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Response of grass species to different fire frequencies in semi-arid rangelands of central Argentina

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This paper is dedicated to the memory of our dear friends Dr Roberto M. Bóo (1944–2007) who, as the leader of our research team, directed this project until his passing, and MS Mirta D. Mayor (1957–2008), an excellent professor and an endeared member of our team.

Abstract. The study was undertaken to quantify the effect of different controlled fire frequencies on foliar cover, density, individual basal area, and mortality of the most common perennial grass species in the semi-arid rangelands of the southern Caldenal in central Argentina over a 20-year period. Cover of bare soil was also assessed. The study comprised three fire treatments: (*i*) high fire frequency (controlled burns every 3–5 years; HFF); (*ii*) low fire frequency (controlled burns every 8 years; LFF); and (*iii*) unburned control (C). Fire treatments, regardless of frequency, induced an increase in foliar cover and density in desirable grasses, no changes in intermediate grasses, and a decrease in undesirable grasses. Individual basal area tended to be higher for desirable grasses and lower for intermediate and undesirable grasses when subject to fire. Most of the species under study exhibited higher mortality rates in the HFF treatment than in the LFF and C treatments. The results of the study suggest that recurrent controlled burns of moderate intensity may favour the herbage production of desirable perennial grasses. This, in turn, assuming appropriate grazing management, may have a beneficial impact on livestock production. Nevertheless, given the effects of fire on the cover of bare soil and mortality of grasses, further research is needed in order to determine the appropriate fire frequency in terms of rangeland sustainability.

Additional keywords: bare soil, controlled burning, fire frequency, herbage cover, perennial grasses.

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Introduction

Fire is considered to play a key role in maintaining grasslands. The frequency of fire may vary across rangelands but there is general agreement that recurring fires are required to control or reduce the establishment, density, and growth of woody plants (Van Auken 2009). In the semi-arid rangelands of the southern Caldenal in Argentina, wildfires are very common and a cause of concern during the hot and dry summer months (Bóo *et al*. 1996). The present-day fire frequency in the province of La Pampa, where most of the Caldenal is located, is about once every 10 years (Lell 1990). Bóo *et al*. (1997) have suggested that the reduction in the herbage mass of grasses due to long-term overgrazing by domestic livestock and the building of firebreaks has increased the fire-free period.

The southern Caldenal is considered dependent on fire, for without it, many species of perennial grasses accumulate old growth and shrub density increases (Bóo 1990). Therefore, some ranchers conduct controlled fires in late summer or early autumn with the aim of increasing the nutritive value of herbage and reducing the abundance of woody species (Peláez *et al*. 2012). Several studies have evaluated the effects of a single fire event on the native grass species (Cano *et al*. 1985; Busso *et al*. 1993; Bóo *et al*. 1996) and on the response of individual plants of some desirable and undesirable perennial grasses exposed to different fire temperature regimes (Peláez *et al*. 1997, 2001, 2003, 2009, 2010). However, information on the cumulative effects of recurrent fires on these species is lacking. The specific objective of this study was to assess the effect of different controlled fire frequencies on cover, density, and mortality of the most common perennial grass species in the Caldenal over a 20-year period as part of a research project that included the simultaneous evaluation of woody species in response to fire (Peláez *et al.* 2012).

Materials and methods

Study site

The study was conducted at a representative site of the Caldenal, situated in the south-eastern corner of the province of La Pampa in central Argentina (38°45′S, 63°45′W) (Fig. 1). A level, 12-ha site was located within a 600-ha pasture with no recent fire history, which had been fenced since 1989 to exclude livestock grazing (Fig. 1). The climate of the region is temperate and semi-arid (Instituto Nacional de Tecnología Agropecuaria 1980). Mean monthly air temperatures range from a low of 7°C in July to a high of 24°C in January, with an annual mean of 15°C. The annual mean temperature fluctuated throughout the study period between 14.6°C and 15.6°C, which translated into unusually cold (1992, 2000 and 2007) or hot (2006 and 2008) weather conditions (Servicio Meteorológico Nacional 2013). Mean annual rainfall is 400 mm, with peaks in March and October. Mean annual potential evapotranspiration is 800 mm. Annual precipitation during the study period averaged 408 mm and was characterised by a 12-year period of near- or above-average records followed by an 8-year period of near-average or markedly below-average precipitation (Instituto Nacional de Tecnología Agropecuaria 2013). Soils are coarse-textured Calciustolls (Sánchez and Lazzari 1999), with a petrocalcic horizon at 60–80 cm depth. The physiognomy of the vegetation is grassland with isolated woody plants (Distel and Bóo 1996). The herbaceous layer is dominated by perennial cool-season grasses (Distel and Peláez 1985).

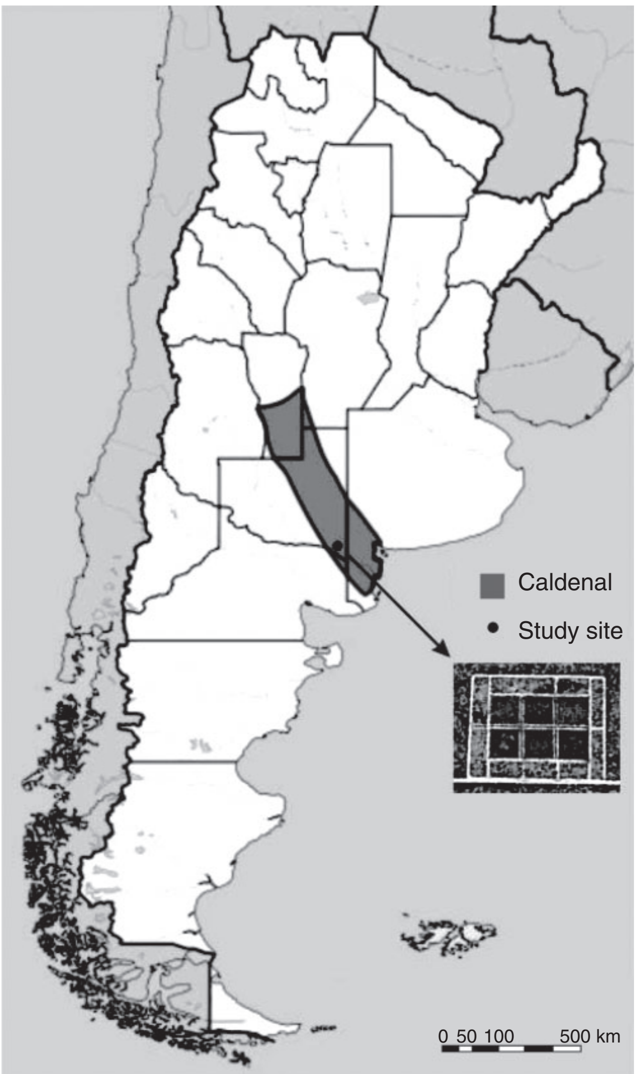

Fig. 1. Geographic location of the Caldenal and satellite image of experimental units.

Fire treatments

The study comprised three fire treatments replicated twice: (*i*) high fire frequency, controlled burns every 3–5 years (HFF); (*ii*) low fire frequency, controlled burns every 8 years (LFF); and (*iii*) unburned control (C). Treatments were randomly assigned to 1-ha experimental units enclosed within the 12-ha research area and were separated from each other by 20-m firebreaks. The HFF treatment experimental units were burnt in 1991, 1994, 1999, 2003 and 2007, and the LFF treatment experimental units were burnt in 1991, 1999, and 2007. Burns were conducted in accordance with a safe fire prescription guide (Wright and Bailey 1982).

Air temperature, relative humidity, and wind speed were measured with field instruments before and immediately after each burn. Mean values were 22–25°C, 32–43% and 12–20 km h^{-1}, respectively.

All burns were conducted as headfires, usually starting at 15:00–16 : 00 in autumn (March–June). Fine fuel loads ranged from 2500 to 4000 kg DM ha^{-1}, variation being due to accumulated rainfall in the growing season before burning. Fine fuel was considered as all material on the ground, including litter, <3 mm in diameter. Grass standing-biomass averaged a dry matter (DM) content of 690 g kg^{-1}.

Six thermocouples type K (chromel–alumel) connected to a 21 XL datalogger (Campbell Scientific, Logan, UT, USA) were used to record temperatures during the controlled burns at 1-s intervals. Thermocouples were randomly located in each experimental unit immediately above the soil surface within plant interspaces.

Vegetation sampling

Ten 20-m transects were randomly placed in each experimental unit at the beginning of the experiment and were used to estimate foliar cover and density of grass species at the end of each growing season (i.e. December) throughout the study period (i.e. from 1989 to 2008). An estimation of bare soil was also made. These data were collected with the canopy-cover method of Daubenmire (1959) and by counting the number of individuals whose base was more than half included in each of 20 quadrats (20 by 50 cm) along each transect. Grass species were classified according to their degree of preference by livestock as desirable, intermediate, and undesirable. Desirable grasses are highly preferred by cattle and are represented by *Piptochaetium napostaense* (Speg.) Hack., *Poa ligularis* Ness, *Nassella clarazii* (Ball) Bark., and *Nassella tenuis* (Phil.) Bark. Intermediate grasses are grazed by cattle in the absence of the former and are represented by *Poa lanuginosa* Poir., *Pappostipa speciosa* (Trin et Rupr.) Rom., *Jarava plumosa* (Spreng.), and *Nassella trichotoma* (Ness) Hack. Undesirable grasses include *Jarava ichu* (Ruiz et Pav.), *Amelichloa brachychaeta* (Godr.) Arriaga et Bark., *Nassella tenuissima* (Trin.) Bark., and *Melica argyrea* Hack. and increase in abundance under heavy and continuous grazing (Distel and Bóo 1996).

In addition, 40 plants of *P. napostaense*, *N. tenuis*, *N. clarazii*, *P. ligularis*, *P. speciosa*, and *J. ichu* were randomly selected in each experimental unit. At each sampling date, the individual basal area was estimated by measuring major and minor diameters of the base of each plant to estimate an elliptical surface area. Dead plants were also recorded to calculate mortality rate of each species.

Statistical analyses

Prior to statistical analysis, data corresponding to grass species cover, density, and individual basal area were subject to arcsine, square-root, and log transformations, respectively, to meet the assumptions of normality and homogeneity of variance (Snedecor and Cochran 1980). Data were analysed using residual maximum likelihood (REML) mixed models to properly account for temporal correlation and random effects attributed to replications (i.e. transect or plant) (Oehlert 2000; O'Neill 2010). The fixed model effects were fire frequency and year. The random model effect was replication within each fire treatment. The Tukey HSD test was used to separate means when significant differences ($P < 0.05$) were found. Mortality data based on the number of individuals were analysed using chi-square test (Snedecor and Cochran 1980). All statistical analyses were performed with JMP 7.0 (SAS Institute 2007).

Results

Visual inspection of experimental units immediately after the fire revealed evenness of burning across them (Fig. 2). Time–temperature curves obtained during the controlled burns were similar in shape. Time–temperature curves obtained during the last controlled burn (June 2007) in the HFF and LFF treatments have been reported elsewhere (Peláez *et al*. 2012).

Fire frequency, year, and their interaction were highly significant ($P < 0.01$) in each statistical analysis performed, the only exception being the individual basal area of *N. tenuis*, which did not show differences among fire treatments.

Foliar cover of desirable grasses in the HFF and LFF treatments was higher than in the C treatment throughout the study period, the only exception being the 1991 sampling date for both treatments and the 1999 and 2003 sampling dates for HFF treatment only (Fig. 3*a*). There were no significant differences between the HFF and LFF treatments at most of the sampling dates. The response of intermediate grasses was more erratic, being higher in the HFF treatment than in the C treatment only in the periods 2000–02 and 2004–06; otherwise, there were no significant differences among treatments (Fig. 3*a*). The foliar cover of undesirable grasses in the HFF and LFF treatments was consistently lower than in the C treatment throughout the study period, although significant differences were not always detected (Fig. 3*a*). Immediately after each controlled burn, the percentage of bare soil in the HFF and LFF treatments was higher than in the C treatment. Afterwards, the percentage of bare soil decreased at varying rates towards values close to those found in the C treatment until a new controlled fire was conducted (Fig. 4).

Density of desirable grasses in the LFF treatment was higher than in the C treatment at all sampling dates (Fig. 3*b*). The density in the LFF treatment also tended to be higher than in the HFF treatment; however, significant differences were not consistently found across sampling dates (Fig. 3*b*). A similar trend was observed between the HFF and C treatments (Fig. 3*b*). Throughout the study period, the density of intermediate grasses in the C treatment was slightly higher than in the LFF and HFF treatments, but no statistical differences were detected at most of the sampling dates (Fig. 3*b*). Immediately after the first controlled fire (April 1991) and throughout the study period, the density of undesirable grasses in the LFF and HFF treatments was consistently lower than in the C treatment (Fig. 3*b*); however, no significant differences were found between the LFF and HFF treatments (Fig. 3*b*).

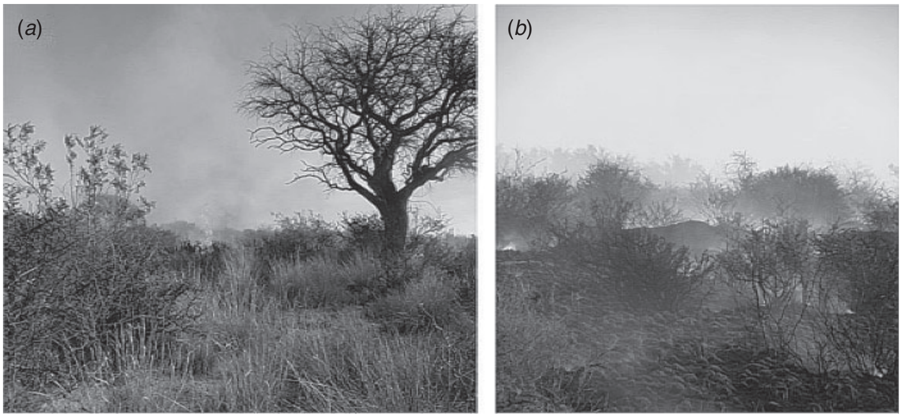

Fig. 2. Landscape view (*a*) at the onset of fire, and (*b*) immediately after burning.

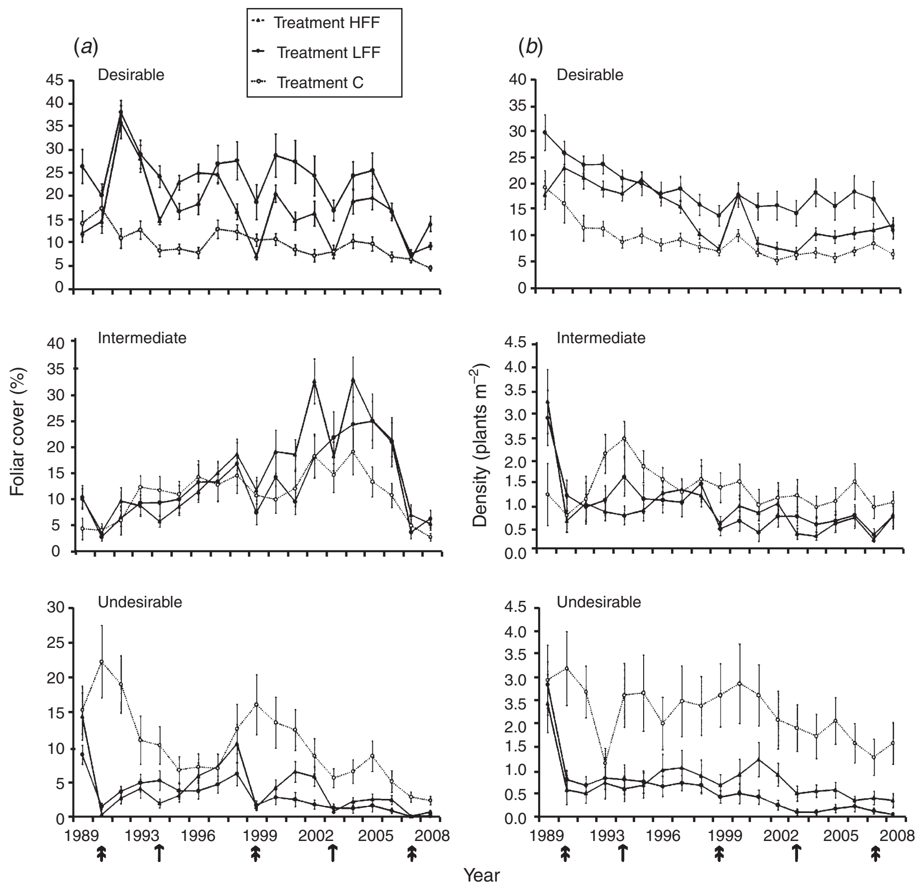

Fig. 3. (*a*) Grass species foliar cover and (*b*) density, in the high fire frequency (HFF), low fire frequency (LFF), and unburned control (C) treatments at the beginning of the study (December 1989) and yearly at the end of the growing season (Dec. 1991–Dec. 2008). Values are means of 20 replicates. Capped bars are ±1 standard error of mean. Simple arrow indicates burning of HFF plots only; double arrow indicates burning of both HFF and LFF plots.

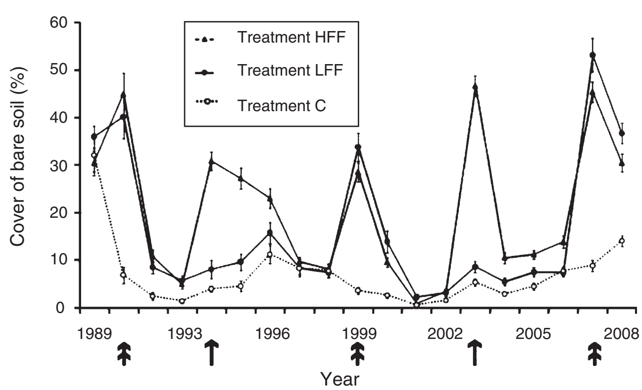

Fig. 4. Cover of bare soil in the high fire frequency (HFF), low fire frequency (LFF), and unburned control (C) treatments at the beginning of the study (December 1989) and yearly at the end of the growing season (Dec. 1991–Dec. 2008). Values are means of 20 replicates. Capped bars are ±1 standard error of mean. Simple arrow indicates burning of HFF plots only; double arrow indicates burning of both HFF and LFF plots.

Individual basal area (Fig. 5) was affected by fire treatment. The pattern of response for each species under study was as follows: (*i*) individual basal area of *P. napostaense* in the HFF treatment was higher than in LFF and C treatments in the periods between two consecutive burns except for the first post-fire growing season; (*ii*) individual basal area of *N. tenuis* showed no consistent differences among treatments throughout the study period; (*iii*) individual basal area of *P. ligularis* increased in response to fire but only after the second controlled burn had been conducted (i.e. 1994 for the HFF treatment and 1999 for the LFF treatment); (*iv*) individual basal area of *N. clarazii* in the HFF treatment was higher than in the C treatment at most of the sampling dates, whereas in the LFF treatment it was higher than in the C treatment only for a period of 2 years after the first post-fire season following each controlled burn; (*v*) individual basal area of *P. speciosa* showed no consistent differences among treatments except for a period of 2 years following the control burn of 1999 in which this parameter was severely reduced by fire; (*vi*) individual basal area of *J. ichu* followed the same pattern as *P. speciosa*.

Mortality rates of the grass species under study at the end of the study period were relatively low regardless of fire frequency treatment (Table 1). There were no significant differences among fire treatments in *P. napostaense* and *P. ligularis*. Mortality rates of *N. clarazii* and *N. tenuis* were higher in the HFF treatment than in the LFF and C treatments (Table 1). Similarly, the mortality rate of *P. speciosa* in the HFF treatment was higher than in the C treatment, but no significant differences were detected between the HFF and LFF treatments or between the LFF and C treatments (Table 1). Mortality rate of *J. ichu* was higher in the HFF treatment than in the LFF treatment, which was higher again than in the C treatment (Table 1).

Discussion

The shape of the time–temperature curves obtained during the controlled fires was similar to those reported by Wright *et al*. (1976) and Bóo *et al*. (1996). Regardless of variation in fine fuel loads, maximum soil surface temperatures reached during the burns (~400°C) were slightly higher than reported for other fires with similar fine fuel loads, which, for grassland headfires with fine fuel loads between 1685 and 7865 kg ha^{-1}, normally range from 102 to 388°C (Wright and Bailey 1982). The higher soil surface temperatures recorded in this study are probably associated with local heavy fuel accumulation and/or intense winds created by the fire itself.

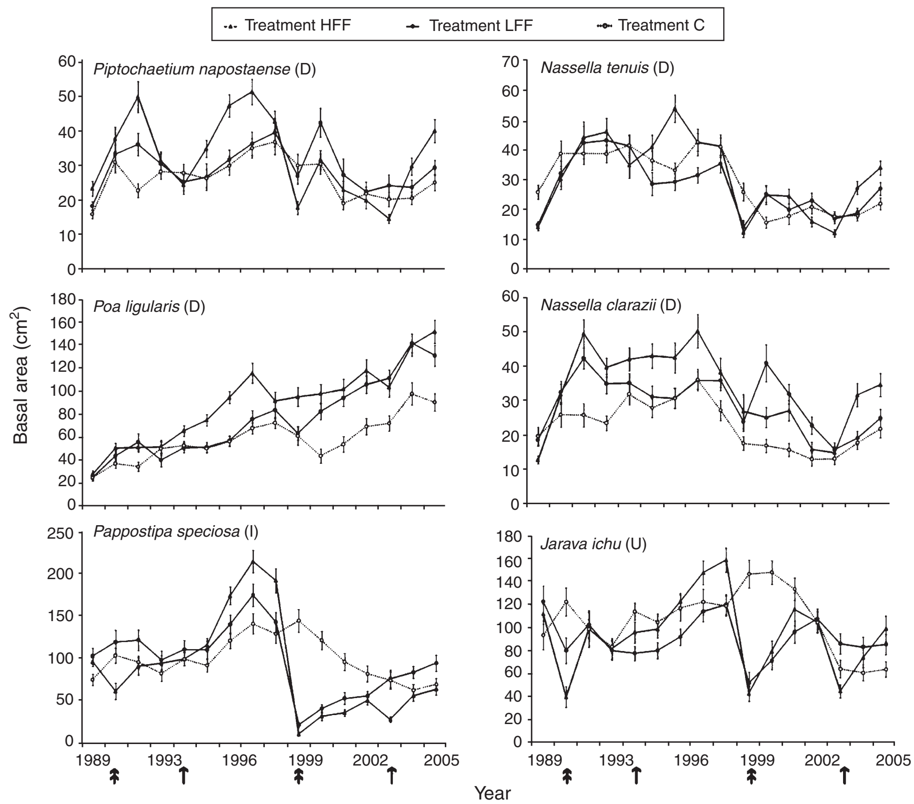

Fig. 5. Individual basal area of desirable (D), intermediate (I), and undesirable (U) grass species in the high fire frequency (HFF), low fire frequency (LFF), and unburned control (C) treatments at the beginning of the study (December 1989) and yearly at the end of the growing season (Dec. 1991–Dec. 2005). Values are means of 80 replicates. Capped bars are ±1 standard error of mean. Simple arrow indicates burning of HFF plots only; double arrow indicates burning of both HFF and LFF plots.

Table 1. Mortality rates (%) of perennial grasses in the high fire frequency (HFF), low fire frequency (LFF), and unburned control (C) treatments at the end of the study period (December 2008)

Within each column, values followed by the same latter are not significantly different ($P > 0.05$)

Treatment	*Piptochaetium napostaense*	*Nassella tenuis*	*Nassella clarazii*	*Poa ligularis*	*Pappostipa speciosa*	*Jarava ichu*
HFF	22.04a	22.68a	11.30a	4.33a	7.92a	9.02a
LFF	23.61a	16.83b	8.40b	5.32a	6.37ab	5.65b
C	21.06a	14.61b	8.65b	5.33a	4.73b	2.13c

Foliar cover of desirable grass species was higher when subject to controlled burns, regardless of frequency, than when deprived of fire (Fig. 3*a*). This may partially explain the rapid recovery of the soil cover between two consecutive burns (Fig. 4). Several variables of the most common woody species in this region, namely *Chuquiraga erinacea*, *Condalia microphylla*, *Larrea divaricata*, *Prosopis caldenia*, and *Prosopis flexuosa*, were evaluated at the same research site as that of the present study from 1990 until 2009. Controlled burns, irrespective of frequency, reduced the percentage cover and the individual height and canopy area of these species (Peláez *et al*. 2012). Reduced competition from woody species for light, water, and/or nutrients after controlled fires might help explain the increase in cover of desirable grass species. Controlled burning of rangelands generally (*i*) reduces consumption of water by woody species, (*ii*) releases plant nutrients in the soil for plant use, (*iii*) reduces temporarily the amount of vegetation that intercepts precipitation from light rains, and (*iv*) reduces the shrub and tree cover (Vallentine 1989). Cable (1967), after a 15-year burning study, concluded that fire had no lasting effects, beneficial or detrimental, on perennial grass cover. Generally, the detrimental effects of fire on most of the perennial grasses lasted only 1–2 years. The results of the present study are in agreement with those obtained by Bóo *et al*. (1996), who reported that *P. napostaense*, *N. clarazii*, and *N. tenuis* showed a sustained increase in foliar cover for two consecutive growing seasons after exposure to different fire intensities. Those authors suggested that the combined effect of fire tolerance, reduced competition, and rest from grazing might have accounted for this response. Furthermore, research conducted at a representative site of the Monte Phytogeographical Province, Argentina (Cabrera 1976) has shown that a fire-induced reduction in the cover of woody species favoured an increase in the canopy area of desirable perennial grasses (Peláez *et al*. 2010).

The foliar cover of intermediate grasses was similar among treatments from the beginning of the experiment until the sampling date in 2000, and the sampling dates in 2007 and 2008. Although differences were not always significant, intermediate grass cover tended to be higher in either of the fire treatments than in the control treatment from 2001 until the sampling date in 2006 (Fig. 3*a*). The first time-frame coincided with a 12-year period of near- or above-average annual rainfall. The 2001–05 period was characterised by near- or slightly below-average annual rainfall and served as a prelude of the severe drought registered in 2006–08 (Instituto Nacional de Tecnología Agropecuaria 2013). These results suggest that fire may favour an increase in the foliar cover of intermediate grasses given near- or slightly below-average annual rainfall but would have no effect under wet or extremely dry conditions. These results seem to be in contrast with findings of Augustine *et al*. (2010), who suggested that periodic fires in semi-arid grasslands of the western Great Plains (USA) would suppress production in dry years and have neutral or positive effects in wet years, potentially mediated by the effect of litter removal on soil moisture limitations in dry *v.* wet years. Nevertheless, these results are in partial agreement with those reported by Bóo *et al.* (1996), who found that foliar cover of *P. speciosa* at the end of the first growing season after exposure to different fire intensities had been significantly reduced, although only 1 year later, the original cover value tended to be re-established. On the other hand, the foliar cover of intermediate perennial grasses of the Monte Phytogeographical Province (*Aristida pallens*, *A. trachyanta*, *A. spegazzinii*, and *J. ichu*) was notably lower in a controlled-burn treatment than in an unburned control treatment, suggesting that intermediate grasses would be less tolerant to fire or the combined effects of fire, drought, and grazing (Peláez *et al*. 2010).

Foliar cover of undesirable grasses tended to be lower in the fire treatments than in the unburned control despite some recovery after each controlled burn (Fig. 3*a*). These results reinforce those obtained by Bóo *et al*. (1996), who found that the foliar cover of *J. ichu* was significantly reduced by different fire regimes, i.e. an accidental fire and two controlled burns. However, the original cover value tended to be re-established at the end of the second post-fire growing season. Furthermore, the results of the present study are in agreement with those of Peláez *et al*. (2003), who found that the average total green length of tillers of *J. ichu* individually burned plants was severely reduced by fire. This effect lasted until the end of the first post-fire growing season and it was more pronounced in high-temperature treatments.

Cover of bare soil (Fig. 4) was influenced by removal of heavy grazing at the onset of the experiment, fire, and rainfall after burning as follows: removal of heavy grazing in 1989 explains the sharp drop in the cover of bare soil in all treatments right after the beginning of the experiment; fire causes a sharp increase in the cover of bare soil on all occasions; and the cover of bare soil tended to be higher (i.e. 2003 and 2007 sampling dates) and/or to decline at a slower rate when rainfall was below average (i.e. 1994 and 2007 sampling dates).

Overall, density data showed an increase in desirable grasses, no statistical differences in intermediate grasses, and a decrease in undesirable grasses in fire treatments *v.* the unburned control treatment (Fig. 3*b*). Density records changed across sampling dates as a consequence of the counterbalance between mortality and seedling establishment. In the absence of grazing, seedling establishment is largely determined by the amount of seed present, the conditions required to induce the germination, and the occurrence of proper environmental conditions for initial seedling growth. The interaction between the seed and its environment determines whether it successfully germinates and establishes. The requirements for successful germination and establishment can differ significantly among species (Whelan 1995; Miller 2000). Wright and Bailey (1982) found that the density of *Aristida glabrata* increased by 34% over the control during the first growing season after burning, a dry year. Nevertheless, after the third growing season, a wet year, the density of *A. glabrata* had increased by 350%. The results of the present study are in partial agreement with previous research in which *N. clarazii* and *J. ichu* decreased while *N. tenuis* increased in density after a controlled fire conducted in autumn; on the other hand, *P. speciosa* decreased in density after a summer wildfire (Bóo *et al*. 1996).

Although not conclusive, the results of the present study suggest that fire has a beneficial effect on the individual basal area of desirable grasses in spite of differences among species and the lack of response of *N. tenuis* (Fig. 5). The latter is in agreement with previous research in which tiller count and tiller dry weight of individuals of *N. tenuis* surviving fire were similar to those of unburned plants as has been reported by Busso *et al*. (1993). On the other hand, fire seemed to have a detrimental effect on the individual basal area of the intermediate and undesirable grass species selected for this study as can be inferred by the drop in basal area of *P. speciosa* and *J. ichu* after the controlled burn in 1999 (Fig. 5). These results are in agreement with those reported by Bóo *et al*. (1996), who, studying the same group of species, found that basal area at the end of the second post-fire growing season had increased in desirable species but did not show significant changes in intermediate and undesirable grass species. Differences in individual basal area response to fire could be partially attributed to species-specific tillering dynamics (Dalgleish and Hartnett 2009). Unfortunately, tiller demography of the species under study has been a neglected research subject and deeper conclusions on this matter cannot be drawn.

At the end of the study, after five controlled burns in the HFF treatment and three controlled burns in the LFF treatment, mortality rates of all grass species were low (Table 1). Within the group of desirable grass species, *N. tenuis* and *N. clarazii* showed an increase in mortality rates when subject to the HFF treatment; otherwise no significant differences were found (Table 1). On the other hand, despite lower values, mortality rates of *P. speciosa* and *J. ichu* increased progressively with fire frequency (Table 1). These results are in agreement with those obtained by Peláez *et al*. (2001), who found higher mortality rates from burning for individual plants of *P. napostaense* and *N. tenuis* than for *J. ichu*. By contrast, Bóo *et al*. (1996) reported mortality rates similar to those of the present study for *P. napostaense* (22.5%) and *N. tenuis* (20.0%) after a controlled fire conducted in autumn (March), but higher mortality rates for *N. clarazii* (27.5%), *P. ligularis* (17.5%), *P. speciosa* (22.5%), and *J. ichu* (37.5%). Moreover, the results of the present study are in contrast to those of Bóo *et al*. (1996), who reported that, after a summer wildfire in a site with a long history of heavy grazing, the mortality rates of the desirable group of species were lower than those of *P. speciosa* and *J. ichu*, ~56% and ~86%, respectively. These latter species are not readily consumed by cattle and accumulate abundant old growth near the growing points (i.e. axillary buds). Consequently, higher temperatures during burning and longer burning periods are to be expected (Bóo *et al*. 1996; Peláez *et al*. 1997); these factors, in turn, may be responsible of their higher mortality rates. As stated by Wright and Bailey (1982), vascular plant tissue is easily killed by heat, and can be killed throughout a wide range of temperatures if any given temperature is maintained for the appropriate length of time. Peláez *et al*. (2001) reported similar thermal death points (~65°C) for *P. napostaense*, *N. tenuis*, and *J. ichu*. Nevertheless, mortality rates of *P. napostaense* and *N. tenuis* could rise from 10% to 55% and from 5% to 85%, respectively, if burning was immediately followed by drought, whereas *J. ichu* showed no significant increase in mortality rate when subject to water stress after burning. Therefore, differences in mortality rates among species should be attributed to species-specific anatomical characteristics, history of grazing, metabolic activity at the time of burning, and susceptibility to post-fire environmental conditions (Whelan 1995; Dalgleish and Hartnett 2009).

Selective grazing by domestic livestock is the dominant mechanism in the process of species replacement and change in species composition in rangelands throughout the world (Anderson and Briske 1995). In the semi-arid rangelands of the southern Caldenal, changes in species composition induced by grazing include the replacement of desirable grasses by intermediate and undesirable grasses (Gallego *et al*. 2004). Overall, the results of the present study suggest that recurrent controlled burns would maintain generally increased levels of foliar cover, density, and individual basal area of desirable grass species, while the opposite would apply for intermediate and undesirable grass species. This, in turn, would allow a shift in the successional tendency imposed by continuous grazing by domestic livestock. Nevertheless, it remains to be elucidated which fire frequency is more advisable not only in terms of rangeland management perspectives and sustainability but in terms of economic feasibility of controlling grazing pressure before and after fire in order to achieve successful burning and re-growth of grasses against the short-term use of herbage of grasses for livestock production. As has been previously reported, controlled burns every 3–5 years would have a more detrimental effect on woody species cover, height, and canopy area than controlled burns every 8 years (Peláez *et al*. 2012). Research conducted at a representative site of the Monte Phytogeographical Province, Argentina (Cabrera 1976), has shown that a fire-induced reduction in the cover of woody species favoured an increase in the canopy area of desirable perennial grasses (Peláez *et al*. 2010) and in average cow and calf weaning weights (Giorgetti *et al*. 2009). However, controlled burns every 3–5 years were associated with higher mortality rates of desirable grass species and higher percentages of bare soil, which could trigger erosion processes. Consequently, although these data provide a greater insight into the response of semi-arid rangelands of the Caldenal to controlled burns, further research is needed in order to prescribe sound management guidelines.

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