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Sustainable use of rangelands of the Mendoza plain (Argentina)

Uso sustentable de los pastizales de la llanura de Mendoza (Argentina)

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Review

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Abstract

This review includes the location, the biogeographic characteristics and the production systems of the Mendoza plain. The procedure for estimating the carrying capacity for cattle was described. For its evaluation, annual forage production was estimated from the dependable annual rain (*f*0.8) and the rain-use efficiency factor (kg DM ha^{-1} $year^{-1}$ mm^{-1}). The yearlong proper use factor of available forage was 30%, while the herbaceous and woody accessible layers to cattle were 80% and 50%, respectively. The estimated carrying capacity was, on average, 24.3 ha AU^{-1}. This evaluation, denoted the need to have forage reserves from 2 years, in 10 not included in the model. The use of spineless cactus was considered as buffer feed reserve. Its benefits and restrictions are mentioned. The major limitation to plantations of *Opuntia ficus-indica* (L.) Mill. for fodder in Mendoza plain is cold winter temperatures. To overcome this constraint, ten progenies of the interspecific cross between *Opuntia lindheimerii* Engelm. (cold hardy) and *O. ficus-indica* were examined for freezing hardiness. Due to the great importance of cactus as suitable crop for livestock production in arid areas, the economic feasibility of its plantation for both cattle and goat production systems was included in the review.

Keywords
carrying capacity • *Opuntia* spp. • economic feasibility • cattle • goats • rangelands • sustainability

Resumen

Esta revisión incluye la ubicación, las características biogeográficas y los sistemas de producción de la llanura de Mendoza. El procedimiento para estimar la receptividad de la misma para ganado bovino fue descripto. Para su evaluación, la producción anual de forraje fue estimada sobre la base de la lluvia anual confiable (*f* 0,8) y el factor de eficiencia de uso de la lluvia (kg MS ha^{-1} $año^{-1}$ mm^{-1}). El factor de uso apropiado durante el año del forraje disponible fue 30%, mientras que los estratos de herbáceas y leñosas accesibles para el ganado fueron 80% y 50%, respectivamente. La receptividad estimada fue, en promedio, 24,3 ha UA. Esta evaluación denota la necesidad de contar con reservas de forraje para los 2 años en 10 no incluidos en el modelo. El uso de cactus sin espinas fue considerado como reserva de forraje de amortiguación. Se mencionan sus beneficios y limitaciones. La restricción principal para las plantaciones de *O. ficus-indica* para forraje en la llanura de Mendoza es la temperatura fría del invierno. Para superar este inconveniente, diez progenies de la cruza interespecífica entre *Opuntia lindheimerii* Engelm. (resistente al frío) y *O. ficus-indica* fueron examinadas por su resistencia al congelamiento. Debido a la gran importancia del cactus como cultivo apropiado para la producción de ganado en zonas áridas, la factibilidad económica de su plantación para los sistemas de producción de bovinos y caprinos fue incluida en la revisión.

Palabras clave
capacidad de carga • *Opuntia* spp. • factibilidad económica • ganado bovino • caprinos • tierras de pastos • sostenibilidad

Introduction

The major use of rangelands is grazing or browsing by livestock and wild herbivores. Semiarid and arid rangelands are often fragile and subjected to accelerated soil erosion if not managed appropriately. If rangelands are mismanaged, so that plants fail to provide sufficient soil cover, the composition of plant community changes, resulting in reduced productivity and increased erosion. Continued abuse of the rangeland system can also result in severe land degradation (23). In this sence, the importance of a correct stocking rate to achieve sustained productivity, the effects of high stocking rates on the decline of livestock productivity, the increase of financial risk and the reduction of long-term economic returns, have been strongly emphasized (22, 24, 34). This review focuses on the importance of determining the carrying capacity of the Mendoza plain and its complementation with the plantation of *O. ficus indica.*

Location, biogegraphic characteristics and production systems of Mendoza plain

Mendoza province (32°52′57'' S; 68°49'19'' W) is located in the central west of Argentina. It covers 148,827 km^2. The plain is situated approximately in the eastern half of Mendoza province and it represents about 38% of the mentioned area.

The vegetation of the Mendoza plain is typical of the Monte phytogeographic province, in which it occupies a geographically central position (32). Vegetation is an open xerophytic savanna and shrubland of *Prosopis flexuosa* DC. The herbaceous layer consists mainly of warm-season perennial grasses.

The shrub layer is made by species of 0.3 to 3.0 m high, and total canopy cover, under best range conditions, may achieve 60 to 80% (12).

The main plant species present, classified according to different life-form, life-cycle and use by cattle, are detailed in table 1 (page 298) (19).

The bioclimatic conditions may be labelled as warm-arid. The long term mean annual precipitation ranges from 150 mm in the north-eastern to 400 mm in the southeast, with a mean annual temperature varying from 13°C in the south, to 20°C in the north (14).

According to the American classification, most of soils are Entisols of the Psamment order and Torripsamment group (33). Soils in the Ñacuñán Biosphere Reserve, located in the centre of the plain (34°02' S; 67°54'W; 540 m a. s. l.) are predominantly deep and silty with sandy patches and local sand sheets covering the alluvium substrate. They present the following characteristics (33): 7.1< pH < 7.9 (fair); 0.5 < SAR < 6.0% (fair), with one exception in the deep layer (130-230 cm in sub sites dominated by *Cercidium praecox* (Ruiz & Pav.) Harms where SAR = 13.2% (high); 0.1< organic matter < 0.6% (very low); 1.5 < C/N < 7.5 (very low); 0.9 < $CaCO_3$ < 6.9% (fair), with one exception of 20.4%; 168 < N < 1,200 ppm (very low to high); 10 < P < 70 ppm (low); 812 < K < 2,300 ppm (high to very high); 0 < clay < 20%; 1.5% < silt < 80%; 20% < sand < 95%; 0.5 < EC < 10 mScm^{-1}.

Six production systems have been studied in the Mendoza arid zone, which have clearly defined characteristics (9). Two of them are located in the Mendoza plain.

The so-called "subsistence system" includes, among other areas, the north-eastern of the plain. It has the following characteristics. Livestock activity constitutes the way of life of the producer, who resides in the farm and contributes with all or a large part of the required labour.

Table 1. Main plant species present in the Mendoza plain classified according to their life-form, life cycle and use by cattle.

Tabla 1. Principales especies de plantas presentes en la llanura de Mendoza clasificadas de acuerdo con sus formas de vida, ciclo de vida y uso por los bovinos.

Specie	Life-form	Life cycle	Use by cattle
Acantholippia seriphioides (A. Gray) Moldenke	S	P	NF
Aristida inversa Hack.	G	P	NF
Aristida mendocina Phil.	G	P	F
Bouteloua aristidoides Griseb.	G	A	F
Capparis atamisquea Kuntze	S	P	F
Chloris castilloniana Lillo & Parodi	G	P	F
Condalia microphylla Cav.	S	P	NF
Conyza bonariensis (L.) Cronquist	H	A	F
Cottea pappophoroides Kunth	G	P	F
Digitaria californica (Benth.) Henrard	G	P	F
Fabiana denudata Miers	S	P	NF
Junellia seriphioides (Gillies & Hook.) Moldenke	S	P	NF
Larrea divaricata Cav.	S	P	NF
Lycium chilense Miers & Bertero var. *minutifolium* (J. Rémy) Terracino	S	P	F
Monttea aphylla (Miers) Hauman	S	P	NF
Panicum urvilleanum Kunth	G	P	F
Pappophorum philippianum Parodi	G	P	F
Prosopidastrum globosum (Gillies ex Hook. & Arm.) Burkart	S	P	F
Prosopis flexuosa DC.	T	P	F
Prosopis flexuosa DC. var. *depressa* F.A. Roig	S	P	F
Setaria leucopila K. Schum.	G	P	F
Sporobus cryptandrus A. Gray	G	P	F
Stipa tenuis Phil.	G	P	F
Tragus berteronianus Schult.	G	A	F

G: grass; S: shrub; T: tree; H: herb; P: perennial; A: annual; F: forage; NF: non-forage.
G: gramínea; S: arbusto; T: árbol; H: hierba; P: perenne; A: anual; F: forrajera; NF: no forrajera

The sociocultural environment has determined a low training context of the producer, resulting in low attached importance to the vegetal resource conservation, on which he depends exclusively.

The presence of goats, in important proportions is linked to the need for self-sufficiency of meat. In the cases in which the farm income exceeds the expenses necessary to meet the family primary needs, the surplus is destined

to increase the animal quantity. This is the strategy adopted by the producer to ensure the farm continuity and the reason why land ownership does not lead to a major infrastructure investment.

Another system, called of "profitability and/or personal valuation" includes the farms located in the central and southeast of the plain. They present the following particularities. The producer lives off the farm, manages it through salaried employees and the farm activity constitutes for him, one among other economic activities. The influence of external factors is favourable or less limiting than in the system firstly described. Almost exclusively cattle are exploited. There is a direct relationship between land ownership and infrastructure investment. Producers are more progressive than those of the other system and pay more attention to vegetal resource conservation.

Conversely, in the extensive cow-calf model in the southwest of Mendoza Province the main critical points were found in the social sphere, due to the limitation on the access to public services, poor training and associativity. The economic risk was the sustainability threshold due to the lack of marketing channels, high dependence on external inputs and low production efficiency (31).

Carrying capacity estimation

The most adequate conceptual framework to understand the factors determining the carrying capacity of animal production systems, is the model of energy flux. It suggests that domestic herbivores may consume only a proportion of Aboveground Net Primary Productivity (ANPP), known as Hervest Index, to make a sustainable use of rangelands ecosystems.

The carrying capacity of a forage resource results from a complex network of environmental factors linked to the availability of forage (rainfall, soil texture and fertility, floristic composition, etc.), environmental factors non-fodder (animal water availability, predators' incidence, extreme cold or heat, floods, snowfalls, etc.) and management factors (instantaneous grazing pressure, grazing method, energy subsidies, etc).

All of these factors interact, in turn, with the producer's decisions, which reflect his business objectives and the level of risk he assumes (7).

For estimating the cattle carrying capacity of the Mendoza plain the following factors were considered (10). Annual forage production was estimated from the dependable annual rains (*f* 0.8) for each of the six subzones of the plain because it constitutes one of the most common dependability indexes (12).

The rain-use efficiency factors (kg DM ha^{-1} $year^{-1}$ mm^{-1}) were 2.15 and 1.4 for the herbaceous and shrub forage, respectively. The herbaceous layer accessible to cattle was 80%, and browse 50%. The inclusion of woody species in the forage supply responded to their important participation in the cattle diet in the dry season: fall-winter (13) (table 2, page 300).

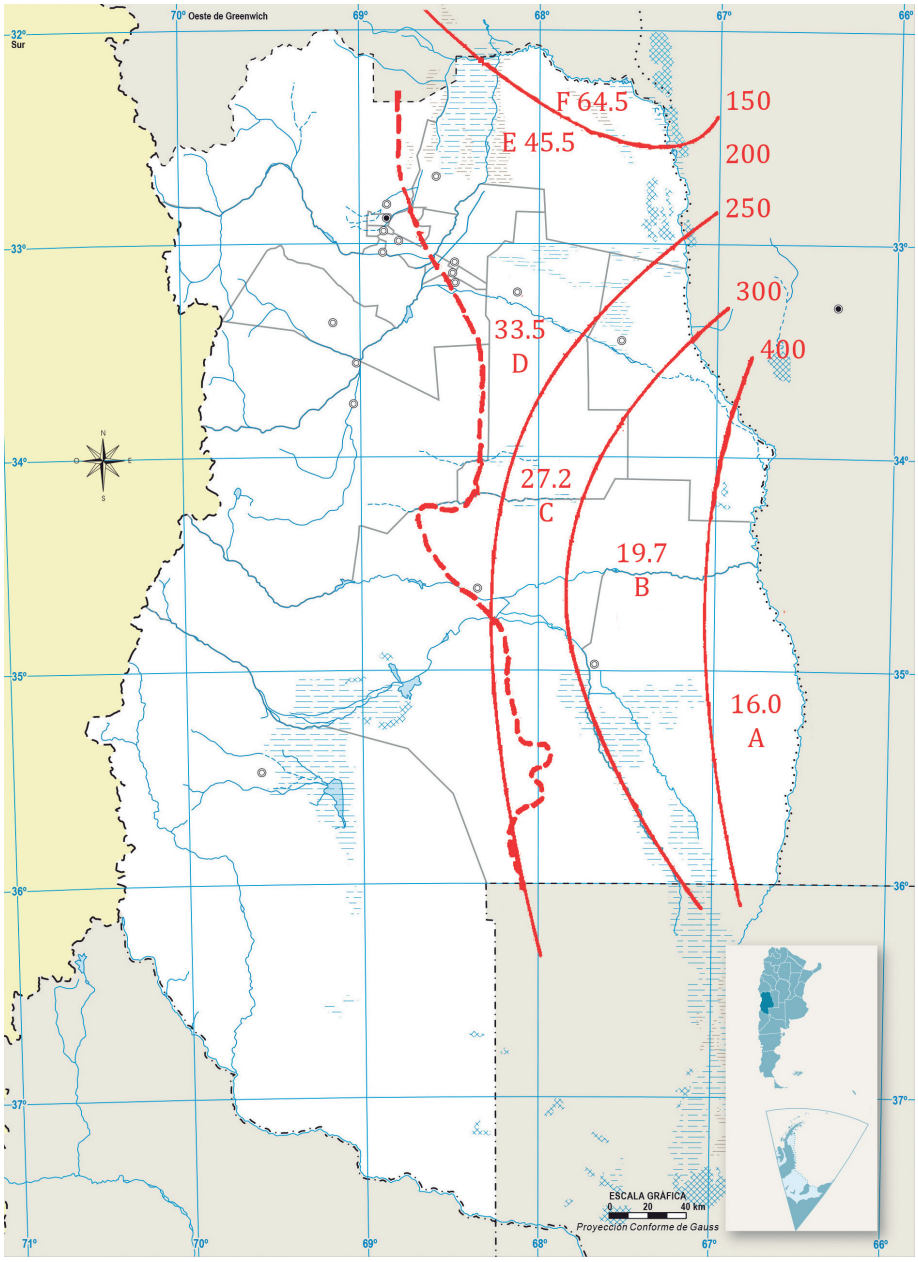
The yearlong proper use factor of available forage was 30%, given there is a growing consensus that only 25 to 30% of the maximum standing crop (MSC) of herbage should be considered as consumable forage when carrying capacity is calculated, rather than the level of 40 to 50% that used for other rangeland ecosystems (12). Further details on the procedure used for the carrying capacity estimation can be found in Guevara *et al.* (1995). The estimated carrying capacity was, on average, 24.3 ha AU^{-1}. It ranged from 64.5 and 16.0 ha AU^{-1} in the north-eastern and southeast of the plain, respectively (figure 1, page 301) (10).

Table 2. Botanical composition (% weight) of cattle seasonal diets.
Tabla 2. Composición botánica (% en peso) de las dietas estacionales de los bovinos.

Food items	Mean dietary composition (±S. D.)		
	RSB	RSH	DSB/DSH
Grasses			
Aristida sp.	2.1 (2.2)	2.8 (1.7)	1.1 (0.9)
Bouteloua aristidoides	+	5.1 (3.4)	1.3 (1.6)
Chloris castilloniana	11.2 (4.7)	12.1 (1.9)	9.0 (6.0)
Digitaria californica	10.0 (5.9)	5.5 (4.0)	5.8 (2.7)
Panicum urvilleanum	21.9 (1.4)	25.6 (7.1)	10.7 (4.2)
Pappophorum philippianum	5.0 (2.5)	7.8 (2.6)	3.9 (1.7)
Setaria leucopila	6.6 (4.9)	6.8 (2.7)	5.4 (4.2)
Sporobolus cryptandrus	7.3 (4.6)	14.1 (7.2)	5.8 (2.7)
Stipa sp.	+	1.6 (2.4)	+
Others	+	2.6 (2.3)	+
Total	65.8 (2.9)	84.0 (3.6)	44.9 (3.8)
Forbs			
Chenopodium papulosum	2.1 (2.1)	+	4.4 (8.2)
Cucurbitella asperata	+	1.6 (1.5)	+
Gomphrena mendocina	+	2.6 (4.8)	1.5 (3.5)
Others	+	2.1 (1.9)	+
Total	2.7 (2.3)	6.4 (4.9)	6.4 (8.6)
Shrubs and trees			
Capparis atamisquea	4.9 (1.8)	2.1 (2.7)	10.8 (5.0)
Ephedra ochreata	5.3 (1.8)	+	3.8 (4.1)
Hyalis argentea var. *latisquama*	12.2 (5.6)	4.2 (2.3)	29.3 (5.5)
Lycium chilense var. *minutifolium*	5.1 (2.4)	+	1.5 (0.8)
Prosopis flexuosa var. *flexuosa*	3.6 (2.3)	+	2.3 (1.2)
Others	+	+	+
Total	31.4 (2.8)	9.6 (4.8)	48.6 (8.2)

RSB=rainy season beginning (spring); RSH=highest point of rainy season (summer); DSB=dry season beginning (fall); DSH=highest point of dry season (winter). +=less than 1%. Species that contributed less than 1% were: *Bromus brevis*, *Cottea pappophoroides*, *Tragus berteronianus* and *Trichloris crinita* (grasses); *Coniza* sp., *Descurainia* sp., *Glandularia tenera*, *Lappula redowskii*, *Lecanophora* sp., *Lepidium* sp., *Plantago patagonica* and *Solanum eleagnifolium* var. *leprosum* (forbs); *Atriplex lampa*, *Bulnesia retama*, *Cassia aphylla*, *Condalia microphylla*, *Fabiana denudata*, *Geoffroea decorticans* and *Prosopidastrum globosum* (shrubs and trees).

RSB: comienzo de la estación lluviosa (primavera); RSH: punto más alto de la estación lluviosa (verano); DSB: comienzo de la estación seca (otoño); DSH: punto más alto de la estación seca (invierno). + = menos del 1%. Las especies que contribuyeron menos del 1% fueron *Bromus brevis*, *Cottea pappophoroides*, *Tragus berteronianus* and *Trichloris crinita* (gramíneas); *Coniza* sp., *Descurainia* sp., *Glandularia tenera*, *Lappula redowskii*, *Lecanophora* sp., *Lepidium* sp., *Plantago patagonica* and *Solanum eleagnifolium* var. *leprosum* (hierbas); *Atriplex lampa*, *Bulnesia retama*, *Cassia aphylla*, *Condalia microphylla*, *Fabiana denudata*, *Geoffroea decorticans* and *Prosopidastrum globosum* (arbustos y árboles).



--- Limit of the plain / — Mean annual rainfall / A to F Subzones / 16.0 to 64.5 Carrying capacity (ha AU^{-1})
Source: IGN (National Geographic Institute - Argentina).

--- Límite de la llanura / — Lluvia media anual / A a F Subzonas / 16,0 a 64,5 Capacidad de carga (ha UA^{-1})
Fuente: IGN (Instituto Grográfico Nacional - Argentina).

Figure 1. Carrying capacity of the Mendoza plain for cattle by subzones in Argentina.

Figura 1. Capacidad de carga de la llanura de Mendoza por subzonas en Argentina.

From the estimation of the carrying capacity, arises the need to have forage reserves standing from 2 years in 10 not included in the estimated model. It is important to have forage reserves for 2 years in 10 since reliable annual rainfall, that is, one that has a probability of occurrence of 80%, has been used for determining the forage production.

In this sense, it is important to bear in mind that the production of natural vegetation is not only related to average rainfall, but also to reliable annual rainfall, that is, those that have a probability of occurrence of 75-80% (12).

Use of cactus as drought insurance and its advantages and restrictions

Plantations of drought-tolerant and water-efficient fodder shrubs, especially *Opuntia* species, have been established as buffer feed reserves, a strategy to mitigate the effects of drought in animal production systems in various arid and semiarid areas of the world. In this strategy, the buffer reserve was aimed not only as "drought insurance" for inter-annual drought but also to bridge over a recurrent annual period of feed scarcity (25).

Opuntia species have the ability to withstand prolonged drought, high temperatures, as well as wind and water erosion (8).

Cactus and other drought-tolerant and water-efficient fodder shrubs can survive under rainfall as low as 50 mm on a particular year, but with neither growth nor production.

Mean annual rainfall of 100-150 mm corresponds to the minimum required to successfully establish rainfed plantations (26), with sandy and deep soils (28).

High mortality of cattle (650,000 head) occurred in northern Mexico between 1993 and 1996 as a consequence of drought. The ranchers with cactus plantations did not have, in general, great losses of livestock compared with those who did not have cactus.

Moreover, reproduction rates and levels of production of cattle, sheep and goats were superior when the ranchers supplement the normal diet of the livestock with cactus during the dry period (6). In Mexico, there are 230,000 ha cultivated with cactus (30).

In Mendoza, about 25% of bovine stock (115,000 animals) died during the dry period which lasted from late summer to October of 2009. This affected around 1,000 producers in the southwest of Mendoza plain, where 65% of cattle are concentrated (3). Also, in the north-east of the Mendoza plain, as a consequence of the mentioned drought, about 75% of the goats died and the pregnancies decreased by almost 80% (4). Producers of cattle and goats affected by drought did not have cactus plantations. In this regard, public policy and credit are essential in order to increase cultivation of this important plant (29).

The government should consider appropriate incentives for establishing fodder cactus plantations and legal tools favouring security land tenure in some areas of the plain. In this sense, the Mendoza Province Government has proposed to carry out two actions: a) to deliver provincial state lands on property to settlers who are willing to implement productive projects and b) to expropriate private land to those who have a debt to the Irrigation General Department (organism that administers the water resource in Mendoza province) that exceeds the appraisal of the land and that it is not in production.

The purpose of the second action is also to deliver these lands to those who have productive projects (5). It is believed that one of these projects would be precisely cactus plantations for fodder.

There are numerous reasons behind the diffusion of *Opuntia* spp. as forage or fodder around the world, and particularly for *O. ficus-indica*. They include: (a) the simple cultivation practices required to grow the crop; (b) rapid establishment soon after introduction in a new area; (c) easy multiplication practices that favour rapid diffusion and exchange of material among users; (d) ability to grow in very harsh conditions characterized by high temperature, lack of water and poor soil; (e) utilization in programs to prevent soil erosion and combat desertification; and (f) its response to atmospheric CO_2 level increase. These and other facts have contributed to such a wide distribution from the regions of origin in Latin America to remote areas, spanning continents, cultures and traditions (29).

On the other hand, some researchers have evaluated the effect of cactus pear inclusion in small ruminant's diets, finding that it effectively enhanced the meat fatty acids composition by increasing the proportion of the n-3 series and conjugated linoleic acid (CLA) which are beneficial to human health (2).

Under different climatic conditions, the thermal limit for frost-sensitive species such as *O. ficus-indica* is indicated by a mean daily minimum temperature of the coldest month (*m*) of 1.5° to 2.0°C (27).

The major limitation to plantations of *O. ficus-indica* for fodder in Mendoza plain, is cold winter temperatures (21). In fact, when temperature in a site located in the north-center of the plain (El Divisadero Cattle and Range Experiment Station, DCRES, 33°45' S; 67°41' W) dropped to -12.3°C in May 1996, almost all the 7-month-old plants of this specie froze to ground level. Similarly, when temperatures dropped to -16°C and -17°C on two consecutive days in August 1999, frost damage in the young cladodes from the 9-month-old plants reached 98% and the 3-year-old plants from different *O. ficus-indica* clones exhibited mean frost damage ranging from 19 to 53% (17).

In none of the four sites studied in the Mendoza plain *m* was higher than 1.5°C (18). To overcome the mentioned limitation, ten progenies of the interspecific cross between two wild, spiny Texas native *Opuntia lindheimerii* accession 1250 male parents (cold hardy, red fruits, bluish pads) and a spineless commercial *O. ficus-indica* fruit type Texas A&M University Kingsville (TAMUK) accession 1281 (low cold hardy, spineless, fast growing, red fruits, greenish pads), *O. ficus-indica* and *O. ellisiana* Griffiths were introduced to Mendoza plain and examined for freeze hardiness (20).

The trial was done during the period May-September 2009 with 320 hours with temperatures below 0°C. The number of total hours with temperatures below 0°C and the minimum temperatures were 6 h and -1.8°C, 77 h and -7.1°C, 146 h and -6.1°C, 37 h and -4.7°C, 54 h and -4.7°C in May, June, July, August and September, respectively. Frost damage in the cladodes of clones 42, 64 and 150 was significantly lower than in those of *O. ficus-indica*. Clones 46, 80, 83, 89, 94 and *O. ellisiana* had zero frost damage during the considered period (20).

Cactus could be cultivated also in Carmen de Patagones where *m* is about 2.5°C. The ten progenies of the interspecific cross previously cited could be cultivated in areas of the southwest of Buenos Aires Province with *m* lower than 1.5-2.0°C (1).

Economic feasibility of cactus plantations in the Mendoza plain

Plantations for cattle

The economic feasibility of 50-200 ha cactus plantations for drought fodder and forage production in the plain was examined by simulation models (15). Models were run with 200-400 mm annual rainfall and two management systems: cut and carry (CAC) and direct browsing (DB). Cactus production was estimated from rain-use efficiency factors: 15 kg DM ha^{-1} $year^{-1}$ mm^{-1} for 200 mm of rain, 18.8 kg DM ha^{-1} $year^{-1}$ mm^{-1} for 300 mm and 22.5kg DM ha^{-1} $year^{-1}$ mm^{-1} for 400 mm.

The value of production was estimated using shadow prices: a) the cost of energy and protein derived from those of concentrates; and b) the price of steer meat on the hoof. Cactus production was found to be feasible in the DB system with 300 mm rainfall on a 100 ha plantation and with 400 mm rainfall on a 50 ha plantation. With 400 mm rainfall, 100-200 ha plantation would be needed if the CAC system was adopted.

The profitability calculations did not take into account the secondary benefits such as runoff and erosion control, climate buffering, increased land fertility, landscaping and amenities, stabilization of animal production and reduction of the amount of water drunk by livestock, and this resulted in a very large underestimation of the economic impact of cactus plantations. Preliminary estimations of some of these benefits are included in the study. The size of cactus plantations necessary to supplement range grazing to 1,576 and 2,273 animal unit year (AUY) in a 37,500 ha cow-calf ranch were estimated to be 123 and 111 ha at 300 and 400 mm rainfall, respectively. If a 3-year cactus production accumulation and a daily consumption of 36 kg fresh material per AU were assumed, the cactus plantations necessary to feed all the cattle in the 37,500 ha cow-calf model for the entire year would be about 0.3% of the ranch size. The establishment cost of the mentioned plantations would increase the ranch investment by 7.4 to 10% at 400 and 300 mm annual rainfall, respectively. It is necessary to point out that without the incorporation of cactus plantations, the cow-calf operation size necessary to yield positive returns in the Mendoza plains was estimated to be 37,500 ha (11). This surprisingly high ranch size was a consequence of: a) the high level of risk involved with range livestock production.

The producer must balance productivity, stability and sustainability. If the production system offers high average profits (high productivity) but a great deal of year-to-year variation (low stability), or risk the long term productivity of the range (low sustainability), it may be less desirable than a system with somewhat lower productivity but greater stability and sustainability; b) the present cow-calf operation is not, in general, an intensive system *i.e.* early weaning, among other management practices, is not applied and there is no integration with cow-steer husbandry under irrigation farming; c) the meat price assumed in this analysis, representative of the 1986-1995 period, was low (15).

Introduction of cactus into goat-production systems

The study was referred to the north-eastern of the plain (16). A simulation model was run with 50, 100, 150 and 200 does and annual rainfall probabilities (*f)* from 0.1 to 0.9. Investments and costs were derived from data recorded through establishment and monitoring of experimental cactus plantations in the site

previously mentioned (DCRES). Cactus production was based on a rain-use efficiency factor of 12.5 kg DM ha^{-1} $year^{-1}$ mm^{-1} and the annual rainfall probabilities in the area (*f* 0.1 = 273.3 mm to 0.9 = 76.7 mm).

The CAC management method was considered for pen feeding during 110 days (last third of pregnancy and 60-day lactation) with 3.6 kg fresh material $goat^{-1}$ day^{-1}. A decrease in goat annual mortality from 10 to 2% and an additional annual amount of kids per goat were considered as direct benefits derived from supplementing goats with spineless cactus in the fall-winter period.

As a consequence of this practice, an additional 0.2 kids appear to be obtainable in field conditions. A secondary benefit was the reduction of water consumption by goats.

The internal rate of return (IRR) corresponding to 0.2 additional kids, and the annual additional amount of kids per goat necessary to reach an IRR equal to the opportunity cost of capital in Argentina (12%), were determined. The establishment cost of cactus plantations ranged from US$ 525 ha^{-1} (50-head goat herd; *f*0.1) to US$ 242 ha^{-1} (200-head goat herd; *f*0.9). Cost of fence installation was the main item of establishment costs in most of the analysed scenarios. This cost may be reduced if a fence made of spiny cactus is established.

If dependable annual rains (*f*0.8) were considered, IRR would be lower than the opportunity cost of capital for all goat-herd sizes, and the additional kids per goat required to reach 12% IRR would range from 0.21 to 0.29 for 200 and 50 does, respectively. If the same rainfall probability is considered, the amount of additional kids to reach 12% IRR decrease as goat-herd size increases. The differences are derived from the inverse relationship between the cost of plantation establishment and the goat-herd size.

Conclusions

The future of the Mendoza plain rangelands depends on: a) the adoption of a sustainable carrying capacity and b) the implementation of suitable crops. Regarding to the carrying capacity it is considered that the use of the dependable annual rain and a factor of use of available forage of 30%, instead of 40-50%, that is assumed for others rangeland ecosystems, would contribute to the sustainability of Mendoza plain rangelands.

The factor of use considered is more conservative due to the fragility of pastoral ecosystems of arid zones. Cactus can meet the second requirement and act as strategic food reserves to mitigate the effects of drought on livestock production systems and it could be successfully developed in the Mendoza plain, provided frost-tolerant species or clones were used.

The studies done so far, such as, identification of *Opuntia* progenies of cold hardiness and also economic feasibility of cactus plantations, are the starting point for further researches. These should address animal performance in both rangeland and feedlot in response to supplementation of its diets with cactus, including it in different forms such as fresh, dehydrated, silage or multi-nutrient blocks.

Others efforts could be directed to provide a propitious abiotic environment for a cactus to achieve higher biomass productivity and improved protein levels by interacting with nurse plants, such as *Prosopis* spp. The establishment costs of cactus plantations appear to be high and out of reach for most livestock producers.

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