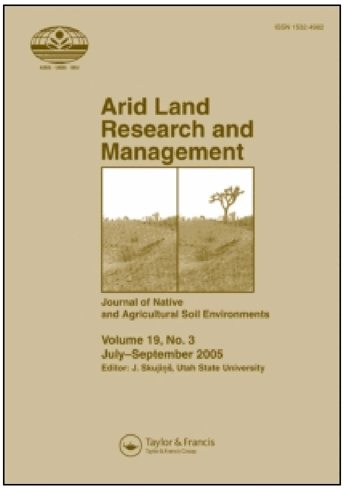

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A. R. von Müller [ab]; R. O. Coirini [b];U. O. Karlin [b]
[a] Instituto Multidisciplinario de Biología Vegetal. Consejo Nacional de Investigaciones Científicas y Técnicas - Universidad Nacional de Córdoba, Córdoba, Argentina [b] Facultad de Ciencias Agropecuarias. Universidad Nacional de Córdoba, Córdoba, Argentina

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Woodland Degradation Effects on Brea Gum (*Parkinsonia praecox*) Production

A. R. von Müller[1,2], R. O. Coirini[2], and U. O. Karlin[2]

[1]Instituto Multidisciplinario de Biología Vegetal. Consejo Nacional de Investigaciones Científicas y Técnicas – Universidad Nacional de Córdoba, Córdoba, Argentina
[2]Facultad de Ciencias Agropecuarias. Universidad Nacional de Córdoba, Córdoba, Argentina

*A comparative study of the effects of woodland degradation on "brea" (*Parkinsonia praecox*) gum production was conducted in the Arid Chaco, Argentina, over a two-year period. We also analyzed the relationship of brea gum yield per tree with rainfall, tree size, soil water content, and other surrounding tree species. The results showed that the woodland degradation state has a strong effect on brea gum yield per tree, with the secondary woodland specimens being the most gum-productive during the dry seasons ($p < 0.0001$). However, during wet years, we found that the woodland degradation state did not affect gum yield ($p = 0.5615$). We found no significant differences in brea gum productivity per hectare between secondary woodland and degraded woodland colonized by* Parkinsonia praecox *($p > 0.05$). In both brea gum production per tree and hectare models, we found a significant covariation with the number of surrounding* Prosopis *spp. trees ($p < 0.0001$), an indicator of good state woodland, which can improve soil water content and thereby enhance brea gum production. Moreover, the number of surrounding* Prosopis *spp. trees was the variable that best predicted brea gum yield in a replicated regression model ($R^2 = 0.41$). The results of this study present the basis for a sustainable brea gum production in the Arid Chaco of Argentina.*

Keywords non-wood forest product, *Parkinsonia praecox*, *Prosopis* spp., plant gum, surrounding trees, woodland degradation

The Arid Chaco is the driest phytogeographic sub-region of the Gran Chaco Americano, extending over an area of approximately 9 million ha. During the last decade, the Chaco has been seriously threatened by the loss of woodlands due to agricultural and grassland expansion (Grau et al., 2005; Boletta et al., 2006). This

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Address correspondence to A. R. von Müller, Instituto Multidisciplinario de Biología Vegetal. Consejo Nacional de Investigaciones Científicas y Técnicas – Universidad Nacional de Córdoba. CC 495, 5000 Córdoba, Argentina. E-mail: axelvm@gmail.com

loss generally exceeds global trends, and forest vegetation is now being reduced to fragments in different states of degradation (Cabido et al., 1992), where previously a continuous cover existed (Zak et al., 2004). In this context, agricultural practices involving the maintenance of native vegetation such as agroforestry managed systems with fodder or non-wood forestry products (NWFP) complemented by livestock production (Catalán et al., 1994), result in a more sustainable agroecosystem (Izac & Sánchez, 2001) and mitigate incipient rural emigrations (Aide & Grau, 2004).

Parkinsonia praecox (Ruiz & Pav.) Hawkins (=*Cercidium praecox* (R. & P.) Harms), is a native tree species of Argentine arid areas that produces a phloematic exudate called "brea gum" (Hawkins et al., 1999; Vilela et al., 2009). Trunks and branches of wounded plants exudate gum from bark up to the *cambium,* which is commonly used as woodland candy (von Müller et al., 2009). The gum has structural and chemical similarities with additives widely used in the food industry, such as arabic gum (Cerezo et al., 1968; León de Pinto et al., 1993). This feature allows its future incorporation as a new native NWFP, thereby contributing to small farmer's income diversification (Garriga & Haas, 1997; Alesso et al., 2003; von Müller et al., 2007). Nevertheless, there are no studies that assess the effects of woodland degradation on brea gum production and the possibility of sustainable management.

Parkinsonia praecox is widespread in woodlands, and is recognized for its ability to facilitate forest restoration by colonizing degraded areas and nursing grasses and trees (Barchuk & Díaz, 1999). This species shows high variability in gum production among trees (Alesso et al., 2003) and has a positive response to tapping intensity (Losano, 1995). Summer is the period of greater exudation, after the fruit maturation and drop (Garriga & Haas, 1997), which also coincides with the time of maximum temperatures and precipitation, as it occurs in other gum productive species of *Prosopis* L. genus (Vilela & Ravetta, 2005).

Woodland degradation has a direct impact on the microclimatic conditions, affecting soil moisture, packing and infiltration rate (Asner et al., 2003; Abril et al., 2005) with different intensity, over the degradation gradient (Rossi & Villagra, 2003). Nevertheless, the impact of environmental changes on arabic gum production was not included as determining factor of yield by Ballal et al. (2005a,b). Other studies report an increase of gum yield with greater soil moisture to ending of rainfall season previous to harvest (Gaafar et al., 2006), and a positive correlation between the soil water content and the arabic gum yield per tree (Raddad & Luukkanen, 2006).

We hypothesize that microclimatic conditions of woodlands will change over a gradient of degradation, thus affecting the brea gum production. The aim of the present study was to determine the effect of woodland degradation on brea gum (*Parkinsonia praecox*) production in the Argentine Arid Chaco and to provide the outlines for a sustainable brea gum production.

Materials and Methods

Study Area

The study was carried out at the community of Chancaní in the Arid Chaco of Argentina at 320 m a.s.l. (31° 20′ 20″ S y 65° 30′ 00″ W), from December 2003 to March 2005. In this region the mean temperature varies from 24°C in the warmest month (January) to 10°C in the coldest month (July) (Cabido et al., 1992). Annual mean precipitation is 300 to 500 millimeters and rainfalls occur mainly during the summer (October–March) (Figure 1). In the winter season (April–September) the water balance is negative, resulting in a soil moisture deficit. The soils are Entisols of alluvial origin, classified as Ustorthents (areas of trees and shrubs) and Ustifluvents (pure grassland area); average soil characteristics are PH 7.6, Carbon content 14.9 g/kg, Nitrogen content 1.3 g/kg, extractable phosphorus content 30.7 mg/kg and bulk density 1.2 g/cm^3 (Mazzarino et al., 1991).

Arid Chaco's agroecosystems are mainly dominated by degraded woodlands with strong desertification processes (Boletta et al., 2006) due to a high use pressure on natural resources, which threaten its sustainability (Izac & Sánchez, 2001). The main productive activities are goat and cattle raising and charcoal and firewood extraction (Bocco et al., 2002). The original abundant woodland was dominated by *Aspidosperma quebracho-blanco* Schltdl. (Cabido et al., 1992), which almost disappeared due to its over-exploitation for charcoal and firewood (Zak & Cabido, 2002; Bonino & Araujo, 2003). This process resulted in secondary woodland after colonization by *Prosopis flexuosa* DC. and *Prosopis chilensis* (Mol.) Stuntz that is considered a "good woodland state" (Cabido et al., 1992; Villagra et al., 2005), because these species increase organic matter contents, the fertility and the water infiltration rate of soils (Mazzarino et al., 1991; Rossi & Villagra, 2003). However, in areas where the use pressure continues, woodlands are colonized by non-forestry productive shrublands dominated by *Larrea divaricata* Cav., the main indicator of degraded woodland (Cabido et al., 1992). Finally, after many years of overstocking, large areas appear with poor soils and signs of gully erosion. The only woody species that can grow in such condition is *Parkinsonia praecox* (Ruiz & Pav.) Hawkins, commonly known as "Brea" (Martínez Carretero, 1998). Brea tree flowering begins in September/October and fruit development occurs from November up to March (Demaio et al., 2002).

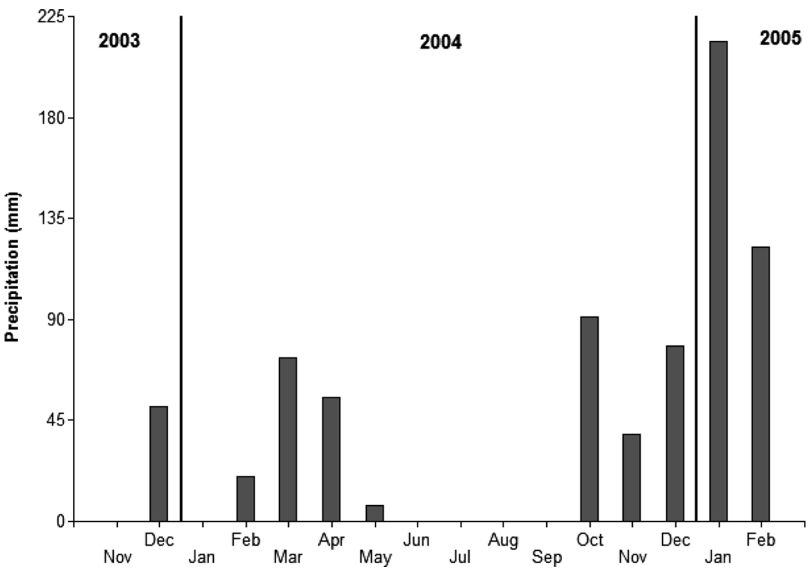

Figure 1. Monthly sum of precipitation during the study period (November 2003–March 2005) at the community of Chancaní, in the Arid Chaco, Argentina.

Sampling Design

Our experiment was carried out in native woodlands of the Arid Chaco, Argentina, during the summer season of the years 2003/2004 and 2004/2005. We sampled 51 plots (50×10 m) randomly selected and classified into three different woodland degradation states using vegetation surveys following the description from Cabido et al. (1992) and the determination of range condition based on plant species indicators from Kunst et al. (2007). From the total sampled plot, only 37 were included in the analyses because some of them did not have brea tree individuals. The degradation states analyzed were: 1) 11 plots within a secondary woodland logged 30 years before and colonized by *Prosopis spp.* with a mean value of 4.20 ± 1.69 brea trees specimens within each plot; 2) 32 plots within a degraded woodland with continuous logging, colonized by the shrub *Larrea divaricata* and with a mean value of 3.00 ± 0.46 brea trees specimens within the plot; and 3) 8 plots of brea woodland within a woodland colonized by *Parkinsonia praecox* with a mean value of 7.40 ± 1.91 individuals per plot. The study was designed to determine brea gum yield per tree and per unit of surface.

All brea trees within a plot were tapped with three wounds cutting up to the cambium and separated 10 centimeters from one another. The tapping was made from early rainy season to after fruit maturation, so the initial tapping could change from one year to the next. The gum was harvested twice after tapping with approximately 45 days among them. This applied tapping technique took into account the traditional way to obtain brea gum in the Arid Chaco.

Brea gum yield per tree and brea gum productivity per hectare, calculated as the sum of all the trees' production within the plot and carried to an hectare, both were analyzed as dependent variables and a) number of surrounding *Prosopis spp.* and *Aspidosperma quebracho-blanco* trees within five meters of each brea trunk; b) diameter at the stump height; and c) soil moisture content at 20 and at 40 cm below the shade of each brea tree, as independent variables. Daily rainfall data were used to determine the influence of seasonal rainfall on gum production (Figure 1).

Data were analyzed using General Linear Models (GLM) with the statistical software package Infostat® (2009) with an interface with the software package R© (2009). Woodland degradation effects were included in the model as a fixed factor and the differences among them were analyzed using Fisher's LSD tests ($p < 0.05$). The plot was included in the model as a random factor nested into woodland degradation, and all the other independent variables were included in the model as covariables (Underwood, 1997). The relationships between yield, diameter at stump height, the number of surrounding trees, and soil moisture content were examined using Pearson's linear correlation coefficient. Finally, further prediction of the Brea gum yield per tree in relation to the number of *Prosopis spp.* surrounding trees was carried out for the harvesting season 2003/2004 by a replicated regression model, using the plot as replication (Cottingham et al., 2005).

Results

Individual Tree Yield (gr/tree)

Statistical linear models showed no effect of the plot nested in degradation states in none of the harvesting seasons (December 2003, $p = 0.7339$; February 2004, $p = 0.6901$; and March 2005, $p = 0.9119$) allowing us to pool it and to analyze individual brea trees production as an independent data within each plot (Underwood, 1997). Brea gum yield was highly variable in all the harvesting seasons and it was found in a total of 29 non-productive trees randomly distributed among different woodland degradation without any significant interaction.

The gum yield per tree in secondary woodland (25.68 ± 5.18 gr) was significantly higher than in degraded woodland (4.98 ± 1.00 gr) and brea woodland (7.69 ± 2.21 gr) in December 2003 ($R^2 = 0.26$; $p < 0.0001$; Figure 2). Moreover, in December 2003 we found a significantly positive covariation with the number of surrounding *Prosopis spp.* trees ($p = 0.0002$) and with soil moisture content at 40 cm ($p = 0.0415$). The same trend occurred in February 2004, when the gum yield of secondary woodland (61.11 ± 14.21 gr) was significantly higher ($R^2 = 0.15$; $p < 0.0001$; Figure 2) than degraded woodland (11.73 ± 4.7 gr) and brea woodland (13.14 ± 5.41 gr). Likewise, we also found in February 2004 a significantly positive covariation with the number of surrounding *Prosopis spp.* trees ($p = 0.0028$). However, we found neither significant differences in brea gum yield among different woodland states in March 2005 ($R^2 = 0.01$; $p = 0.5615$; Figure 2), nor significant covariables. The mean values of this last harvesting season were 30.95 ± 10.91 gr in secondary woodland, 28.55 ± 6.36 gr in degraded woodland, and 18.51 ± 7.2 gr in brea woodland.

The linear correlation between the number of surrounding trees of *Prosopis spp.* and brea gum yield in December 2003 (Coeff. = 0.50) and February 2004 (Coeff. = 0.39) was highly significant ($p < 0.001$; Table 1a). On the contrary, there was no significant linear correlation between these variables surrounding trees of *Prosopis spp.* and brea gum yield in the harvesting season of March 2005

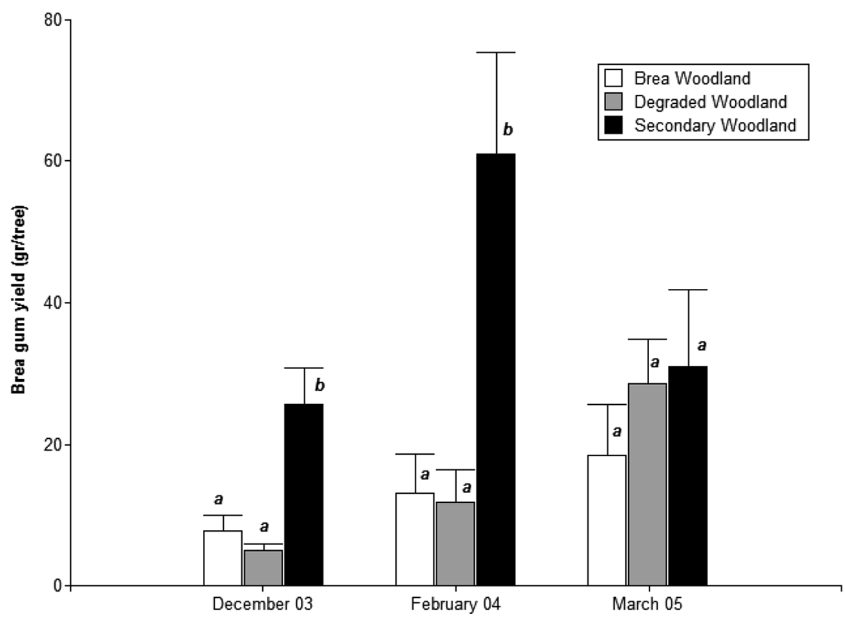

Figure 2. Brea Gum yield per tree in the different harvesting seasons for different woodland degradation states. Bars indicate the mean values of brea gum yield per tree ± standard error. Means followed by different letters are significantly different according to LSD Fisher at $p < 0.05$.

Table 1a. Pearson's correlations between brea gum yield per tree with surrounding trees from *Prosopis* spp. and *Aspidosperma quebracho-blanco*, with the diameter at the stump height (n = 125)

	December 03	February 04	March 05
Prosopis spp.	0.50**	0.39**	0.16
Apidosperma quebracho-blanco	−0.11	−0.01	0.12
Diameter at the stump height	0.26*	0.17	0.13

*Significant at 0.01; **Significant at 0.001.

Table 1b. Pearson's correlations between brea gum productivity per hectare with number of *Prosopis* spp., *Aspidosperma quebracho-blanco* and brea trees within the plot (n = 37)

	December 03	February 04	March 05
Prosopis spp.	0.84**	0.81**	0.57*
Apidosperma quebracho-blanco	−0.13	0.13	0.40*
Brea trees	0.59**	0.62**	0.67**

*Significant at 0.01; **Significant at 0.001.

(Coeff. = 0.16; p = 0.08; Table 1a). We also found no significant correlations between brea gum yield and the presence of surrounding *Aspidosperma quebracho-blanco* trees in none of the harvesting seasons (Table 1a). This species was represented with very low densities in the study area with respect to *Prosopis spp.*, being 0.56 ± 0.09 surrounding *Aspidosperma quebracho-blanco* trees only for degraded woodland, and was almost absent in the other two woodland states.

The diameter at stump height (Coeff. < 0.26) and soil moisture content at 20 cm were not correlated with brea gum yield (Coeff. < 0.14). However, the soil moisture content at 40 cm was positively correlated with brea gum yield in the harvesting season 2003/2004 (Coeff. = 0.65; p < 0.0001).

Production Per Hectare

Brea gum productivity per hectare in December 2003 differed significantly among treatments ($R^2 = 0.32$; p = 0.0015; Figure 3). Secondary woodland (2096 ± 1084 gr/ha) and brea woodland (1328 ± 698 gr/ha) have significantly higher production per hectare with respect to degraded woodland (267 ± 60 gr/ha). Likewise, there was a significantly positive covariation with *Prosopis spp.* trees density within the plot (p < 0.0001). Additionally, we found significant differences in *Parkinsonia praecox* tree density per hectare among woodland states ($R^2 = 0.23$; p = 0.0119). Brea woodland (148 ± 34 breas/ha) has a significantly higher number of individuals per hectare with respect to secondary woodland (84 ± 19 breas/ha) and to degraded woodland (60 ± 38 breas/ha).

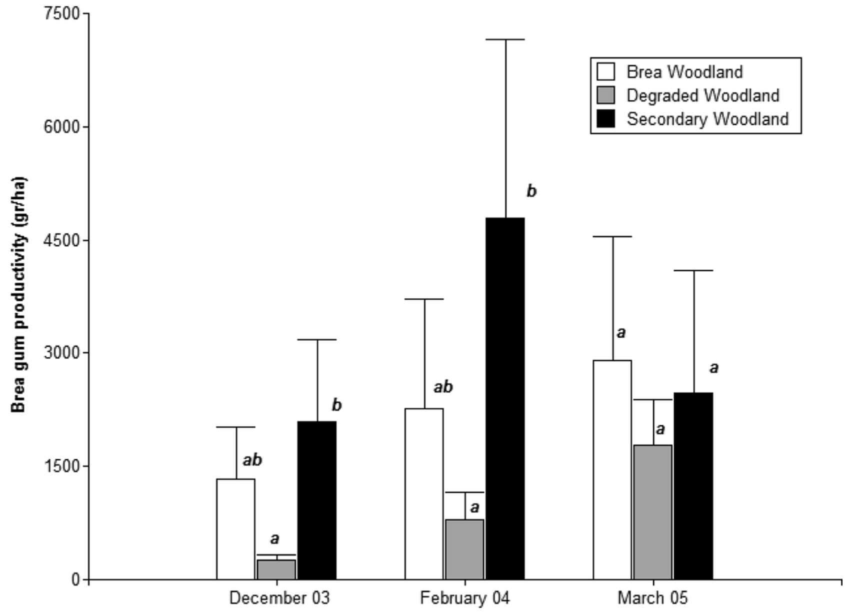

Figure 3. Brea Gum productivity per hectare in the different harvesting seasons for different woodland degradation states. Bars indicate the mean values of brea gum productivity per hectare ± standard error. Means followed by different letters are significantly different according to LSD Fisher at $p < 0.05$.

Similar trends were observed in February 2004 ($R^2 = 0.22$; $p = 0.0154$; Figure 3), in which the mean value of gum productivity of secondary woodland (4784 ± 2373 gr/ha) and brea woodland (2272 ± 1445 gr/ha) significantly differed from degraded woodland (789 ± 375 gr/ha). We also found a significantly positive covariation of brea gum productivity with *Prosopis spp.* density ($p < 0.0001$). The GLM including the covariable *Prosopis spp.* in both the December 2003 and February 2004 harvests gave values of $R^2 = 0.77$ and 0.68, respectively, indicating that *Prosopis spp.* specimens within the plot explained more variability than those of the treatment.

Regarding the harvesting season of March 2005, we found no significant differences among the treatments ($R^2 = 0.02$; $p = 0.7374$). The average brea gum productivity in secondary woodland was 2464 ± 1632 gr/ha, whereas degraded woodland reached 1772 ± 604 gr/ha and brea woodland 2908 ± 1638 gr/ha (Figure 3). The model significantly covariated with *Parkinsonia praecox* tree density ($p < 0.0001$), explaining this term more variability than that of the treatment ($R^2 = 0.51$).

A positive linear correlation was found between the number of *Prosopis spp.* specimens within the plot and gum productivity per hectare. This correlation was higher during the season of 2003/2004 (Coeff. > 0.80; $p < 0.001$; Table 1b), and lower in 2004/2005 (Coeff. = 0.57; $p = 0.01$; Table 1b). On the other hand, we found no correlation between brea gum productivity and number of surrounding *Aspidosperma quebracho-blanco* during the season 2003/2004, but a significant positive correlation during 2004/2005 (Coeff. = 0.40; $p = 0.01$; Table 1b). A positively significant correlation with the number of *Parkinsonia* *praecox* tree density was found for all of the harvesting seasons (Coeff. > 0.59; $p < 0.001$; Table 1b).

Predictive Variable of Brea Gum Yield

The independent variable that was most related to brea gum yield and productivity was the number of surrounding *Prosopis spp*. trees. A replicated regression model showed a 2nd order polynomial correlation between brea gum yield in the harvesting season 2003/2004 and the number of surrounding trees of *Prosopis spp.* ($R^2 = 0.41$; Figure 4). It was observed that brea gum production per tree increased when the individuals were surrounded by up to four *Prosopis spp.* trees and then production fell down to lower values. Related to this result, we found that secondary woodland had the higher number of *Prosopis spp.* surrounding trees, with an average of 2.74 ± 0.38, significantly higher than degraded woodland (1.10 ± 0.15) and brea woodland (0.86 ± 0.21) ($R^2 = 0.19$; $p < 0.0001$; see Figure 4).

There was no clear correlation between brea gum yield and the diameter at stump height due to the data variability (Figure 5). However, by using a regression model, it was possible to determine that the highest brea gum yield per tree was at intermediate sizes of diameter at stump height (8 to 20 cm) ($R^2 = 0.07$; Figure 5).

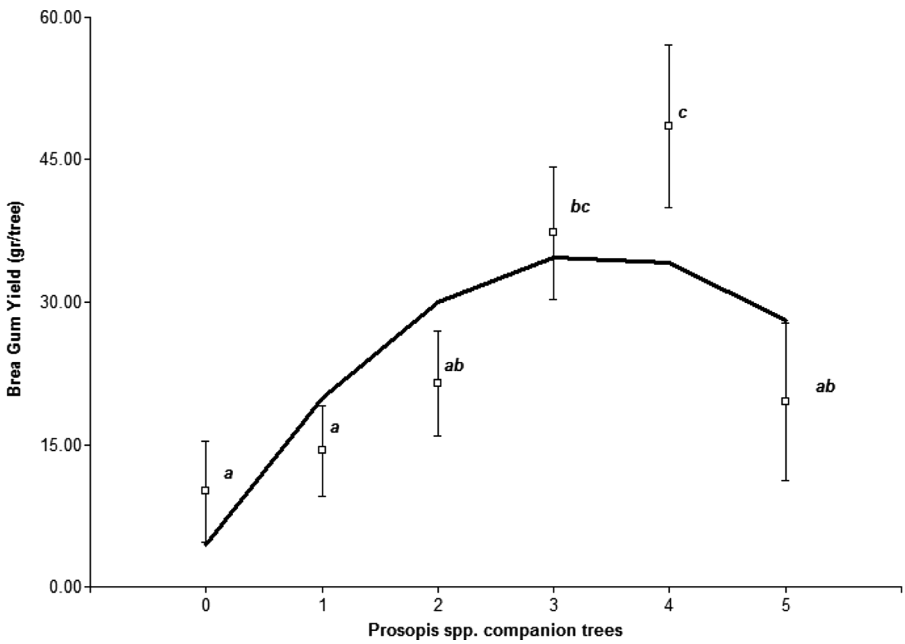

Figure 4. Brea gum yield per tree in relation to number of *Prosopis spp.* companion trees determined for each brea tree individual ($n = 125$). Data from all the woodland degradation states for the harvesting season 2003/2004. Brea Gum Yield $= (-2.6798)x^2 + (18.131)x - 4.4357$ [$R^2 = 0.41$]. Means followed by different letter are significantly different according to LSD Fisher at $p < 0.05$.

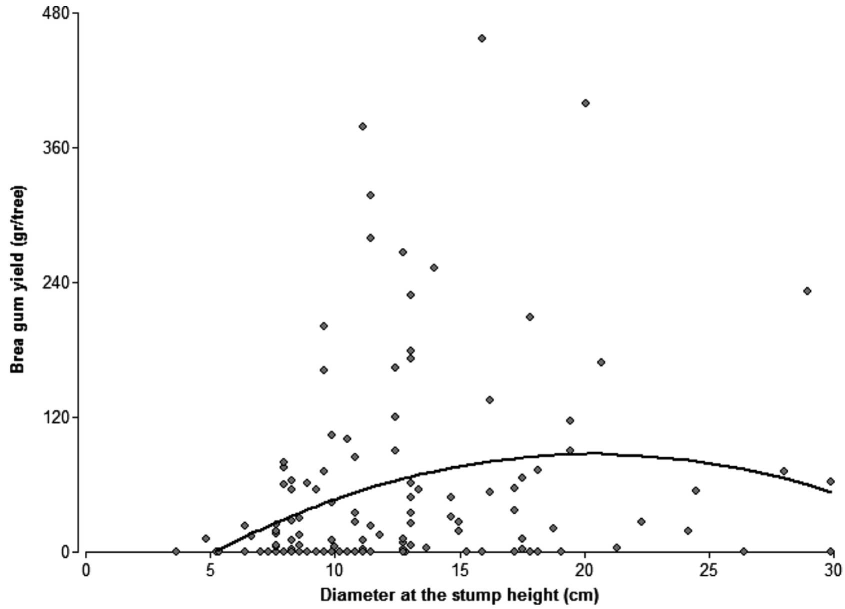

Figure 5. Brea gum yield per tree in relation to diameter at the stump height determined for each brea tree individual (n = 125). Data from all the woodland degradation states for the harvesting season 2003/2004. Brea Gum Yield = $(-0.3751)x^2 + (15.286)x - 68.494$ [$R^2 = 0.0697$].

Discussion

The great variability observed in the brea gum yield among trees and the presence of non-productive specimens coincide with previous studies related to *Parkinsonia praecox* (Losano, 1995; Alesso et al., 2003). These findings could be related to the fact that *Parkinsonia praecox* is not a domesticated species, therefore, it is reasonable to found a great variability in this parameter. Other genera of gum plant producers, such as *Acacia spp., Astragalus spp*., and *Sterculia spp.* have been subjected to a long selection process and their gum yield is more sustained and higher than in *P. praecox* (Ballal et al., 2005a; Gaafar et al., 2006; Raddad & Luukkanen, 2006). The higher Brea gum yield at late maturation season coincided with that observed in other gum productive species of *Prosopis* genus (Vilela and Ravetta, 2005).

Gum average yield per tree in the summer season 2003/2004 (Figure 2), characterized by precipitation below average values (Figure 1), was higher in the secondary woodland with abundant *Prosopis spp.* specimens. On the contrary, in the harvesting season from 2005, characterized by above average precipitations (Figure 1), we did not find differences among woodland degradation states (Figure 2). The same trend occurred for brea gum productivity per hectare (Figure 3). These results suggest that this species has a strong influence on brea gum production during dry seasons due to its aptitude to improve soil conditions in the woodland areas (Rossi & Villagra, 2003) and could enhance gum yield, as it occurs in *Acacia senegal* (Ballal et al., 2005b). Likewise, Losano et al. (2000) stated that brea gum production was determined by the water potential in the tree, and it is directly correlated with the water soil content. In more wet years with higher water content in the soil, brea gum production is not dependent from enhanced conditions provided by *Prosopis spp.* individuals (Rossi

& Villagra, 2003), being the individual yield similar in all the different woodland states. The presence of *Prosopis spp.* trees could be related with a greater soil water content at the sub-superficial layer (below 40 centimeters), and influenced positively the brea gum production (Table 1a & b). The axial root structure of *P. praecox* seems to justify the lack of correlation between the superficial soil water content and brea gum production so the roots grow deeper (Martínez Carretero, 1998).

The number of *Prosopis spp.* trees could be used to estimate the brea gum yield per tree in the Arid Chaco of Argentina (Figure 4). Brea trees significantly increase gum yield in degraded woodlands with up to four surrounding *Prosopis spp.* trees. When the number of *Prosopis spp.* trees increases, the competition for resources produced a decrease in gum production (Gaafar et al., 2006; Raddad & Luukkanen, 2006). Due to the scarcity of *Aspidosperma quebracho-blanco* individuals in all of the woodland states, we could not find a relationship with brea gum production.

The lack of clear correlation between brea gum yield and the diameter at the stump height seems to indicate that this parameter is not useful to estimate brea gum yields per tree. However, it was possible to observe that average sized trees of diameter at the stump height between 8 and 20 cm were the most productive ones (Figure 5). Gum biosynthesis demands a certain maturity of the tree, suggesting that gum production competes with growth in younger trees (Joseleau & Ullmann, 1990). On the contrary, trees with higher diameters at the base of the stump generally did not produce any gum. These results could be related to fungi contamination of the tissues needed for gum biosynthesis (Gedalovich & Fahn, 1985; Khan et al., 1989).

As a management implication of the present study, we suggest that *Parkinsonia praecox* should be tapped once a year during harvesting season, as the best way to contribute to a sustainable production. Secondary woodland must be included in production at first. Then, if there is sufficient labor available it will be possible to include the tapping of individuals from brea woodland (von Müller et al., 2007). It makes no sense to tap brea trees in degraded woodland, because production obtained is lower. However, in wet years it is viable to perform tapping in all the woodland conditions.

Conclusion

Parkinsonia praecox gum has the potential to be included as a new non-wood forestry product in the Arid Chaco of Argentina. Our results, revealed susceptibly to the degradation state of woodland. Secondary woodland colonized by *Prosopis spp.* produced the highest gum yield with respect to the most degraded ones. However, brea gum productivity per hectare in the secondary woodland and brea woodland were similar due to differences among *P. praecox* tree density. Gum yield also increased with the number of *Prosopis spp.* surrounding trees due to its ability to improve microclimatic conditions by increasing the soil moisture content and, consequently, contributing to a higher gum yield.

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