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Abstract. Pyric-herbivory, defined as fire-driven grazing, was applied as patch-burn grazing management and compared to traditional management (grazing without fire) for the potential to mitigate horn flies, *Haematobia irritans* (L.), on cattle in Iowa and Oklahoma. Stocking rate was conservative at both locations, and all cattle were black angus, *Bos taurus* (L.). Study design was two treatments replicated three times for a total of six pastures at each location. Average pasture sizes were 27 ha in Iowa and 55 ha in Oklahoma. The primary objective was to assess response of the Eurasian origin horn fly to fire and grazing disturbances. Numbers of horn flies were assessed at both locations and analyzed for location, treatment, and interaction (location × treatment). Numbers of horn flies differed only between treatments. Patch-burn grazing management resulted in 41% reduction of horn flies, less than in the traditional management system regardless of location ($P < 0.0001$). Cattle in pastures managed with patch-burn grazing were near the universally accepted economic threshold for treatment (200 flies per cow) compared to double the economic threshold on cattle under traditional management. Cattle in pastures managed with patch-burn grazing were below the behavioral threshold of 300 flies per cow and were expected to have increased grazing time associated with a reduction in stress annoyance behaviors. These results demonstrated that grazing management that includes fire can reduce horn flies on cattle in rangeland systems.

Introduction

Grasslands of central North America developed under fire and ungulate grazing, the most important ecosystem drivers aside from climate. Lightning and anthropogenic ignited fires (Moore 1972) and preferential selection by bison, *Bison bison*, for recently burned areas for tender, palatable regrowth (Wallace and Crosthwaite 2005) was the characteristic disturbance pattern (Fuhlendorf et al. 2009). Settlers moving westward suppressed fires and essentially eliminated bison (Axelrod 1985). The introduction of European cattle ultimately led to the introduction of horn flies, *Haematobia irritans* (L.), in approximately 1884 (McLintock and Depner 1954). Eurasian flies that rely on feces or vegetative refuse for reproduction may not be adapted to fire, and re-integrating fire into the management plan could offer a non-chemical method for reducing losses associated with horn flies.

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Horn flies are the most economically damaging and widespread ectoparasite affecting livestock production, with a 1991 estimate of annual losses on US pastured cattle production of $876 million (equal to $1.46 billion adjusted for inflation in 2012) (Kunz et al. 1991, Byford et al. 1992). In pasture-based beef production systems, horn flies complete the life cycle by deriving blood meals and oviposition resources from grazing animals. Production losses in cattle-grazing operations are associated with blood loss, reduction in weight, stress from annoyance, decreased milk production, and other associated problems (Laake 1946, Granett and Hansens 1957). In central North America, horn flies overwinter by entering diapause (triggered by day length and cooler temperatures) as a puparium in or directly below fecal pats (Lysyk and Moon 2001).

Treating cattle for horn flies decreases stress annoyance behaviors such as head throwing, tail flicking, skin twitching, and leg stomping while resulting in increased grazing (Harvey and Launchbaugh 1982, Boland et al. 2008). Control of horn flies enhanced weaning weights of calves (Campbell 1976, Steelman et al. 2003), weight gains of grazed yearling cattle (Harvey and Brethour 1979, Haufe 1982, Kunz et al. 1984, DeRouen et al. 1995), and calf growth in cow-calf operations (DeRouen et al. 2009). Table 1 summarizes central North American research documenting positive production benefits to horn fly control on cattle.

Effective primary strategies for controlling horn flies on beef cattle rely on insecticide. In the 1980s, synthetic pyrethroid ear tags began providing season-long control, but resistance is currently widespread internationally (Quisenberry and Strohbehn 1984, Oyarzún et al. 2008). Resistance to pyrethroids has been confirmed using nonradioactive single-fly microassay for permethrin hydrolysis that quantified permethrin tolerance in aging female horn flies (Pruett et al. 2000). Diazinon, an organophosphate, has been an effective tool in managing resistance to pyrethroids (Byford et al. 1999). Resistance to organophosphate and pyrethroid insecticides was studied in Louisiana from 1989 to 1992, and the efficacy of 20%

Table 1. Studies Documenting Impact Associated with Horn Fly Control

Location	*Weight increase	Method	Source
Calf weaning weights			
Arkansas	25 kg/calf	IGR bolus	Steelman et al. 2003
Canada	4.7 kg/calf	Ear tag	Haufe 1986
Iowa	5.6 kg/calf	Ear tag	Quisenberry and Strohbehn 1984
Nebraska	5.8 kg/calf	Dust bags	Campbell 1976
Oklahoma	7.4 kg/calf	Ear tag	Kunz et al. 1984
Texas	12.5 kg/calf	Ear tag	Cocke et al. 1989
Yearling cattle gains			
Canada	0.19 kg/day	Ear tag	Haufe 1982
Kansas	8 kg/hd gain	Dust bags	Harvey and Brethour 1979
Louisiana	17% greater gains	Ear tag	DeRouen et al. 1995
Louisiana	0.03 kg/day	Ear tag	DeRouen et al. 2003
Louisiana	0.08 kg/day	IVM/Ear tag	Sanson et al. 2003
Mississippi	0.10 kg/day	Spray	Roberts and Pund 1974
Oklahoma	0.10 kg/day	Ear tag	Kunz et al. 1984
Pennsylvania	0.23-0.30 kg/day	Spray	Cheng 1957

*Significant at alpha 0.05

diazinon-impregnated ear tags decreased from >20 weeks to just 1 week of control (Barros et al. 2001). The continued rapid development by horn flies of resistance to insecticide drives the need to develop alternative control strategies.

A spatial and temporal approach to returning the interaction of fire and grazing has been termed 'pyric-herbivory' or fire-driven grazing (Weir et al. 2007, Fuhlendorf et al. 2009). Data collected from the southern Great Plains suggest the response of free-roaming ungulates to random fires enhances heterogeneity, biological diversity, and ecosystem function of fire-dependent ecosystems in North America and Africa (Fuhlendorf et al. 2009). Patch-burn grazing management, a pyric-herbivory technique, is an application of prescribed fire and grazing in which the timing and location of the grazed and burned patches are varied (Fig. 1) (Engle et al. 2008, Doxon et al. 2011). Traditional management, which excludes fire, promotes homogenous landscapes that may promote only certain segments of the invertebrate community that prefer undisturbed habitat (Fuhlendorf and Engle 2001, Doxon et al. 2011).

Fig. 1. Patch-burn grazing pasture in Iowa with focal grazing response by cattle to the most recently burned patch. Year of burn is noted and patch boundaries visually obvious.

Patch-burn grazing optimized stocker cattle production in mixed-grass prairie and sustained stocker and cow-calf operations in tallgrass prairie, while reducing variation in cattle performance over time (Limb et al. 2011). Furthermore, ungulates (both cattle and bison) preferred recently burned areas and avoided areas with greater time since fire that is associated with the inverse relationship of forage quality and time-since-fire and is the driving influence for pyric-herbivory (Allred et al. 2011). Attraction of herbivores to recently burned areas (Fig. 1) has been termed the "magnet effect" (Archibald et al. 2005), and burning one third of a pasture annually resulted in cattle spending 75% of grazing time in the burned patch (Fuhlendorf and Engle 2004).

Primary reasons for the use of fire in livestock operations has been for brush control and to enhance forage quality, but a secondary benefit could be control of external parasites. It is not clear how the horn fly, an organism that originated in a non-fire-dependent ecosystem, responds to historical fire and grazing disturbances in rangeland ecosystems. The objectives of this study were to evaluate horn flies on cattle in patch-burn grazing managed pastures and compare those to cows under traditionally managed grazing (without fire) at two locations in the central North American grasslands.

Materials and Methods

Location and Experimental Design. The study design involved two treatments: 1) pyric-herbivory applied via patch-burn grazing (one third of the pasture is burned annually and cattle have access to the entire pasture) and 2) traditional management (pastures not burned and cattle have access to the entire pasture). The design was applied at two locations in the central North American grasslands: Stillwater, OK (36° 03' 53.97" N, 97° 13' 53.72" W) and Kellerton, IA (40° 38' 44.73" N, 94° 07' 50.24" W). Patch-burn grazing field studies were in place before the 2011 sampling period. The patch-burn grazing projects were initiated in 1999 in Oklahoma and in 2006 at the Iowa location, with the same basic design and fire treatment used at both study locations. Each location was replicated three times, for six pastures per location (12 total herds combined).

Two fundamental differences existed in study design between locations. The Oklahoma location was a year-round grazing system and the Iowa location was a seasonal grazing system (May to October). Fire was applied during the growing and dormant seasons at the Oklahoma location and during the dormant season at the Iowa location. Because of burn bans, no fire was used during the growing season in Oklahoma; thus, the two studies had similar fire treatments in 2011. Patches in Oklahoma were burned on 9, 10, and 28 March and patches in Iowa were burned on 16 and 18 March. A three-year fire-return interval will be used at both locations.

The Oklahoma pastures averaged 55.3 ha and eight head of cattle per pasture (year-long grazing) and the Iowa pastures averaged 27.2 ha and seven head of cattle per pasture (seasonal-grazing). Mean stocking rates were 2.6 ± 0.1 AUM's/ha (Animal Unit Months per hectare) for Oklahoma and 1.8 ± 0.2 AUM's/ha for Iowa. All cattle were black angus, *Bos taurus* (L.), and similar in frame and condition.

Assessment of Horn Flies. In 2011, both locations were sampled during peak horn fly activity twice weekly for 4 weeks. Sampling in Iowa began on 15 July and sampling in Oklahoma began on 2 September. Sampling two locations in 2011 provided an evaluation of two distinct environments that differed by location and climate. Binoculars were used to assist in visually counting (Schreiber 1985, Schreiber and Campbell 1986, DeRouen 1995, Morrison 1995) from a distance of 5 to 20 m horn flies on one side of four individual cows per pasture. Change as a percentage we considered the potential decrease in horn flies associated with patch-burn grazing pastures was calculated between treatments by using the formula:

$$\text{Change} = [(\text{PBG} - \text{TRAD}) / \text{TRAD}] * 100$$

where PBG = mean horn flies in the patch-burn grazing treatment and TRAD = mean horn flies in the traditional grazing treatment. Analysis of variance (ANOVA) at the 95% confidence level and means separated by an LSD test were used to analyze the numbers of horn flies (SAS Institute). Location, treatment, and interactive (location x treatment) effects were evaluated individually on numbers of horn flies.

Results and Discussion

In Iowa, cattle in pastures managed with patch-burn grazing averaged 128 ± 8 horn flies per cow side compared to cattle managed traditionally that averaged 196 ±11. In Oklahoma, cattle in pastures managed with patch-burn grazing averaged 110 ± 10 horn flies per cow side compared to cattle managed traditionally that averaged 206 ± 15. Numbers of horn flies differed only between treatments. Patch-burn grazing management resulted in 41% reduction of horn flies, less than in the traditional management system regardless of location (P < 0.0001) (Table 2, Fig. 2).

Cattle in pastures managed with patch-burn grazing were near the universally accepted economic threshold for treatment (200 flies per cow) (Kunz et al. 1984, Oyarzún et al. 2008) compared to double the economic threshold on cattle in pastures managed without fire. Cattle in pastures managed with patch-burn grazing were below the behavioral threshold of 300 flies per cow (Harvey and Launchbaugh 1982) and are expected to have increased grazing time associated with a reduction in stress annoyance behaviors. These results demonstrated the impact of patch-burn grazing on horn flies especially because traditionally managed cattle were in pastures managed without fire and no cattle were under a conventional horn fly management program.

Successful implementation of patch-burn grazing in ranching depends on proper grazing management (stocking rate, timing, intensity) to allow for adequate accumulation of fuel. Understanding the potentially effective time-frame for burning would be dependent on the region-specific dormancy period of horn flies. In south-central Texas, horn flies enter diapause in October and November and begin emerging in late February to early May (Thomas and Kunz 1986). Flies enter diapause in September in Missouri (Thomas et al. 1987) and late July through early September in Alberta, Canada (Lysyk and Moon 2001).

Table 2. Effect of Location, Treatment, and Interaction on Horn Fly Load

Effect	Mean square	*F* value	**P* value
Location	1479.3	0.11	0.7365
Treatment	689682.3	52.9	<0.0001
Location x Treatment	18937.2	1.5	0.2289

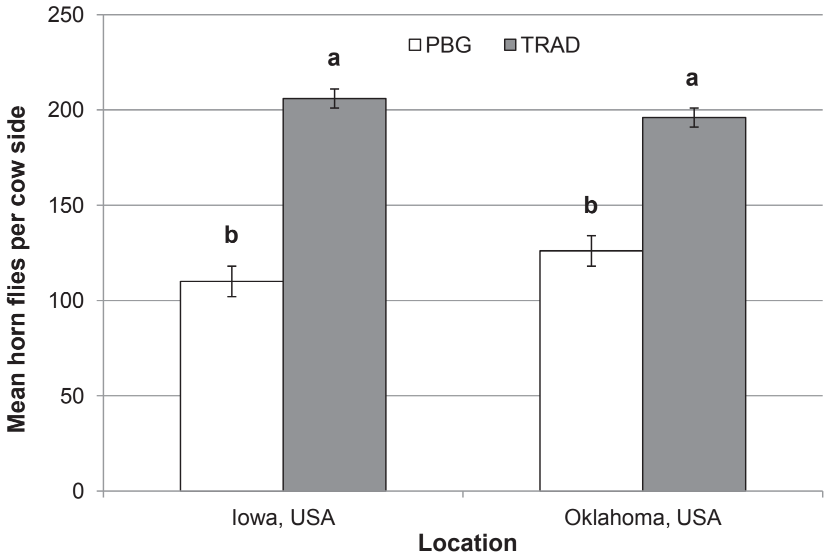

Fig. 2. Mean (± standard error) horn flies per cow side by location and treatment. Treatments with the same letter do not differ significantly

The effective spatial and temporal specifics of application of patch-burn grazing to manage horn flies remains a question, so reduction of horn flies might be increased by varying the spatial and temporal prescription of patch-burn grazing. Horn flies were fewer in central Texas following the movement of cattle in early July and again in early September to a new large pasture of 243 to 405 ha, with distances between pastures ranging from 11 to 19 km (Pruett et al. 2003). A small-scale study evaluated stocking rates and rotation as alternative strategies for managing horn flies that did not result in reducing horn fly numbers in small pastures (1.3 to 3.2 ha) (Steelman et al. 2003). Preliminary evidence from research in the northwestern US indicated that the efficacy of rotational grazing to minimize face fly loads is scale dependent, requiring distances of 1 to 2 km or greater between pastures (Walsh et al. 2010). This concept of scale dependency must take into consideration the dispersal ability of horn flies (as far as 8 km with physical barriers not preventing migration, Byford et al. 1987) and adjacent management practices by landowners.

An alternative to applying insecticide is the use of cultural control techniques. One such technique is the disturbance of horn fly breeding habitats by modifying the manure to allow it to dry (Swiger and Tomberlin 2011), but cultural control has historically been considered impractical in large areas (Powell 1995). Applying fire in a spatial and temporal rotation may enhance drying of fecal pats. This effect may be an underutilized and undervalued benefit to beef producers (Davidson et al. 1994) especially in areas lacking technical training and resources for prescribed burning (Scasta et al. 2011).

Patch-burn grazing management is a framework that allows producers and managers to integrate fire and grazing without sacrificing goals for livestock production (Limb et al. 2011). Patch-burn grazing is a means of rotational grazing without interior cross fences (Weir et al. 2007) that restores the historical fire-grazing interaction. The application of patch-burn grazing should be considered in conjunction with other alternative control measures such as fly-resistant cattle breeds, judicious applications of insecticides, or integration of biological control strategies (Steelman et al. 2003). Using fire as a horn fly-management tool applies to other ungulates; for example, horn flies have also been observed on bison on the tallgrass prairie of Oklahoma (Scasta unpublished).

Although patch-burn grazing could be a viable option for cattle producers in central North American grasslands, effectiveness might be limited in other regions, especially in warmer climates. In Central America (such as Mexico or Argentina), diapause does not occur (Maldonado-Simán et al. 2006) and thus could potentially limit the effect of fire on overwintering pupae. Future research should include quantifying fecal pat combustion and the survival of horn flies overwintering as puparium in and under fecal pats after a fire event. This would further the understanding of the relationship between fire ecology and flies. Because our results demonstrate the potential for patch-burn grazing to reduce flies below the economic threshold, we plan to expand our assessment of horn flies at both patch-burning experiments in 2012 and 2013. In these studies we will adopt digital images for counting horn flies, assess season-long effects, and monitor two additional flies--face fly, *Musca autumnalis* (De Geer) and horse fly, *Tabanus spp.*.

It is important to distinguish between the variable application of fire (both spatially and temporally) in this study compared to other studies that applied fire to the entire landscape. We suggest that the fire-grazing interaction that results in a plant and animal response that moves across the landscape differently each year is as important as the actual fire in reducing the number of horn flies on cattle. The synergistic ecological effects of fire and grazing may offer a management alternative to address livestock parasites as chemical resistance becomes more difficult to manage.

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