Effect of *Prosopis* spp. as a nurse plant on nutrient content and productivity of *Opuntia ellisiana* Griffiths

Efecto de *Prosopis* spp. como planta nodriza sobre el contenido de nutrientes y la productividad de *Opuntia ellisiana* Griffiths

Josefina María Grünwaldt *, Juan Carlos Guevara, Eduardo Martínez Carretero, Eduardo Guillermo Grünwaldt

Originales: *Recepción:* 23/09/2017 - *Aceptación:* 04/05/2018

Abstract

In arid conditions, the low quality of the forage and water shortage could be attenuated by the introduction of *Opuntia* species. Several plant species grows well under *Prosopis* canopy, responding to a higher nutrient content in the soil, It was hypothesized that productivity and nutrient content, mainly crude protein (CP), of *Opuntia ellisiana* planted under *Prosopis* would be higher than of those planted outside the canopy, and that these parameters would be influenced by the cactus position: north or south from the centre of the tree. Sampling was done in 18 plants under the canopy of *Prosopis* and 23 outside of it. After one year of the plantation, the totality of cladodes was harvested. The productivity per plant was 3.1 and 5.7 cladodes and 34.9 and 48.1 g of dry matter (DM), outside and under the canopy, respectively. The bromatological values (%) were moisture: 89.1 and 91.9, organic matter (OM): 76.7 and 79.8, CP: 4.4 and 8.1, acid detergent fiber (ADF): 13.7 and 18.2, neutral detergent fiber (NDF): 29.0 and 31.5, K: 3.1 and 3.6, P: 0.07 and 0.11, Ca: 5.5 and 4.4, Na: 0.04 and 0.02, outside and under the canopy, respectively. Crude protein, moisture, OM, ADF, NDF, K, P and productivity per plant were higher under the canopy, whereas Ca and Na values were higher outside the canopy ($p<0.05$). Magnesium (1.9 and 1.9%) was not affected by the position outside or under the canopy. The north or south orientation did not influence any of the analysed parameters.

Keywords

bromatological composition • crude protein • food reserve • agrosystem enrichment • arid lands

Argentine Institute for Arid Land Research (IADIZA-CCT-CONICET Mendoza)
Av. Adrián Ruiz Leal s/n. Parque Gral. San Martín. 5500 Mendoza. Argentina.
* jgrunwaldt@mendoza-conicet.gob.ar

Resumen

En condiciones de aridez, la baja calidad del forraje y la escasez de agua podrían ser atenuadas con la introducción de especies de *Opuntia*. Varias especies tienen buen crecimiento bajo la canopia de *Prosopis* spp*.,* respondiendo a un contenido más alto de nutrientes en el suelo. Se hipotetizó que la productividad y el contenido de nutrientes, principalmente proteína cruda (PC), de *Opuntia ellisiana* establecidas bajo la canopia de *Prosopis* serían más altos que los implantados fuera de la misma y que estos parámetros serían influenciados por la posición del cactus: norte o sur respecto del centro del árbol. Se muestrearon 18 plantas de cactus bajo la canopia y otras fuera de la misma. Después de un año de crecimiento, se cosechó la totalidad de los cladodios. La productividad por planta fue 3,1 y 5,7 cladodios y 34,9 y 48,1 g de materia seca (MS), fuera y bajo la canopia, respectivamente. Los valores bromatológicos (%) fueron humedad: 89,1 y 91,9, materia orgánica (MO): 76,7 y 79,8, PC: 4,4 y 8,1, fibra detergente ácida (FDA): 13,7 y 18,2, fibra detergente neutra (FDN): 29,0 y 31,5, K: 3,1 y 3,6, P: 0,07 y 0,11, Ca: 5,5 y 4,4, Na: 0,04 y 0,02, bajo y fuera de la canopia, respectivamente. Proteína cruda, humedad, MO, FDA, FDN, K, P y productividad por planta fueron más altas bajo la canopia, mientras que los valores de Ca y Na fueron más altos fuera de la canopia ($p<0.05$). Magnesio (1,9 y 1,9%) no fue afectado por la posición bajo y fuera de la canopia, respectivamente. La orientación norte o sur no influenció los parámetros analizados.

Palabras clave

composición bromatológica • proteína cruda • reserva de alimento • enriquecimiento del agroecosistema • tierras áridas

Introduction

There are numerous reasons behind the diffusion of cacti as forage or fodder around the world, such as the simple cultivation practices required to grow the crop, rapid establishment in a new area, easy multiplication practices (18). Also they have the ability to withstand prolonged drought, high temperatures as well as soils affected by wind and water erosion (16). This aptitude has made the cactus plantations suitable as food supply and they have become strategic to mitigate the effect of drought over animal production systems in various arid and semi-arid areas of the world. Cacti have greater water-use efficiency due to Crassulacean Acid Metabolism (CAM) photosynthetic pathway (24) and this makes them especially suited for forage productions in arid lands.

Opuntia species are not a balanced feed: rich in energy, calcium and beta carotene, but poor in fiber and nitrogen (4). As evidenced by various studies, some efforts have been made with the purpose of increasing the nitrogen content in cactus for using as forage (8, 10, 17).

Opuntia spp. can be cultivated in a wide range of environments. The major limitation to cultivation of cactus in many areas of the world are severe cold winter temperatures such as happens in the region of Mendoza, Argentina (16), northern Mexico (5), the Mediterranean Basin (22), the arid highland steppes of western Asia (23) and the south-western United States (25). *O. ellisiana* has a lower growth and productivity compared to other *Opuntia* species such as *O. ficus-indica* (L.) Mill. but it stands out for its resistance to sub-zero temperatures proper of the arid lands.

Prosopis spp. has the capacity of tolerating drought and unfavourable edaphic conditions, such as salinity, as well as being well adapted to the herbivory. All these are the main reasons of its dominant position in the silvopastoral systems of the arid and semi-arid areas of America. On the other hand, they generate spatial heterogeneity that affects the distribution of the shrub and herbaceous layers due to the modification of the microclimatic conditions under its canopy (29).

The improvement in the forage value of cactus under the *Prosopis* crown indicates the better condition of the site as a result of the higher nutrient content of the soil (26). In arid ecosystems, dominant woody plants are likely to cause changes in microclimate and soil properties by mitigating harsh environmental conditions such as high temperature and solar radiation (6, 19). Also, shrub species play an important role in arid land vegetation, since in several cases, they act as "nurse plants" improving micro-climatic conditions, increasing water and nutrient availability, and offering protection against herbivory (13).

The objective of this work was to determine the effect of associating tree-cactus over the bromatological parameters and DM productivity per plant of *Opuntia ellisiana* Griffiths, implanted under and outside the *Prosopis* spp. canopy, considering the north and south location respect to the tree. It was hypothesized: a) productivity and nutrient content, mainly crude protein (CP), of cactus under the *Prosopis* will be greater than those planted outside the canopy and b) these parameters will be influenced by the location of cacti plantation, north or south, with respect to the *Prosopis* trunk.

Materials and methods

The experience was carried out in the campus of the CCT-CONICET-Mendoza (32°53'45" S; 68°52'28" W, 840 m a. s. l.) Mendoza, Argentina. The maximum and minimum absolute temperatures (2014-2015 period) were 38.0 and 0.9°C in summer and winter, respectively. Precipitation is characterized by high spatial and temporal variability, it occurs in summer mostly as intense precipitations and the mean for the 2014 and 2015 period was 324.2 mm year^{-1}, during an exceptionally wet period given that the mean of the past 10 years was 226.7 mm year^{-1}. Soils in the study area are of alluvial origin with heterometric clasts in a sandy matrix, normally non-structured, deep, well drained, belonging to the order of Torripsamments. Soluble salts are washed into the profile increasing the electrical conductivity between 25-40 cm deep.

In the soils, texture (Boujoucos), N (Kjeldahl), P (UV visible spectrophometry), K (Pratts), Na (flame photometry), Ca and Mg (complexometry with EDTA), pH and electrical conductivity were determined. Samples of soil for analysis were taken from the first 20 cm of the soil, bearing in mind that 91 to 100% of the roots of the *O. ficus indica* are found in the top 15 cm of the ground (27). To know the soil parameters at greater depth, other soil samples were also extracted at 40 cm depth.

O. ellisiana was used in this study due to its resistance to low temperature (12). This experience started in the autumn of 2014. Double cladodes, homogeneous in size, provided by the IADIZA experimental collection, were used for the plantation. They were cut before they started giving out new cladodes.

Sampling of cladodes took place at the end of the growing period, as from the month of April. Organic matter (OM), dry matter (DM), neutral detergent fiber (NDF) and acid detergent fiber (ADF) (Van Soest and Wine), crude protein (CP) by Kjeldahl, P (vanadomolibdophosphoric complex colorimetric, Spectronic 21 Bausch & Lomb.), K and Na (flame photometry, Metrolab 315), Ca and Mg (atomic absorption spectroscopy, Perkin Elmer AAnalyst 200) were determined in the cladodes. The samples were obtained from the south and from the north, under the *Prosopis* canopy; a similar sampling being carried out outside the influence of the canopy.

The experimental design included 18 and 23 plants located under and outside of the *Prosopis* canopy, respectively. Under the canopy of five trees, four plants were implanted, two to the north and two to the south, equidistant between the trunk and the edge of the canopy. Five plots with five double cladodes in each of them were also used as controls. Two plants under *Prosopis* spp. and control, respectively, did not thrive in their growth. After a year of the plantation, all the cladodes were collected, with the exception of the double cladodes planted when initiating the experience.

In order to determine the photosynthetically active radiation (PAR), a linear radiometer (Apogee MQ 300) was applied. To quantify the air temperature at 1 m height from the ground and 5 cm deep in the ground, a multichannel digital thermometer was used.

The data for PAR and temperature were registered in spring (September), summer (February) and winter (June), between 11 a.m. and 1 p.m. These reports were taken in the centre of the tree and outside the influence of the canopy; the orientation being north-south.

The data were analysed using multivariate analysis with InfoStat statistics software. As confirmation, multivariate analysis of variance (MANOVA) of the nutritional variables was performed. To compare mean vectors between the groups, a Hotelling test was used (21).

Results and discussion

In each sampling period the air temperature had very similar values both outside and under the canopy. The values of radiation and soil temperature were higher outside the canopy (table 1, page 133). Although the influence of the radiation level on the growth and productivity of *Opuntia* has been demonstrated (1, 9, 11, 14), in this experiment the *Prosopis*' effect on the cactus was more important than the higher radiation received by the cladodes outside the canopy. Shadow of *Prosopis* influenced the incident radiation with a decrease of 20% in summer, 15% in winter and 32% in spring, compared to outside the canopy. During the post-implant and the harvest of the cladodes the temperatures recorded were not low enough to evaluate any damage by frost, having registered -0.7 and 1°C as the coldest days of winter of 2014 and 2015, respectively.

In soil, under *Prosopis* canopy, the contents of N, OM and others elements such as P and K were greater than those found outside it (table 2, page 133).

The contribution of nitrogen by *Prosopis* mulch under its cover could be explained by the redistribution of the nutrients absorbed by the radical system (3, 28) and the biological fixation of nitrogen by *Rhizobium* (15), and in addition, through of the litter accumulated under the canopy.

Table 1. Values of photosynthetically active radiation, air and soil temperature in February, June and September outside and underside of *Prosopis* canopy.

Tabla 1. Valores de radiación fotosintéticamente activa, temperatura del aire y del suelo en febrero, junio y setiembre bajo y fuera de la canopia de Prosopis.

	February		June		September	
	Outside	Underside	Outside	Underside	Outside	Underside
PAR[1] (μmol m^{-2} s^{-1})	1352	273	775	119	1354	587
AT[2] (°C)	31.9	31.4	15.0	14.8	30.4	29.9
TS[3] (°C)	24.5	16.0	5.0	0.0	31.0	19.9

[1] Photosynthetically active radiation. / [1] Radiación fotosintéticamente activa.

[2] Air temperature. / [2] Temperatura del aire

[3] Soil temperature. / [3] Temperatura del suelo.

Table 2. Soil components at 20 and 40 cm depht outside and under the *Prosopis* canopy.

Tabla 2. Componentes del suelo a 20 y 40 cm de profundidad bajo y fuera de la canopia de *Prosopis*.

	N (ppm)	OM (%)	pH	EC (μS cm^{-1} 25°C)	P (ppm)
20 cm outside	532	1.6	7.1	2650	9.0
20 cm under	1708	3.5	7.4	3130	16.4
40 cm outside	560	2.1	7.5	4960	7.4
40 cm under	798	2.2	7.5	5210	7.9

	K (ppm)	Ca (ppm)	Mg (meq l^{-1})	Na (meq l^{-1})
20 cm outside	1095	14.5	12.5	3.0
20 cm under	2581	9.2	12.9	2.5
40 cm outside	938	17.8	13.8	27.0
40 cm under	1642	15.9	21.8	12.8

Throughfall effects are generally attributed to leaching from leaves, but canopies also filter and capture atmospheric nutrients, and these processes contribute large amounts nutrients to the understory.

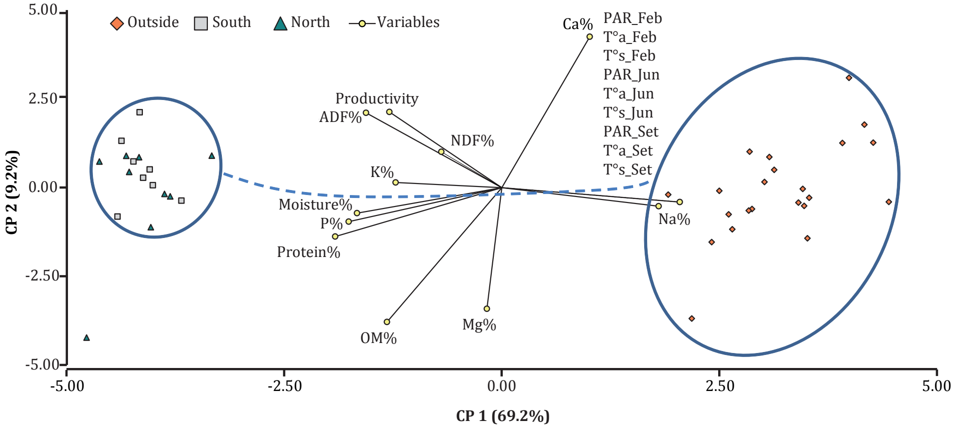
The high percentages of nitrogen, derived from atmosphere in wood and leaves, clearly indicate that *Prosopis* is actively fixing nitrogen (15).

There is evidence that canopy filtration of atmospheric nutrients provided K, Mg, Ca, Na and P (7).

In the principal component analysis (PCA), considering the data obtained from cladodes and soil, the first two axes of variation explain 78.4% of the total variability (figure 1, page 134).

The first component separates cladodes according to the nutrient contents and productivity; to the right, cladodes under the canopy with higher values, to the left cladodes outside the canopy and closely related to environmental variables.

No differences were found in the variables measured for cacti located in the northern and southern parts of the canopy.



T°a: air temperature; T°s: soil temperature; PAR: photosynthetically active radiation; OM: organic matter; ADF: acid detergent fiber; NDF: neutral detergent fiber.

T°a: temperatura del aire; T°s: temperatura del suelo; PAR: radiación fotosintéticamente activa; OM: materia orgánica; ADF: fibra detergente ácida; NDF: fibra detergente neutra.

Figure 1. Biplot obtained by principal component analysis on nutritional and environmental parameters under and outside the *Prosopis* canopy for 41 *Opuntia* plants. Different symbols indicate under/outside location and north/south orientation below the canopy.

Figura 1. Gráfico biplot obtenido por análisis de componentes principales sobre los parámetros nutricionales y ambientales fuera y bajo la canopia de *Prosopis* para 41 plantas de *Opuntia*. Diferentes símbolos indican la ubicación bajo/fuera y la orientación norte/sur debajo de la canopia.

Furthermore, to compare mean vectors between groups and confirm the information given by PCA, a Hotelling test was used.

Table 3 (page 135), presents the bromatological values and cladode quantity per plant of *O. ellisiana* planted outside and under the *Prosopis* canopy.

Dry matter productivity per plant (g) were 34.9 ± 16.1 and 48.1 ± 24.1 outside and under the canopy, respectively. Under the *Prosopis* canopy, the nutritional values of *O. ellisiana* were increased, the nitrogen content, to almost double its value. Productivity cladodes per plant and concentrations of moisture, OM, ADF, NDF, K and P in the cladodes were also significantly higher under *Prosopis*, while Ca and Na were higher outside the canopy. Magnesium values were not affected by the position, under or outside the canopy. Under the crown of the tree the effective precipitation is greater than outside of it, due to the runoff of the branches and trunk (20), which favors the leaching of Na in the soil; while an increase in N and P reduces the uptake of Ca and Na (8).

The improvement in the forage value of cactus under the *Prosopis* crown indicates the better condition of the site as a result of the higher nutrient content of the soil and the contribution of OM as mulch, resulting in the formation of fertility islands (26).

Table 3. Means and standard deviations of bromatological values and yield of cladodes per plant of *O. ellisiana* planted outside and under *Prosopis* canopy.

Tabla 3. Medias y desviaciones estándar de valores bromatológicos y producción de cladodios por planta de *O. ellisiana* bajo y fuera de la canopia de *Prosopis*.

Parameters	Outside the canopy (n=23)	Under the canopy		
		North (n=9)	South (n=9)	North and South (n=18)
Moisture (%)	89.1 ±1.3 a	91.9±0.9 b	91.9 ±1.2 b	91.9 ±1.0 b
Organic matter (%)	76.7 ±2.5 a	80.2±2.7 b	79.4 ±1.0 b	79.8 ±2.1 b
Na (%)	0.04±0.01a	0.02±0.01b	0.02 ±0.005b	0.02±0.01b
K (%)	3.1 ±0.4 a	3.5±0.4 b	3.7 ±0.4 b	3.6 ±0.4 b
P (%)	0.07±0.02a	0.11±0.02b	0.12±0.02 b	0.11±0.02b
Ca (%)	5.5 ±1.4 a	4.3±1.2 b	4.7 ±0.4 b	4.4 ±0.9 b
Mg (%)	1.9 ±0.2 a	1.9±0.2 a	1.8 ±0.2 a	1.9 ±0.2 a
Crude protein (%)	4.4 ±1.0 a	8.1±1.3 b	8.0 ±0.5 b	8.1 ±1.0 b
Acid detergent fiber (%)	13.7 ±2.4 a	17.7±1.9 b	18.8± 1.0 b	18.2 ±1.6 b
Neutral detergent fiber (%)	29.0 ±4.2 a	31.8±2.4 b	31.2 ±1.3 b	31.5 ±1.9 b
Cladode quantity per plant	3.1 ±1.2 a	5.7±2.7 b	5.6 ±2.1 b	5.7 ±2.3 b

Hotelling test Alfa=0.05. Means with a letter in common are not significantly different (p>0.05).

Prueba de Hotelling Alfa=0,05. Medias con letra en común no son significativamente diferentes (p>0,05).

In arid and semiarid ecosystems, dominant woody plants are likely to cause changes in microclimate and soil properties by mitigating harsh environmental conditions (*e.g.*, high temperature and radiation) and by modifying soil characteristics, resource availability (*e.g.*, water and nutrients) and spatial distribution of nutrients (2, 6, 19).

The nurse effect of *Prosopis* improves the nitrogen content of cladodes in the same way as cattle manure applied to soil (10). The high doses of chemical fertilizers applied almost doubled the CP mean content of the 1-year-old cladodes when it was compared with the treatment in which no fertilizer was added: 7.8 and 4.3% DM, respectively (17).

Conclusions

There is no significant influence (p>0.05) of the north/south orientation under the canopy on the measured variables.

There are significant differences (p<0.05) in productivity and nutrient content for cactus planted under and outside the *Prosopis* canopy. The nurse effect of *Prosopis* improves the nitrogen content of cladodes in the same way as cattle manure or high doses of chemical fertilizers applied to soil. The enrichment of the pastoral system in arid environments by the introduction of *Opuntia* associated to *Prosopis* increases both the productivity and forage quality of the system.

Sol Curto
Ilustradora

Nombre de la obra: *Prosopis flexuosa* II
Técnica: Grafito sobre papel
Tamaño: 12cm x 12cm
Año 2018

References

1. Acevedo, E.; Badilla, I.; Nobel, P. S. 1983. Water relations, diurnal acidity changes, and productivity of a cultivated cactus, *Opuntia ficus-indica*. Plant Physiology. 72: 775-780.
2. Alvarez, J. A.; Villagra, P. E.; Rossi, B. E.; Cesca, E. M. 2009. Spatial and temporal litterfall heterogeneity generated by woody species in the Central Monte desert. Plant Ecology. 205: 295-303.
3. Barth, R. C.; Klemmedson, J. O. 1982. Amount and distribution of dry matter, Nitrogen, and organic Carbon in soil-plant systems of mesquite and palo verde. Journal of Range Management. 35: 412-418.

4. Ben Salem, H. 2010. Nutritional management to improve sheep and goat performances in semiarid regions. Revista Brasileira de Zootecnia. 39: 337-347. Suppl.spe Viçosa.
5. Borrego-Escalante, F.; Murillo-Soto, M. M.; Parga-Torres, V. M. 1990. Potencial de producción en el norte de México de variedades de nopal (*Opuntia* spp.) tolerantes al frío. In: Felker, P. (Ed.). Proceedings of the First Annual Texas Prickly Pear Council. Caesar Kleberg Wildlife Research Institute. Kingsville. Texas. p. 49-73.
6. Callaway, R. M. 1995. Positive interactions among plants. The Botanical Review. 61: 306-349.
7. Callaway, R. M. 2007. Direct mechanisms for facilitation. In: Positive interactions and interdependence in plant communities. Springer Dordrecht. The Netherlands. 15-116.
8. Da Silva, J. A.; Bonomo, P.; Donato, S. L. R.; Pires, A. J. V.; Rosa, R. C. C.; Donato, P. E. R. 2012. Composição mineral em cladódios de palma forrageira sob diferentes espaçamentos e adubações química. Revista Brasileira de Ciências Agrárias. 7: 866-875.
9. da Silva, T. G. F.; Primo, J. T. A.; de Morais, J. E. F.; da Silva Diniz, W. J.; de Souza, C. A. A.; da Conceição Silva, M. 2015. Crescimento e produtividade de clones de palma forrageira no semiárido e relações com variáveis meteorológicas. Revista Caatinga. 28: 10-18.
10. Donato, P. E. R.; Vieira Pires, A. J.; Rodrigues Donato, S. L.; Da Silva, J. A.; De Aquino, A. A. (2014). Valor nutritivo da palma forrageira 'gigante' cultivada sob diferentes espaçamentos e doses de esterco bovino. Revista Caatinga. 27: 163-172.
11. Doussouline E.; Acevedo, E.; García de Cortázar, V. 1989. Arquitectura, intercepción de radiación y producción en tuna *Opuntia ficus-indica* (L.) Mill. Idesia. 11: 7-17.
12. Felker, P. 1995. Forage and fodder production and utilization. In: Barbera, G.; Inglese, P.; Pimienta-Barrios, E. (Eds.). Agro-ecology, cultivation and uses of cactus pear. FAO. Rome. Italy. 144-154.
13. Fernández, M. E.; Passera, C. B.; Cony, M. A. 2016. Sapling growth, water status and survival of two native shrubs from the Monte Desert, Mendoza, Argentina, under different preconditioning treatments. Revista de la Facultad de Ciencias Agrarias. Universidad Nacional de Cuyo. 48(1): 33-47.
14. García de Cortázar, V.; Nobel, P. S. 1986. Modeling of PAR interception and productivity of a prickly pear cactus *Opuntia ficus-indica* L., at various spacings. Agronomy Journal. 78: 80-85.
15. Geesing, D.; Felker, P.; Bingham, R. L. 2000. Influence of mesquite (*Prosopis glandulosa*) on soil nitrogen and carbon development: Implications for global carbon sequestration. Journal of Arid Environments. 46: 157-180.
16. Grünwaldt, J. M.; Guevara, J. C.; Grünwaldt, E. G.; Martínez Carretero, E. 2015. Cacti (*Opuntia* sps.) as forage in Argentina dry lands. Revista de la Facultad de Ciencias Agrarias. Universidad Nacional de Cuyo. 47(1): 263-282.
17. Guevara, J. C.; Felker, P.; Balzarini, M. G.; Paez, S. A.; Estevez, O. R.; Paez, M. N; Antúnez, J. C. 2011. Productivity, cold hardiness and forage quality of spineless progeny of the *Opuntia ficus-indica* 1281 x *O. lindheimerii* 1250 cross in Mendoza plain, Argentina. Journal of the Professional Association for Cactus Development. 13: 48-62.
18. Guevara, J. C.; Estevez, O. R. 2018. Sustainable use of rangelands of the Mendoza plain (Argentina). Revista de la Facultad de Ciencias Agrarias. Universidad Nacional de Cuyo. 50(1): 295-307.
19. Gutiérrez, J. R.; Meserve, P. L.; Contreras, L. C.; Vásquez, H.; Jaksic, F. M. 1993. Spatial distribution of soil nutrients and ephemeral plants underneath and outside the canopy of *Porlieria chilensis* shrubs (Zygophyllaceae) in arid coastal Chile. Oecologia. 95: 347-352.
20. Horno, M. E. 1993. Interceptación de la precipitación por algarrobo. In: IADIZA (Ed.), Contribuciones mendocinas a la quinta reunión regional para América Latina y el Caribe de la Red de Forestación del CIID. Conservación y mejoramiento de especies del género *Prosopis.* Mendoza. Argentina. IADIZA. 93-97.
21. InfoStat. 2008. InfoStat version 2008. Grupo InfoStat, Facultad de Ciencias Agropecuarias, Universidad Nacional de Córdoba, Argentina.

22. Le Houérou, H. N. 1996a. The role of cacti (*Opuntia* spp.) in erosion control, land reclamation, rehabilitation and agricultural development in the Mediterranean Basin. Journal of Arid Environments. 33: 135-159.
23. Le Houérou, H. N. 1996b. Utilization of fodder trees and shrubs (TRUBS) in the arid and semi-arid zones of western Asia and northern Africa (WANA): history and perspectives. A review. ICARDA/CIHEAM. Hammamet. Tunisia. 51 p.
24. Nobel, P. S. 2003. Ecofisiología de *Opuntia ficus-indica.* In: Mondragón-Jacobo, C.; Pérez-González, S. (Eds.), El nopal (*Opuntia* spp.) como forrage. Estudio FAO Producción y Protección Vegetal 169. p. 17-24.
25. Parish, J.; Felker, P. 1997. Fruit quality and production of cactus pear (*Opuntia* spp.) fruit clones selected for increased frost hardiness. Journal of Arid Environments. 37: 123-143.
26. Pugnaire, F. I.; Haase, P.; Puigdefabregas, J. 1996. Facilitation between higher plant species in a semiarid environment. Ecology. 77: 1420-1426.
27. Snyman, H. A. 2005. A case study on *in situ* rooting profiles and water-use efficiency of cactus pears, *Opuntia ficus-indica* and *Opuntia robusta*. Journal of the Professional Association for Cactus Development. 7: 1-21.
28. Tiedemann, A. R.; Klemmedson, J. O. 1972. Effect of mesquite on physical and chemical properties of the soil. Journal of Range Management. 26: 27-29.
29. Villagra, P. E. 2000. Aspectos ecológicos de los algarrobales argentinos. Multequina. 9: 35-51.

Acknowledgements

We appreciate the contributions of Enrique Mas and Ricardo A. Mauricio (IADIZA); Ricardo Ortega and Valeria Saldaño (Comisión Nacional de Energía Atómica -CNEA-), for their collaboration in the analysis of soil and nutrient content of *Opuntia* cladodes. We are also thankful to Cecilia Regairaz for her edaphic advice and Oscar R. Estevez for the preparation of tables and statistical analysis.
The authors are most grateful to the reviewers for their comments on the early text.
This study was supported by Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET) of Argentina, PIP 2013-2015 GI.