Fuel Characteristics of a Kentucky Bluegrass Monoculture Indicate Potential Changes in Invaded Fuel Beds

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Land managers are increasingly restoring natural fire regimes using prescribed fire to promote native species in invaded grasslands. Exotic grass invasions can transform fuel characteristics and alter fire behavior in grasslands, but possible changes associated with Kentucky bluegrass (Poa pratensis, hereafter bluegrass) invasion in the northern Great Plains remain unknown. A hallmark of bluegrass invasion is the development of a thickened thatch layer of dead plant material on the soil surface. Surface fuels, like those of rangeland ecosystems, are regarded as having uniform fuel arrangement. This may not be the case with bluegrass invasion because thatch appears visually denser than standing fuels above it. Therefore, we conducted a field study to quantify the fuel characteristics of a bluegrass monoculture in the northern Great Plains. Our aim was to determine if bluegrass thatch and standing bluegrass fuels are different fuel components by comparing their bulk density and fuel moisture content under wet and dry environmental conditions.

We found that bluegrass thatch was denser and drier than standing bluegrass fuels regardless of environmental conditions. Furthermore, prevailing environmental conditions influenced the fuel moisture content of thatch but not standing bluegrass fuels. Thatch moisture content also was less affected by hourly changes in relative humidity than standing bluegrass fuels. Therefore, bluegrass thatch and standing bluegrass fuels possess different fuel characteristics, and bluegrass invasion likely is altering fuel arrangement in the northern Great Plains. Land managers need to be aware of these differences because they have the potential to affect fire behavior differently during prescribed burn operations.

Introduction

Frequent fires of varying intensity, scale and origin formed and maintained North American rangelands (Axelrod, 1985). Alterations to natural fire regimes since European establishment have reduced and simplified the face of rangeland ecosystems (Samson and Knopf, 1994).

Invasive species, among other anthropogenic alternations, are further altering rangelands and reducing native biodiversity (Twidwell et al., 2016). In severe cases, novel ecosystems have emerged with no historical precedent to guide management (Hobbs et al., 2009). Managers are increasingly recognizing the importance of restoring natural fire regimes for biodiversity conservation, but many questions remain regarding specific effects and proper implementation (Driscoll et al., 2010).

Prescribed fire is a cost-effective tool that managers can use to impose a fire regime (Kelly et al., 2015). Predicting fire behavior is necessary for safe and effective management (Johnson and Miyanishi, 1995) and requires an understanding of the effects of invasive species on fuel characteristics. Research has documented the effects of exotic species changes in fuel arrangement of canopy fuels (biomass that's at least 2 meters above the ground, as in forests) but not North American surface fuels, such as those found in rangelands, to our knowledge.

Fuel particles are considered uniformly arranged, or evenly distributed, throughout rangeland fuel beds in North American fuel models. This does not account for changes in litter. Increased litter, also known as thatch, associated with Kentucky bluegrass (*Poa pratensis*; hereafter bluegrass) invasion is developing novel ecosystems in the northern Great Plains and displacing native prairie species (Toledo et al., 2014).

Thatch is a tightly interwoven layer of dead plant material that lies between the soil surface and plant canopy. Thatch not only reduces light penetration of the understory but also acts as a buffer that moderates environmental conditions experienced at the soil surface (Murray and Juska, 1977).

Differences in fuel particle distribution in bluegrass-invaded rangelands appear substantial as thatch accumulates but have not been quantified. Therefore, bluegrass invasion provides a relevant case study to test for alterations in fuel arrangement in a rangeland ecosystem.

The purpose of this study was to investigate Kentucky bluegrass (*Poa pratensis*; hereafter bluegrass) invasion in the northern Great Plains as a model of an invasive exotic grass potentially altering surface fuel arrangement. In a bluegrass monoculture on idle rangeland, we quantified fuel characteristics separately for bluegrass thatch and standing bluegrass fuels.

Our objectives were to compare their average bulk densities, moisture content under wet and dry conditions, and the influence of hourly changes in relative humidity (RH) on their moisture content under different prevailing conditions. This information can help improve fire behavior predictions and enhance the restoration of natural fire regimes for biodiversity conservation in novel ecosystems such as those invaded by bluegrass.

Methods

We quantified fuel bed characteristics in a bluegrass monoculture on idle rangeland at the Central Grassland Research Extension Center (CGREC) during the 2017 and 2018 growing seasons. We selected a 20– by 20-meter (m) fenced site excluded from grazing for the previous three years where bluegrass dominated the community composition. On each of four different days, we collected bluegrass thatch and standing bluegrass fuels as separate fuel sample types. Fuels were sampled during wet and dry conditions during the growing season.

We collected wet samples immediately following precipitation events in excess of 0.5-inch in total and dry samples when the site received less than 0.5-inch total precipitation during the previous 72 hours. Data collection occurred on the following dates: Aug. 3, 2017 (wet); May 27, 2018 (dry); July 4, 2018 (wet); and Aug. 17, 2018 (dry). We retrieved all weather data from the Streeter (6NW), N.D., Agricultural Weather Network station (NDAWN, 2018).

Thatch sample collection in an idle bluegrass monoculture.

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Sampling began the hour of sunrise (dry) or the hour after precipitation ceased (wet) and ended the hour of sunset on each of the four sampling days. Grasses are classified as one-hour fuels because they are less than 1/4 inch in diameter. Thuse, we collected hourly samples because the moisture content of one-hour fuels is expected to change hourly with corresponding changes in relative humidity (RH) (Rothermel, 1972).

We sampled bluegrass thatch and standing bluegrass fuels separately each hour from 10 random points characterized by a bluegrass monoculture. At each point, we sampled standing bluegrass fuel by measuring the height of and clipping all aboveground biomass (including live and dead fuels) to the top of the thatch layer within a 10.8-centimeter (cm) diameter area.

We then cut a 10.8-cm diameter thatch-fuel core from the same point, measured thatch depth and separated thatch (including live and dead material) from the mineral soil. All samples were placed

Approximately 6.5-inch-deep Kentucky bluegrass (*Poa pratensis*) thatch sample collected during the 2018 growing season.

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immediately in plastic bags and weighed wet, and then were oven dried to constant weight and weighed dry.

Statistical Analyses

To accomplish our first objective, we calculated bulk density for each fuel sample type by dividing dry weight (g) by volume (cm^3, calculated as a cylinder with a 10.8-cm diameter and height determined by height of the respective sample). We measured bulk density because it influences the oxygen supply available for combustion and, therefore, can affect fire behavior (Rothermel, 1972).

Bulk density measurements were averaged for each sampling day, regardless of environmental conditions, because moisture content has no influence on this measurement. Thus, this analysis included four repetitions ($n = 4$). We tested for differences in the bulk density of bluegrass thatch and standing bluegrass fuels with one-way analysis of variance (ANOVA) procedures in the IBM-SPSS Statistics software package (Version 25; IBM Corp.).

Next, we determined percent fuel moisture for each fuel sample type with the following formula: [(wet weight – dry weight)/dry weight] × 100. Fuel moisture is influenced by environmental conditions, and our second objective was to test for differences in fuel moisture content between bluegrass thatch and standing bluegrass fuels.

Therefore, fuel moisture content for each fuel sample type was averaged within environmental conditions, so we analyzed two repetitions ($n = 2$) for samples collected on wet and dry days. We used ANOVA procedures and Tukey's B mean separation in the IBM-SPSS Statistics software package (Version 25; IBM Corp.) to compare averages across fuel sample types and conditions.

Finally, we used regression analysis to test for differences among fuel sample types in their relationship between fuel moisture content and hourly RH on wet and dry days. All observations (10 samples of each fuel type collected hourly) were treated as independent samples. Hourly RH values were obtained from the Streeter (6NW), N.D., Agricultural Weather Network station (NDAWN 2018).

We used regression analysis (IBM-SPSS Version 25; IBM Corp.) to determine the strength of the relationship (r^2) between relative humidity (RH) and fuel moisture for bluegrass thatch and standing bluegrass fuels under wet and dry conditions. A significant regression slope indicated a relationship between fuel moisture (dependent variable) and RH (independent variable).

Results

Bulk density and moisture content differed between bluegrass thatch and standing bluegrass fuels. Bluegrass thatch had approximately 290 times the bulk density of standing bluegrass fuels (Figure 1).

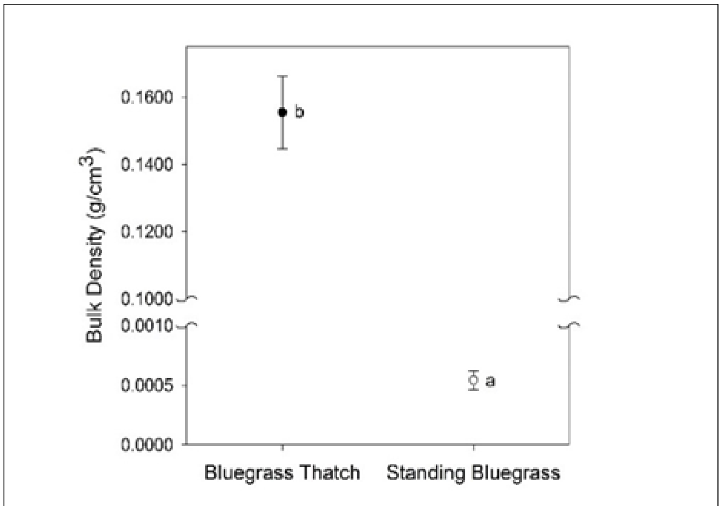

Figure 1. Bluegrass thatch and standing bluegrass fuel mean bulk density (g/cm3, n = 4 daily averages) of an idle bluegrass monoculture sampled on four random days (n = 4). Note the y-axis break and different scaling pre- and post-break.

Moisture content differed among fuel types under both environmental conditions, and the difference was more pronounced under dry (34.11 ± 1.10 percent) than wet conditions (15.53 ± 1.15 percent) (Figure 2). Wet conditions resulted in higher bluegrass thatch moisture than dry conditions, while conditions (wet or dry) did not influence average standing bluegrass fuel moisture (Figure 2).

The data revealed a positive relationship between fuel moisture content and RH for bluegrass thatch and standing bluegrass fuels under wet and dry conditions (Figure 3). Moisture content of both fuel types declined throughout the day as RH declined. The relationship was strongest for bluegrass thatch (r^2 = 0.33) and standing bluegrass fuel moisture (r^2 = 0.34) under wet conditions (Figure 3a).

The data also revealed a stronger influence of RH on standing fuel moisture than thatch fuel moisture in both scenarios (Figure 3b). Moreover, standing fuel moisture changed at a rate that was 187

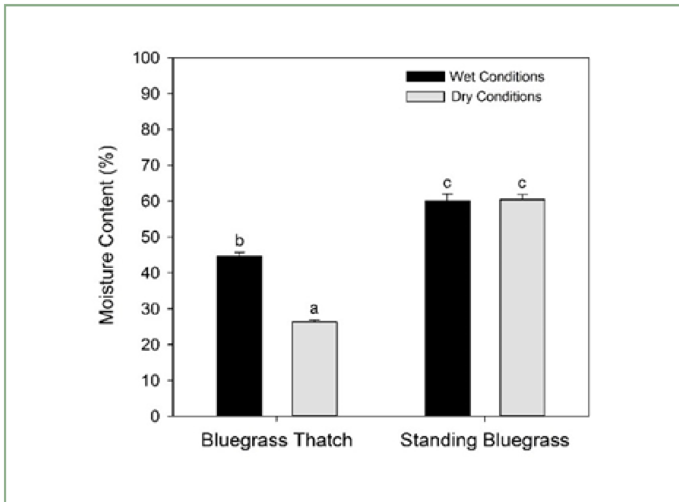

Figure 2. Bluegrass thatch and standing bluegrass fuel mean moisture content (%) under wet and dry conditions (each at n = 2).

and 420 percent that of bluegrass thatch under wet and dry conditions, respectively. Thatch fuel moisture was nearly constant under dry conditions (Figure 3b).

Discussion

Effective restoration of fire regimes in fire-prone grassland ecosystems can aid efforts to control invasive species spread and maintain native biodiversity (Kelly et al., 2015). However, invasive species can complicate the success of prescribed burn management where they alter fuel bed characteristics (D'Antonio and Vitousek, 1992; McGranahan et al., 2012). Bluegrass invasion in the northern Great Plains is developing a thickened thatch layer on the soil surface, but research has not investigated its influence on fuels, fire behavior or prescribed fire management (Toledo et al., 2014).

Our results indicate that bluegrass thatch and standing bluegrass fuels differ in bulk density, moisture content and their fuel moisture relationship with hourly RH. Consequently, our results may be the first to suggest that an exotic grass invasion has the potential to alter fuel arrangement in a rangeland ecosystem.

We found that bluegrass thatch was roughly two orders of magnitude more dense than standing bluegrass fuels (Figure 1), indicating lower oxygen concentration for combustion in bluegrass thatch. North American surface fuel models assume that fuel particles are uniformly distributed throughout the fuel bed (Rothermel, 1972; Pastor et al., 2003), but our findings provide no support for this assumption in idle bluegrass-invaded rangelands. Thus, we propose that bluegrass likely is altering fuel arrangement where it has invaded rangelands through the development of a thickened thatch layer.

Fire spread declines as bulk density of a fuel bed increases, while maximum temperature and burning time increase (Grootemaat et al., 2017). The percentage of fuel combustion also declines as fuels become more tightly packed (Gillon et al., 1995). Therefore, bluegrass thatch may burn slower and longer than standing bluegrass fuels and its combustion may be limited as its density increases.

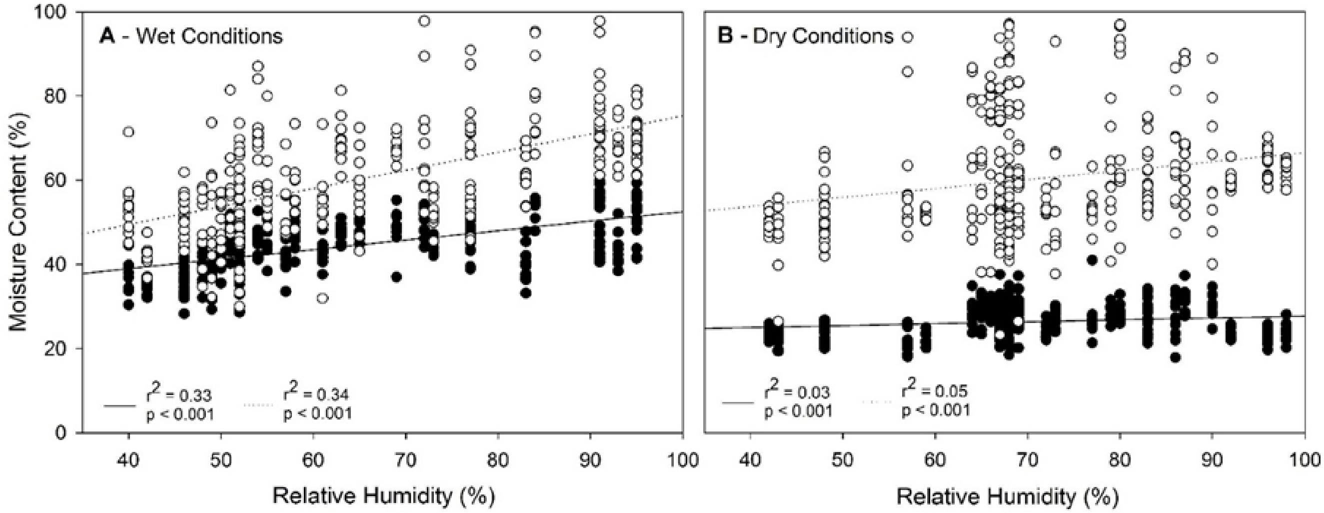

Figure 3. Fuel moisture content of bluegrass thatch and standing bluegrass fuels along a gradient of relative humidity (RH) in a bluegrass monoculture under wet (A) and dry (B) growing season conditions. Solid circles and solid lines represent bluegrass thatch, while open circles and dashed lines represent standing bluegrass fuels (wet, bluegrass thatch y = 30 + 0.23x; wet, standing bluegrass y = 32.31 + 0.43x; dry, bluegrass thatch y = 12.17 + 0.05x; dry, standing bluegrass y = 45.3 + 0.21x).

The moisture content of bluegrass thatch was always less than that of standing fuels, regardless of environmental conditions (Figure 2). We also found that as RH declines throughout the day, the moisture content of standing bluegrass fuels declines nearly twice as fast as bluegrass thatch under wet conditions (Figure 3a). Moreover, RH had almost no influence on the moisture content of bluegrass thatch during dry conditions (Figure 3b).

Minor changes in fuel moisture can elicit drastic changes in fire behavior (Jolly, 2007). Therefore, we propose that observed differences in moisture dynamics between bluegrass thatch and standing bluegrass fuels also have the potential to elicit differences in fire behavior characteristics in bluegrass-invaded rangelands.

Management Implications

Research on the use of prescribed fire as a management tool for bluegrass invasion in the northern Great Plains indicates that it has the potential to control bluegrass, but management specifics remain largely unknown and the success often is short-lived (Bahm et al., 2011; Kral et al., 2018). Furthermore, reductions often are dependent upon precipitation and soil type (Engle and Bultsma, 1984). We argue that differences in fuel behavior among bluegrass thatch and standing bluegrass fuels also may play an important role in the success of prescribed burns for bluegrass control and require consideration.

For instance, bluegrass thatch may burn slower and longer than standing bluegrass fuels, and the difference may be more pronounced during wet conditions when fuel moisture declines more slowly for bluegrass thatch than standing fuels as RH declines by the hour. Therefore, burning when the weather is the driest may be necessary to remove bluegrass thatch accumulations effectively.

In agreement with this argument, evidence suggests that conducting prescribed burns during the summer, when bluegrass is dormant, can reduce bluegrass cover without negatively affecting native species by removing the inhibiting effects of thatch (Kral et al., 2018).

Determining how invasive species alter ecosystem properties, such as fuel bed characteristics, will aid in developing management strategies that conserve biodiversity and maintain valuable ecosystem services. As a whole, our findings reinforce the importance of research investigating the effects of invasive species on fuel bed and fire behavior characteristics.

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Standing dead bluegrass falls over and contributes to thatch, which makes walking through heavily invaded areas difficult.

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