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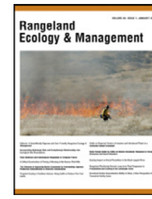

Pyric-herbivory and Hydrological Responses in Tallgrass Prairie☆

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ABSTRACT

Pyric-herbivory is the spatial and temporal interaction of fire and grazing on area resources that results in site selection by animals on recently burned areas. Pyric-herbivory promotes heterogeneity by increasing bare ground on some patches and litter and aboveground biomass on other patches. The influences of this heterogeneity on hydrological properties and sediment transport are not well documented. We monitored the pattern of cattle occupancy on annually burned and patch burned pastures under moderate stocking rates of steers in the Tallgrass Prairie Preserve and quantified surface runoff and sediment transport for simulated rainfall of 10-year return storm intensity applied to different phases of the fire-grazing interaction in 2011 and 2012. Results showed that patch burn altered grazing distribution with cattle spending 70% of their time within the most recently burned areas. Our rainfall simulation results showed the high-intensity grazing following a spring fire did not have a prolonged, ecologically meaningful detrimental impact on hydrological properties of the burned patch in comparison with annually burned grazing pasture. Instead, the increased spatial and temporal heterogeneity of hydraulic properties could potentially enhance resource conservation through runoff and runon interactions within the patch-burned pasture. Further study focusing on quantifying pyric-herbivory effects on runoff and sediment transport at watershed scale will provide needed insights for managing tallgrass prairie for improving ecosystem services.

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Introduction

In tallgrass prairie ecosystems, grazing and fire are interactive disturbances that play a primary role in shaping rangeland communities. This interaction, called *pyric-herbivory*, occurs with varied frequency and intensity across multiple spatial scales and defines prairie structure and function, which regulates prairie ecosystem services (Fuhlendorf et al., 2012). Improved understanding of the underlying mechanisms of pyric-herbivory has assisted development of a new rangeland management scheme commonly called *patch burning* or *patch burn grazing* (Fuhlendorf and Engle, 2004). Under patch burn management, pastures are delineated into patches, which are then burned on a rotation across years. Grazers are drawn to and then spend the majority of their time within recently burned patches. For a pasture on a 3-year fire return interval, a patch may experience an increased grazing pressure by up to threefold within the same year of being burned but will have 2 subsequent years of minimal grazing pressure when cattle are attracted to other more recently burned patches. This variable site selection has been shown to result in increases of aboveground biomass accumulation as time since fire increases (Fuhlendorf and Engle, 2004).

Recent studies have investigated topics ranging from the effect of patch burning on biological responses, such as vegetative structure and composition, to changes in bird, mammal, and insect species diversity and richness, to more abiotic responses such as soil nitrogen and shifts in soil temperatures (Coppedge and Shaw, 1998; Fuhlendorf and Engle, 2004; Anderson et al., 2006; Coppedge et al., 2008; Limb et al., 2009; Fuhlendorf et al., 2010). However, there are very few studies that have considered the potential effects of burning and focal herbivory on hydrological functions in tallgrass prairies (Fuhlendorf et al., 2010).

Focal grazing can influence aboveground biomass accumulation and soil disturbance. Increased grazing pressure for recently burned grasslands decreases cover, which will lead to an increase of raindrop impact and soil detachment (Kinnell, 2005). In addition, extensive trampling from increased cattle occupancy exacerbates the break-up of aggregates (Warren et al., 1986). The excessive loss of cover and an increase in soil surface disturbance as a collective effect of fire and intense grazing were documented to accelerate runoff and sediment transport in sand sagebrush mixed prairie in northwestern Oklahoma (Vermeire et al., 2005) and semidesert grassland in Arizona (O'Dea and Guertin, 2003; Field

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et al., 2011). All of these factors, along with increased soil bulk density from trampling, have the potential to decrease the soil's hydraulic conductivity and increase sediment transport into aquatic systems (Wilcox et al., 1990; Hester et al., 1997; Kato et al., 2009; Casali et al., 2010; Gonzalez-Pelayo et al., 2010).

Tallgrass prairies in the Flint Hills and Osage Hills regions within the southern Great Plains comprise highly productive rangeland and can have adequate residue biomass to support annual burning under average precipitation amounts and appropriate grazing management. The convention in these regions is to burn the entire pasture in spring to uniformly increase palatable forage for cattle (Fuhlendorf and Engle, 2001). This contrasts the historic, more stochastic fire return frequency and interactive grazing that occurred in this region (Fuhlendorf et al., 2009). Burning portions of a landscape to create a patchlike disturbance pattern on both spatial and temporal levels has demonstrated an increase of landscape heterogeneity and biodiversity while simultaneously maintaining cattle production (Fuhlendorf and Engle, 2004). However, the added disturbance of immediate high-intensity grazing following a spring fire has the potential to substantially decrease infiltration capacity, resulting in increased runoff and sediment transport compared with rates observed under fire or grazing disturbance alone, especially under extreme precipitation events.

Burning on rotation leads to changes in both the spatial and temporal dynamics of vegetative cover and grazing intensity, ultimately leading to changes in hydrological properties and function such as saturated hydraulic conductivity, which describes the amount of water that will infiltrate the soil under saturated conditions. A burned grassland will experience increases in bare soil and decreases in litter and vegetative cover the first 10 months after fire (Hart and Frasier, 2003; Fuhlendorf and Engle, 2004) and usually takes about 3 years to reach prefire levels depending on rangeland types and vegetation cover (Fuhlendorf et al., 2006; Spasojevic et al., 2010). Under heavy grazing intensity, vegetative cover in tallgrass prairies has been noted to recover in 6 to12 months once grazing is removed; bulk density has been observed to decrease within 1 year of rest after heavy trampling (Townsend and Fuhlendorf, 2010). Using burned patches to encourage focal cattle grazing behavior is considerably different from intensive rotational grazing management where grazing intensity is focused for a few months followed by several months of rest. Burning patches on rotation involves uniformly stocking the area every year and rotating the burn location to encourage the movement of focal grazing from one area to the next. It has not been adequately documented how vegetation, ground cover, and saturated hydraulic conductivity in tallgrass prairie will be affected by the spatial and temporal dynamics associated with pyric-herbivory.

The overall objective of our study was to understand how rangeland management, specifically the use of fire paired with grazing, alters hydrologic functions within native tallgrass prairie. The specific objectives were to contrast the spatial and temporal variability of surface runoff, saturated hydraulic conductivity, and sediment yield under uniform grazing pressure from an annual burn and focal, rotating grazing pressure from an annually rotating patch burn. Vegetative cover, biomass, and litter cover were measured on the plots at each sampling period to assist in interpretation of observed differences in hydrological responses.

Methods

Study Site

Our study site was within the Nature Conservancy's Tallgrass Prairie Preserve (36°50′46′N, 96°25′22′W), located in the southern edge of the Flint Hills region of the Great Plains in Osage County, Oklahoma, United States (Fig. 1). The bedrock is composed of shale, sandstone, and limestone (Web Soil Survey, 2011). The landscape is rolling hills with a high percentage of rock in the uplands. As a result, this land has never been cultivated and is one of the largest remnants of the historic tallgrass prairie ecosystem. The mean annual precipitation from 1999 to 2013 was 953 mm with typically 64% occurring from April through September on the basis of data from the Foraker station, Oklahoma Mesonet (Mesonet, 2014). Vegetation is dominated by C_4 native grasses such as big bluestem (*Andropogon gerardii* Vitman), indian grass [*Sorghastrum nutans* (L.) Nash], switchgrass [*Panicum virgatum* (L)], and little bluestem [*Schizachyrium scoparium* (Michx.) Nash].

Two large adjacent pastures were selected (see Fig. 1). The pasture to the north (604.5 ha in size) was burned annually in the spring, and the pasture to the south (534.7 ha) was part of a patch burn grazing experiment started in 2006 (Fuhlendorf et al., 2009). The annual burn pasture represented the conventional grazing management approach in the Osage Hills region, which was to burn pastures every year in the spring (Fuhlendorf et al., 2009). The whole annual burn pasture was viewed as a single treatment. The pasture directly south had one third of the pasture burned every year so that, in a 3-year span, the whole pasture experienced fire at some point. This created patches within the field that were at different stages of recovery from fire disturbance and were variable in the distribution of grazing disturbance (see Fig. 1). Each third was considered a separate treatment so that results could be analyzed in relation to time since fire. There were no fences present within the southern pasture, but the burn patches were consistent from year to year. For both the annual burn pasture and patch burn pasture, burning occurred in April and cattle were allowed to graze from after the burn to September. Cattle were stocked at the rate of one steer per two hectares within both pastures.

Experimental Design

To meet our overall objective of evaluating the interactions of burning regimen, grazing pressure, and hydrological function, we chose to use a rainfall simulator to deliver consistent known amounts of rainfall to small plots within our treatment patches. For the annual burn pasture, three temporary plots were selected for each simulated rainfall run. For the patch burn pasture, three plots were selected within each of the three patch burn patches for a total of nine plots for each simulated rainfall run. For both pastures, temporary rainfall simulation plot locations were randomly selected from within areas that had similar slope (3–8%), soil type (sandy loam), and percent rock (3–5%) in order to isolate the hydrological response from fire and grazing disturbance. All plots were within a Lucien–Coyle soil complex (Web Soil Survey, 2011), the major soil type of the Tallgrass Prairie Preserve.

For the initial rainfall simulation in October 2011, simulation plots measured 2 × 2 meters and were constructed by carefully inserting metal borders 5–10 cm into the soil. Borders tapered to a flume at the downslope side of the plot for water collection, and the edges were sealed with wax. In order to increase replicates, the 2 × 2 plots were divided lengthwise, creating temporary plots measuring 2 meters in length × 1 meter in width for the runs in 2012. Each half mirrored the other in spatial variation.

Rainfall Simulation

A rainfall simulator based on the design by Miller (1987) was used to control the amount, rate, and duration of rainfall, so hydrological responses to a large storm event could be quantitatively assessed (Humphry et al., 2002). One TeeJet nozzle, with a maximum flow rate of 210 $mL \cdot s^{-1}$ was located in the center of the simulator 305 cm above the soil surface. Rainfall intensity was controlled using a solenoid and an electrical box that controlled water flow. The rainfall intensity was calibrated using an array of small cups distributed around the entire plot at the beginning of the simulation, which also helped check the spatial variation of our simulated rainfall. Three rain gauges were placed within the plot during the simulation to provide the true rainfall used in the result. Wind effect was minimized by surrounding the rainfall simulator with tarps staked down to the ground. Because grasslands are known to be resilient and the greater danger of erosion occurs under high-intensity rainstorms (Elliott and Vose, 2005), we selected

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