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ORIGINAL ARTICLE

How do the wets burn? Fire behavior and intensity in wet grasslands in the Brazilian savanna

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Abstract Although wetlands are commonly managed with fire by local communities and managers in tropical savannas, little is known about fire behavior in these ecosystems. We measured fire intensity and temperature in 13 experimental early (June) and late (September) dry season fires in wet grasslands in the Brazilian savanna, the "Cerrado". We aimed to characterize "Cerrado" wet grasslands fire behavior and to understand how fire season (early vs. late dry season) and time since last fire affect fire behavior and intensity. We compared fire intensities in biennially burnt areas to areas unburned for 5 years. Experimental fires consumed 60–98 % of the fuel and were of low intensity (240–1083 kW m^{-1}) compared to those in dry savanna grassland with similar fuel loads (0.4–1.3 kg m^{-2}). Fires in areas with contrasting times since last fire (2 and 5 years) had similar intensities. Late dry season fires tended to be more intense than early dry season fires, but the difference was not significant. The low fire intensities are probably due to high soil water availability year around, a characteristic of wetlands. Maximum temperatures were low (149–442 °C, mostly at 50 cm in height) compared to fires in dry savanna ecosystems. Our results can directly contribute to plan and implementation of fire management programs in the "Cerrado", where it is mostly still not carried out.

Keywords *"Campos úmidos"* · "Cerrado" · Eriocaulaceae · Fire management · Fire season · Fire temperatures · Protected areas

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Introduction

Historically and at present, fire is a common tool applied in the management of several fire-prone ecosystems (Whelan 1995; Bond et al. 2005; Furley et al. 2008). People set fire to open new areas for agriculture to induce the resprouting and flowering of plant species harvested by humans and grazed by livestock, to aid in hunting, to help avoid poisonous animals, and to improve access to new areas (Mistry 1998; Yibarbuk et al. 2001; McGregor et al. 2010).

Although fire is present in the "Cerrado", the Brazilian savanna, for millennia (Simon et al. 2009), the conservation policy for natural areas, including all legally protected areas (PAs), is mostly to avoid natural and human-induced fires (Ramos Neto and Pivello 2000). For the past several decades, the most common management approach in Brazilian PAs has been to focus on preventing, fighting, and controlling any type of fire, including natural, caused by lighting, and the controlled fires historically carried out by traditional communities (Durigan and Ratter 2016). Even with this 'zero-fire policy,' wildfires have not been eliminated from nearly any "Cerrado" PA, which have been affected by large-scale wildfires, especially during late dry season (August–September), every 2–3 years (França 2010; Pivello 2011; Pereira Junior et al. 2014).

As for other tropical and sub-tropical savannas (Andersen et al. 1998; Savadogo et al. 2007; VanWilgen et al.

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2007), prescribed fires could be applied to manage “Cerrado” ecosystems to avoid uncontrolled fires, protect fire-sensitive vegetation, and maintain biodiversity. Recently, management agencies have started to consider the possibility of implementing Integrated Fire Management (Myers 2006; VanWilgen et al. 2007) in some “Cerrado” PAs (Lobo 2014). However, Integrated Fire Management (IFM) implementation requires information on fire intensity, fire behavior, as well as plant community and population responses to fire in all “Cerrado” physiognomies. The lack of this information is commonly indicated as one of the challenges for establishing fire management policies in “Cerrado” PAs, since fire intensity and fire behavior influence the effects of fire on plant individuals, populations, communities, and ecosystems (Govender et al. 2006). On the other hand, plant community structure and composition affect fuel (biomass) characteristics, production, and accumulation which influence fire behavior and intensity (Bond and Keeley 2005). Therefore, basic information on fire intensity, fire behavior, and biomass production can significantly contribute to fire management implementation (Govender et al. 2006).

Savannas are characterized by marked seasonal rainfall and a mosaic of soils with varying fertilities and drainages, which support a mosaic of physiognomies from inundated to dry forests, including wet and dry grasslands with a significant variation in tree density (Furley 2004). Fire behavior and fire intensity vary widely among savanna physiognomies. Open savanna physiognomies, with continuous grass layer, carry fast surface fires, which are usually more intense than fires in savanna physiognomies with higher tree density (Trollope and Trollope 2002; Miranda et al. 2009). Also, aboveground biomass production and accumulation is faster in mesic savannas compared to dry savannas (Bond and Keeley 2005). These features influence fire return intervals across different savannas in the world and also across the various savanna physiognomies (Bond and Keeley 2005; Miranda et al. 2009).

Within savannas, areas such as inundated forests, swamps, and wet grasslands are islands of water availability all year around (Cianciaruso and Batalha 2008). Specifically in the Brazilian savanna, wet grasslands are economically and culturally important for local communities and are commonly managed with fire for cattle raising, subsistence agriculture, harvest of plant parts, and to protect adjacent riparian areas (Barbosa and Schmitz 1998; Schmidt et al. 2007; Falleiro 2011). Despite the cultural and socio-economic importance of wetlands, most studies on fire behavior in savannas are concentrated in the dry physiognomies (Andersen et al. 1998; VanWilgen et al. 2007; Furley et al. 2008; Miranda et al. 2009). Studies in perennial savanna grasslands are rarer (Zimmermann et al. 2010), and to our knowledge, no study to date has characterized fire behavior in tropical or sub-tropical savanna wetlands.

The Jalapão region (Tocantins state, northwest Brazil) encompasses one of the largest continuous areas of conserved “Cerrado” with the largest continuous legally protected areas in the “Cerrado” biome: Serra Geral Ecological Station, 713,000 ha and Jalapão State Park, 158,000 ha, which are contiguous with the Parnaiba Springs National Park, 733,000 ha (Silva and Bates 2002). Since these areas have been officially protected only since 2001, most of the area is still traditionally managed by local communities. In the wet grasslands, fires are regularly set to induce resprouting of native grasses for cattle grazing, as well as to stimulate flowering of *Syngonanthus nitens* (Bong.) Ruhland (Eriocaulaceae) (Schmidt et al. 2007). The local communities in Jalapão consider annual fires to be too frequent and are associated with decreases in vegetation cover and consequent soil erosion; a biennial fire regime is considered to be ideal for both cattle grazing and *S. nitens* flower stalk harvest. However, fires in areas unburned for five or more years are considered more intense and, therefore, detrimental to the wet grassland plant community, including *S. nitens* and forage grasses than more frequent fires. On the other hand, fire at any time during the dry season (May–September) is believed to induce *S. nitens* flowering the following year (Schmidt 2011).

In this study, we aimed to characterize “Cerrado” wet grasslands fire behavior, including fire intensity, maximum temperatures, and high-temperature residence time. Specifically, we address the following questions: (i) Are late dry season fires (September) more intense than early dry season fires in “Cerrado” wet grasslands? (ii) Do areas with longer fire return interval have significantly higher fuel loads and, therefore, more intense fires than areas burned more frequently?

Experimentally characterizing basic fire behavior and intensity characteristics under contrasting conditions (early vs. late fires) as well as different frequencies (2 vs. 5 years since last fire) can help on the dialog between PA managers and local communities. These data can also inform environmental planning and fire management in the “Cerrado” region, where fire management is still incipient.

Methods

The study was performed in wet grasslands inside the Jalapão State Park (10°15′S; 44°40′W). The wet grasslands in Jalapão occur on organosoils and are dominated by Poaceae and Xyridaceae species with virtually no shrubs or trees. The wet grasslands form belts around palm swamps (*"veredas"*), which frequently are mono-dominated by *Mauritia flexuosa* L.f. (Arecaceae) (Ratter et al. 1997). Local annual precipitation is around 1700 mm, with 90 % of rainfall concentrated between October and April, and mean annual temperature is 27 °C (ANA 2010). Water table is superficial in the wet grasslands, which can be flooded during the rainiest months (November–January) (personal observation).

We performed experimental fires in five wet grasslands (sites 1–5), ranging from 3 to 27 km apart, historically managed with biennial fire by three local communities in Jalapão for both cattle grazing and *S. nitens* harvesting. All study sites were chosen in collaboration with local harvesters, are considered good harvesting areas, and had been burned by local harvesters in 2005, the year before the experiments were established (Schmidt and Ticktin 2012). In each wet grassland, we had three experimental plots: one burned biennially in early dry season (June); another burned biennially in late dry season (September); and a control plot (last fire in 2005) (Fig. 1). In each wet grassland, the plots varied from 100 m^2 (10×10 m^2) to 625 m^2 (25×25 m^2) depending on the length of the wet grassland. The size of the plots, as well as a distance of at least 5 m between experimental plots allowed experimental fires to spread naturally after being started, and the measurements of the air temperature during fires were made at least 5 m from the starting point of the experimental fire. Study areas were fenced in June 2006 to avoid cattle grazing.

Prescribed fires were carried out in June and September 2009 (biennial fires) and in September 2010 (5 years without fire). The biennial plots had been experimentally burned in 2007, whereas the plots burned in 2010 had been protected from fires since 2005. For each fire, we estimated fuel load, fuel consumption, the rate of spread, fire intensity, and air temperature. Immediately before each fire, we measured wind velocity, air temperature, and humidity. All prescribed fires were head fires performed by the Jalapão State Park fire brigade and set between 8:30 am and 2:00 pm.

We estimated fuel load by collecting all the aboveground fine biomass (<0.6 cm) from six quadrats (0.25×0.25 m) immediately before each fire. Quadrats were randomly distributed in the plots, at least 3 m away from the border. The same procedure was carried out immediately after the fires to estimate fuel consumption. The collected biomass was oven-dried (80 °C, for 72 h). We estimated fire rate of spread by measuring the time taken by the fire line to pass through two poles, 5 m apart, in the center of each plot. We calculated fire intensity according to the equation $I = h.w.r$ (Byram 1959), where I is the fire intensity (kW m^{-1}); h is the heat yield of the fuel (kJ kg^{-1}); w is the fuel consumed per unit area (kg m^{-2}); and r is the rate of fire spread (m s^{-1}). We considered the heat yield of the fuel to be 15,500 kJ kg^{-1} (Griffin and Friedel 1984), as for other studies carried out in "Cerrado" (Miranda et al. 2009; Pivello et al. 2010). We calculated heat released multiplying h (the heat yield of the fuel, in kJ kg^{-1}) by w (fuel consumed per unit area, in kg m^{-2}) (Whelan 1995).

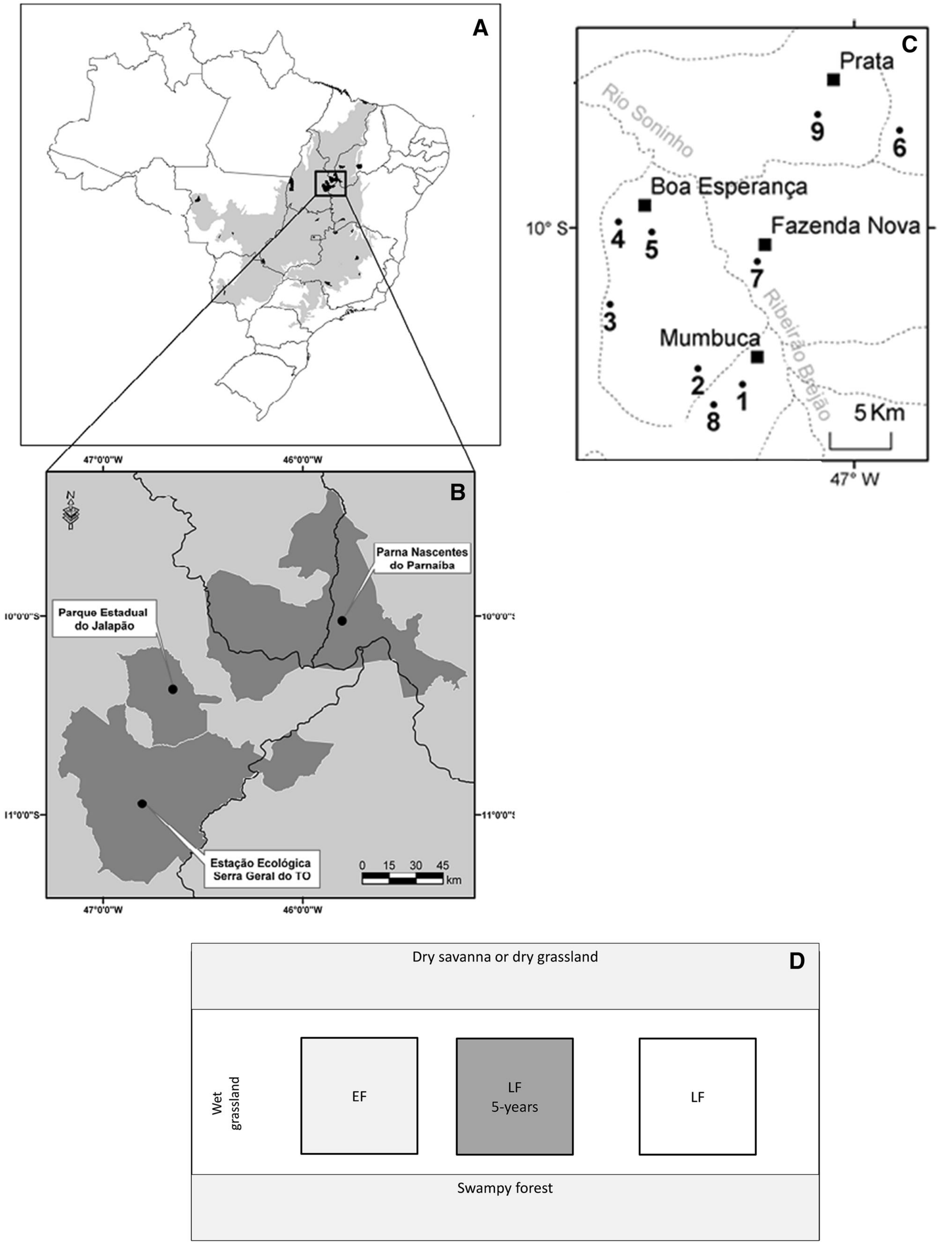
We measured air temperatures during experimental fires using four chromel–alumel thermocouples (32 SWG) with temperatures recorded at one-second intervals, using a Campbell 21X data logger. Thermocouples were located at 1 cm, just above *S. nitens* rosettes, and 50 cm above the soil surface, ca. height of the herbaceous layer vegetation. As fires are regularly set in the wet grasslands to stimulate flowering of *S. nitens* in the following dry season, two thermocouples were placed inside randomly selected *S. nitens* rosettes, and the relative water content (water mass/dry mass) was determined for 50 rosettes in the late dry season fires of 2009 and 2010. The rosettes diameter varied from 3 to 4 cm, which represents the average size of adult individuals in the plots (Schmidt 2011). Temperatures above 60 °C are commonly considered lethal for plant tissues (Kayll 1968; Dayamba et al. 2010); therefore, we characterized the residence time of such high temperatures (>60 °C) for all thermocouples used during our experimental fires.

In September 2009, the burning was uneven in the experimental plot in site 1 and the data were not considered in the analysis. Due to a wildfire in 2007, there was no control plot (protected from fire for 5 years) in site 5. Therefore, the site was not burned in September 2010.

We compared fuel load across sites and dates using one-way ANOVA. The effect of time of fire (fire after 2 vs. 5 years since last fire), early and late dry season fires, in fire intensities and biomass consumption for the experimental fires in 2009 was tested with a paired t test. To better understand the influence of abiotic parameters (wind speed, air temperature, and humidity) as well as fuel load in fire intensity, we performed linear regressions between each of these parameters and fire intensity. All data analyses were performed using R Program (Development Core Team 2016).

Results

Fuel load varied between 0.4 and 1.3 kg m^{-2} (Table 1) and was similar across sites at each fire period (June 2009: $F_{1,28} = 1.41$, $P = 0.24$; September 2009: $F_{1,28} = 0.002$, $P = 0.97$; September 2010: $F_{1,22} = 0.17$, $P = 0.68$). Fuel load (±SD) was also similar in the experimental areas with different times since fire: 0.84 ± 0.16 and 0.69 ± 0.14 kg m^{-2} for September 2009 (burned biennially) and September 2010 (protected from fire for 5 years) ($F_{1,52} = 2.0$, $P = 0.16$). Fuel consumption varied from 60


A
C
Prata
Rio Soninho
9
6
Boa Esperança
10° S
Fazenda Nova
4
5
7
3
Ribeirão Brejão
Mumbuca
2
1
8
5 Km
47° W
47°0'0"W
46°0'0"W
B
Parna Nascentes
do Parnaíba
Parque Estadual
do Jalapão
10°0'0"S
11°0'0"S
Estação Ecológica
Serra Geral do TO
0 15 30 45
km
D
Dry savanna or dry grassland
Wet
grassland
EF
LF
5-years
LF
Swampy forest

◀**Fig. 1** Brazilian territory with "Cerrado" biome delimited in *grey* with borders of the state of Tocantins in black and Jalapão region highlighted in the eastern Tocantins state (**A**); Jalapão region with the three main protected areas (**B**); distribution of four local communities (*squares*) within the Jalapão State Park who manage the five study sites of wet grasslands (*circles*) (**C**); schematic distribution of wet grasslands between swampy forests and dry grasslands of savanna vegetation (**D**), each of the five studied wet grasslands were divided into three plots which were experimentally burned biennially in early or late dry season (June and September 2009, EF and LF, respectively) or burned at late dry season 5 years since last fire

to 98 % of the fuel load in the wet grasslands (Table 1) and was similar between early and late fires in 2009 ($t = -1.4194$, df = 3, $P = 0.25$) and between late fires (September 2009 and 2010, paired t test, $t = -0.6807$, df = 2, $P = 0.57$).

Fire intensity in wet grasslands in Jalapão ranged from 241 to 1090 kW m^{-1}. Mean fire intensity (±SD) was 470 ± 236 kW m^{-1} for early fires, 750 ± 147 kW m^{-1} in September 2009, and 761 ± 231 kW m^{-1} in September 2010. The differences between early and late fires in the areas that were burned biennially (experimental fires in 2009) varied across sites and were not statistically significant ($t = -2.4$, df = 3, $P = 0.1$). Fire intensity values were not significantly correlated to air temperature, air humidity, or fuel load ($P > 0.6$); however, increases in wind speed values at the time of the experimental fires significantly increased fire intensity ($P < 0.05$).

In 2009, the maximum temperatures during the experimental fires were recorded mostly at 50 cm height and varied from 150 to 442 °C (Table 2). The temperatures at 1 cm above the soil surface, just above the *S. nitens* rosettes, varied from 57 to 330 °C and were higher than the temperature measured in the rosettes (33 to 183 °C; Table 2). The relative water content (±SE) was 190 ± 18 % in late dry season fire of 2009 and 104 ± 17 % in 2010.

The residence time of temperatures above 60 °C, considered lethal for plant tissues (Kayll 1968), was mostly below 3 min at 1 cm in height (115 ± 21 s–mean ± SE). Lethal temperatures tended to persist longer than 3 min at 50 cm in height (mean: 212 ± 64 s). The temperature inside *S. nitens* rosettes exceeded 60 °C in only four out of 13 rosettes measured, mostly ($n = 3$) during the late fires (Table 2). Lethal temperatures persisted for more than a minute in three of these four rosettes (Table 2; Fig. 2).

Discussion

We found no differences in total fuel load between areas unburned for 2 years compared to areas unburned for 5 years. These results contradict local communities' impression that longer fire intervals would potentially increase biomass and, consequently, fire intensity in the wet grasslands. Our results are comparable to other studies in humid and sub-humid savanna areas reporting that fuel load recovers within 2 years after fire or less (e.g., Chidumayo 2003; Cianciaruso et al. 2010; Miranda et al. 2010).

The fire intensities estimated in our experimental fires in "Cerrado" wet grasslands were lower (mostly <50 %) than the fire intensities found in other tropical and sub-tropical

Table 1 Fire behavior and abiotic parameters of 13 experimental fires in five wet grasslands in Jalapão region, in the Brazilian "Cerrado", during the early (June) dry season of 2009 and dry seasons of 2009 and 2010

Sites	Fire type	Date	Years since last fire	Fuel load (kg $(m^2)^{-1}$)	Fuel consumption (%)	Fire spread (km h^{-1})	Fire intensity (kW m^{-1})	Heat released (J $(m^2)^{-1}$)	Air temperature (°C)	Relative humidity (%)	Wind speed (km h^{-1})
1	Early	June 2009	2	0.779	80.27	0.132	355.2	12069.3	33.3	67.0	2.50
2	Early	June 2009	2	0.438	60.58	0.210	240.1	6795.2	31.0	75.3	0.79
3	Early	June 2009	2	1.327	78.30	0.150	671.0	20567.5	35.8	56.5	4.00
4	Early	June 2009	2	0.805	81.06	0.240	674.6	12482.7	32.1	67.7	2.33
5	Early	June 2009	2	0.890	72.90	0.105	293.2	13788.8	32.4	73.3	2.14
2	Late	Sept. 2009	2	1.040	93.98	0.214	901.8	16120.0	28.3	95.8	4.38
3	Late	Sept. 2009	2	0.858	89.65	0.250	827.9	13297.8	32.9	74.7	5.37
4	Late	Sept. 2009	2	0.654	69.40	0.375	733.2	9942.3	34.5	73.7	0.17
5	Late	Sept. 2009	2	0.830	93.93	0.167	559.4	12861.3	29.0	86.5	2.08
1	Late	Sept. 2010	5	0.811	97.70	0.187	636.6	12565.3	34.7	53.4	9.30
2	Late	Sept. 2010	5	0.515	82.32	0.593	1083.3	7989.7	35.1	54.5	9.44
3	Late	Sept. 2010	5	0.793	96.98	0.225	745.3	12295.4	35.2	56.2	6.60
4	Late	Sept. 2010	5	0.654	96.70	0.210	572.2	10143.6	39.3	46.1	7.39

Table 2 Maximum temperatures and maximum residence time of temperatures above 60 °C registered in nine experimental early (June 2009) and late (September 2009) dry season fires in five wet grasslands in Jalapão region, in the Brazilian "Cerrado"

Sites	Fire type	Years since last fire	Maximum temperatures during fires (°C)			Residence time – of lethal temperatures (>60 °C (s))			Fire intensity (kW m^{-1})
			50 cm	1 cm	*Syngonanthus nitens* rosette	50 cm	1 cm	*S. nitens* rosette	
1	Early fire	2	186	294	144	108	140	83	355.2
2	Early fire	2	150	110	34	64	114	0	240.1
3	Early fire	2	416	185	43	148	122	0	671.0
4	Early fire	2	222	227	51	158	115	0	674.6
5	Early fire	2	442	57	51	233	0	0	293.2
2	Late fire	2	363	331	183	191	237	120	901.8
3	Late fire	2	405	189	47	709	96	0	827.9
4	Late fire	2	226	237	97	145	150	103	733.2
5	Late fire	2	229	153	70	152	63	21	559.4

Thermocouples were placed at 50 and 1 cm above soil surface and inside *Syngonanthus nitens* adult plant rosettes

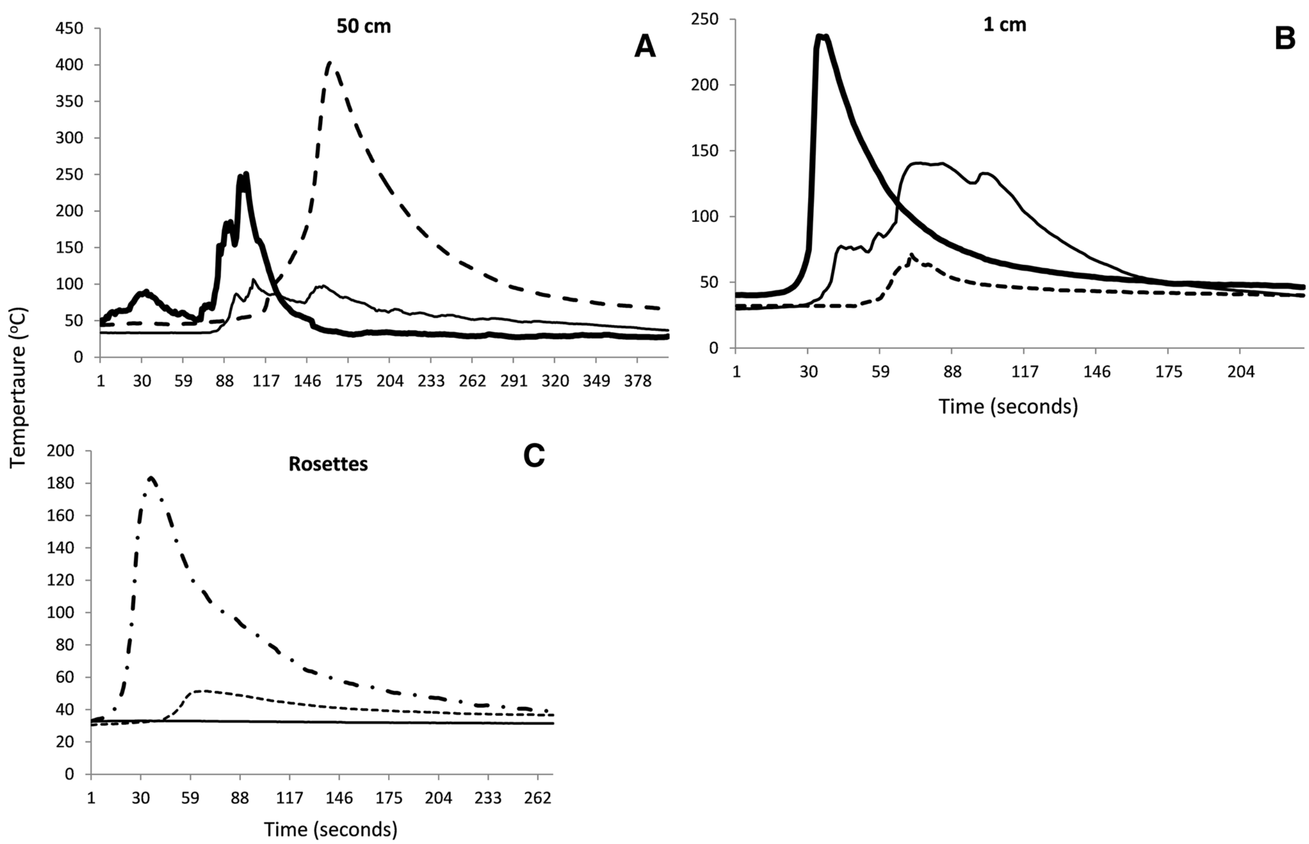


Fig. 2 Typical temperature curves during early and late dry season fires in wet grasslands in Jalapão, Brazil. In each panel, the *bold continuous line* represents the most common temperature profile curve during experimental fires; the other two curves per panel are other examples of observed profiles during nine experimental fires in five sites. **a**, thermocouples at 50 cm height, just above the herbaceous layer vegetation; **b** 1 cm height and **c** thermocouples placed inside *Syngonanthus nitens* rosettes

savannas physiognomies, where fuel load was similar (Table 3). This includes studies in "cerrado" dry grasslands ("*campo sujo*") and woodlands (*"Cerrado"* sensu stricto) reviewed by Miranda et al. (2009); grasslands and parklands in the Amazonian savannas in Northern Brazil (Barbosa and Fearnside 2005); woodlands in Zambia, South Africa (Shea et al. 1996; Govender et al. 2006); and Northern Australia (Williams et al. 1998).

Table 3 Comparative table of fuel load and fire intensities found in this study and reported for other experimental fires in savanna environments

Study	Physiognomy	Region	Intensity (kW m^{-1})		Fuel load (kg $(m^2)^{-1}$)
			Minimum	Maximum	
This study	Wet grasslands	Central Brazil	240	1083	0.43–1.04
Barbosa and Fearnside (2005)	Grassland	Roraima, Brazil	1256	16,394	0.2–0.4
Cardoso et al. (2000)	Wet grasslands	Pantanal, Brazil	–	–	0.3–0.5
Govender et al. (2006)[a]	Woodland savanna	S. Africa	638	2664	0.3–0.4
Miranda et al. (2009)	Grasslands	Central Brazil	1200	20,393	0.2–1.6
Shea et al. (1996)	Woodland savanna	S. Africa, Zambia	480	6130	2.2–5.5
Williams et al. (1998)	Eucalypt savanna	N. Australia	500	18,000	1.5–13

[a] Mean values obtained from 956 experimental fires, over 21 years

The lower fire intensity, we found compared to that in dry savannas physiognomies, can probably be attributed to the higher soil water availability year around in the wet grasslands, which allows for perennial plants to keep high moisture contents even during the dry season (Cardoso et al. 2000; Cianciaruso and Batalha 2008). Field measurements indicate that most (71–81 %) of the aboveground biomass in wet grasslands is still moist and alive even at the end of the dry season (Fidelis et al. 2013), in contrast to the dry aboveground biomass that characterize "Cerrado" dry grasslands and woodlands (Miranda et al. 2002, 2010).

Although we found no significant difference between early and late fires in the areas burned biennially, fire behavior and intensity varied across our five study sites. The two least intense fires—early fire in sites 2 and 5 (Table 1)—were associated with the lowest fuel combustion percentage. These two fires were carried out under the highest air relative humidity (>73 %) among all our early-season fires, and their low intensities might have been a consequence of higher fuel moisture as hypothesized by Baeza et al. (2002). With a low fuel load, the early fire in site 2 also had the lowest maximum temperatures among all 13 fires. On the other hand, the high fuel load in site 5 allowed for very high temperatures to occur especially at 50 cm height (Table 2).

Fire intensity was not affected by time since last fire. Fire intensities in the areas burned after 2 or 5 years since last fire were similar, mostly due to the fast recovery of the biomass of the herbaceous layer after fires (e.g., Chidumayo 2003; Cianciaruso et al. 2010; Miranda et al. 2010). Schmidt (2011) found that interannual rainfall variation has large effects on the population dynamics of one wet grassland species, *S. nitens,* with significantly higher mortality in low rainfall years. Also, low rainfall during the rainy season can cause soil water availability to decrease in wet grasslands during the following dry season, causing changes in the aboveground biomass (Toogood et al. 2008), which can drastically change fire behavior (Whelan 1995). However, that seems not to be the case during the study years; precipitation in 2009 (1961 mm) and 2010 (1895 mm) were high (ANA 2010). Therefore, the fast recovery of the herbaceous layer biomass associated with similar climatic condition (Table 1) resulted in similar fire rate of spread and fuel consumption resulting in similar fire intensities in the late dry season fires of 2009 and 2010.

Although fire intensity is an important measure of fire behavior, high temperature and residence time can be better predictors of fire impacts on the plant community, i.e., fire severity (Govender et al. 2006). The higher relevance of fire residence time compared to fire intensity seems to be even more important for predicting and understanding the effects of fire in grass and herbaceous species (Andersen et al. 2005). The residence times of high temperatures in our experimental fires were short and similar to those reported in other savanna physiognomies (Miranda et al. 1993; Savadogo et al. 2007).

Maximum air temperatures in our experimental fires were lower than the temperatures measured for other "Cerrado" fires (Miranda et al. 1993, 2009). These relatively low temperatures and a short residence time of high temperatures at 1 cm above the soil surface indicate that wet grassland fires are likely to have low impact on soil nutrients and water repellence. Chemical and physical processes that may cause water repellence start at about 170 °C, organic matter and nitrogen volatilization occur at temperatures above 200 °C, and the volatilization of nutrients such as potassium, phosphorous, and calcium only occur above 500 °C (reviewed by Certini 2005; Pivello et al. 2010). We rarely recorded temperatures above 170 °C close to the soil surface, and these lasted less than 30 s. We therefore expect only short-term changes in soil properties due to fire in "Cerrado" wet grasslands, if at all (Certini 2005; Silva and Batalha 2008; Pivello et al. 2010). Soil structure and nutrient analyses from control (unburned) and late burned areas in all our study sites revealed no differences in soil properties that could be attributed to burning, nine months after the late fires of 2009 (Schmidt 2011).

Our results indicate that temperatures inside *S. nitens* rosettes might frequently remain below levels considered lethal (60 °C) during fires in the wet grasslands. The plant architecture, with leaves superimposed in a rosette format and high water content may insulate and protect plant essential tissues (Gill and Ingwersen 1976; Whelan 1995). Although our results might suggest that late dry season fires have a more severe effect on *S. nitens* compared to early fires (temperatures above 60 °C inside *S. nitens* rosettes—Table 2), this can also be a result of the reduced sample size (temperature measured inside 13 rosettes, with only four of them exceeding 60 °C). We did not assess the survival of the 13 rosettes within which we placed the thermocouples during the experimental fires. Schmidt (2011) considering a much larger sample, found very similar survival rates among *S. nitens* adult individuals subject to late and early burns, as well as in control populations (94 % survival, $n = 735$; 92 %, $n = 730$ and 93 %, $n = 592$, respectively) in the same five wet grasslands sites.

To our knowledge, these are the first data on fire intensity and fire behavior on "Cerrado" wet grasslands. Although wet grasslands represent a small portion of the Brazilian "Cerrado" and other tropical savannas, these areas are ecologically very important in terms of water cycling and biodiversity. In addition, wet grasslands are commonly managed with fire for productive reasons by local communities (Dixon 2003), as well as for conservation purposes for managers. Therefore, better understanding fire behavior in such areas may help to better understand the fire effects on these environments, as well as inform management decisions on the needed fire management in tropical savannas, especially in the "Cerrado", where fire management is much needed (Durigan and Ratter 2016).

Our results showed that fires in wet grasslands tend to be less intense than in most dry savanna vegetation types, and that fire intensity and behavior remain similar after 2 or 5 years since last fire. Additionally, fires in early or late dry season have similar fire intensity and behavior; however, since late dry season fires tend to be more intense and would turn much harder to control if they were to scape to riparian or dry vegetation adjacent to wet grasslands, we suggest that early dry season fires are preferable to use for fire management purposes. This information is directly useful for the planning and implementation of fire management. This is especially important, since fire management in wet grasslands is key to prevent wildfires to reach fire-sensitive vegetation such as swampy forest and other riparian forests in "Cerrado".

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