Biol Invasions (2015) 17:423–431
DOI 10.1007/s10530-014-0740-z

ORIGINAL PAPER

How can an invasive grass affect fire behavior in a tropical savanna? A community and individual plant level approach

Elizabeth Gorgone-Barbosa · Vânia R. Pivello · Susana Bautista · Talita Zupo · Mariana Ninno Rissi · Alessandra Fidelis

Received: 6 January 2014 / Accepted: 21 June 2014 / Published online: 28 June 2014

Abstract Some invasive grasses have been reported to change fire behavior in invaded plant communities. *Urochloa brizantha* is an aggressive invasive grass in the Brazilian Cerrado, an ecosystem where fire is a common disturbance. We investigated the effects of *U. brizantha* on fire behavior in an open Cerrado physiognomy in Central Brazil. Using experimental burnings we compared fire behavior at both the community and the individual plant level in invaded (UJ) and non-invaded (NJ) areas burned in July. We also assessed the effect of fire season in invaded areas by comparing July (UJ) and October (UO) burnings. We evaluated the following variables: fuel load, fuel moisture, combustion efficiency, maximum fire temperature, flame height, and fire intensity. Additionally, we evaluated the temperatures reached under invasive and native grass tussocks in both seasons. Fuel load, combustion efficiency, and fire intensity were higher in NJ than in UJ, whilst flame height showed the opposite trend. Fuel amount and fire intensity were higher in October than in July. At the individual plant level, *U. brizantha* moisture was higher than that of native species, however, temperatures reaching ≥600 °C at ground level were more frequent under *U. brizantha* tussocks than under native grasses. At the community level, the invasive grass modified fire behavior towards lower intensity, lower burning efficiency, and higher flame height. These results provide essential information for the planning of prescribed burnings in invaded Cerrado areas.

Keywords African grass · Cerrado · Fire behavior · Fire intensity · Fuel load · *Urochloa brizantha*

E. Gorgone-Barbosa (✉) · T. Zupo · M. N. Rissi · A. Fidelis
Instituto de Biociências, Departamento de Botânica, UNESP – Univ. Estadual Paulista, Rio Claro, SP, Brazil
e-mail: elizabethgorgone@yahoo.com.br

V. R. Pivello
Departamento de Ecologia, Universidade de São Paulo, São Paulo, SP, Brazil

S. Bautista
Department of Ecology and IMEM, University of Alicante, Alicante, Spain

Introduction

Invasive plants cause significant changes in the composition, structure and processes of natural ecosystems (Cronk and Fuller 1995; Pimentel et al. 2000; Vilà et al. 2011; Pyšek et al. 2012). They can reach high densities and dominance in invaded communities, thus being able to modify soil properties and functions, plant productivity, microclimate, fire regime, and interspecific relationships in the community (D'Antonio and Vitousek 1992; Mack et al. 2000; Setterfield et al. 2010; McGranahan et al. 2012). In fire-prone environments such as savannas, invasive grasses may considerably change the nature of the fuel bed, and consequently affect fire behavior and severity (Mack and Antonio 1998; D'Antonio 2000; Mack et al. 2000; Brooks et al. 2004; Klinger 2011).

The impact of invasive grasses on fire regimes, as well as their influence on post-fire species interactions and ecosystem processes, have been studied and documented for a variety of ecosystems (e.g., Hughes and Vitousek 1993; Bilbao and Medina 1996; D'Antonio et al. 1998; Rossiter et al. 2003; Setterfield et al. 2010). By increasing horizontal fuel continuity, invasive exotic grasses may greatly increase fire extent and frequency (D'Antonio and Vitousek 1992). Furthermore, areas invaded by exotic grasses normally burn at higher fire intensities than areas of native vegetation (Rossiter et al. 2003; Mcdonald and Mcpherson 2013), since invasive grasses can greatly increase the fuel load (Bilbao and Medina 1996; Rossiter et al. 2003; Setterfield et al. 2010).

The Brazilian tropical savannas–Cerrado–are considered a biodiversity hotspot (Myers et al. 2000). However, it is estimated that 55 % of the original area of Cerrado has been changed to monocultures and planted pastures (Klink and Machado 2005). The spread of exotic grasses and dry season wildfires are the major threats to the biodiversity of Cerrado (Klink and Machado 2005; Pivello 2006; Durigan et al. 2007). Fire has been an important agent of evolution in Cerrado for at least 4 million years (Simon et al. 2009). The structure of plant communities influences fire behavior and frequency. In turn, fire characteristics influence the regeneration and structure of post-fire communities, resulting in a feedback process between fire and the Cerrado plant community (Kauffmann et al. 1994; Miranda et al. 2009).

Several African grass species (C_4) were introduced in Brazil for cattle grazing, and later became a serious threat to the Cerrado plant community (Klink 1994; Pivello et al. 1999a, b). Nowadays, most of these African grasses (e.g., *Melinis minutiflora* P. Beauv., *Hyparrhenia rufa* (Nees) Stapf, *Panicum maximum* Jacq. *Urochloa* spp.) can be found in almost every Cerrado nature reserve (Pivello et al. 1999b; Pivello 2006). *Urochloa* species are the most common and aggressive invasive grasses in Cerrado areas (Pivello et al. 1999a; Almeida-Neto et al. 2010; Lannes et al. 2012), and can drastically decrease the abundance of native grasses (Pivello et al. 1999a) and forbs (Almeida-Neto et al. 2010) and dominate the herbaceous community.

Given that fire plays an important role in the Cerrado, and that extensive Cerrado areas are invaded by *Urochloa* species, it is of crucial importance to understand how these invasive grasses affect fire behavior, especially focusing on the management of such areas. Therefore, the aim of this study was to investigate how the invasive grass *Urochloa brizantha* (A. Rich.) R.D. Webster may affect fire behavior in Cerrado, as well as the potential mechanisms involved. By using experimental burnings we assessed the effect of *U. brizantha* on the fuel bed and on fire behavior at both the community (plot) and the individual plant level (IPL) scales. We also evaluated if and how fire would differ between seasons (dry season and beginning of rainy season) in the invaded areas. We hypothesized that the presence of *U. brizantha* in the herbaceous community would affect fire behavior by increasing fire intensity through changes in the fuel load. Additionally, we expected that fire at the beginning of the rainy season would be more intense due to the accumulation of dead fuel generated by the invasive grass after the dry season.

Methods

Study area

The study was conducted at the Serra do Tombador Nature Reserve (RNST), in Central Brazil (47°45'; 47°51′W and 13°35'; 13°38′S; 560–1118 m a.s.l.). The regional climate is tropical with wet summers and dry winters, and average annual rainfall between 1,300 and 1,500 mm (AER 2009). The RNST comprises approximately 8,900 ha, which encompasses different Cerrado physiognomies, where the *campo sujo*—a grassland type with scattered forbs and small shrubs (Coutinho 1978)–prevails.

Before becoming a nature reserve, in 2007, the RNST was a cattle ranching farm, and for this reason invasive grasses, such as *Urochloa* spp and *Melinis minutiflora*, dominate several disturbed and degraded areas. The entire reserve has patches with different fire histories; most fire events were accidental or criminal and occurred during the dry season (June to October). All experiments were carried out in *campo sujo* physiognomy, where many patches of *U. brizantha* can be found. The experimental area has not been burned or grazed since 2007.

Experimental design and data sampling

Fire behavior in invaded versus non-invaded sites

In the study area, the invasive species was found in patches of different sizes separated by areas of native grasses. To conduct the experimental fires, we selected individual patches of invaded and non-invaded areas and established one single plot per patch. In July 2012 (dry season), we established ten plots of 20 × 15 m: six with *U. brizantha* covering at least 30 % of the plot (UJ treatment), and four plots without *U. brizantha*, having only native vegetation (NJ treatment). To guarantee the independence of experimental units and treatments, head fires were conducted individually on each plot. To avoid the spread of fire to the nearby vegetation, 3 m wide firebreaks were established around each plot. All experimental fires were carried out with the assistance of the reserve's fire brigade and were conducted at the beginning and/or end of the day.

Weather conditions such as air temperature, relative air humidity and wind speed were measured before and during the fires with a portable digital Thermo-Hygrometer (HT-300 Instruthem®) and a digital Thermo-Anemometer (TAD-500 Instruthem®), respectively.

Before the fires, we determined fuel load (kg m^{-2}) for each plot by sampling aboveground biomass in six 0.25 × 0.25 m subplots. In the invaded plots, we used a stratified random sampling (three subplots were located on tussocks of *U. brizantha* and three subplots on tussocks of native species). Each sample was weighed in the field to determine fuel moisture (live + dead biomass). Biomass was then separated into the following classes: dead biomass, dead and live *U. brizantha* biomass, coarse biomass (stems + graminoid crowns), and fine biomass (leaves + culms). Biomass was dried at 70 °C for 3 days and weighed to constant dry weight. The fuel load value obtained for each plot was adjusted with weighted averages according to the percentage of *U. brizantha* cover on each plot.

Maximum height (including the reproductive structures) of *U. brizantha*, herbaceous plants (forbs and native grasses), and shrubs were also measured on each plot before the fires. After the fires, residual biomass was sampled on six subplots of 0.25 × 0.25 m, dried and weighed. We then estimated combustion efficiency by comparing pre- and post-fire biomass.

The maximum temperatures reached during the fires were assessed by using pyrometers made of aluminum plates painted with color-change crayons (ColeParmer®) with a temperature range of 120–600 °C. The pyrometers were placed 2 cm belowground, at soil surface, and 50 cm aboveground, where most of the biomass was found. In UJ plots, pyrometers were placed, at each of the three heights described above, under five *U. brizantha* tussocks and under five tussocks of native grasses; in NJ plots, pyrometers were randomly placed. We also used open-calorimeters made of aluminum cans (350 ml) following methods proposed by Pérez and Moreno (1998). The cans were filled with 200 ml of water and sealed. They were unsealed just before the burnings and sealed again right after fires, when they were weighed to calculate the amount of water evaporated during the passage of fire. We used 10 calorimeters for each plot, five under *U. brizantha* tussocks and five under tussocks of native grasses. Furthermore, ten calorimeters were used as a control, being left outside the experimental plots, and sealed/unsealed at the same time as the ones that were in experimental plots.

To measure fire rate of spread (m s^{-1}) we established three observation points (5, 10 and 15 m) on one side of the plot and measured the time taken for the fire line to reach each of the points. From these values, we calculated the average rate of spread per plot. From the same three observation points and with the aid of a 5 m long scale, we visually estimated flame height (cm). Finally, we estimated fire-line intensity (kW m^{-1}) for each plot using the Byram's equation and considering a constant value of heat yield for savannas, of 15,500 kJ kg^{-1} (Griffin and Friedel 1984).

Fire behavior in invaded sites at different seasons

In October 2012 (early-rainy season), we conducted a second set of experimental burnings on invaded plots (UO treatment; six 20 × 15 m plots on patches where *U. brizantha* covered at least 30 % of the ground), and compared results with those from the burnings conducted in July (UJ treatment; dry season; six 20 × 15 m plots). The experimental fires in October were carried out as described above for UJ burnings; the same variables were assessed in both seasons.

Statistical analyses

We used one-way analysis of variance (ANOVA) applied to randomization tests (Euclidean distance between sampling units, 10,000 iterations) to evaluate differences between invaded and non-invaded plots (community level), *U. brizantha* and native species tussocks (individual plant level), and between July and October fires (fire season). We also performed linear regression modeling to analyze the relationships between some fuel load properties and fire intensity, and between the amount of water evaporated from the calorimeters and the frequency that the pyrometers registered at least 600 °C. All statistical analyses were performed using the software MULTIV (Pillar 2005) and Statistica (StatSoft 2007).

Results

Fire behavior in invaded and non-invaded communities

Weather conditions were similar for all experimental fires, including both NJ and UJ treatments: high air temperatures (29.7 ± 1.0 and 28.9 ± 1.8 °C for UJ and NJ, respectively), low relative air humidity (36.5 ± 6.0 % in UJ and 31.3 ± 2.4 % in NJ plots) and low wind speed (0.8 ± 0.2 and 0.9 ± 0.3 m s^{-1} for UJ and NJ, respectively).

U. brizantha tussocks (ranging from 109 to 159 cm in height) were significantly taller ($P < 0.001$) than both native grasses/forbs (49–55 cm) and shrubs (40–79 cm). However, total fuel load was higher in NJ plots (Table 1). Most of the total biomass in the NJ plots consisted of dead and fine live biomass (78 and 16 %, respectively), whilst coarse live biomass corresponded to only 5 %. In UJ plots, native species biomass accounted for 65 % of total biomass (where 48 % was dead biomass), *U. brizantha* biomass represented about 35 % (dead + live), and coarse biomass represented only 8 % (Table 1). Total fuel moisture (dead + live) did not differ between UJ and NJ plots (24 ± 2 and 29 ± 1 %, respectively, $P = 0.56$). However, considering only the invaded plots, total fuel moisture was higher for *U. brizantha* (30 ± 2 %) than for native grasses (18 ± 3 %, $P < 0.001$).

In both invaded and non-invaded plots, maximum temperature at soil level and 50 cm aboveground reached values higher than 600 °C, but temperatures >600 °C were most frequent at soil surface. Temperatures 2 cm belowground were lower than 120 °C in all experimental plots. Flame height was significantly higher ($P = 0.001$, Fig. 1a) in UJ (478 ± 33 cm) than in NJ plots (266 ± 31 cm). Nevertheless, combustion efficiency in UJ plots was on average 73 %, while in NJ plots it was ca. 90 % (Fig. 1b, $P = 0.04$). The rate of flame spread was not significantly different between treatments ($P = 0.7$) and fire-line intensity was lower in the UJ (310 ± 58 kW m^{-1}) compared to the NJ plots (731 ± 217 kW m^{-1}, Fig. 1c, $P = 0.001$).

Fire behavior under different seasons and *U. brizantha* effects

Weather conditions were similar between dry (July) and early rainy seasons (October) ($p > 0.05$ for all variables). In general, air temperature was higher than 29 °C, relative air humidity was lower than 40 %, and wind speed varied from 0.8 ± 0.2 to 1.3 ± 0.3 m s^{-1}.

No significant difference was found in the height of *U. brizantha* between UJ (132 ± 10 cm) and UO (101 ± 6 cm, $P = 0.06$). Total fuel load in UO was twice the amount sampled in UJ ($P = 0.007$), and was mainly composed of dead biomass (*U. brizantha* and natives, Table 1). Total fuel moisture (dead + live) was similar in both seasons (29 ± 2 % in July and 27 ± 3 % in October; $P = 0.55$). As in UJ, maximum temperatures registered in UO fires were higher than 600 °C in all plots, both at soil level and 50 cm aboveground, while temperatures belowground did not exceed 120 °C. All measured fire variables did not differ significantly between UJ and UO (Table 2). However, fire intensity in UJ (dry season) was lower (from 140 to 499 kW m^{-1}) than in the early rainy season (UO, from 212 to 1,611 kW m^{-1}, $P = 0.03$) (Table 2).

The dead fuel of natives explained 48 % ($P = 0.01$) of the variation of fire intensity. Moreover, dead fuel and moisture content of *U. brizantha* were also good predictors, both explaining more than 30 % of the variation of fire intensity independently of the season ($P = 0.05$ for both, Fig. 2a, b). Relationships between fire-line intensity and other fuel properties such as fine, coarse and live *U. brizantha* biomass were not significant.

Fire behavior at the individual plant level (IPL): tussocks of *U. brizantha* and native grasses

The volume of water lost in calorimeters under *U. brizantha* and under native species did not differ in either July or October fires ($P = 0.14$ and

Table 1 Fuel load (kg m^{-2}, mean ± SE) per fuel class in non-invaded plots (NJ), invaded plots in July fires (UJ), and invaded plots in October fires (OJ) at Serra do Tombador Nature Reserve, Central Brazil

Fuel load	Treatments			P values (NJ × UJ)	P values (UJ × UO)
	NJ	UJ	UO		
Dead native	0.47 ± 0.11	0.17 ± 0.01	0.26 ± 0.03	0.04[a]	0.04[a]
Dead *Urochloa brizantha*	–	0.11 ± 0.02	0.23 ± 0.04	–	0.02[a]
Total dead	0.47 ± 0.11	0.28 ± 0.02	0.49 ± 0.06	0.49	0.01[a]
Live fine native	0.10 ± 0.03	0.03 ± 0.01	0.04 ± 0.01	0.05[a]	0.20
Live coarse native	0.02 ± 0.02	0.03 ± 0.01	0.04 ± 0.01	0.16	0.35
Live *Urochloa brizantha*	–	0.01 ± 0.01	0.05 ± 0.01	–	0.04[a]
Total *Urochloa brizantha* (dead + live)	–	0.12 ± 0.02	0.26 ± 0.04	–	0.006[a]
Total fuel load	0.61 ± 0.14	0.35 ± 0.02	0.62 ± 0.06	0.01[a]	0.001[a]

[a] $P \leq 0.05$

$P = 0.17$, respectively). However, pyrometers at soil surface under *U. brizantha* reached 600 °C more frequently (70 % of pyrometers in both July and October—Fig. 3) when compared to those under the tussocks of native grasses (40 %, $P = 0.03$ and $P = 0.05$ for July and October, respectively). At 50 cm aboveground and 2 cm belowground there was no significant difference between *U. brizantha* and tussocks of native grasses.

Discussion

Fire behavior in invaded and non-invaded communities and at the individual plant level

The presence of the invasive grass *U. brizantha* in the Cerrado *campo sujo* modified fire behavior towards lower fire intensity, lower combustion efficiency, and higher flame height at the community level, and increased the frequency of high temperatures at the IPL.

The type, amount, and moisture content of the fuel load are strongly related to fire behavior, especially fire intensity and rate of spread (Whelan 1995). The amount and type of fuel in Cerrado is related to the physiognomy (Castro and Kauffmann 1998; Miranda et al. 2002) and to time since last fire (Oliveras et al. 2013; Fidelis et al. 2013): open physiognomies have more fine fuel and accumulate dead fuel if not burned frequently. According to Miranda et al. (2002), fuel load in *campo sujo* varies from 0.60 to 0.96 kg m^{-2}, similar values to those found in the non-invaded plots (NJ) of this study. Several studies show that invasive grasses usually increase the amount of fine fuel (D'Antonio and Vitousek 1992; D'Antonio et al. 1998; Brooks et al. 2004). However, there have been cases where the invasive grass reduced the fuel load of the invaded areas (McGranahan et al. 2013). Surprisingly, we found lower fuel load in invaded plots (UJ) than in non-invaded plots. *U. brizantha* forms dense and tall tussocks (Milles et al. 1996), an architecture quite different than most native grasses in the area, giving this species great potential for changing fuel characteristics of invaded campo sujo areas. The presence of the invasive grass also decreases the native fuel load, especially biomass of native grasses and forbs (Gorgone-Barbosa, unpublished data), which contributed to the change in fuel load and could partially explain the lower fire intensity found in UJ plots.

At the community level, total fuel moisture was not significantly different between UJ and NJ. However, the moisture content of *U. brizantha* biomass was higher than that of native species, also contributing to lower combustion efficiency and lower fire intensity in the invaded plots. Modeling simulations with another African grass invasive of the Cerrado, *Melinis minutiflora*, showed that it could promote more intense fires (Mistry and Berardi 2005), which could be related to plant architecture, fuel moisture, and higher fuel load promoted by the invasive species. In Australian eucalypt-dominated savannas, *Andropogon gayanus* doubled the moisture content of the fuel load. However, it increased fire intensity in these savannas (Setterfield et al. 2010).

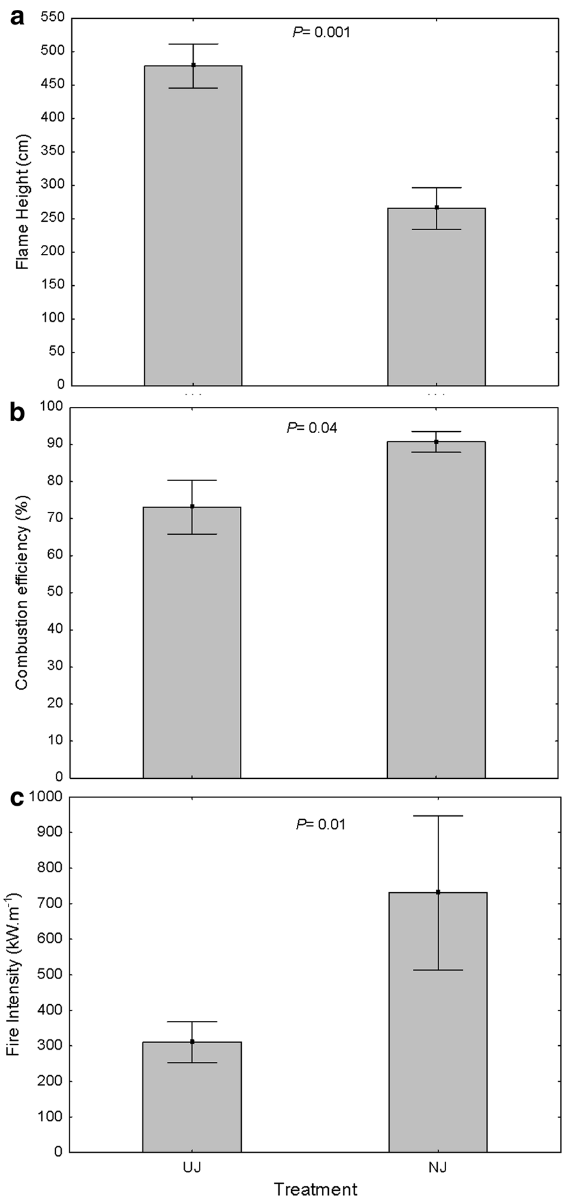

Fig. 1 Fire characteristics of experimental burnings in the invaded (UJ) and non-invaded plots (NJ, mean ± SD) at the Serra do Tombador Nature Reserve, Central Brazil: **a** Flame height (cm), **b** Combustion efficiency (%), **c** Fire Intensity (kW m^{-1})

Nevertheless, temperatures above 600 °C were more frequently reached under tussocks of *U. brizantha* than under native grasses, for both July and October fires. High temperatures can lead to high plant mortality rates, since plant tissues usually die at 60 °C (Bova and Dickinson 2005). Seed and bud mortality could also increase after being exposed to high

Table 2 Fire-behavior variables (mean ± SE) in invaded plots in July, dry season (UJ), and October, beginning of the rainy season (UO), at the Serra do Tombador Nature Reserve (RNST), Central Brazil

Fire parameters	UJ	UO
Flame height (cm)	478 ± 30	404 ± 51
Combustion efficiency (%)	73 ± 7	87 ± 5
Fire intensity (kW m^{-1})	310 ± 57	788 ± 196[a]
Frequency of temperature >600 °C (%) (under tussocks of *Urochloa brizantha*)	66 ± 4	80 ± 7
Frequency of temperature >600 °C (%) (under tussocks of native grasses)	40 ± 8	40 ± 13

[a] $P \leq 0.05$

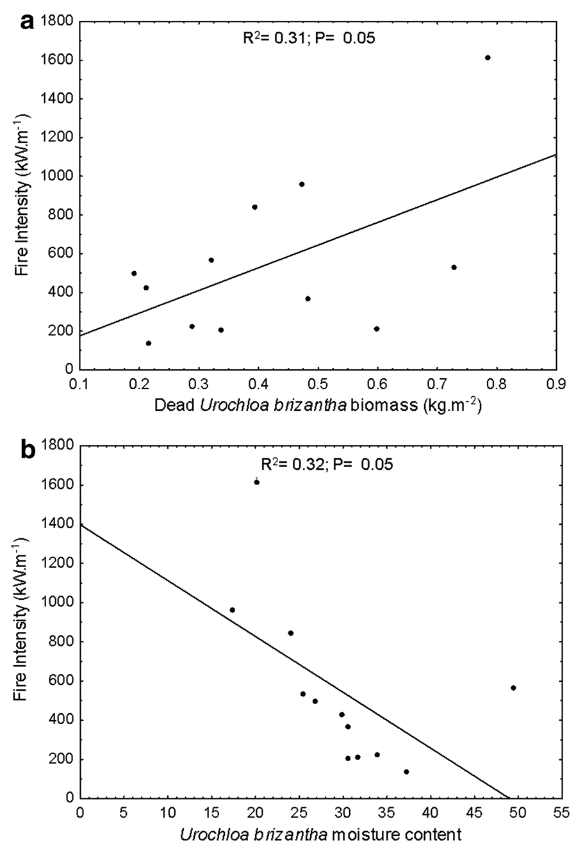

Fig. 2 Relationship between **a** fire intensity and dead biomass of *U. brizantha* (kg m^{-2}) in UJ + UO treatments, and **b** fire intensity and moisture content of *U. brizantha* (live + dead biomass, %) in UJ + UO treatments at the Serra do Tombador Nature Reserve, Central Brazil

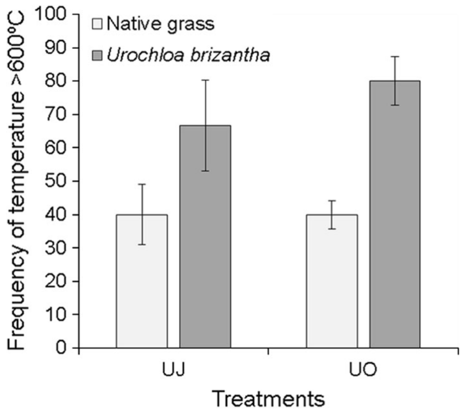

Fig. 3 Frequency of temperatures exceeding 600 °C under tussocks of native grasses and tussocks of *U. brizantha* both in July fires (UJ) and October fires (UO, mean ± SD) at the Serra do Tombador Nature Reserve, Central Brazil (mean ± SE)

temperatures, which would negatively affect the regeneration of native vegetation. As postulated by the "kill the neighbor" theory (Bond and Midgley 1995), more flammable individuals would have an advantage, since they would kill their neighbors and facilitate their own regeneration after fire. Our results suggest that at the individual plant level, *U. brizantha* can alter fire temperatures, killing their neighbors, and thus, creating more open space to regenerate and spread out after fire. High fire temperatures do not seem to affect the resprouting ability of *U. brizantha* (Gorgone-Barbosa, unpublished data), which could be related to its capacity to retain more moisture (compared to native grasses), resulting in a more efficient insulation of buds and protection of living tissues.

Cerrado fires are surface fires: they spread very fast, consume nearly all the herbaceous layer and rarely topkill the woody vegetation (Miranda et al. 1993). We showed in this study that *U. brizantha* doubled the height of flames; this may increase the mortality of shrubs and trees by topkill, favoring the dominance of the herbaceous layer, a typical feedback process of savanna environments (Kauffmann et al. 1994). In Cerrado, the presence of *U. brizantha* will probably lead to increasingly open physiognomies and to vegetation homogenization, and consequently, the diversity of physiognomies, habitats and species would decrease. The maintenance of the mosaic of phytophysiognomies that compose the Cerrado (grasslands, savanna-like vegetations and forest, Coutinho 1978) is essential to maintain its huge biodiversity. However, more studies are needed, not only in different physiognomies of Cerrado, but also evaluating shrub and tree survival after fires in the presence of *U. brizantha* in order to corroborate our hypothesis. In addition, higher flames can also increase the risk of fire nearby, since they could jump to neighboring areas more easily.

It is important to consider that the patterns we found and report here resulted from a moderate level of *U. brizantha* invasion. In our study area, the invasion of *U. brizantha* occurred in patches of different sizes interspersed in a matrix of native vegetation. In general, Cerrado nature reserves may have higher proportions of invasive grasses, such as *U. brizantha* and other *Urochloa* species, which create large and continuous invaded areas. Thus, in such areas, the effects of the invasive species on fire behavior might be intensified, leading to different results from the ones we found.

Fire behavior under different seasons

The fire season greatly influenced fire intensity, with more intense fires at the beginning of the rainy season (October fires). This can be mostly attributed to differences in fuel load. For the invaded sites, total fuel load was significantly higher in UO than in UJ, and dead biomass almost doubled between July and October, particularly for *U. brizantha*. Due to the lack of rain in the region from June to September, the aerial tissues of graminoids and forbs dry out (Filgueiras 1992) and, if fire does not occur, dead biomass accumulates from one season to the other, increasing the risk and intensity of fires in the following dry season. In Cerrado wet grasslands dead biomass can also accumulate during the rainy season and is attributed to low decomposition rates (Fidelis et al. 2013). The amount of live biomass of *U. brizantha* was also higher in UO than in UJ, while live biomass of native species hardly varied. These results indicate that *U. brizantha* resprouts and grows fast at the beginning of the rainy season, faster than native graminoids. This is an advantageous strategy in this ecosystem, since *U. brizantha* can rapidly use the nutrients available after the first spring rains and exclude other species that were not able to establish (by resprouting or germination) so quickly. However, more studies should be performed in order to quantify and test this hypothesis.

Implications for management

Fire properties such as intensity and rate of spread influence the post-fire distribution and abundance of plants in the community. In turn, the species composition is also an important factor affecting fire characteristics (Kauffmann et al. 1994). Invasive species alter the community species composition and may lead to changes in fire behavior that reinforces such changes in community composition. Thus, it is important to understand how these invasive grasses will change fire behavior in order to estimate fire risk and vegetation responses to fire.

Urochloa species are aggressive invasive species and a major concern regarding the conservation of Cerrado, being present in almost all protected areas of Cerrado (Pivello 2006). Our results showed that *U. brizantha* has a great potential to influence fire behavior–both at the community and the IPL and modify the post-fire plant community. This potential seems to be modulated by factors such as the abundance of the invasive grass and the stage of degradation (amount of bare ground) of the area. Thus, the effects of *U. brizantha* we found in this study can be intensified in places where invasion is more severe. Moreover, this invasive species could increase the risk of fire and alter the frequency of fires in Cerrado at the end of dry season, due to the prolonged production of biomass, extending into the beginning of the dry season, and to the high amount of dead biomass accumulated during this period. Therefore, further studies considering the effects of different levels of *U. brizantha* infestation on fire regime (frequency, season, intensity) are needed to fully understand the overall role of this species in relation to fire.

Regardless of the presence of the invasive species, decisions about fire management in Cerrado areas must consider fire season as an important factor. The large amount of biomass (especially dead biomass) that is available at the beginning of the rainy season led to more intense and hotter fires, which are harder to control and potentially more damaging for Cerrado ecosystems.

Acknowledgments We thank the Fundação Grupo Boticário de Proteção à Natureza (Termo de Parceria No 0106_2011_PR), Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES/DGU 227/2010), and the Ministry of Education (PHB2009-0073-PC) and of Science and Innovation (FEEDBACK Project; CGL2011-30515-C02-01) of the Spanish Goverment for financial support. We are grateful to Jonathan Galdi Rosa and Heloíza Lourenço Zirondi for their help during the fire experiments. We also thank the fire fighters from the Serra do Tombador Nature Reserve for their remarkable help during fieldwork and fire experiments. Finally we thank the editor and two anonymous reviewers for their contribution.

References

AER (2009) Elaboração do diagnóstico ambiental e zoneamento da Reserva, Natural Serra do Tombador, Calvalcante, GO

Almeida-Neto M, Prado PI, Kubota U et al (2010) Invasive grasses and native Asteraceae in the Brazilian Cerrado. Plant Ecol 209:109–122. doi:10.1007/s11258-010-9727-8

Bilbao B, Medina E (1996) Types of grassland fires and nitrogen volatilization in tropical savannas of Calabozo, Venezuela. In: Levine LS (ed) Biomass burn and global change. MIT Press, Cambrigde, pp 569–574

Bond WJ, Midgley JJ (1995) Kill thy neighbour : an Individualistic argument for the evolution of flammability for the evolution kill thy neighbour : an individualistic argument of flammability. Oikos 73:79–85

Bova AS, Dickinson MB (2005) Linking surface-fire behavior, stem heating, and tissue necrosis. Can J For Res 822:814–822. doi:10.1139/X05-004

Brooks ML, Antonio CMD, Richardson DM et al (2004) Effects of invasive alien plants on fire regimes. Bioscience 54:677–688

Castro EA, Kauffmann JB (1998) Ecosystem structure in the Brazilian Cerrado : a vegetation gradient of aboveground biomass, root mass and consumption by fire. J Trop Ecol 14:263–283

Coutinho Leopoldo M (1978) O conceito de cerrado. Rev Bras Botânica 1:17–23

Cronk QCB, Fuller JL (1995) Plant invaders: the threat to natural ecosystems. Chapman & Hall, London

D'Antonio CM (2000) Fire, plant invasions and global change. In: Mooney H, Hobbs R (eds) Invasive species in a changing world. Island Press, Washington, pp 65–94

D'Antonio C, Vitousek P (1992) Biological invasions by exotic grasses, the grass/fire cycle, and global change. Annu Rev Ecol Syst 23:63–87

D'Antonio CM, Hugles FR, Mack MC et al (1998) The response of native species to removal of invasive exotic grasses in a seasonally dry Hawaiian woodland. J Veg Sci 9:699–712. doi:10.2307/3237288

Durigan G, de Siqueira MF, Franco GADC (2007) Threats to the Cerrado remnants of the state of São Paulo, Brazil. Sci Agric 64:355–363. doi:10.1590/S0103-90162007000400006

Fidelis A, Lyra MFDS, Pivello VR (2013) Above- and below-ground biomass and carbon dynamics in Brazilian Cerrado wet grasslands. J Veg Sci 24:356–364. doi:10.1111/j.1654-1103.2012.01465.x

Filgueiras TS (1992) Gramíneas Forrageiras no Distrito Federal, Brasil. Pesqui Agropecuária Bras 27:1103–1111

Griffin GF, Friedel MH (1984) Effects of fire on central Australian rangelands. I. fire and fuel characteristics and changes in herbage and nutrients. Aust J Ecol 9:381–394

Hughes F, Vitousek PM (1993) Barriers to shrub reestablishment following fire in the seasonal submontane zone of Hawai'i. Oecologia 93:557–563. doi:10.1007/BF00328965

Kauffmann JB, Cummings DL, Ward DE (1994) Relationships of fire, biomass and nutrient dynamics along a vegetation gradient in the Brazilian Cerrado. J Ecol 82:519–531

Klinger RC (2011) Fire regime. In: Simberloff D, Rejmánek M (eds) Encyclopedia Biological Invasions. University of California Press, Berkeley, CA, pp 223–228

Klink CA (1994) Effects of clipping on size and tillering of native and African grasses of Brazilian savannas (the Cerrado). Oikos 70:365–376

Klink CA, Machado RB (2005) Conservation of the Brazilian Cerrado. Conserv Biol 19:707–713. doi:10.1111/j.1523-1739.2005.00702.x

Lannes LS, Bustamante MMC, Edwards PJ, Venterink HO (2012) Alien and endangered plants in the Brazilian Cerrado exhibit contrasting relationships with vegetation biomass and N: p stoichiometry. New Phytol 196:816–823. doi:10.1111/j.1469-8137.2012.04363.x

Mack MC, Antonio CMD (1998) Impacts of biological invasions on disturbance regimes. Trends Ecol Evol 13:195–198

Mack RN, Simberloff D, Lonsdale WM et al (2000) Biotic invasions: causes, epidemiology, global consequences, and control. Ecol Appl 10:689–710

Mcdonald CJ, Mcpherson GR (2013) Creating hotter fires in the Sonoran Desert: buffelgrass Produces copius fuels and high fire temperatures. Fire Ecol 9:26–39. doi:10.4996/fireecology.0902026

McGranahan DA, Engle DM, Fuhlendorf SD et al (2012) An invasive cool-season grass complicates prescribed fire management in a native warm-season grassland an invasive cool-season grass complicates prescribed fire management in a native warm-season grassland. Nat Areas J 32:208–214

McGranahan DA, Engle DM, Miller JR, Debinski DM (2013) An invasive grass increases live fuel proportion and reduces fire spread in a simulated grassland. Ecosystems 16:158–169. doi:10.1007/s10021-012-9605-4

Milles JW, Maass BL, Valle CB, Kumble V (1996) Brachiaria: biology, agronomy, and improvement. EMBRAPA/CNPGC (CIAT Publication no. 259), Cali

Miranda AC, Miranda HS, de Dias I FO, Dias BF S (1993) Soil and air temperatures during prescribed cerrado fires in Central Brazil. J Trop 9:313–320

Miranda HS, Bustamante MMC, Miranda AC (2002) The fire factor. In: Olivera P, Marquis R (eds) The Cerrados of Brazil. Ecology and Natural History of a Neotropical Savanna. Columbia University Press, New York, pp 51–68

Miranda HS, Sato MN, Neto WN, Aires FS (2009) Fire in the Cerrado, the Brazilian savanna. In: Cochrane MA (ed) Tropical fire ecology: climate change, land use, and ecosystem dynamics. Springer-Praxis, Heidelberg, pp 427–450

Mistry J, Berardi A (2005) Assessing fire potential in a Brazilian savanna nature reserve. Biotropica 37:439–451

Myers N, Mittermeier RA, Mittermeier CG et al (2000) Biodiversity hotspots for conservation priorities. Nature 403:853–858

Oliveras IA, Meirelles ST, Hirakuri VL et al (2013) Effects of fire regimes on herbaceous biomass and nutrient dynamics in the Brazilian savanna. Int J Wildl Fire 22:368–380

Pérez B, Moreno JM (1998) Methods for quantifying fire severity in shrubland-fires. Plant Ecol 139:91–101

Pillar V (2005) MULTIV: multivariate exploratory analysis, randomization testing and bootstrap resampling

Pimentel D, Lach L, Zuniga R, Morrison D (2000) Environmental and economic costs of nonindigenous species in the United States. Bioscience 50:53–55

Pivello V, Carvalho V, Lopes P (1999a) Abundance and distribution of native and alien grasses in a "Cerrado"(Brazilian savanna) biological reserve1. Biotropica 31:71–82

Pivello VR, Shida CN, Meirelles ST (1999b) Alien grasses in Brazilian savannas : a threat to the biodiversity. Biodivers Conserv 8:1281–1294

Pivello VR (2006) Manejo de fragmentos de cerrado: princípios para a conservação da biodiversidade. In: Scariot A, Sousa Silva JC, Felfili JM (eds) Cerrado: ecologia, biodiversidade e conservação. Ministério do Meio Ambiente, Brasília, pp 402–413

Pyšek P, Jarošík V, Hulme PE et al (2012) A global assessment of invasive plant impacts on resident species, communities and ecosystems: the interaction of impact measures, invading species' traits and environment. Glob Chang Biol 18:1725–1737. doi:10.1111/j.1365-2486.2011.02636.x

Rossiter NA, Setterfield SA, Douglas MM, Hutley LB (2003) Testing the grass-fire cycle: alien grass invasion in the tropical savannas of northern Australia. Divers Distrib 9:169–176. doi:10.1046/j.1472-4642.2003.00020.x

Setterfield S, Rossiter-Ranchor NA, Hutley LB et al (2010) Turning up the heat: the impacts of Andropogon gayanus (gamba grass) invasion on fire behaviour in northern Australian savannas. Divers Distrib 16:854–861. doi:10.1111/j.1472-4642.2010.00688.x

Simon MF, Grether R, de Queiroz LP et al (2009) Recent assembly of the Cerrado, a neotropical plant diversity hotspot, by in situ evolution of adaptations to fire. Proc Natl Acad Sci USA 106:20359–20364. doi:10.1073/pnas.0903410106

Statsoft Inc (2007) STATISTICA (data analysis software system), version 8.0. www.statsoft.com

Vilà M, Espinar JL, Hejda M et al (2011) Ecological impacts of invasive alien plants: a meta-analysis of their effects on species, communities and ecosystems. Ecol Lett 14:702–708. doi:10.1111/j.1461-0248.2011.01628.x

Whelan RJ (1995) The ecology of fire. Cambridge University Press, Cambridge