Research Note

Combustion of Cattle Fecal Pats Ignited by Prescribed Fire

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Abstract

Cattle fecal pats readily ignite, are a common source of spot fires, and release extreme amounts of energy when burning. Moreover, dung-dependent livestock parasites can be reduced by combusting fecal pats in prescribed burns. We conducted a study to identify factors that influence combustion of cattle fecal pats. Fifty fecal pats were located in each burn unit before 10 prescribed fires and then rated for combustion after each fire. Combustion of cattle fecal pats was highly variable across fires, with average proportion of combustion of individual pats from the 10 fires ranging from 2 ± 2 to $98 \pm 1\%$ (mean $\pm$ SE). Of 10 fecal pat, fuel, and weather variables assessed, only fecal pat condition, 10-h time-lag dead fuel moisture (DFM), and fuel load entered as variables in a stepwise selection method of constructing a multiple regression model of combustion of fecal pats ($R^2 = 0.94$, $P < 0.01$). Condition of fecal pats (a function of elapsed time since deposition, fuel moisture, and decomposition) explained the greatest variation of pat combustion (partial $R^2 = 0.75$), followed by 10-h DFM (partial $R^2 = 0.12$) and fuel load (partial $R^2 = 0.07$). Combustion was $< 10\%$ when 10-h DFM exceeded 13% regardless of pat condition. For every 1 $Mg \cdot ha^{-1}$ increase in fuel load, combustion of older and drier fecal pats increased by about 7%, but combustion of fresh fecal pats always averaged $< 20\%$ and was unrelated to fuel load. Our results demonstrate that combustion of pats can be managed to meet a variety of ecological and production goals.

Key Words: disturbance, ecology, fuel, grazing, parasites, weather

INTRODUCTION

Combustion of cattle fecal pats has a wide range of implications for fire management, ecological effects on soil and plant resources, and livestock production on rangelands. Fecal pats readily ignite and are a source of spot fires in semiarid grasslands, and smoldering pats should be moved from the perimeter to the interior of burn units (Bunting and Wright 1974; Weir 2009). The historical interaction of wildfire and ungulate grazing in central North America suggests a fecal pat-fire interaction may be an important ecological disturbance of grasslands (Wallace and Crosthwaite 2005). The extreme heat released by burning bison pats (as much as 74 $MJ \cdot m^{-2}$ compared to 15 $MJ \cdot m^{-2}$ for herbage-fueled fires) may also influence landscape heterogeneity (Crockett and Engle 1999).

Fecal pats serve as a habitat resource for horn flies (*Haematobia irritans*), brown stomach worm (*Ostertagia ostertagia*), and other internal and external livestock parasites (Rossanigo and Gruner 1995; Temeyer 2009). Patch-burning reduced horn fly numbers attributed to the alteration of fecal resources, grazing patterns, and biological cycles (Scasta et al. 2012). However, managers need to know the factors that influence fecal pat combustion so they can manipulate prescribed fire conditions to increase or decrease combustion to meet various goals. Furthermore, previous studies noted that fecal pat age confounded the relationship between fecal pat combustion and fuels, fire weather, and season of burning (Crockett and Engle 1999). Quantifying fecal pat combustion, as influenced by fecal pat age and condition, will enhance our understanding of the impact of fire on dung-dependent parasites, fire management, and disturbance ecology.

The goal of the research reported herein was to identify factors that influence combustion of fecal pats on grazed rangelands. The primary objectives of this project were to 1) quantify combustion of fecal pats, 2) determine the relationship of fecal pat combustion with fire weather, dead fuel moisture, fecal pat characteristics, and fuel load, and 3) construct a predictive model of fecal pat combustion.

METHODS

Data were collected at the Oklahoma State University Range Research Station in north-central Oklahoma, USA (36°03′N, 97°13′W), in four grazed pastures ranging in size from 12 to 46 ha. Three of the pastures (SE, 17, and 9) were managed with patch-burning by burning two patches each year, with each patch being one-sixth of the pasture. Burns conducted in these three pastures represented 9 of the 10 fires in this study. The fourth pasture (CTER) had not been grazed for over a year. Angus cow-calf pairs were stocked at 2.3 to 2.8 $AUM \cdot ha^{-1}$ year round. Cattle diets were grass based, supplemented with dried distiller's grains at 5.4 $kg \cdot head^{-1} \cdot wk^{-1}$ during periods of low forage quality, from late summer through the winter.

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Vegetation in the pastures was dominated by C4 perennial grasses.

Fifty cattle fecal pats were located in each burn unit before each prescribed fire using Trimble GPS units with a 20-m buffer from the perimeter of the burn unit. We recorded height, long-axis length, and long-axis width of pats similar to the method described by Crockett and Engle (1999). Visual obstruction at each cardinal direction was used to estimate fuel load around each fecal pat and calibrated with herbage mass clipped within 10, 0.1-m^2 quadrats as described by Vermeire and Gillen (2001). Herbage mass regressed on visual obstruction produced a good-fit equation for estimating fuel load from visual obstruction ($R^2=0.95$). We visually estimated condition of pats based on an index of 1=Fresh/Moist, 2=Fresh/Dry, and 3=Old/Dry. Fire weather (relative humidity, temperature, wind speed) and modeled time-lag dead fuel moisture (DFM) (1-h, 10-h, 100-h, and 1 000-h classes) were obtained from the Oklahoma Mesonet for the Marena observation station. Moisture content of dead fuel determines the amount of heat required to ignite a fuel particle. Dead fuels are classified on the basis of time, or timelag, required for the fuel to adjust to atmospheric moisture, determined by fuel particle diameter (1-h DFM: ≤ 0.6 cm; 10-h DFM: 0.6–2.5 cm; 100-h DFM: 2.5–6.7 cm; 1 000-h DFM: 7.6–20.3 cm) (Pyne et al. 1996). DFM values were calculated from a calibrated version of the Nelson dead fuel moisture model (Carlson et al. 2007), which is the model used in the OK-FIRE wildland fire management system (Carlson 2010). All burn units were < 5 km from the Marena Mesonet station. About 30 d after the prescribed fire, fecal pat locations were revisited, and the proportion (in increments of 10%) of each fecal pat that was consumed by fire (combustion) was visually estimated.

Ten prescribed fires were conducted from 2011 to 2013 in the spring and fall under a range of fuel and fire weather conditions (Table 1). Mean ($\pm$ SE) fine herbaceous fuel load (based on mean of 50 visual obstruction readings per pasture) ranged from 1.46 ± 0.19 to 4.61 ± 0.35 $Mg \cdot ha^{-1}$ with fuel load surrounding individual pats ranging from 0 to 11.55 $Mg \cdot ha^{-1}$. All burns in this study were conducted during the dormant season, and fuels consisted primarily of dead fuels (live herbaceous fuels were minimal with no woody fuel present). Prescribed fires in this study were conducted across a broad range of weather and fuel conditions that represent the range of safe and effective prescriptions (Bidwell et al. 2004).

Forward stepwise regression using all 10 independent variables (fecal pat condition, fecal pat volume, fuel load, relative humidity, temperature, wind speed, and dead fuel moisture for each of the four DFM classes) was used as an initial step in choosing a subset of independent variables at the $\alpha=0.05$ level of entry into the regression. Normality and variance were assessed using the Shapiro-Wilks test and a constant variance test. Three variables entered the model: fecal pat condition entered the model first, followed by 10-h DFM, then fuel load. Multicollinearity was assessed before and after the stepwise selection process, and the final model does not include correlated predictor variables. As additional predictor variables entered the model, each new model was subjected to ANOVA, and significance was subject to Bonferroni correction (P value$\times K+1$) for multiple comparisons between two or more explanatory variables. In the presence of significance ($P \leq 0.05$), coefficient estimates for each variable, partial coefficients of determination, and model coefficients of determination (R^2) were used to assess the direction and strength of correlation of individual variables and the multiple regression model (SAS Institute 2011). Based on the multiple regression model, we then used ordinary linear least squares regression to parse out the relationship of independent variables by fecal pat condition class (SysStat 2012). Samples for 8% 10h-DFM and pat condition of three were omitted from the regression in Fig. 1a because of suspected sampling error (samples identified as condition score 3 appear to include samples of other condition scores confounding the true relationship).

RESULTS

Combustion of cattle fecal pats was highly variable across fires, with average proportion of combustion of individual pats from the 10 fires ranging from 2 ± 2 to $98 \pm 1\%$ (mean $\pm$ SE). The majority of fecal pats were exposed to headfires, but given the logistics of conducting prescribed fires under dynamic field conditions, some pats may have been exposed to backfires or flankfires, a potential source of variation. Variables that failed to enter the stepwise model were relative humidity, temperature, wind speed, fecal pat volume, 1-h, 100-h, and 1 000-h DFM moisture. Variables that entered the model included fecal pat condition, 10-h DFM, and fuel load. The multiple regression model is a strong predictor of fecal pat combustion ($R^2=0.94$, $P < 0.01$) (Table 2):

$$\text{Combustion}(\%) = -115 + 74\, \textit{Pat condition} - 4\, \textit{10} - \textit{hDFM} + 7.51\, \textit{Fuel load}. \quad [1]$$

Fecal pat condition and fuel load increased combustion (i.e., combustion increases as fecal pats dry out, deteriorate, and age, and as fuel load increases), whereas combustion of fecal pats was inversely related to 10-h DFM (Figs. 1a and 1b). We found no relationship of fire weather to fecal pat combustion.

DISCUSSION

Understanding the dynamics of fecal pat combustion has implications for fire management, livestock production, and ecological patterns and processes. Because combusting fecal pats are a major source of spot fires, knowledge of factors that influence combustion can assist in constructing prescriptions that minimize spot fire potential and combustion of fecal pats. Bunting and Wright (1974) found that if 10-h DFM was greater than 13%, fecal pats did not readily ignite, which is generally reflected in our results. However, our study parsed out fecal pats by condition, which is meaningful because fecal pats that were older, drier, and had deteriorated (index of 3) had a mean combustion of 40% at a 10-h DFM of 13% (Fig. 1a). Therefore, we suggest a threshold of 10-h DFM at 16% to minimize combustion, especially in burn units with old fecal pats.

This relationship also could be used by livestock producers who seek to reduce habitat resources for dung-dependent

Table 1. Summary data for fecal pat combustion and characteristics, fuel, and fire weather for ten prescribed fires at the Oklahoma State University Range Research Station, Oklahoma, USA, 2011–2013. Data from the Oklahoma Mesonet station at Marena were used for fire weather and dead fuel moisture for all four time-lag fuel moisture classes.

	Prescribed fire and pasture details									
Month/day/year	20 October 2011	20 October 2011	21 October 2011	17 February 2012	21 February 2012	24 February 2012	15 October 2012	31 October 2012	19 February 2013	12 March 2013
Pasture and unit name	SEU1	17U1	9U1	SEU2	9U2	17U2	17U3	9U3	SEU4	CTER1
% Combustion (± SE)	62 ± 6	58 ± 5	51 ± 6	16 ± 4	2 ± 2	36 ± 5	44 ± 6	54 ± 6	43 ± 6	98 ± 1
	Independent variables by prescribed fire and pasture									
Fecal pats										
Condition index 1 *n*	10	3	8	10	10	7	12	3	8	1
Condition index 2 *n*	15	19	18	23	27	30	5	12	24	3
Condition index 3 *n*	25	28	24	17	13	13	33	35	18	46
Pat volume (dm^3)	3.06 ± 0.36	1.91 ± 0.24	2.21 ± 0.26	6.18 ± 0.56	6.27 ± 0.44	5.36 ± 0.41	4.44 ± 0.63	2.77 ± 0.26	5.85 ± 0.71	4.00 ± 0.39
Fuels										
Fuel load ($Mg \cdot ha^{-1}$)	4.61 ± 0.35	3.94 ± 0.32	3.52 ± 0.32	3.32 ± 0.27	2.28 ± 0.21	3.60 ± 0.29	2.79 ± 0.33	1.46 ± 0.19	2.26 ± 0.22	3.59 ± 026
1-h moisture (%)	6	9	11	11	10	10	5	12	7	6
10-h moisture (%)	10	11	11	13	16	9	8	11	9	9
100-h moisture (%)	9	10	10	15	15	12	15	11	12	13
1 000-h moisture (%)	9	9	10	14	13	13	12	10	10	16
Weather										
Relative humidity (%)	31	37	48	66	43	45	25	52	32	35
Temperature (°C)	17	12	14	11	8	7	29	11	9	14
Wind ($km \cdot h^{-1}$)	6	11	11	6	15	11	16	8	23	3

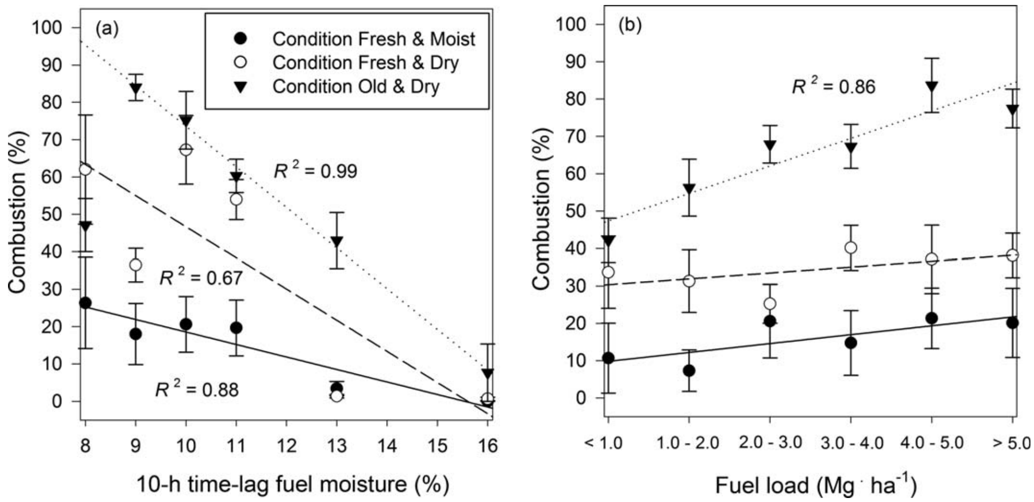

Figure 1. Combustion (mean ± SE) of fecal pats as a function of (**a**) 10-h time-lag fuel moisture and (**b**) fuel load and as a function of a fecal pat condition score index. Coefficients of determination (R^2) are noted for lines with a significant slope ($P \leq 0.05$).

parasites by burning when 10-h DFM is 8% to 10% to maximize combustion (Fig. 1a). However, selection of prescriptions must ensure safe prescribed fires, and the lower end of prescriptions should include measures to minimize spotting because fire behavior becomes increasingly extreme as 10-h DFM drops below 10% (Wright and Bailey 1982). During the period encompassed by our study (October 2011 to March 2013), the range in dead fuel moisture in the four classes was 2–85% (1-h), 3–60% (10-h), 4–3% (100-h), and 5–23% (1 000-h). The minimum values would be out of prescription for most burns because the preferred range for 1-h DFM is 7–20% and 10-h DFM is 6–15% (Wright and Bailey 1982).

Management of fuel load and fuel moisture can enhance combustion of older, extremely dry fecal pats with little combustion of younger fecal pats. These relationships could be combined by managing grazing and burning so prescribed fire timing coincides with periods when the parasite life cycle is most susceptible to disruption and when fecal pats harboring parasites are most susceptible to combustion. For example, a period of high susceptibility is the late dormant overwintering period when fecal pats containing horn fly larvae have deteriorated but pupae have not yet emerged. In the southern Great Plains this susceptible period is likely January through March. Prior to this period, horn flies deposited eggs in fecal pats in October, and the parasite is overwintering as pupae. Furthermore, fecal pats containing pupae have deteriorated for 90 to 150 d, and burning strategically at this time is before spring emergence begins. Understanding the biology of parasites and burning at susceptible times, combined with managing for greater fuel load, might maximize combustion for the greatest impact on parasitic organisms in fecal pats.

That fecal pat condition has more influence than fuel and weather variables on proportion of fecal pats combusted is an important insight gained from our study. A previous study found no significant correlation between bison fecal pat combustion and grassland fire behavior, and the authors noted that fecal pat age confounded the relationship, especially as it related to season of burning (Crockett and Engle 1999). The effect of 10-h DFM and fuel load becomes pronounced as fecal pats deteriorate as time elapses after deposition. Furthermore, for every 1 Mg · ha^{-1} increase in fuel load, combustion of older and drier fecal pats (condition score index of 3) increased by about 7%, but combustion of fresh fecal pats averaged < 20% and was unrelated to fuel load.

Although fecal pat combustion and DFM were correlated, it is important to consider that time-lag DFM describes moisture content of elevated, horizontal wooden dowels, not the moisture content of fecal pats (Carlson et al. 2007). Even so, 10-h DFM appears to be a good indicator of ignition of fecal pats as pats deteriorate (Bunting and Wright 1974).

IMPLICATIONS

Our study showed that fecal pat combustion varies across the landscape as influenced by variation in fecal pat condition (a function of elapsed time since deposition), fuel load, and 10-h fuel moisture. Furthermore, fluctuating fuel moisture and fuel

Table 2. Summary of results of forward stepwise selection of variables used to model combustion (%) of cattle fecal pats under prescribed rangeland fires in tallgrass prairie.

Step	Variable entered (units)	Model	Model R^2	Model F value	Model P value
1	Pat condition (index 1–3)	Combustion (%) = −158 + 87 pat condition	0.75	23.70	< 0.01
2	10-h DFM (%)	Combustion (%) = −78 + 72 pat condition – 4 10-h DFM	0.87	6.72	< 0.01
3	Fuel load (Mg · ha^{-1})	Combustion (%) = −115 + 74 pat condition – 4 10-h DFM + 7.51 fuel load	0.94	6.72	< 0.01

load affect combustion of older, drier fecal pats more than fresher pats. Implications of these results vary for different management objectives and scenarios. Maximizing fecal pat combustion could be strategically applied by livestock producers to alter parasite resources and be integrated with other methods of parasite control. Minimizing fecal pat combustion by recognizing the potential for specific fecal pats to combust under certain conditions will assist land managers in reducing the risk of spot fires and escapes. Understanding these relationships creates awareness and assists in managing liability associated with burning rangelands that are grazed by cattle. Furthermore, disturbance caused by combusting fecal pats can contribute to landscape heterogeneity.

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