

Month		Mean Ticks	Standard Error	*F* value	p-value
April	Control	35.3	4.23	1.79	0.183
	PMB Treated	25.7	3.12		
May	Control	20.8	3.37	5.93	0.018
	PMB Treated	8.4	1.49		
June	Control	29.8	3.63	13.28	0.0005
	PMB Treated	12.2	1.94		
July	Control	17.7	3.88	4.77	0.033
	PMB Treated	6.1	1.26		
August	Control	12.8	2.89	0.86	0.357
	PMB Treated	9.4	2.76		
September	Control	15.7	2.73	6.84	0.011
	PMB Treated	5.8	1.30		
October	Control	6.5	3.08	0.61	0.439
	PMB Treated	2.7	0.74		

Table 5. Overall tick burden on adult cows in PMB treated and control pastures by month.

Month		Mean Ticks	Standard Error	*F* value	p-value
April	Control	59.6	10.01	4.42	0.037
	PMB Treated	24.6	3.86		
May	Control	69.4	12.53	14.55	0.0002
	PMB Treated	18.9	2.88		
June	Control	79.3	13.56	16.89	0.0001
	PMB Treated	28.6	3.06		
July	Control	22.1	4.80	0.74	0.393
	PMB Treated	14.7	3.01		
August	Control	17.1	5.48	2.15	0.147
	PMB Treated	6.3	1.61		
September	Control	26.3	5.72	4.77	0.032
	PMB Treated	10.1	2.73		
October	Control	6.9	1.94	0.24	0.625
	PMB Treated	7.7	4.29		

Table 6. Average tick burden on calves in PMB treated and control pastures by life stage.

Month		Adult Tick				Nymph				Larva			
		Mean	Std Error	*F* value	p-value	Mean	Std Error	*F* value	p-value	Mean	Std Error	*F* value	p-value
	Control	15.1	2.07			9.7	2.69			0.0	0.00		
April	PMB Treated	11.6	1.28	2.67	0.104	4.9	1.17	2.71	0.102	0.0	0.00	0.00	1.000
	Control	11.8	1.87			15.7	4.06			0.1	0.09		
May	PMB Treated	5.8	0.99	7.21	0.009	4.4	1.15	7.53	0.009	0.0	0.02	0.02	0.898
	Control	19.8	1.93			16.8	4.11			0.0	0.00		
June	PMB Treated	8.7	1.08	25.57	<.0001	6.3	2.01	11.11	0.002	0.0	0.00	0.00	1.000
July	Control	5.8	0.98	1.30	0.257	1.4	0.38	0.57	0.456	10.5	3.13	7.17	0.010

	PMB Treated	3.8	0.62			0.3	0.10			1.9	0.85		
	Control	0.9	0.22			5.1	1.42			6.8	2.05		
August	PMB Treated	0.9	0.17	0.03	0.855	1.9	0.58	1.95	0.171	6.6	2.42	0.21	0.646
	Control	0.4	0.12			8.7	1.53			9.1	2.12		
Sept.	PMB Treated	0.6	0.14	0.09	0.763	3.9	0.99	4.07	0.051	2.8	1.08	7.47	0.009
	Control	0.4	0.13			0.8	0.26			5.5	3.02		0.290
October	PMB Treated	0.3	0.09	0.02	0.895	0.7	0.18	0.00	0.978	1.9	0.69	1.15	

Table 7. Average tick burden on adult cows in PMB treated and control pastures by life stage.

Month		Adult Tick				Nymph				Larva			
		Mean	Std Error	*F* value	p-value	Mean	Std Error	*F* value	p-value	Mean	Std Error	*F* value	p-value
April	Control	29.0	4.89	6.86	0.009	2.8	0.64	0.80	0.373	0.0	0.00	0.00	1.00
	PMB	12.2	1.93			0.1	0.11			0.0	0.00		
May	Control	49.4	9.23	23.31	<.0001	21.7	6.81	6.40	0.012	0.0	0.00	0.00	1.00
	PMB	14.7	2.42			5.9	1.58			0.0	0.00		
June	Control	54.9	6.99	25.14	<.0001	41.7	16.37	20.56	<.0001	0.0	0.00	0.00	1.00
	PMB	23.7	2.28			7.5	2.09			0.0	0.00		
July	Control	15.0	3.19	2.35	0.129	3.3	1.19	1.19	0.279	3.8	1.85	0.09	0.764
	PMB	8.9	1.96			0.9	0.46			4.9	2.22		
August	Control	2.8	0.70	0.55	0.463	5.4	1.92	1.66	0.202	8.9	4.19	2.36	0.129
	PMB	1.7	0.51			1.4	0.44			3.1	1.19		

September	Control	1.1	0.32	0.29	0.594	13.0	3.18	4.98	0.028	15.3	4.35	3.80	0.056
	PMB	0.7	0.23			6.0	2.31			6.1	1.91		
October	Control	0.5	0.14	0.15	0.699	0.9	0.33	0.46	0.499	5.9	1.86	0.26	0.611
	PMB	0.3	0.11			0.2	0.11			7.4	4.28		

Table 8. Average daily gain (ADG) for PMB treated pasture calves vs. control pasture calves.

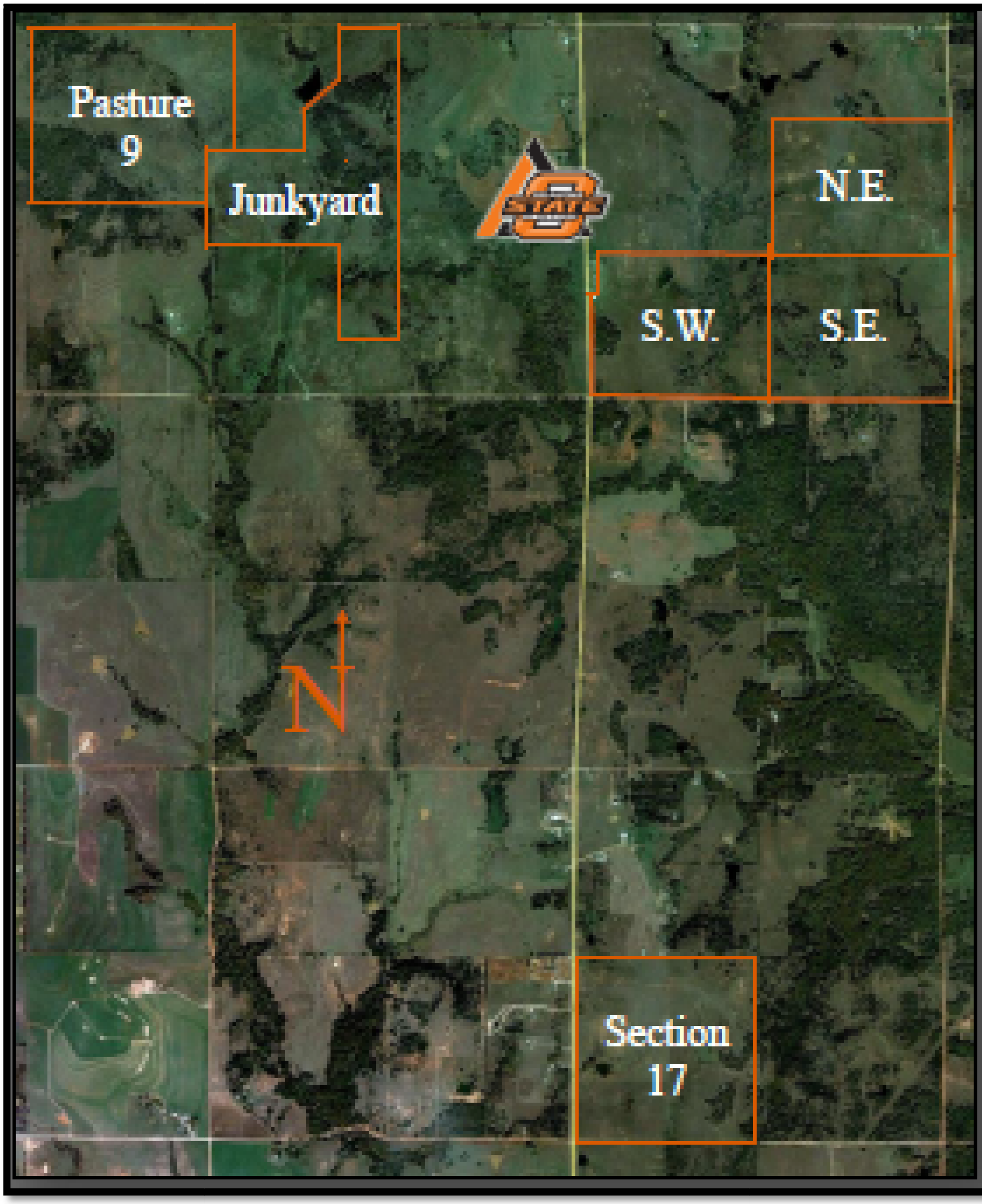
Month	Pasture Type	Mean ADG (kg/day)	Standard Error
May- June	PMB Treated	0.80	0.19
	Control	0.81	0.22
June- July	PMB Treated	0.70	0.11
	Control	0.64	0.11
July- August	PMB Treated	0.45	0.14
	Control	0.54	0.19
August- September	PMB Treated	0.62	0.16
	Control	0.54	0.09
September- October	PMB Treated	0.34	0.22
	Control	0.49	0.16

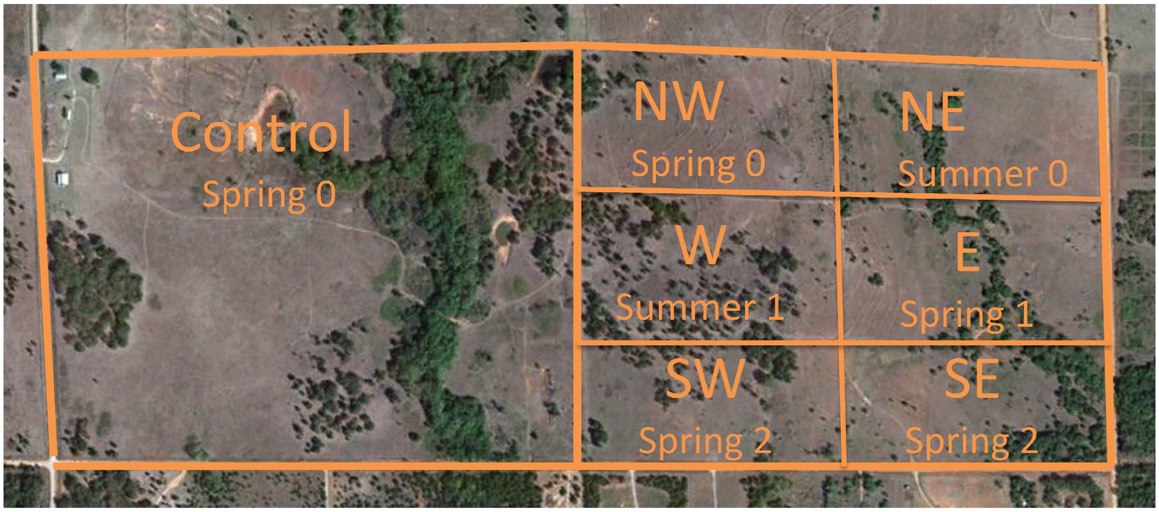
Figure Captions

Figure 3. Six pastures used for field trials; PMB pastures were Patch 9 (P9), Section 17 (S17), and Southeast (SE) and control pastures were Northeast (NE), Junkyard (JY), and Southwest (SW).

Figure 4. (A) Reference name and burn schedule for PMB treated subplots and control pasture. Control pastures were burned once every three years. (B) Aerial view of a PMB treated pasture: Note the blocks formed by the variation in vegetation due to rotational burn pattern used.

Figure 5. Chute used during tick counting on cattle. Bottom panel folded down to allow access to udder; panels with bars can also be opened to allow access to main body.


Pasture 9
Junkyard
N.E.
S.W.
S.E.
N
Section 17


Control
Spring 0
NW
Spring 0
NE
Summer 0
W
Summer 1
E
Spring 1
SW
Spring 2
SE
Spring 2

CHAPTER IV

MICROHABITAT CHANGES INDUCED BY PATCH MOSAIC BURNING AND EFFECTS ON TICK SURVIVAL

ABSTRACT

Suitable microhabitats are necessary for ticks to complete biological processes such as oviposition, egg development, molting, and questing. One burning regimen, patch mosaic burning (PMB), utilizes spatially discrete fires within a single pasture at various seasons and years. This type of prescribed burning and focal grazing by cattle in recently burned areas may significantly impact tick populations by inducing a complex vegetation structure within pastures. The objective of the present study was to determine if a PMB regimen altered the temperature, relative humidity (RH) or saturation deficit (SD) of microhabitats and thereby reduced tick survival. To test this, survival sites were placed in subplots of three PMB treated pastures and three control pastures. Data loggers used to record temperature and RH along with 20 unfed adult *Amblyomma americanum* and 20 unfed adult *Dermacentor variabilis* were placed at each survival site. The SD calculated from temperature and RH was determined for each subplot. Temperature, RH, and SD did not differ among PMB subplots but were significantly correlated to tick survival.

Observations were divided into one of two groups (HI or LO) for temperature, RH, and SD with the mean of each variable used to set an approximate pivot point. For temperature, this pivot point was set at 33° C, relative humidity at 42%, and saturation deficit at 26. Survival for each variable was significantly different between the HI and LO groups. Environmental values and survival values were also analyzed to formulate predictions for survival of both species at various temperatures, RH, and SD. Tick survival was monitored weekly but was not significantly different between pastures or among PMB subplots. Survival between *A. americanum* and *D. variabilis* was similar.

INTRODUCTION

Patch mosaic burning (PMB) is a regimen that applies spatially discrete fires at different seasons and years within a single pasture. Along with focal grazing of ruminants, these disturbances create a shifting mosaic of vegetation (Fuhlendorf and Engle, 2004; Vermeire et al. 2004). This type of variation in the plant community structure and composition alters the microenvironments where three-host ixodid ticks spend 94-97% of their lives (Needham and Teel, 1991). Ticks are sensitive to fluctuations in temperature and relative humidity (RH) within these microhabitats. Processes that can be affected by temperature and RH include oviposition, egg development, molting, and questing behavior (Harlan and Foster, 1986; Harlan and Foster, 1990; Chilton and Bull, 1994; Bertrand and Wilson, 1997; Schulze and Jordan, 2003).

Prescribed burning has been shown to be a useful tool in reducing tick populations within a certain area (Jacobson and Hurst, 1979; Warren et al., 1987; Scifres et al., 1988; Davidson et al., 1994; Cully, 1999; Allan, 2009). In these previous studies, one burn interval was applied to an entire pasture. Annual burning of pastures has been shown to reduce tick populations most reliably but is not a sustainable practice as burning on this frequent of a basis leads to changes in the soil chemistry (Duncan, 2003). However, burn intervals longer than 2-3 years allow the re-establishment of leaf litter and other protective cover increasing the amount of favorable habitat for ticks. In a PMB regimen, subplots are rotationally burned and allowed to "rest" for a period of time afterwards. This helps prevent detrimental changes from burning too often while still supplying cattle with recently burned, nutritious re-growth of vegetation. The purpose of the present study was to determine the effect PMB had on the temperature, RH, and saturation deficit (SD) of microhabitats within pastures and to then determine if these environmental differences influenced the survival of tick populations.

MATERIALS AND METHODS

Tick survival studies were done at the Oklahoma State University (OSU) Research Range located 21-km southwest of Stillwater, Oklahoma in north-central Oklahoma. A total of six pastures were used for the present study, three control pasture replicates and three PMB treatment pasture replicates. Control pastures were burned entirely once every three years and PMB treatment pastures were divided into 6 subplots and burned rotationally. One subplot was burned each spring (March- May) and one subplot was burned each summer (July- September), giving each subplot a three year burn return interval. The three-year burn regimen was chosen as a control because it had the same burn return time as an individual PMB subplot. Unburned pastures were not used as controls because fire suppression would not have the same effects of plant growth regeneration and woody vegetation suppression (Warren et al., 1987). All pastures used were primarily tall-grass with some wooded sections. Pastures were moderately grazed year round by mixed cow / calf herds.

Tick survival was monitored in each of the six subplots of the PMB treated pastures and at one site in control pastures. Only one site was placed in each control pasture because the entire pasture was uniformly burned and vegetation was in the same stage of re-growth throughout unlike the PMB pastures where different subplots had different time since burns. Each site was marked with a painted T-post for easy identification. At each survival site, twenty unfed adult, laboratory reared *Amblyomma americanum* and *Dermacentor variabilis* were placed in enclosures, with one enclosure per species. Half of the twenty adults used were females and the other half were males for each species. Tick enclosures consisted of a holding bag held upright inside a 6" atrium cover (NDS, Staines, United Kingdom). The holding bag was made from a fine mesh drain cover material (Carriff Corporation, Midland, North Carolina) which was white in color for the first 4 field trials. White material was no longer available when bags were replaced for the spring 2011 field trial so black mesh material was used. These black bags were also used in the following fall 2011 trials. Color was not considered important since bags were not placed in direct sunlight.

Mesh material was attached via hot glue to a Ziploc bag (S. C. Johnson & Son, Racine, Wisconsin) with the bottom half of the bag removed (Figure 6). Mesh material was 15.24 cm (6") wide and cut to 15.24 cm (6") in length. One end was sewn shut and the other end glued to the Ziploc bag top. This allowed the bag to be quickly sealed with the Ziploc closure while the mesh allowed the surrounding relative humidity and air temperature to reach the ticks. The plastic Ziploc top was rolled down and clipped in place with two medium binder clips (Staples, Framingham, Massachusetts) (Figure 7). This bag was suspended inside the atrium cover with two large safety pins run through the binder clips. The bottom 5cm of the mesh bag was covered with loose soil. This enabled the ticks to seek shelter at the bottom portion of the bag or quest at the top of the mesh portion and be exposed to ambient environmental conditions. The entire enclosure was then secured to the ground with 30.48 cm (12”) spikes (Prime Source Building Products, Inc., Dallas, Texas) (Figure 8) to prevent it from blowing over or being tampered with by cattle.

HOBO data loggers (Onset Co., Cape Cod, Massachusetts) were placed at the center of the survival site, attached to a T-post with zip-ties, to record temperature and relative humidity (RH) 10 cm above ground level every 30 minutes. This height was chosen to represent the conditions questing ticks may encounter. The average maximum temperature and average minimum RH were calculated for each observation period (7-10 days). Average maximum temperature and average minimum RH were chosen because of their biological significance to tick survival (Harlan and Foster, 1986; Harlan and Foster, 1990; Chilton and Bull, 1994; Schulze and Jordan, 2003). These temperature and RH recordings were combined to calculate the saturation deficit (SD) of the microhabitats (Randolph and Storey, 1999). Saturation deficit combines temperature and relative humidity to estimate the drying power of the atmosphere; it is a unit-less index where higher numbers represent more desiccating environments. Saturation deficit is calculated using the following formula:

$$\text{Saturation Deficit} = (1\text{-RH}/100)*4.9463e^{0.061\text{T}}$$

During weekly survival checks, ticks identified as dead were removed and placed in vials with 70% ethanol. Holding bags were breathed upon and ticks that showed no movement and appeared desiccated were identified as dead (Bertrand and Wilson, 1997). At colder temperatures, more breaths and a longer response time was given to ticks. The number of dead ticks removed and the number of live ticks remaining in the bag were recorded before bags were placed back into atrium covers and secured down. Bags were inspected every week for holes and when necessary, bags were either replaced or patches were made with safety pins, tape or binder clips. Holes developed rarely around the hot glue seal between the Ziploc bag and mesh bottom or towards the bottom end of the bag. If a hole did develop in a bag between weekly checks, any unaccounted for ticks were not included in the analyses.

A total of 6 field trials were conducted; three in the spring season and three in the fall season. Dates for the six field trials are listed in Table 9. Prior to the start of the spring 2011 study, the posts and sites were moved 10 meters west due to evident paths and vegetation trampling from the previous studies.

In fall 2011, two studies were performed with one beginning about 2 weeks before the other. Ticks were initially placed in the field on August 24th and at the first observation period (day 11) the majority of the ticks were already dead. This trend was not seen in any other the field trials. Due to this complication, a second fall 2011 study was conducted.

Data were analyzed with SAS Version 9.2 (SAS Institute, Cary, NC). Analysis of covariance (ANCOVA) with time as a covariate was used to compare environmental variables and survival between subplots. This analysis was conducted for each year and season. Simple linear correlation coefficients among environmental variables and survival values were calculated. Observations were divided into one of two groups (HI or LO) for temperature, RH, and SD. The mean of each variable was used to set an approximate pivot point. Survival of ticks in HI and LO groups were compared with t-tests. Environmental values and survival values were also analyzed using a binary response model (probit regression) to formulate predictions for survival at various temperatures, RH, and SD.

RESULTS

Comparisons of environmental variables between PMB subplots and control pastures did not reveal significant differences, the only exception to this was the average minimum RH in the fall 2011 study (F = 2.60, df = 6, P = 0.031) (Table 10). There were no other differences detected in microhabitat temperature, RH, or SD between the PMB subplots and control pastures. All three variables did have significant effects on tick survival in PMB subplots and control pastures (Table 11). Based on the data gathered, predictions for the probability of *A. americanum* and *D. variabilis* survival from 1% to 99% for temperature, RH, and SD were made (Appendix A). Survival between HI and LO groups of temperature, RH, and SD was also significantly different for both species (t = -6.17, df = 691.3, P = <0.0001; t = 7.28, df = 1109.9, P = <0.0001; and t = -8.7, df = 324.1, P = <0.0001, respectively for *A. americanum* and t = -6.46, df = 681.2, P = <0.0001; t = 6.94, df = 1129.3, P = <0.0001; and t = -7.9, df = 319.3, P = <0.0001, respectively for *D. variabilis*). For temperature, the pivot point was set at 33° C. Survival above this point was 81.3% for *A. americanum* and 86.3% for *D. variabilis*. Below 33°C survival was 92.5% for *A. americanum* and 95.4% for *D. variabilis (*Table 12). The pivot point for RH was set at 42%. Above this point tick survival was 95.1% and 96.7%, below this point survival was only 84.7% and 89.4% for *A. americanum* and *D. variabilis* respectively (Table 13). The SD pivot point was 26. Above this point survival was only 71.9% and 79.8% and below this point was 93.3% and 95.6% for *A. americanum* and *D. variabilis* (Table 14).

Both species exhibited high survival rates in the enclosures: *A. americanum* at 88.1% and *D. variabilis* at 91.8%. Because the majority of both tick species survived, a difference in survival between treatment subplots and control pastures in the field trials was not detected except for in the first fall 2011 study (Tables 15 and 16). In fall 2011, there were significant differences between *A. americanum* and *D. variabilis* survival between the subplots (F = 9.59, df = 6, P = <.0001; and F = 4.38, df = 6, P = 0.0004) (Table 17).

Survival of *A. americanum* and survival of *D. variabilis* were also compared to one another. A difference between the two species' survival was only present in the SW subplot in the spring 2009 study (F = 4.97, df = 1, P = 0.026) and in the fall 2011 study (Table 17). Overall, both tick species had similar patterns for survival in PMB treated pastures and control pastures.

DISCUSSION

Temperature, RH, and SD had significant effects on tick survival. This finding is in agreement with other studies that have shown correlations between tick survival and temperature, RH, and SD. Conditions with high temperatures and low RH, such as those with high SD values, create a desiccating environment that is not suitable for ticks (Semtner et al., 1971; Sterett Robertson et al., 1975; McEnroe, 1978; Koch, 1984; Clark, 1995; Bertrand and Wilson, 1997; Randolph and Storey, 1999; Randolph, 2000). Both species of ticks showed similar survival which was expected as both *A. americanum* and *D. variabilis* have established populations in Oklahoma (Wright and Barker, 2006). Aside from the fall 2011 study, the only other time a difference in species survival occurred was in the SW subplot in the spring 2009 field trial. The SW subplot had a time since burn of one year at this time. This difference was probably not due to a variation in the response of the two tick species to environmental conditions, but rather a sampling error.

The initial fall 2011 study did not follow a pattern similar to the other field trials. Late summer and early fall of 2011 were two of the hottest seasons on record for Oklahoma (NOAA, 2011). The temperature and RH during this time period could have been held above or below certain points for a longer duration than previously seen in any of the prior field trials and thereby altered the survival significantly. Time since burn of PMB subplots in this field trial also remained unchanged from the previous spring 2011 study due to a burn ban imposed by the high heat and drought conditions.

In the present study, environmental data and survival were combined to estimate pivotal points where tick survival significantly changed. These points may be useful in identifying when the microenvironment shifts from ideal to less suitable. For temperature, a significant reduction in survival for both *A. americanum* and *D. variabilis* occurred at 33° C. Survival of both species was significantly different above and below the RH of 42%. Though this may seem low, it was commonly reached throughout the course of these field trials. Relative humidity / water loss rates are proposed to be the key factor that determines tick survival (Randolph, 2000). The pivot point for SD combines the temperature and RH to give a more accurate picture of the drying power of the atmosphere (Randolph and Storey, 1999) and was set at 26. From data collected in the present field studies, predictions for *A. americanum* and *D. variabilis* survival were formulated. Predictions for species specific survival in relation to average maximum temperature, average minimum RH, and average maximum SD are in Appendix A.

Even though differences were observed in survival at pivot points, overall tick survival rates for both *A. americanum* and *D. variabilis* were high throughout the study. This high overall survival rate led to little variation between survival in PMB subplots and control pastures. High survival rates were not initially expected but agree with findings from Koch's (1984) study. In his study, Koch (1984) showed high levels of survival for *A. americanum* ticks in southeastern Oklahoma. He found that about 96% of adult ticks and nymphs survived the first summer and 91% of adults and 59% of nymphs survived the first winter. Fifty-one percent of adult ticks and 26% of nymphs survived the second summer and no ticks survived through the third summer.

Survival in the present study was predicted to be lower because all ticks were placed in meadow / prairie habitat. Koch's (1984) study was conducted in a bottomland oak-hickory site, which was more favorable tick habitat (Semtner et al., 1971). Semtner et al. (1971) compared *A. americanum* survival in meadow, persimmon and upland oak-hickory, and bottomland oak-hickory habitats in Cherokee Co., Oklahoma. Ticks placed in meadow habitat survived an average of less than 32 days after a release on June 1, 1970, whereas ticks in bottomland oak-hickory habitats survived more than 65 days (Semtner et al., 1971).

Variation among results in habitat survival studies may also be due to differences in enclosure styles. Koch (1984) used polyester bags under available leaf litter, Semtner et al. (1971) used screen cage containers, and in a third study by Bertrand and Wilson (1997), mesh bags containing ticks inside plastic conduit pipes were used. In the present study, enclosures consisted of a mesh bag inside an atrium cover. The large cover used in this study may have interfered with the influence of environmental variables and provided unnatural shelter to ticks. With the present sampling method, all ticks in every subplot had 5cm of loose soil placed over the bottom of the bag. Ticks were able to use this loose soil as refuge from the external environment, which is something ticks on the most recently burned pastures would not have had access to otherwise. The atrium cover and loose soil created the same artificial shelter for ticks in all the different subplots and thereby may have reduced the effect of the various burn intervals. Vegetation did not grow within the atrium cover, reducing its ability to mimic the environment around it. Vegetation surrounding atrium covers was also disrupted by weekly observations. Accessing survival sites caused trampling of plant growth which further impacted the microhabitat influences ticks were exposed to.

Environmental variables measured in the present study were also not significantly different in subplots with different burn intervals. Even though vegetation structure had been altered by burn interval, its influence on environmental variables was not detected. Differences may have occurred in other environmental variables that impact tick populations. Variables such as solar radiation on ground, amount of leaf litter, or soil temperature have also been shown to impact tick populations (Atwood and Soneshine, 1967; McEnroe, 1975; Sterett Robertson et al., 1975; Bertrand and Wilson, 1997). Microhabitat differences were expected since other studies have shown the ability of prescribed burning to reduce tick populations by altering the microenvironment (Davidson et al., 1994; Cully, 1999).

Cully (1999) observed reduced tick abundance on annually burned tall-grass prairie plots compared to other plots with longer burn intervals. The longer burn intervals allowed leaf litter and larger, protective vegetation to become reestablished. Cully (1999) demonstrated that microhabitats only remain inhospitable to ticks for about 1 to 2 years following a prescribed burn. Davidson et al. (1994) also observed reductions in the number of ticks living in annually burned plots compared to biennially burned plots. This population reduction was also associated with reduced litter depths that removed the moist, cool microhabitat used for protection from desiccating sunlight, heat, and wind by ticks. Both of these studies observed reductions in natural tick populations, whereas the present study used ticks kept in enclosures. Once again, the enclosures and vegetation trampling may have modified the environmental influences.

Most studies that have assessed microhabitat requirements for *A. americanum* and *D. variabilis* have focused on rates of reproductive success (ovipostion and hatchability) (Campbell and Harris, 1979; Chilton and Bull, 1994; Yoder et al., 2004), molting (Semtner and Hair, 1973; Koch, 1984), or cold hardiness (McEnroe, 1975; McEnroe, 1978; McEnroe, 1982; Clark, 1995). In the present study, the adult stage was used. This development stage is considered the most resilient. It is possible that the PMB regimen could have effects on the survival of tick populations by regulating developmental stages but alterations are not large enough to regulate adult ticks.

Semtner et al. (1971) noted that *A. americanum* nymphs succumbed much faster to desiccation than adult ticks. Davidson et al. (1994) stated that microhabitats may have the largest influence on survival and oviposition of replete females. Without favorable oviposition sites, eggs had decreased survival and hatchability. Bertrand and Wilson (1997) also suggested that habitat associated mortality is more prominent during the larval instar stage. If habitat associated mortality mainly influences larval populations, then measuring adults would also not adequately reflect this type of mortality.

Temperature, RH, and SD were all shown to have significant influences over tick survival in the present study. Differences between these components of microhabitats within PMB treated pastures and from control were not detected, but other variables may have been altered that could also influence tick survival. Pivotal points for where significant changes in survival occurred due to temperature, RH, and SD were determined and provide additional information on habitat suitability gathered from a field setting. Sampling methodology may have influenced survival between subplots, and could be improved in future studies by potentially using immature stages of ticks and enclosures that modify the microhabitat less.

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Table 9. Dates and reference names for field trials.

Dates	Reference name
May 6- July 22	Spring 2009
August 5- November 20	Fall 2009
April 23- August 9	Spring 2010
August 24- January 7	Fall 2010
April 22- July 26	Spring 2011
August 24- January 15	Fall 2011 (1)
September 9- January 15	Fall 2011 (2)

Table 10. Differences in environmental variables between PMB subplots.

Season	Variable	*F* value	p-value
Spring 2009	Average Max Temp	0.45	0.824
Spring 2010	Average Max Temp	1.71	0.250
Fall 2010	Average Max Temp	0.63	0.705
Spring 2011	Average Max Temp	1.58	0.242
Fall 2011	Average Max Temp	1.25	0.292
Spring 2009	Average Min RH	1.04	0.402
Spring 2010	Average Min RH	1.46	0.207
Fall 2010	Average Min RH	0.82	0.587
Spring 2011	Average Min RH	1.62	0.144
Fall 2011	Average Min RH	2.60	0.031
Spring 2009	Average Max SD	0.52	0.783
Spring 2010	Average Max SD	3.60	0.074
Fall 2010	Average Max SD	1.12	0.429
Spring 2011	Average Max SD	1.89	0.085
Fall 2011	Average Max SD	0.72	0.609

Table 11. Correlation of environmental variables to tick survival.

Species		Avg. Max Temp	Avg. Min RH	Avg. Max SD
A. americanum	*r²*	-0.404	0.323	-0.565
	p-value	(<.0001)	(<.0001)	(<.0001)
D. variabilis	*r²*	-0.419	0.305	-0.598
	p-value	(<.0001)	(<.0001)	(<.0001)

Table 12. Tick survival above (HI) and below (LO) the 33°C temperature pivot point.

Species	Temp	# Observations	Mean % Alive	Std.Dev	Std. Error	t value	p-value
A. americanum	HI	443	81.3	33.7	1.60	-6.17	<.0001
	LO	675	92.5	22.1	0.85		
D. variabilis	HI	457	86.3	27.0	1.26	-6.46	<.0001
	LO	699	95.4	16.6	0.63		

Table 13. Tick survival above (HI) and below (LO) the 42% RH pivot point.

Species	RH	#Observations	Mean % Alive	Std. Dev	Std. Error	t value	p-value
A. americanum	HI	365	95.1	16.4	0.86	7.28	<.0001
	LO	753	84.7	31.4	1.14		
D. variabilis	HI	385	96.7	10.7	0.54	6.94	<.0001
	LO	771	89.4	25.2	0.91		

Table 14. Tick survival above (HI) and below (LO) the 26 saturation deficit pivot point.

Species	RH	#Observations	Mean % Alive	Std. Dev	Std. Error	t value	p-value
A. americanum	HI	275	71.9	39.1	2.36	-8.70	<.0001
	LO	843	93.3	20.4	0.70		
D. variabilis	HI	277	79.8	31.8	1.91	-7.96	<.0001
	LO	879	95.6	15.7	0.53		

Table 15. *Amblyomma americanum* survival in relation to subplot burn schedule. For significant trials, letter designation was used to show which means were significantly different. Two means with the same letter were not significantly different from each other.

Season YR	Treatment	Burn Schedule	Mean % Alive	Standard Error	*F* value	p-value
	Control	Spring 0	83.1	7.03		
	PMB-E	Spring 2	82.5	5.75		
	PMB- NE	Summer 0	77.6	7.45		
S 2009	PMB- NW	Spring 0	81.3	7.15	1.20	0.308
	PMB-SE	Summer 1	82.8	6.92		
	PMB-SW	Spring 1	80.4	7.26		
	PMB-W	Summer 2	97.9	1.15		
	Control	Spring 0	97.1	2.08		
	PMB-E	Spring 2	99.1	0.54		
	PMB- NE	Summer 1	90.5	5.19		
F 2009	PMB- NW	Spring 0	99.5	0.32	0.27	0.952
	PMB-SE	Summer 2	97.1	1.99		
	PMB-SW	Spring 1	94.9	2.39		
	PMB-W	Summer 0	96.8	0.93		
	Control	Spring 1	90.9	4.35		
	PMB-E	Spring 0	84.1	5.13		
S 2010					0.43	0.859
	PMB- NE	Summer 1	90.9	3.44		
	PMB- NW	Spring 1	91.1	3.99		

	PMB-SE	Summer 2	86.5	4.34		
	PMB-SW	Spring 2	89.9	3.55		
	PMB-W	Summer 0	87.8	4.25		
	Control	Spring 1	98.7	0.64		
	PMB-E	Spring 0	94.4	1.85		
	PMB- NE	Summer 2	96.8	1.95		
F 2010	PMB- NW	Spring 1	96.4	2.14	0.16	0.987
	PMB-SE	Summer 0	95.0	2.99		
	PMB-SW	Spring 2	99.1	0.43		
	PMB-W	Summer 1	98.7	0.64		
	Control	Spring 2	85.4	5.76		
	PMB-E	Spring 1	84.5	6.17		
	PMB- NE	Summer 2	87.6	5.77		
S 2011	PMB- NW	Spring 2	89.5	5.55	0.51	0.803
	PMB-SE	Summer 0	81.0	10.19		
	PMB-SW	Spring 0	82.6	6.65		
	PMB-W	Summer 1	83.1	5.84		
	Control	Spring 2	84.2 a	5.28		
F 2011	PMB-E	Spring 1	74.3 ab	7.92	9.59	<.0001
	PMB- NE	Summer 2	72.1 b	8.62		

PMB- NW	Spring 2	80.6 ab	7.07
PMB-SE	Summer 0	0 c	0.0
PMB-SW	Spring 0	70.4 b	8.57
PMB-W	Summer 1	73.7 ab	9.87

Table 16. *Dermacentor variabilis* survival in relation to subplot burn schedule. For significant trials, letter designation was used to show which means were significantly different. Two means with the same letter were not significantly different from each other.

Season YR	Treatment	Burn Schedule	Mean % Alive	Standard Error	*F* value	p-value
	Control	Spring 0	85.9	5.66		
	PMB-E	Spring 2	91.8	3.82		
	PMB- NE	Summer 0	85.9	4.91		
S 2009	PMB- NW	Spring 0	85.8	5.59	0.81	0.567
	PMB-SE	Summer 1	85.9	5.58		
	PMB-SW	Spring 1	92.2	4.26		
	PMB-W	Summer 2	98.3	1.06		
	Control	Spring 0	99.5	0.31		
	PMB-E	Spring 2	100	0.00		
	PMB- NE	Summer 1	99.8	0.23		
F 2009	PMB- NW	Spring 0	99.3	0.38	0.06	0.999
	PMB-SE	Summer 2	97.3	1.16		
	PMB-SW	Spring 1	97.0	1.55		
	PMB-W	Summer 0	98.0	0.67		

	Control	Spring 1	81.8	5.72		
	PMB-E	Spring 0	87.9	4.05		
	PMB- NE	Summer 1	88.1	4.03		
S 2010	PMB- NW	Spring 1	86.8	4.48	0.68	0.669
	PMB-SE	Summer 2	90.4	3.74		
	PMB-SW	Spring 2	92.3	2.76		
	PMB-W	Summer 0	85.6	4.28		
	Control	Spring 1	98.9	0.73		
	PMB-E	Spring 0	96.7	1.91		
	PMB- NE	Summer 2	97.8	1.01		
F 2010	PMB- NW	Spring 1	98.6	0.65	0.21	0.972
	PMB-SE	Summer 0	92.7	2.89		
	PMB-SW	Spring 2	97.9	0.86		
	PMB-W	Summer 1	98.2	1.19		
	Control	Spring 2	84.9	6.34		
	PMB-E	Spring 1	90.4	3.88		
	PMB- NE	Summer 2	87.8	5.67		
S 2011	PMB- NW	Spring 2	85.2	5.59	0.15	0.989
	PMB-SE	Summer 0	86.4	5.19		
	PMB-SW	Spring 0	87.9	4.49		
	PMB-W	Summer 1	89.9	3.89		

	Control	Spring 2	94.2 a	2.96		
	PMB-E	Spring 1	88.1 ab	4.88		
	PMB- NE	Summer 2	84.2 bcd	7.28		
F 2011	PMB- NW	Spring 2	67.2 cd	9.73	4.38	0.0004
	PMB-SE	Summer 0	75.8 d	7.42		
	PMB-SW	Spring 0	81.8 bc	6.94		
	PMB-W	Summer 1	86.2 abc	5.54		

Table 17. Differences between *Amblyomma americanum* and *Dermacentor variabilis* survival in subplots of PMB treated pastures and control pastures.

Season YR	Treatment	Burn Schedule	*F* value	p-value
	Control	Spring 0	0.49	0.483
	PMB-E	Spring 2	3.03	0.082
	PMB- NE	Summer 0	3.09	0.079
S 2009	PMB- NW	Spring 0	1.36	0.244
	PMB-SE	Summer 1	0.45	0.502
	PMB-SW	Spring 1	4.97	0.026
	PMB-W	Summer 2	0.00	0.966
	Control	Spring 0	0.10	0.747
	PMB-E	Spring 2	0.01	0.903
	PMB- NE	Summer 1	1.52	0.218
F 2009	PMB- NW	Spring 0	0.00	0.976
	PMB-SE	Summer 2	0.00	0.977
	PMB-SW	Spring 1	0.08	0.777
	PMB-W	Summer 0	0.03	0.870
S 2010	Control	Spring 1	1.72	0.190
	PMB-E	Spring 0	0.66	0.418

	PMB- NE	Summer 2	0.16	0.689
	PMB- NW	Spring 1	0.47	0.495
	PMB-SE	Summer 1	0.69	0.405
	PMB-SW	Spring 2	0.29	0.592
	PMB-W	Summer 0	0.14	0.711
	Control	Spring 1	0.00	0.972
	PMB-E	Spring 0	0.08	0.772
	PMB- NE	Summer 2	0.03	0.867
	PMB- NW	Spring 1	0.13	0.720
F 2010	PMB-SE	Summer 0	0.31	0.576
	PMB-SW	Spring 2	0.04	0.843
	PMB-W	Summer 1	0.02	0.888
	Control	Spring 2	0.26	0.613
	PMB-E	Spring 1	0.73	0.393
	PMB- NE	Summer 2	0.00	0.994
	PMB- NW	Spring 2	0.57	0.452
	PMB-SE	Summer 0	0.66	0.415
S 2011	PMB-SW	Spring 0	0.72	0.395
	PMB-W	Summer 1	0.63	0.429
	Control	Spring 2	6.34	0.012

	PMB-E	Spring 1	3.87	0.049
	PMB- NE	Summer 2	2.65	0.104
	PMB- NW	Spring 2	5.58	0.018
F 2011	PMB-SE	Summer 0	49.54	<0.0001
	PMB-SW	Spring 0	2.48	0.116
	PMB-W	Summer 1	3.01	0.083

Figure Captions

Figure 6. Tick enclosure bag- Ziploc bag top secured to mesh bottom. Darkening on bottom shows portion of bag where loose soil covered.

Figure 7. Tick enclosure- Ziploc bag folded done and sealed with binder clips.

Figure 8. Tick survival site- atrium enclosures secured to the ground and HOBO Logger placement.


Ziploc
DV

CHAPTER V

TICK ABUNDANCE IN RELATION TO TIME SINCE BURN IN PATCH MOSAIC BURNED PASTURES

ABSTRACT

Patch mosaic burning (PMB) uses frequent, spatially discrete fires throughout a single pasture. The use of multiple times since burn within one pasture creates variation in the composition and structure of the plant community. The complex vegetation changes incurred from this type of burning regimen and the focal grazing of cattle PMB induces should reduce tick populations by creating less favorable microhabitats. To test if a reduction in tick populations occurred on PMB pastures, three PMB treated pastures and three control pastures were dragged with $1m^2$ flannel cloth panels to estimate tick abundance at both the pasture and subplot level for four years (2006, 2007, 2009, and 2010). PMB treated pastures were divided into 6 subplots burned rotationally with one subplot burned each spring and one subplot burned each summer. This rotation meant each subplot was burned only once every three years. Control pastures were burned entirely once every 3 years. Each subplot in PMB treated pastures was dragged, whereas 2 subplots in each control pasture were dragged. Data were log transformed to normalize

the values and equalize variances and compared using analysis of variance. Difference between the number of free-living ticks in PMB treated pastures and the number in control pastures were not significant except for the number of adult ticks recovered in 2006. Subplots within PMB pastures were also not significantly different from one another except for number of adult ticks recovered in 2007.

INTRODUCTION

Ticks are sensitive to fluctuations in temperature and relative humidity (RH) within microhabitats (Harlan and Foster, 1986; Harlan and Foster, 1990; Chilton and Bull, 1994; Bertrand and Wilson, 1997; Schulze and Jordan, 2003). Favorable tick microhabitats contain a layer of leaf litter and accumulated biomass which retains moisture. After losing 4-5% of their body weight to evaporation during unsuccessful questing attempts, ticks will return to the leaf litter to rehydrate (Harlan and Foster, 1990). *Amblyomma americanum* begins using energy to actively reabsorb moisture through its water up-take system when RH drops below 74-89% (Needham and Teel, 1991). When a humid refuge above this RH is not available to ticks, they are at risk for desiccation.

Prescribed burning alters microhabitats and reduces leaf litter and protective vegetation that create these humid refuges (Scrifres et al., 1988; Davidson et al., 1994; Cully, 1999; Fuhlendorf and Engle, 2004). This reduction leads to a general drying in the environment (Warren et al., 1987; Scrifres et al., 1988). Since three-host ixodid ticks spend between 94-97% of their life in the environment (Needham and Teel, 1991), application of prescribed fires in cattle pastures could possibly be used as a natural method of tick control.

Ticks are obligate blood feeders that can cause lowered weight gains, irritation, pruritus, gotch ear, and stress in cattle (Seebeck et al., 1971; Stacy et al., 1978; Williams et al., 1978; Barnard and Morrison, 1985; Scrifres et al., 1988; Byford et al., 1992; Jonsson et al., 1998; Cully, 1999; Tolleson et al., 2010). Ticks can also serve as vectors for bacterial, rickettsial, viral, and protozoal disease agents (de Castro and Newson, 1993; Jongejan and Uilenberg, 2004). Losses to the cattle industry in the U.S. from *Amblyomma americanum*, one of the most abundant ticks in Oklahoma, were estimated at $82 million in 1987, which is equivalent to over $165 million USD in 2012 (Clymer et al., 1970; Drummond, 1987).

Since ticks are an economically important pest of livestock, various control methods have been implemented. The most commonly used form of control has been acaricides. With continued use over time, acaricides resistance has developed. The cost to develop a new anti-parasitic drug was estimated to exceed $100 million USD in 2004 (Graf et al., 2004; Willadsen, 2006; de la Fuente et al., 2007). In 2012, this would be equal to more than $121 million USD. Because of issues with resistance and drug development cost, interest in the use of prescribed burning as a means of natural tick control has been growing (Jacobson and Hurst, 1979; Warren et al., 1987; Scifres et al., 1988; Davidson et al., 1994; Cully, 1999).

One burning regimen that has not been studied for its effects on tick populations is the patch mosaic burning (PMB) regimen. PMB entails dividing one pasture into smaller subplots to which spatially discrete fires are rotationally applied. Along with focal grazing of ruminants, these disturbances create variation in the composition and structure of the plant community (Fuhlendorf and Engle, 2004; Vermeire et al., 2004). In recently burned subplots, the plant community structure and composition may be less suitable tick habitat. The purpose of the present study was to determine if PMB reduced the free-living tick populations in pastures. To test if a reduction in tick populations occurred on PMB pastures, three PMB treated pastures and three control pastures were sampled for ticks by dragging with $1m^2$ cloth panels.

MATERIALS AND METHODS

Research was done at the Oklahoma State University (OSU) Research Range located 21 km southwest of Stillwater, Oklahoma in north central Oklahoma. The OSU Research Range is predominantly tall-grass prairie. In the present study, six pastures varying in size from 45 to 65 ha were used. Three of these pastures were used as PMB treated pastures and three were used as control pastures. Treatment pastures were divided into six subplots with each subplot measuring approximately 200 m by 400 m. One subplot was burned each spring (March to May) and one subplot was burned each summer (July to September), creating a burn return time of three years for the each subplot in a PMB treated pasture (Figure 9). Control pastures were burned entirely once every three years. This three-year burn regimen was chosen as a control because it had the same burn return time as each PMB subplot. Unburned pastures were not used as controls because fire suppression would not have the same effects of plant growth regeneration and woody vegetation suppression (Warren et al., 1987). Pastures were moderately grazed year round by mixed cow / calf and yearling herds.

Thirty-three transects were identified each pasture. Transects were evenly spaced and identified by a number. The order transects were sampled was randomly chosen using a random number generator in Microsoft Excel (Microsoft, Redmond, Washington). Three transects were sampled using a 1m² cloth panel drag twice a month in April, May, and June and three transects were sampled once a month in March, July, August, September, and October. Months sampled twice were those with highest levels of tick activity (Wright and Barker, 2006). No transect was sampled twice in a year. In treatment pastures, all six subplots were sampled whereas only two subplots were sampled in control pastures (Figure 10). Surveys were restricted to the period from 2 hours after sunrise to 2 hours before sunset and were not conducted during or immediately after periods of precipitation because ticks cannot cling to wet drag cloths.

The flannel cloth panels were visually checked every 30 m for ticks. Tick species and life stage were recorded for each individual. Workers dragging transects were guided by handheld GPS units. When heavy tree canopies interfered with satellite signals, compasses were used to maintain a straight heading.

Data were analyzed with SAS Version 9.2 (SAS Institute, Cary, NC). Tick numbers for all life stages were log transformed to normalize the values and equalize variances to meet assumptions for conducting analyses of variance (ANOVA). Simple effects of treatment given year or subplots were assessed using a two factor model. Pasture was considered a blocking variable. Significance was determined at a 0.05 level.

RESULTS

The present study was conducted for four years (2006, 2007, 2009, and 2010). Overall, no difference was observed in the total number of ticks from PMB treated pastures and control pastures during the four years of sampling (Table 18). No differences were detected in number of larvae or the number of nymphs recovered from PMB treated pastures and control pastures. Adult ticks were significantly reduced in PMB treated pastures compared to control pastures in 2006 (F = 7.81, df = 1, P = 0.011) (Table 19). No other year had a significant difference between the number of adult ticks. Analysis was not performed for larvae in 2010 since no larval ticks were recovered from PMB treated pastures and very few were recovered from control pastures that year.

Differences in tick abundance were not detected among subplots within PMB treated pastures. Similarly, significant differences between the number of nymphs or the number of larvae recovered in PMB treated pasture subplots were not detected. The only difference observed was between adult ticks in 2007 (F = 4.83, df = 5, P = 0.022) (Table 20).

DISCUSSION

Significant differences in number of ticks recovered from PMB treated pastures and control pastures with flannel cloth dragging were not detected. Abundance of ticks among subplots within PMB treated pastures was also not significant. This was unlike other studies where recently burned subplots had reductions in tick numbers (Davidson et al., 1994; Cully, 1999).

Davidson et al. (1994) used two different burning regimens (annual and biennial) and monitored tick abundance with cloth drags and CO_2 baited traps in central Georgia. The authors witnessed reductions in the number of ticks in the most recently burned plots which they associated with reduced litter depths. Reducing the leaf litter removed the moist, cool microhabitat that protected ticks from desiccating sunlight, heat, and wind. The most consistent reduction was associated with the number of larvae which was thought to be correlated with impaired survival and oviposition of replete females. Female ticks did not have favorable oviposition sites which led to decreased egg survival and hatchability. In the present study, there was no difference in the number of larvae found between recently burned subplots and older subplots.

Cully (1999) also noted reduced tick abundance using cloth panel sampling on annually burned tall-grass prairie plots but did not see similar results when longer burn intervals were used. The longer burn intervals allowed leaf litter and larger, protective vegetation to become reestablished. Cully (1999) demonstrated that microhabitats only remain inhospitable to ticks for about 1 to 2 years following a prescribed burn. This window where survival of ticks is negatively affected was not detected in the present study.

Significant differences in tick abundance between PMB treated pastures and control pastures were not detected, nor were differences detected in the abundance of ticks among subplots within PMB treated pastures. The lack of differences in the present study may have been caused by the sampling methodology used. Cloth panel dragging has been faulted as a sampling method to assess free-living tick populations in other studies (Semtner et al., 1971; Barnard, 1981; Petry et al., 2010). Semtner et al. (1971) and

Petry et al. (2010) suggested that dragging to sample tick populations of *A. americanum* and *D. variabilis* can produce an erroneous picture of abundance. Variation in dragging results is thought to be caused by tick behavior and vegetation type. Environmental influences can cause ticks to cease activity but do not always cause mortality. High temperatures stimulate ticks to migrate downwards and remain in leaf litter which can prevent cloth drags from contacting them (Semtner et al., 1971).

Vegetation type may also impact the ability of flannel cloth dragging to reach ticks. Some vegetation types may make contact with ticks more difficult (Petry et al., 2010). Older, denser vegetation like that found in PMB subplots not recently burned may have more ticks, but fewer are contacted. The dense vegetation can prevent the cloth drag from reaching some of the ticks. This limited contact would have caused lowered numbers of ticks recovered from subplots with longer time since burns. In contrast, a PMB subplot that was more recently burned would have thinner, less dense vegetation and may have fewer ticks overall, but more ticks are likely to be exposed to the cloth panel. This increased contact would have inflated the number of ticks recovered from PMB subplots more recently burned.

Petry et al. (2010) performed a comparison between sampling free-living *A. americanum* and *D. variabilis* ticks with dry ice baiting and with cloth panel dragging. In their study, more *A. americanum* larvae were captured with dragging and more *A. americanum* nymphs were captured with dry ice baiting. Few *D. variabilis* nymphs were recovered but more *D. variabilis* larvae were recovered with dragging. By only using cloth panel dragging in the present study, the data may have also been biased towards one life stage over another. Dry ice sampling was not used in the present study because windy conditions reduce its effectiveness in Oklahoma.

The goal of the present study was to determine if PMB regimen reduced tick populations in cattle pastures. Barnard (1981) proposed that sampling the environment for ticks is also not always the best representation of the number of ticks that will feed on cattle. Populations of *A. americanum* ticks recovered from pastures with the use of cloth dragging or CO_2 trapping, did not reflect numbers gathered from assessing tick burden on cattle (Barnard, 1981). It is possible that a similar phenomenon was detected in the present study since previous work demonstrated that cattle in PMB treated pastures had fewer ticks than cattle in control pastures (Polito, unpublished data).

Although a reduction in tick abundance in recently burned subplots was not observed with cloth panel dragging, it still may have occurred. Gathering an accurate picture of natural abundance can be difficult and dragging alone may not provide a reliable estimate for the number of ticks that will be parasitic to cattle. Other studies on prescribed burning have shown the large effect fire can have on microhabitats. Reduced leaf litter depths and altered vegetation structure create less suitable microenvironments for free-living tick populations. Potential future studies on PMB and ticks could improve upon the present study by utilizing multiple methods of sampling for tick abundance. An alternative sampling method could be sampling multiple, small sites within pastures. All the leaf litter, vegetation, and top soil could be collected from .5m^2 areas and brought back to a laboratory to be closely examined for ticks. This in-depth look at multiple small areas may provide a better picture of tick populations.

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Table 18. Average overall number of ticks from PMB treated and control pastures by year.

Year		Mean	Standard Error	*F* value	p-value
2006	Control	163.5	121.6	1.19	0.319
	PMB Treated	83.6	52.9		
2007	Control	425.7	193.9	0.62	0.440
	PMB Treated	353.7	147.2		
2009	Control	880	322.9	0.74	0.437
	PMB Treated	686.9	247.0		
2010	Control	13.5	3.8	0.16	0.710
	PMB Treated	19.5	4.9		

Table 19. Average number of ticks by life stage and year recovered by cloth panel dragging.

Year		Adult ticks				Nymphs				Larvae			
		Mean	Std. Error	*F* value	p-value	Mean	Std. Error	*F* value	p-value	Mean	Std. Error	*F* value	p-value
2006	Control	27.3	4.7	7.81	0.011	14.7	4.4	0.80	0.417	121.5	121.5	0.89	0.487
	PMB Treated	11.7	2.4			9.1	2.6			64.8	50.7		
2007	Control	5.5	1.9	0.23	0.639	3.2	1.2	0.94	0.367	417.0	193.4	0.60	0.460
	PMB Treated	4.2	0.9			5.3	1.9			344.3	145.3		
2009	Control	21.2	7.9	1.66	0.247	86.8	36.2	0.75	0.432	772.0	321.1	0.09	0.779
	PMB Treated	10.1	2.1			41.7	8.8			635.1	243.5		
2010	Control	8.6	3.1	0.03	0.865	4.8	1.1	1.33	0.310	0.1	0.1	NA	NA
	PMB	8.6	2.1			10.9	3.1			0	0		

Treated

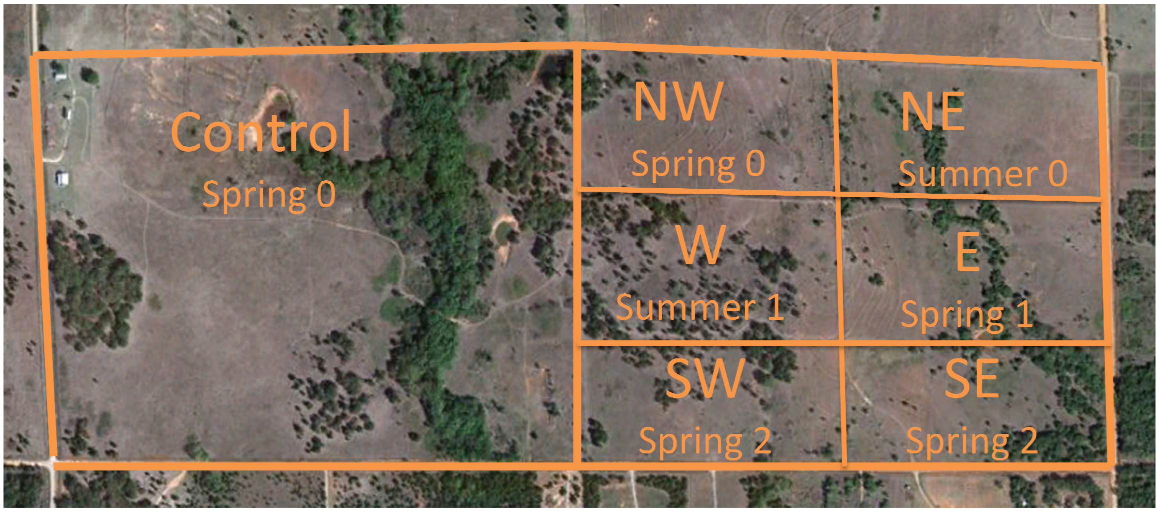
Table 20. P-values between PMB treated subplots for each year and life stage.

	2006	2007	2009	2010
Total tick	0.802	0.711	0.559	0.585
Adults	0.095	0.022	0.745	0.397
Nymphs	0.666	0.134	0.546	0.237
Larva	NA	0.1513	0.162	NA

Figure Captions

Figure 9. PMB pasture and control pasture layout and burn schedule.

Figure 10. Transects in PMB pasture (right half) and control pasture (left half). Orange lines represent fenced pasture boundaries, grey dotted lines represent subplot (no fence lines present), and red lines represent transects used in one sampling.


Control
Spring 0
NW
Spring 0
NE
Summer 0
W
Summer 1
E
Spring 1
SW
Spring 2
SE
Spring 2

CHAPTER VI

CONCLUSIONS

Ticks are an important pest of cattle and can impair their growth and productivity (Barnard and Morrison, 1985; Scifres et al., 1988; Byford et al., 1992; de Castro and Newson, 1993; Tolleson et al., 2010). Acaricides have played a major role in controlling ticks and curbing these negative effects but issues with increasing drug development cost, resistance, and the risk for environmental pollution have left researchers searching for other forms of control (de Castro and Newson, 1993; Graf et al., 2004; Willadsen, 2006; de la Fuente et al., 2007). One alternative method of natural tick control proposed has been prescribed burning (Jacobson and Hurst, 1979; Warren et al., 1987; Scifres et al., 1988; Davidson et al., 1994; Cully, 1999; Allan, 2009). The use of fire can directly kill ticks in the area and can induce longer lasting microhabitat changes by removing leaf litter and causing a general drying of the environment (Warren et al., 1987; Scifres et al., 1988). Ticks are sensitive to these changes in temperature and vegetation structure, including the modifications generated by a prescribed burn (Davidson et al., 1994). Habitat associated mortality is thought to play a large role in the regulation of the tick population size (Bertrand and Wilson, 1997). One prescribed burning regimen of particular interest is patch mosaic burning (PMB). The PMB regimen applies multiple burns in different seasons at different times within a single pasture to create variation in the structure and composition of the vegetative communities within pastures. The overarching objectives of the research presented in this thesis have been to gain a better understanding of the effects of patch mosaic burning (PMB) on tick populations in cattle pastures.

STUDY 1 (CHAPTER 3)

The goal of this study was to determine if PMB reduced cattle infestation by ticks. PMB treated pasture animals had significant reductions in tick infestation in months of peak tick activity for both adult cattle and calves. Adults ticks were significantly reduced on PMB treated animals in April, May, and June which correspond to the times when adult ticks are most active in Oklahoma (Clymer et al., 1970; Barker et al., 2004). Nymphs, which are most active spring and early summer (Zimmerman et al., 1987), were significantly reduced May, June, and September. Larvae were reduced on PMB pastures in July and September, which is also when they are most common in Oklahoma (Semtner and Hair, 1973; Zimmerman et al., 1987).

Average daily gain in calves was not increased in PMB treated pasture animals. It was likely that we were not able to detect a difference in ADG of calves in PMB treated versus control plot if one truly existed because of the inaccuracy of the weight sampling. A weigh tape was used to estimate weights since a livestock scale was not available for use. Weigh tapes are notoriously inaccurate and may not have been a sensitive enough method. The relatively low stocking density and overall high plane of nutrition in our cattle may have also masked any adverse effects from tick feeding in the present study. This study showed the ability of PMB to significantly reduce tick infestations on cattle.

<u>STUDY 2 (CHAPTER 4)</u>

Suitable microhabitats are necessary for tick survival. Previous work has shown the ability of prescribed burning to reduce tick populations by altering the microenvironment (Davidson et al., 1994; Cully, 1999). In this study, the various microhabitats created by the rotational use of fire in PMB treated pastures were studied. Temperature, RH, and SD had significant effects on tick survival but microhabitat and survival differences between subplots with different burn intervals were not detected. Tick survival was correlated to environmental variables, but only three were measured. Other unmeasured variables could also play significant roles in tick survival. Variables such as solar radiation on ground, amount of leaf litter, or soil temperature have also been shown to impact tick populations (Atwood and Soneshine, 1967; McEnroe, 1975; Sterett Robertson et al., 1975; Bertrand and Wilson, 1997).

Ticks placed in enclosures may have also not been completely exposed to the microhabitats created by different burn intervals. The large atrium covers used possibly excluded some of the effects of environmental factors. Inside the atrium cover, ticks were also supplied with artificial shelter when the bottom 5cm of the mesh bags were covered in loose soil. This type of protection may not have actually been present to ticks in all the subplots. Possibly using mesh bags and covering them with only leaf litter available at that site would produce more accurate results. Vegetation also did not grow within the atrium cover, which reduced its ability to mimic the environment around it.

Another sampling issue could have also been caused by the use of adult ticks instead of immature stages. Adults are considered to be the most resilient development stage and can survive for long periods of time (Semtner et al., 1971; Koch, 1984). It is possible that the PMB regimen could have effects on the survival of tick populations by regulating developmental stages but alterations are not large enough to regulate adult ticks.

Though significant differences were not detected in between microhabitats or survival of ticks within PMB treated pastures, they may have existed. The present study could be improved by using earlier life stages of ticks, measuring more environmental variables, and trying different types of enclosures that might not create as much artificial shelter.

STUDY 3 (CHAPTER 5)

The final study in the present thesis monitored tick abundance. Reductions in the tick population were not detected in the more recently burned subplots. However, only one method of sampling, flannel cloth dragging, was employed. Flannel cloth dragging has been criticized as a sampling method to assess free-living tick populations (Semtner et al., 1971; Barnard, 1981; Petry et al., 2010) and may not always be the best representation of the number of ticks that will be parasitic on cattle (Barnard, 1981). Variations in vegetation and tick behavior can produce an inaccurate picture of tick abundance. Differences in vegetation between subplots were predicted because of fire's ability to reduce the moist, cool microhabitat that protected ticks from desiccating sunlight, heat, and wind (Davidson et al., 1994). Although a reduction in tick abundance in recently burned subplots was not observed with cloth panel dragging, it still may have occurred. Other work done with prescribed burning has shown the large effect reduced leaf litter depths and altered vegetation structure have on free-living tick populations. Further investigations of tick abundance in PMB treated pastures, possibly utilizing other sampling methods, are warranted

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APPENDIX A

PREDICTION ESTIMATES FOR TICK SURVIVAL

Probability of Survival: *Amblyomma americanum*- Average Maximum Temperature (°C)

Probability of survival	Avg. Max Temp	95% Fiducial Limits	
0.01	77.8	120.4	129.4
0.02	74.7	113.8	122.1
0.03	72.8	109.6	117.5
0.04	71.3	106.4	114.0
0.05	70.1	103.9	111.8
0.06	69.1	101.7	108.8
0.07	68.2	99.8	106.7
0.08	67.4	98.1	104.8
0.09	66.7	96.5	103.1
0.10	66.0	95.1	101.6
0.15	63.2	89.1	95.0

0.20	61.0	84.4	89.8
0.25	59.2	80.3	85.4
0.30	57.5	76.7	81.4
0.35	55.9	73.3	77.7
0.40	54.4	70.1	74.2
0.45	52.9	66.9	70.8
0.50	51.5	63.9	67.5
0.55	50.1	60.8	64.2
0.60	48.7	57.7	60.8
0.65	47.2	54.5	57.3
0.70	45.6	51.1	53.6
0.75	43.9	47.4	49.7
0.80	42.0	43.2	45.3
0.85	39.8	38.3	40.3
0.90	37.1	32.1	34.0
0.91	36.4	30.6	32.5
0.92	35.7	28.9	30.9
0.93	34.9	27.2	29.1
0.94	33.9	25.1	27.1
0.95	32.9	22.8	24.9
0.96	31.8	20.0	22.3
0.97	30.3	16.6	19.0
0.98	28.4	12.1	14.8

0.99	25.3	4.9	8.1

Probability of Survival: *A. americanum*- Minimum RH (%)

Probability of survival	Avg. Min RH	95% Fiducial Limits	
0.01	-44.5	-50.8	-39.0
0.02	-38.3	-44.1	-33.3
0.03	-34.4	-39.9	-29.6
0.04	-31.5	-36.7	-26.9
0.05	-29.0	-34.2	-24.6
0.06	-27.0	-31.9	-22.7
0.07	-25.2	-30.1	-21.1
0.08	-23.6	-28.3	-19.6
0.09	-22.2	-26.8	-18.2
0.10	-20.9	-25.3	-16.9
0.15	-15.3	-19.4	-11.8
0.20	-10.9	-14.6	-7.7
0.25	-7.1	-10.6	-4.1
0.30	-3.7	-6.9	-0.9
0.35	-0.6	-3.6	1.9
0.40	2.4	-0.4	4.8
0.45	5.3	2.8	7.5
0.50	8.1	5.8	10.1
0.55	10.9	8.8	12.8

0.60	13.8	11.9	15.5
0.65	16.8	15.1	18.3
0.70	19.9	18.5	21.3
0.75	23.4	22.1	24.5
0.80	27.1	26.1	28.1
0.85	31.5	30.7	32.3
0.90	37.1	36.3	37.8
0.91	38.4	37.7	39.2
0.92	39.9	39.1	40.7
0.93	41.5	40.6	42.3
0.94	43.2	42.4	44.2
0.95	45.3	44.3	46.3
0.96	47.7	46.6	48.9
0.97	50.6	49.4	51.9
0.98	54.5	53.1	56.1
0.99	60.7	58.9	62.7

Probability of Survival: *A. americanum*- Average Maximum Saturation Deficit

Probability of survival	Avg. Max SD	95% Fiducial Limits	
0.01	124.7	120.4	129.4
0.02	117.8	113.8	122.1
0.03	113.4	109.6	117.5
0.04	110.1	106.4	114.0
0.05	107.4	103.9	111.2
0.06	105.1	101.7	108.8
0.07	103.1	99.8	106.7
0.08	101.3	98.1	104.8
0.09	99.7	96.5	103.1
0.10	98.2	95.1	101.6
0.15	91.9	89.1	95.0
0.20	86.9	84.4	89.8
0.25	82.7	80.3	85.4
0.30	78.9	76.7	81.4
0.35	75.4	73.3	77.7
0.40	72.0	70.1	74.2
0.45	68.8	66.9	70.8
0.50	65.6	63.9	67.5
0.55	62.4	60.8	64.2

0.60	59.8	57.7	60.8
0.65	55.8	54.5	57.3
0.70	52.3	51.1	53.6
0.75	48.5	47.4	49.7
0.80	44.2	43.2	45.3
0.85	39.3	38.3	40.3
0.90	33.1	32.1	34.0
0.91	31.6	30.6	32.5
0.92	29.9	28.9	30.9
0.93	28.1	27.2	29.1
0.94	26.1	25.1	27.1
0.95	23.9	22.8	24.9
0.96	21.2	20.0	22.2
0.97	17.9	16.6	19.0
0.98	13.5	12.1	14.8
0.99	6.5	4.9	8.1

Probability of Survival: *Dermacentor variabilis*- Average Maximum Temperature (°C)

Probability of survival	Avg. Max Temp	95% Fiducial Limits	
0.01	73.8	71.5	76.5
0.02	71.2	69.0	73.7
0.03	69.5	67.5	71.9
0.04	68.2	66.3	70.5
0.05	67.2	65.3	69.4
0.06	66.4	64.5	68.5
0.07	65.6	63.8	67.6
0.08	64.9	63.1	66.9
0.09	64.3	62.6	66.2
0.10	63.7	62.0	65.6
0.15	61.3	59.8	63.1
0.20	59.4	58.0	61.1
0.25	57.8	56.5	59.3
0.30	56.4	55.2	57.8
0.35	55.0	53.9	56.3
0.40	53.7	52.7	54.9
0.45	52.5	51.5	53.6
0.50	51.3	50.4	52.3
0.55	50.1	49.2	51.0

0.60	48.8	48.1	49.7
0.65	47.6	46.9	48.3
0.70	46.2	45.6	46.9
0.75	44.8	44.2	45.4
0.80	43.1	42.7	43.7
0.85	41.3	40.8	41.7
0.90	38.9	38.5	39.2
0.91	38.3	37.9	38.7
0.92	37.7	37.3	38.0
0.93	36.9	36.6	37.4
0.94	36.2	35.8	36.6
0.95	35.4	34.9	35.8
0.96	34.3	33.9	34.8
0.97	33.1	32.5	33.6
0.98	31.4	30.8	31.9
0.99	28.8	27.9	29.5

Probability of Survival: *D. variabilis*- Average Minimum Relative Humidity (%)

Probability of survival	Avg. Min RH	95% Fiducial Limits	
0.01	-52.5	-60.3	-45.9
0.02	-46.1	-53.3	-39.9
0.03	-42.0	-48.9	-36.9
0.04	-38.9	-45.5	-33.4
0.05	-36.5	-42.8	-31.0
0.06	-34.3	-40.5	-29.1
0.07	-32.5	-38.5	-27.3
0.08	-30.8	-36.7	-25.8
0.09	-29.3	-35.0	-24.4
0.10	-27.9	-33.5	-23.1
0.15	-22.1	-27.3	-17.7
0.20	-17.5	-22.3	-13.5
0.25	-13.6	-17.9	-9.8
0.30	-10.0	-14.1	-6.5
0.35	-6.8	-10.6	-3.5
0.40	-3.6	-7.2	-0.6
0.45	-0.6	-3.9	2.2
0.50	2.3	-0.7	4.9
0.55	5.3	2.5	7.7

0.60	8.3	5.8	10.5
0.65	11.4	9.1	13.4
0.70	14.7	12.7	16.5
0.75	18.3	16.5	19.8
0.80	22.2	20.7	23.5
0.85	26.8	25.6	27.9
0.90	32.6	31.7	33.5
0.91	33.9	33.1	34.8
0.92	35.5	34.6	36.3
0.93	37.2	36.3	38.0
0.94	39.0	38.1	39.9
0.95	41.1	40.2	42.1
0.96	43.6	42.6	44.8
0.97	46.7	45.5	48.0
0.98	50.8	49.4	52.4
0.99	57.2	55.4	59.3

Probability of Survival: *D. variabilis*- Average Maximum Saturation Deficit

Probability of survival	Avg. Max SD	95% Fiducial Limits	
0.01	125.5	120.9	130.5
0.02	118.8	114.6	123.5
0.03	114.6	110.6	119.0
0.04	111.4	107.6	115.7
0.05	108.8	105.1	112.9
0.06	106.6	103.0	110.7
0.07	104.7	101.2	108.6
0.08	102.9	99.5	106.8
0.09	101.4	98.0	105.2
0.10	99.9	96.7	103.7
0.15	93.9	90.9	97.4
0.20	89.2	86.4	92.4
0.25	85.2	82.5	88.1
0.30	81.5	79.0	84.2
0.35	78.1	75.8	80.6
0.40	74.9	72.7	77.3
0.45	71.8	69.7	73.9
0.50	68.7	66.8	70.8
0.55	65.6	63.9	67.6

0.60	62.5	60.9	64.3
0.65	59.3	57.8	60.9
0.70	55.9	54.5	57.4
0.75	52.2	50.9	53.6
0.80	48.2	47.0	49.4
0.85	43.4	42.4	44.5
0.90	37.4	36.5	38.4
0.91	35.9	35.0	36.9
0.92	34.4	33.4	35.4
0.93	32.7	31.7	33.6
0.94	30.7	29.7	31.7
0.95	28.5	27.5	29.6
0.96	25.9	24.9	27.0
0.97	22.8	21.6	23.9
0.98	18.6	17.2	19.8
0.99	11.9	10.3	13.4

APPENDIX B

TICK DRAGGING TOTALS

Sum of ticks recovered from cloth panel dragging in 2006

Pasture	Type	Subplot	Sum Ticks	Sum Adults	Sum Nymphs	Sum Larvae
JY	Control	SW	770	28	13	729
		W	20	16	4	0
NE	Control	E	52	37	15	0
		SE	14	11	3	0
SW	Control	SW	55	33	22	0
		W	70	39	31	0

P9	PMB Treated	E	26	9	17	0
		NE	12	6	6	0
		NW	20	13	7	0
		SE	9	2	7	0
		SW	36	28	8	0
		W	36	23	13	0
S17	PMB Treated	E	12	10	2	0
		NE	41	4	3	34
		NW	1	1	0	0
		SE	12	11	1	0
		SW	10	6	4	0
		W	12	12	0	0
SE	PMB Treated	E	186	15	10	161
		NE	8	7	1	0
		NW	74	4	11	59
		SE	968	8	48	912
		SW	19	10	9	0
		W	58	41	17	0

Sum of ticks recovered from cloth panel dragging in 2007

Pasture	Type	Subplot	Sum Ticks	Sum Adults	Sum Nymphs	Sum Larvae
JY	Control	SW	407	8	5	394
		W	5	4	1	0
NE	Control	E	646	2	7	637
		SE	55	1	0	54
SW	Control	SW	1264	4	5	1255
		W	177	14	1	162
P9	PMB Treated	E	41	4	1	36
		NE	1	1	0	0
		NW	565	12	16	537
		SE	56	5	6	45
		SW	1937	14	30	1893
		W	1836	1	14	1821
S17	PMB Treated	E	90	7	5	78
		NE	102	1	2	99
		NW	0	0	0	0

		SE	62	9	1	52
		SW	8	3	5	0
		W	54	1	0	53
		E	41	6	3	32
		NE	220	0	0	220
SE	PMB Treated	NW	2	2	0	0
		SE	195	2	0	193
		SW	6	6	0	0
		W	1151	1	12	1138

Sum of ticks recovered from cloth panel dragging in 2009

Pasture	Type	Subplot	Sum Ticks	Sum Adults	Sum Nymphs	Sum Larvae
JY	Control	SW	1977	27	90	1860
		W	1557	2	30	1525
NE	Control	E	49	11	38	0
		SE	22	14	8	0
SW	Control	SW	972	16	103	853
		W	703	57	252	394
P9	PMB Treated	E	59	18	41	0
		NE	9	2	7	0
		NW	985	9	56	920
		SE	16	2	14	0
		SW	2078	31	109	1938
		W	507	16	29	462
S17	PMB Treated	E	35	8	27	0
		NE	53	1	5	47
		NW	4	3	1	0

		SE	864	11	28	825
		SW	951	1	5	945
		W	20	3	17	0
SE	PMB Treated	E	1929	5	72	1852
		NE	86	9	77	0
		NW	34	5	29	0
		SE	693	27	136	530
		SW	73	18	55	0
		W	3968	13	43	3912

Sum of ticks recovered from cloth panel dragging in 2010

Pasture	Type	Subplot	Sum Ticks	Sum Adults	Sum Nymphs	Sum Larvae
JY	Control	SW	5	3	2	0
		W	2	1	1	0
NE	Control	E	8	6	2	0
		SE	9	6	3	0
SW	Control	N	10	3	7	0
		S	30	23	7	0
		SW	14	5	9	0
		W	30	22	7	1
P9	PMB Treated	E	12	9	3	0
		NE	3	1	2	0
		NW	33	8	25	0
		SE	5	5	0	0
		SW	72	38	34	0
		W	11	4	7	0
S17	PMB Treated	E	7	4	3	0
		NE	2	1	1	0
		NW	2	2	0	0

		SE	20	15	5	0
		SW	9	5	4	0
		W	2	2	0	0
		E	10	4	6	0
		NE	28	10	18	0
	PMB	NW	19	7	12	0
SE	Treated	SE	20	8	12	0
		SW	28	10	18	0
		W	68	22	46	0

VITA

Victoria Jean Polito

Candidate for the Degree of

Master of Science

Thesis: EFFECTS OF PATCH MOSAIC BURNING ON TICK BURDEN ON CATTLE, TICK SURVIVAL, AND TICK ABUNDANCE

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Name: Victoria Jean Polito Date of Degree: July, 2012

Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: EFFECTS OF PATCH MOSAIC BURNING ON TICK BURDEN ON CATTLE, TICK SURVIVAL, AND TICK ABUNDANCE

Pages in Study: 162 Candidate for the Degree of Master of Science

Major Field: Veterinary Biomedical Sciences

Scope and Method of Study: Patch mosaic burning (PMB) is a regimen that applies spatially discrete fires with different burning intervals. Along with focal grazing of ruminants, these disturbances create a shifting mosaic of vegetation. Variation in plant community structure and composition has been implicated as a means of tick control by decreasing suitable tick habitat. We hypothesize that since ticks are sensitive to fluctuations in temperature and relative humidity within microhabitats, PMB will alter the vegetation structure enough to negatively affect tick populations. To test this, we used three PMB pastures and three control pastures to study cattle infestation, microhabitat effects on tick survival, and tick abundance. Levels of infestation on cattle were determined by counting the number of ticks on cows and calves once a month from April to October. To study microhabitat differences, twenty adult, unfed *Amblyomma americanum* and *Dermacentor variabilis* were placed in enclosures twice per year in control pastures and in all subplots of PMB treated pastures. Data loggers were used to record temperature and relative humidity every 30 minutes. Tick survival was monitored weekly. For tick abundance, flannel cloth panels were dragged through control pastures and all subplots of PMB pastures to estimate abundance of ticks.

Findings and Conclusions: A total of 13,609 ticks were recovered from cattle in 2009, 2010, and 2011. Of these, 4,028 (29.6%) were on animals kept on PMB treated pastures whereas 9,581 (70.4%) ticks were on control animals. Significant differences were observed in months of peak tick burden. Few significant differences were observed in the microhabitat study partially due to high survival of ticks. Environmental conditions measured were correlated to tick survival but were not significantly different between PMB subplots. Abundance of ticks in both PMB treated and control pastures were not significantly different. Nor were differences between PMB treated subplots. A lack of differences in these two studies could possibly be due to issues with sampling methods. These studies warrant further investigations into tick abundance and microhabitat changes of PMB.

ADVISER'S APPROVAL: Dr. Mason Reichard