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Response of hardwood tree regeneration to surface fires, western Chaco region, Argentina

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ABSTRACT

We assessed the response of seedlings and pole-sized individuals of *Aspidosperma quebracho-blanco* Schlecht., *Schinopsis lorentzii* (Griseb.) Engler and *Ziziphus mistol* Griseb. to surface fires. We assessed traits of fire resistance (bark thickness and bark density) and fire tolerance (mortality and sprouting type, basal or epicormic) in each species. Burns were carried out using two fine fuel loads (high, 8000 kg ha^{-1}; and low 4000 kg ha^{-1}, respectively) and two dates of fire application (early and late fire season). Field work was performed during 2008 and 2009. Using a randomized design, 120 2 m × 2 m plots were burnt each year. Using ANOVA, we tested the effect of species, fuel load and date of fire on the bark char height of the bole. The resprouting pattern (basal or epicormic) and post-fire mortality (complete or top-kill) were analysed using a logistic regression approach. There were a significant effect of species ($p < 0.0001$), fuel load ($p < 0.0001$) and of the interaction year of burning *date of fire ($p < 0.0001$) on the mean char height. *A. quebracho-blanco* had greater char height than *S. lorentzii* and *Z. mistol* ($p < 0.05$), but differences between the latter two species were no significant. Diameter to breast height (DBH) was significant and positively correlated to char height for *A. quebracho-blanco* and *Z. mistol*. High fuel load produced higher char height than the low fuel load fires. *A. quebracho-blanco* had the greatest total, inner and outer bark thickness, and the lowest bark density among the studied species. It was followed by *S. lorentzii*, while *Z. mistol* had the lowest total bark thickness, the highest inner bark proportion and the highest bark density ($p < 0.05$). The likelihood of complete mortality was significantly larger in *Z. mistol* than in A. *quebracho-blanco and S. lorentzii.* Mortality and top-kill were lower in the late season burns ($p < 0.05$). Sprouting type was significantly affected by species ($p < 0.05$), DBH, date of fire and by the interactions species × DBH and season of fire × DBH ($p < 0.0001$). *A. quebracho-blanco* presented only basal resprouts, while the other two species showed both epicormic and basal resprouts. The two species with greater bark thickness had lower mortality than *Z. mistol*. Epicormic resprouts were not observed at the more severe late burns. The three species studied showed high resistance and tolerance to medium to high severity fires.

1. Introduction

The native vegetation of the Chaco region of Argentina is composed by forests, woodlands, savannas and shrublands (Morello and Adámoli, 1974; Bucher, 1982). Fire is a main ecological disturbance in the region and it is widely used as a tool for vegetation management (Morello and Saravia Toledo, 1959; Bravo et al., 2001a; Tálamo and Caziani, 2003). The most common fires in the Chaco are surface fires occurring in the savannas of *Elionurus muticus* (Spreng) Kuntze, a grass species whose foliage is terpene-rich, making it highly flammable. In some extreme weather circumstances, savanna fires may propagate to the surrounding hardwood forests, dominated by trees of the genera *Schinopsis*, *Aspidosperma*, *Prosopis* and *Ziziphus*, in the form of crown fires, creating grasslands of *Trichloris crinita* Lag. Parodi, *T. pluriflora* E. Fourn, and *Setaria* sp. (Morello and Saravia Toledo, 1959; Bravo et al., 2001a).

In recent decades, fire recurrence in the Chaco region has increased, promoted by deep modifications in land use and climate change, affecting both fuel availability and ignition probabilities (Tálamo and Caziani, 2003; Boletta et al., 2006; Grau et al., 2005; Bravo et al., 2010). Secondary forests and brush thickets, created by timber operations exceeding regeneration rates, livestock

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overgrazing and misuse of fire are converted in grazing paddocks through roller-chopping and seeding of tropical grass species belonging to the genus *Panicum*, such as *P. maximum* cv Gatton (Kunst et al., 2014). These exotic grass species have different plant structure and potential to generate heavier fine fuel loads than native grass species, thus modifying the intensity and severity of surface fires (McDonald and McPherson, 2011). These facts convert the South American Chaco region, encompassing Argentina, Paraguay and Bolivia into one of the most threatened world ecosystems because of the conversion of native vegetation to pastures is economically more profitable (Kennard and Putz, 2005).

Currently, there is a major concern in the world as well as in the Chaco about the need to conserve the structure and dynamics of forest ecosystems due to the valuable products and services that they provide for the global and local communities (Krieger, 2001). On the other hand, fire is a natural disturbance that structures the plant communities of the Chaco region (Morello and Saravia Toledo, 1959) and prescribed fire could be a useful tool to manage the balance between woody and grass species in livestock operations (Kunst et al., 2000). Because of these issues, there is a need for more precise knowledge about the response to fire of native hardwood tree species of the Chaco region.

Available information on the native tree species of the Chaco region suggests a high resistance to fire of mature individuals because of their thick bark and high crown height (Giménez et al., 1998; Tálamo and Caziani, 2003; Bravo et al., 2001a,b, 2008). These features avoid direct contact of the flames of the surface fires with the cambium tissue and the buds located in the stem and crown, thus giving fire resistance to the trees (Pausas, 1998; Gignoux et al., 1997; García Núñez and Azocar, 2004). The ability of resprouting after a fire is considered to be the main trait responsible of fire tolerance, allowing fire sensitive species to restore their aerial structure following fires (Catry et al., 2009; Clark et al., 2012).

Tree regeneration is critical for sustainable forest management (Van Mantgem and Schwartz, 2003; Esquivel et al., 2008). However, specific data about fire resistance of saplings and poles of native hardwood tree species from the Chaco region are scarce. The objectives of this research were to assess the response to surface fires of saplings and poles of three native hardwood species from the Chaco region: *Aspidosperma quebracho-blanco* Schlecht. *Apocynaceae*; *Schinopsis lorentzii* (Griseb.) Engler, *Anacardiaceae* and *Ziziphus mistol* Griseb, Rhamnaceae.

The following hypothesis were examined: (a) the response to fire severity of saplings and poles of hardwood trees vary among species, according to fire behavior and to specific traits of fire resistance such as bark thickness and density; and (b) bark features would influence fire tolerance due to the protection given to axillary buds. Therefore, species with thick bark would predominantly produce epicormic sprouts after fires, while species with thin bark would recover mainly by basal sprouts due to the high susceptibility of the aerial structure to fire damage. These hypotheses were derived from a literature review suggesting that: (i) native woody species of the Argentine Chaco region present high fire resistance (Bravo et al., 2001a,b, 2008; Tálamo and Caziani, 2003); and (ii) thickness and density of bark affect the fire tolerance of woody species because of thick barks more effectively protect the cambium and the meristematic tissues responsible of resprouting after fires (Henst and Dawson, 1994; Van Mantgem and Schwartz, 2003; Montenegro et al., 2004; Clark et al., 2012).

Studies about specific traits and their influence on the response of native hardwood tree species to fire could contribute to improve environmental decisions related to restoration of burned areas of the Chaco region, and to adjust prescribed fire protocols applied on pastures adjacent to forest areas with the goal of enhancing forest conservation.

2. Materials and methods

Research was conducted at the 'La María' Experimental Ranch, Instituto Nacional de Tecnología Agropecuaria Santiago del Estero, Santiago del Estero, Argentina (28°03′S 64°15′E). Climate is semiarid, with 574 mm of annual average rainfall (1934–2000 series, INTA Santiago del Estero Experimental Station, 2010). Winters are cold and dry, and summers hot and rainy (Boletta et al., 2006). Mean annual temperature is 19.8 °C, and the mean of the warmest (January) and coldest (July) months are 26.1 °C and 10.6 °C, respectively. Freezing temperatures can occur from May to October, reaching extreme temperatures of −10 and −12 °C (Torres Bruchmann, 1981).

Soils belong to the order Entisols, suborder Eutric Regosol (Lorenz, 1995). In the Chaco, the fire season extends from April to October in coincidence with the dry and cold weather season. During this season, the moisture content of the soil and native vegetation usually decreases generating changes in fuel conditions and ignition probability (Bravo et al., 2001b). Rainfall reported here corresponds to the amount recorded during the active growth season of plants before each experiment, October to April. Rainfall data were obtained from the Experimental Ranch INTA meteorological station.

The hardwood tree species selected for this study are dominant in the dry forests of the western Chaco region (Araujo et al., 2008; Tortorelli, 2009). *S. lorentzii* is a deciduous species that may reach a height around 20–30 m, with an average life span of 250 years (Giménez and Ríos, 1999). *A. quebracho-blanco* is a perennial species, with a height around 25–30 m and an average life span of 200 years (Moglia, 2000). *Z. mistol* is a deciduous species that could reach a height of 4–10 m. The three species have a high-density wood, ranging from 0.85 to 1.16 kg dm^{-3} (Tortorelli, 2009) and different bark thickness at their mature state (Bravo et al., 2008). Previous reports indicate that individuals with a diameter at breast height (DBH) smaller than 15 cm correspond to juvenile individuals, according to the growth curves of the species (Giménez and Ríos, 1999; Juárez de Galíndez et al., 2006).

To assess plant responses to fire we used two different approaches: (a) we characterized bark features of the selected species in the lab; and (b) we conducted fieldwork for testing the response to surface fires. The first approach gave us information about specific traits directly related to fire resistance, such as bark thickness and density and allow a better understanding and interpretation of field results. In the second approach, by manipulating fuel loads and timing of fire, we overcame limitations of research based on observations conducted after wildfires, in which intensity, rate of spread, severity and other descriptors of fire behavior that help to characterize and classify a fire event are usually unknown. This approach, by permitting changes in fire intensity and severity, is a useful tool to associate the descriptor of the disturbance to the response of plant species (Vega et al., 2000; Drewa, 2003; Quevedo Dalmau et al., 2007; Brando et al., 2012). Parameters of a disturbance, such as intensity and severity, can be used to predict possible outcomes and facilitate the transfer of knowledge (Norkko et al., 2006; Buhk et al., 2007).

2.1. Estimating bark traits

Bark description was performed using 10–14 individuals of each species (DBH $\leqslant$ 15 cm), randomly selected in a dry forest of the Experimental Ranch, near the fire testing area. The DBH of each tree was recorded, and cross sections (approximate average thickness 5 cm) of the bole were extracted with a chainsaw at the following heights from the ground: (1) 0.30 m; (2) 1.3 m and (3) 2.3 m. The diameter (cm) of each cross section was measured,