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Simulation of the economic feasibility of fodder shrub plantations as a supplement for goat production in the north-eastern plain of Mendoza, Argentina

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The economic feasibility of *Atriplex nummularia* Lindl. and spineless cactus (*Opuntia* spp.) plantations for supplementing goats in the north-eastern plain of Mendoza (mean annual rainfall = 175 mm) during the fall–winter period was examined by a simulation model. It was run with 50–200 goats and annual rainfall probability (p;10–90% probability of occurrence). Cactus production was estimated from a rain-use efficiency factor of 12·5 kg DM ha^{-1} year^{-1} mm^{-1} and the annual rainfall probabilities in the area. Saltbush production (1·88 t DM ha^{-1}year^{-1}) was assumed not to be affected by annual rainfall thanks to the presence of a, 5–10 m deep, moderately saline water table (3·5–5·0 dSm^{-1}). A decrease in goat mortality and an additional number of kids per goat were considered as annual benefits derived from supplementing the goat diet. The establishment cost (US\$ ha^{-1}) ranged from 812 (50 goats; $p_{0\cdot1}$) to 317 (200 goats; $p_{0\cdot9}$) for cacti plantations and from 691 (50 goats) to 378 (200 goats) for saltbush plantations, amounts that not all stockmen could afford. The cost of metallic fence installation was the main item of establishment cost for both shrubs. The nutrient costs for shrub production were lower than those for alfalfa hay, the conventional feed used by stockmen. A decrease in doe mortality from 10% to 2% and an increase in annual kid crop ranges from 0·17 to 0·32 would economically justify shrub plantations for stockmen having more than 50 goats at annual rainfall probabilities from $p_{0\cdot1}$ to $p_{0\cdot8}$. Limitations of the modelling effort and the feasibility of using the model in other areas of the world were stated.

Keywords: simulation model; *Atriplex nummularia*; spineless cactus; forage deficit; goat supplementation; costs; benefits; internal rate of return

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Introduction

Goats are the predominant livestock species in the rangelands of the north-eastern Mendoza plain (Guevara, 1991). In 1999, this area of some 10,000 km^2 had 75,000 goats, which represented 17% of the goat herd of Mendoza. Goat production is undertaken by some 460 small stockmen; 85% of which have less than 220 goats (D. Oribe, pers. comm., 1998). Goats have been traditionally kept for meat production. Goat parturition occurs in two periods of the year: spring–summer (November–December) and fall–winter (May–July). About 70% of goats kid in the latter period, in which there is no kid production in other goat husbandry zones of Mendoza. The mean annual kid crop is 0·8–1·0 $goat^{-1}$ (J.A. Paez, pers. comm., 2001).

Mean annual rainfall in this area is 175 mm (S.D. = 77·4), most of which falls during the spring–summer period. Goats are basically fed on rangelands, and the forage on offer during fall–winter is insufficient to meet the nutrient requirements of goats. Moreover, the dry matter digestibility of the available forage is low, i.e. 50–55% (Guevara *et al.*, 1991; Van den Bosch *et al.*, 1997). As a consequence of this situation there is a high kid (40%) and doe (10%) mortality. On the other hand, not all the surviving kids reach, at the end of lactation, the fatness state required by the market. Because the demand for kids has decreased in the last few years (private buyers pers. Comm., 2001), the kid buyers were interested only in the fat-ready-to-slaughter-kids. Some stockmen use to buy alfalfa hay to supplement goats in the fall-winter period.

Plantations of fodder shrubs have been established as buffer feed reserves as a strategy to mitigate the effects of drought in animal production systems of various arid and semi-arid zones of the world (Le Houérou, 1991; Le Houérou *et al.*, 1991). In this strategy the buffer reserve was aimed not only as 'drought insurance' for inter-annual drought but also to bridge up a recurrent annual period of feed scarcity (Le Houérou, 1991), i.e. fall–winter until the onset of the new rainy season. In the north-eastern Mendoza plain, this period is actually critical because it combines feed scarcity and low forage intake with the peak of goat nutrient requirements (late pregnancy and lactation).

The ecological conditions of the area suggest that *Atriplex nummularia* Lindl. and spineless cactus [*Opuntia* spp., particularly *O. ficus indica* L. f. *inermis* (Web.) Le Houér.] appeared to be the most promising fodder shrubs among those used on a large scale in various arid lands of the world.

Atriplex nummularia is rich in nitrogen and constitutes an ideal complement to fibre- and energy-rich roughages such as range vegetation in the dry season (Silva Colomer *et al.*, 1986; Le Houérou, 1994). However, only 55% of its digestible nitrogen is retained (Le Houérou, 1992). The digestible nitrogen that is not retained in the digestion processes and is eliminated in urine and faeces is non-protein; about 50% of it is glycinebetaine. This quaternary ammonium compound is amenable to degradation by the rumen microflora when sufficient energy is available for the micro-organisms to develop and the animals and their microflora have had time to adjust to the salt content of the diet and to the consumption of non-proteic nitrogen (Le Houérou, 1992). Therefore, when the above conditions are met, the digestible nitrogen retained could be much higher than 55% as shown via pen-fed animal performance such as 100 g daily body weight gain in 45 kg fat-tail sheep (Le Houérou, 1991, 1992, 2000). On the other hand, water consumption in free-ranging animals feeding on mixed diets increased as the amount of *Atriplex* forage increased in the diet (Le Houérou, 1991). Thus, the inclusion of spineless cactus in a mixed diet with saltbush would contribute to increase the energy content of the diet and to compensate the increase in water consumption since cactus cladodes contain 80-90% water (Monjauze & Le Houérou, 1965; Le Houérou, 1991; Boza *et al.*, 1995). Moreover, data from Le Houérou (1991) suggested a very significant synergetic effect, in terms of shrub consumption and animal performance, when two or three shrubs are mixed together in the ration.

Economic aspects of spineless cactus and/or *Atriplex* spp. plantations have been studied in various areas of the world such as Tunisia (De Montgolfier-Kouèvi & Le Houérou, 1980; Le Houérou, 1989), Chile (Benjamin, 1980), NW Coast of Egypt (Le Houérou, 1997*b*), Palestine (Le Houérou, 1998*a*), the Mediterranean isoclimatic zone (Le Houérou, 2002) and Argentina (Guevara *et al.*, 1999*a, b*).

Our basic hypothesis was that the production cost of shrubs is lower than that of alfalfa hay, the conventional feed used in the area for supplementing goats during the period of forage deficit. The purpose of this study was a cost–benefit simulation analysis of the introduction of these fodder shrubs in the goat production systems of the north-eastern plain of Mendoza. This analysis includes only the direct benefits derived from shrub plantations. The external or secondary benefits such as runoff and erosion control, microclimate buffering, land fertility enhancement, landscaping and amenities, wildlife shelter and food (Le Houérou, 1994, 1996, 2002) will be assessed in a further paper.

The study area

The north-eastern Mendoza plain is located between latitudes 32–33°S and longitudes 67–69°W, approximately. The plant community includes three structural layers (Roig *et al.*, 1992): the tree layer composed of *Prosopis flexuosa* DC., and *Geoffroea decorticans* (Gill. ex Hook.) Burkart, the latter present in depressions; the shrub layer composed of *Atriplex lampa* Gill. ex Moq., and *Capparis atamisquea* Kuntze; and the herbaceous layer composed of perennial grasses and several annual grasses and forbs. Topography is almost flat. Soils are Torrifluvents and Torripsamments of a silty to loamy texture occasionally overlain by a more or less shallow layer of coarse sand. About 50% of them are saline soils; sodic soils are found in depressions. The water-table is 5–10 m deep, with EC from 3·5 to 5·0 $dS\,m^{-1}$, i.e. too saline for most conventional crops. The mean daily minimum temperature of the coldest month, '*m*', ranged from 1·1 to 3·2°C (Estrella *et al.*, 1979).

Methods

The economic feasibility of shrub production was examined by a simulation model performed on spread sheets. The model was run varying the goat herd size (50, 100, 150 and 200 does) and the annual rainfall probabilities, i.e. $p_{0\cdot1}$–$p_{0\cdot9}$ ($p_{0\cdot1}$ = 10% probability of rainfall occurrence). For establishing the goat herd sizes, the number of goats per farm was grouped into a size frequency distribution: 25–75, 76–125, 126–175 and 176–225 goats. The averages of goats per farm for these groups were about 50, 100, 150 and 200, respectively. These four goat herds comprised about 75% of the goats existing in the study area. The rainfall probabilities were estimated using the mean (175 mm) and the standard deviation (77·4 mm) and assuming a normal distribution, which is close to reality and to the variability index performance (D9−D1/D5) (Le Houérou, 1999).

Experimental bases and assumptions considered for building the simulation model

Propagation, cultivation and management of the shrubs

The basic information, derived from studies of Le Houérou (1983, 1989, 1992, 1994, 1995*a*, 1996, 1997*a, b*, 1998*b*) is shown in Table 1. This study assumed shrub

Table 1. *Basic data on propagation, cultivation and management of shrubs*

	Spineless cactus		*Atriplex nummularia*
Propagation material	Single cladodes		Nursery-grown speedlings (establishment rate = 70%)
Spacing and density		1 × 5 m; 2000 shrubs ha^{-1}	
Beginning of shrub utilization (years after planting)	5		3
Full production (years after planting)	7		6
Management system		Cut-and-carry for pen feeding	
Life-span under adequate management (years)	More than 50		More than 80

plantations would be established in areas near settlements of the herders where native vegetation is scarce, degraded and little current grazing can actually occur. Grasses which could grow in the inter-row alleys are scarce and, hence, the opportunity cost of prohibited grazing in the shrub plantations was not considered.

Each of the two species should be established in separate paddocks because *A. nummularia* shows the best development and highest productivity on medium-to-fine-textured deep soils (Le Houérou, 1992) and cacti perform better on deep, light-textured, including coarse drifting sand (Le Houérou, 1994). On the other hand, saltbush is an alternate phreatophyte species; it may be able to reach water tables as deep as 10 m below ground surface (Le Houérou, 1992). On the contrary, under favourable soil conditions, cactus roots penetrate no more than 30–50 cm into the soil. Furthermore, cacti are little tolerant to salinity above 3·0–3·5 dSm^{-1} in the saturated extract of the soil (Monjauze & Le Houérou, 1965; Le Houérou, 1996).

Planting material for cactus plantations is scarce in the study area and, hence, the establishment of a cactus nursery was considered. Because saltbush and cacti fodder can be harvested from 3 and 5 years after planting, respectively, we inferred that *Atriplex* plantation would be established 2 years later than that of cactus.

The saltbush will be established by transplanting of 'speedlings', i.e. small plantlets (5–10 cm) grown in nursery in small plastic containers for 1–5 weeks. The cost of this establishment method is lower than those for 'seedlings' (plants raised in nursery in large containers of polyethylene bags or sheaths for 12–14 weeks), but the use of speedlings significantly reduces the establishment rate in the field, particularly in arid zones (Le Houérou, 1989, 1992, 1994).

Shrub yield

Yield information from shrub plantations in Argentina is scarce (Le Houérou, 1999; Guevara *et al.*, 2000) and, hence, we appealed for data from other areas of the world. These data from abroad are commensurate, under similar circumstances, with the scant Argentina figures available.

A rain-use efficiency (RUE) factor of 12·5 kg DM ha^{-1} $year^{-1}$ mm^{-1} (Le Houérou, 1994, 1996) and the annual rainfall probabilities were used to estimate cactus yield. This RUE factor is obtainable in arid zones provided the soil is deep and sandy and

Table 2. *Cactus production according to annual rainfall probabilities and years after planting*

Annual rainfall probability (*p*)	Annual rainfall (mm)	Cactus production (t DM ha^{-1} $year^{-1}$)		
		Year 5	Year 6	From year 7 onwards
0·1	273.3	0·85	1.71	3·42
0·2	240·0	0·75	1.50	3·00
0·3	215·2	0·67	1.35	2·69
0·4	194·4	0·61	1.22	2·43
0·5	175·0	0·55	1.09	2·19
0·6	155·7	0·49	0.97	1·95
0·7	134·8	0·42	0·84	1·69
0·8	110·0	0·34	0·69	1·38
0·9	76·7	0·24	0·48	0·96

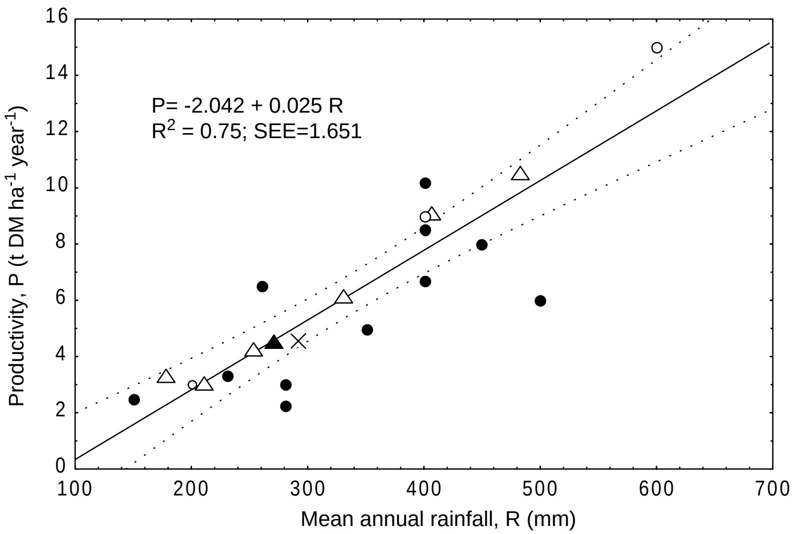

Figure 1. Relationship between productivity of cactus and mean annual rainfall estimated on the basis of data from: (▲) Libya; (○) overall Mediterranean Basin; (△) South Africa; (●) Tunisia. (×) productivity for Mendoza plain.

the competition from native vegetation and weeds is kept under control (Le Houérou, 1996). Using previous growth data from Tunisia (De Montgolfier-Kouèvi & Le Houérou, 1980; Le Houérou, 1989), we estimated cactus yields as a function of age as presented in Table 2. On the other hand, mean annual rainfall (mm) was regressed on cacti productivity (t DM ha^{-1} $year^{-1}$) based on data ($n = 22$) from cacti plantations in the overall Mediterranean Basin Countries (Le Houérou, 1996) and particularly in Tunisia (Monjauze & Le Houérou, 1965; Le Houérou, 2002) and Libya (Le Houérou, 1995*b*, 2002), and South Africa (De Kock, 1980; Le Houérou, 1994). The cactus productivity obtained in the Mendoza plain (Guevara *et al.*, 2000) was within the 95% confidence limits for the predicted values (Fig. 1). This result indicates that yields included in the model, estimated on the basis of the RUE factor corresponding to arid lands of the world (Le Houérou, 1994, 1996) could be safely extrapolated to the study area.

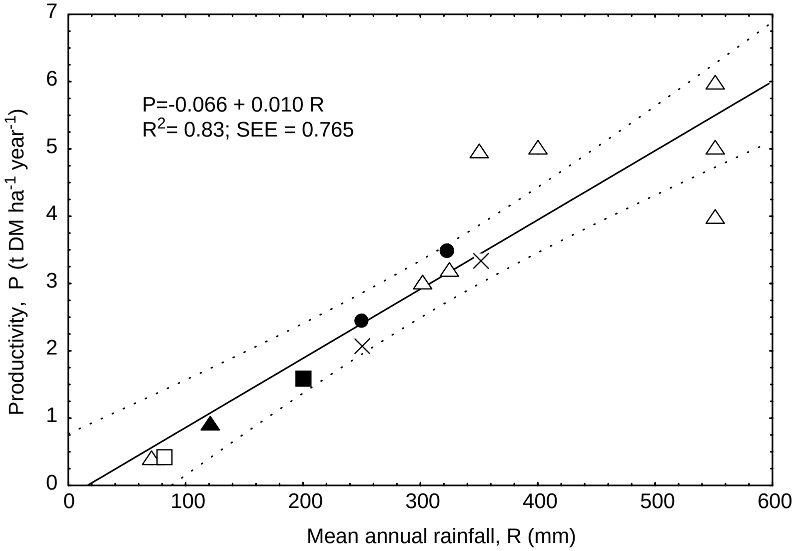

Figure 2. Relationship between productivity of *Atriplex nummularia* and mean annual rainfall estimated on the basis of data from: (■) Algeria; (□) Chile; (▲) Libya; (△) South Africa; (●) Tunisia. (×) productivity for San Juan, Argentina.

Yields for *A. nummularia* were derived from values reported by Le Houérou (pers. comm., 1992, 2001). Based on the growth data from Tunisia (De Montgolfier-Kouèvi & Le Houérou, 1980; Le Houérou, 1989), *A. nummularia* production (t DM ha^{-1} $year^{-1}$) was estimated to be 0·47 (year 3 after planting), 0·94 (year 4), 1·41 (year 5), and 1·88 (from year 6 onwards). The presence of a water-table in the study area ensures a high and regular production of satlbush and, hence, the effect of periodical droughts on its yield would be negligible (Le Houérou, pers. comm., 2001). A linear regression equation was estimated based on mean annual rainfall (mm) and saltbush productivity (t DM ha^{-1} $year^{-1}$) data (n = 13) from satlbush plantations in Tunisia (Franclet & Le Houérou, 1971; Le Houérou, 2002), Algeria and Libya (Le Houérou, 1986), South Africa (Franclet & Le Houérou, 1971; Le Houérou, 1994, 2002) and Chile (Le Houérou, 1995*c*). Saltbush productivity reported for San Juan (Le Houérou, 1999), an area located in the vicinity of the north-eastern Mendoza plain, was also within the 95% confidence limits for the predicted values (Fig. 2). As in the case of cactus, this result would indicate that saltbush yields from other areas of the world could be safely extrapolated to the study area.

Shrub intake and supplementation strategy

Data on intake of the shrubs included in the present study have been reported for treatments in which one single shrub was provided under pen-feeding conditions: saltbush (Correal & Sotomayor, 1995, 1997) or spineless cactus (F.M. Tacchini, pers. comm., 1999). Therefore, the amount of shrub browse consumed by goats included in the simulation model (0·7 kg $head^{-1}day^{-1}$ = 0·35 kg cactus + 0·35 kg saltbush) was derived from sheep feeding experiments in which the two shrubs were mixed together in the ration. The results of the large-scale experiment that involved a large number of animals and a duration of 196 days, carried out in the Libyan arid zone by Le Houérou (1991), indicate that the daily intake of *Atriplex* + cactus was 45·8 g DM $kg^{-0·75}$. This figure corresponds to a pen-feeding combined with free grazing treatment under fair to good range condition. The shrubs were sun-cured for 24 h before they were provided to the animals. The above intake would translate into a daily intake of 728 g day^{-1} for a mature 40 kg live weight goat. Coincident with the above results, the experiment carried out by Nefzaoui (2000) showed that the daily intake of Barbarine sheep wether ranged from 751 to 786 g DM when the animals fed diets based on 80% cactus and *Atriplex*. Limited amounts of wheat straw (180 g day^{-1}) and commercial mineral and vitamins supplement (30 g day^{-1}) were provided in the trial.

This study assumed that goat diet would be supplemented with shrubs (sun-cured for 24 h) for 110 days per year, i.e. during the last third of pregnancy (50 days) and the lactation (60 days).

Investment and operating costs

Information obtained by the present authors during the establishment and maintenance of experimental cactus and saltbush plantations in the Mendoza plains was used to estimate investment and operating costs.

Investment costs included: (1) removal of the scarce native vegetation present in the plantation area; (2) plantation costs (production and transport of cladodes or speedlings, planting proper, and three watering of the speedlings: one at the time of planting and the others after planting); (3) maintenance costs until the shrubs reach full production (patrolling and control of native vegetation, rodents and ants); and (4) cost of establishing a metal fence for protection against livestock and lagomorphs (US\$ 1·23 m^{-1}). The fence included one post every 10 m, two strands without electricity and an additional netwire in the lower 1 m.

Operating costs included: (1) costs of maintenance (patrolling and control of native vegetation, rodents and ants), and (2) cost of cutting and transport of fodder shrubs for pen-feeding.

Ten per cent of goat herders are salaried workers outside the goat farm. The care of shrub plantations requires occupation of total available labour and, therefore, the herder labour opportunity cost considered was 10% of the wage, i.e. US\$1.25 day^{-1}.

The mean cost of shrub production was compared to the cost of the conventional feed used in the area. Comparison was done in terms of metabolizable energy (ME) and digestible protein (DP) costs.

Benefits derived from goat supplementation and saltbush wood production

A decrease in goat annual mortality from 10% to 2% and an annual additional amount of kids per goat that could be sold at the end of lactation were considered as direct benefits derived from the supplementation of goats in the fall–winter period. This additional number of kids would derive from a decrease in kid mortality and an increase in the number of surviving kids reaching at the end of lactation the fatness state required by the market. An annual additional amount of 0·3 kids $goat^{-1}$ appear to be obtainable in practice as a consequence of supplementing goats with saltbush and cactus.

The wood production in *A. nummularia* plantations is of great significance in the study area where fuelwood is scarce and valued. Therefore, the monetary value of saltbush wood production was included as financial output in the economic analysis. The monetary value was estimated based on: (1) the ratio between forage and wood (50%) reported by Le Houérou (1983, 1986); (2) the caloric content of the saltbush wood (3400 cal kg^{-1} DM) found by Le Houérou (1992); (3) the caloric content of the *Prosopis* spp. wood (4650 cal kg^{-1}DM) reported by Braun & Candia (1980); and (4) the selling price of *Prosopis* wood at farm gate (US\$ 0·03 kg^{-1}DM).

Assessment of the economic feasibility of shrub plantations

The internal rate of return (IRR) corresponding to 0·3 additional kids, and the annual additional amount of kids per goat necessary to reach an IRR of 12% were determined. The opportunity cost of capital in Argentina was considered to be 12%. A period of 30 years was used for the economic analysis. The selling prices for a kid and a goat were US$ 16 and 11, respectively. The monetary value of saltbush fuelwood was US$ 0·022 kg^{-1} DM.

Result and discussion

Plantation sizes required for supplementing goats

Atriplex plantation size required to produce enough fodder to supplement one goat during fall–winter was about 205 m^2 (Fig. 3), i.e. 1·03 and 4·11 ha for 50 and 200 goats, respectively. On the other hand, cacti plantation size necessary to feed one goat depends on annual rainfall probability, i.e. cacti plantation area ranges from 112 m^2 at $p_{0\cdot1}$ to 400 m^2 at $p_{0\cdot9}$. This translates into plantation sizes which range from 0·56 ha (50 goats; $p_{0\cdot1}$) to 8·02 ha (200 goats; $p_{0\cdot9}$). If goat herders would like to ensure enough cacti fodder for feeding goats at least in 8 years out of 10, i.e. according to cacti yields determined by the dependable annual rains, they should establish 280 m^2 $goat^{-1}$. In this case, it would be necessary to establish 2100 ha of cacti and 1538 ha of saltbush to supplement all goats in the study area, i.e. 0·0021% and 0·0015% of the area, respectively.

Establishment cost

The cost of establishment of cacti plantations (US$ ha^{-1}) decreases as both annual rainfall probability and goat herd size increase (Fig. 4). Establishment cost ranges

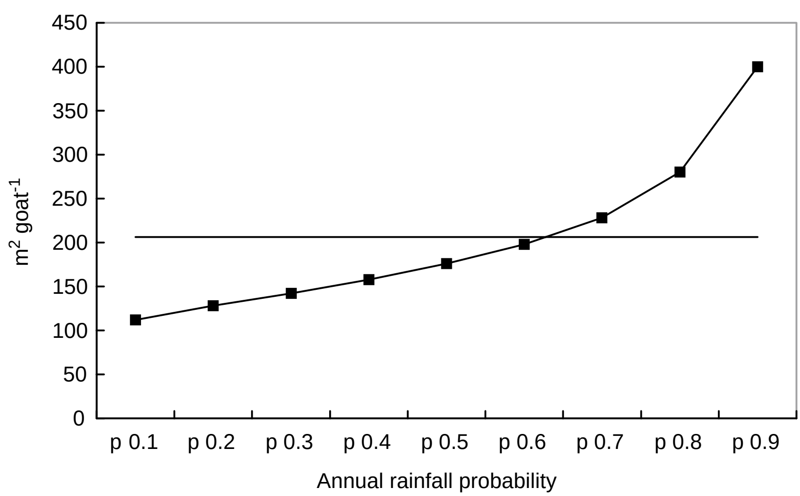

Figure 3. Shrub plantation sizes required to supplement a goat for 110 days in the fall–winter period. (–■–) Spineless cactus; (——) *Atriplex nummularia*.

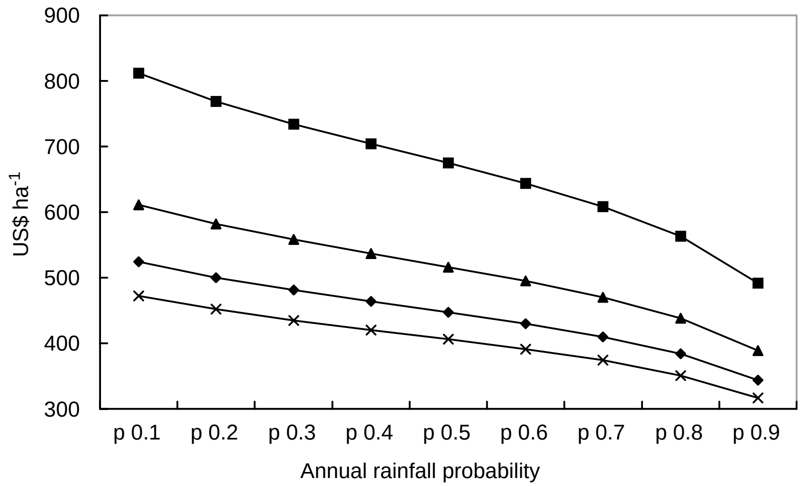

Figure 4. Cost of establishment of cacti plantations according to goat herd size and annual rainfall probability. (—■—) 50 goats; (—▲—) 100 goats; (—◆—) 150 goats; (✱) 200 goats.

from US$ 812 (50 goats; $p_{0\cdot1}$) to 317 (200 goats; $p_{0\cdot9}$). As mentioned above, cactus plantation size increases as both goat herd size and rainfall probability increase and, hence, the differences observed in the cost of establishment per hectare are derived from the decreasing importance of the cost of fence installation as plantation size increases. The mean cost of fence installation for cactus plantations represents about 77% and 63% of the establishment cost of cactus plantations for 50 and 200 goats, respectively, and about 75% and 61% for $p_{0\cdot1}$ and $p_{0\cdot9}$ rainfall probabilities, respectively. The cost of establishment, excluding the cost of fence installation, was US$ 0·073 shrub^{-1} for all goat herd sizes and rainfall probabilities.

The establishment cost of saltbush plantation (US$ ha^{-1}) varies with the goat herd size: 691, 501, 423, and 378 for 50, 100, 150 and 200 goats, respectively. These differences are also derived from the decreasing importance of the cost of fence installation as goat herd size increases, i.e. as plantation size increases. In fact, the cost of fence installation represents 71%, 68%, 66%, and 64% of the establishment cost of saltbush plantations for 50-, 100-, 150-, and 200-head goat herds, respectively. On the other hand, there are economics of scale derived from the decreasing cost of transport of speedlings as the plantation size increases. The mean cost of establishing saltbush, excluding the cost of fence installation, was slightly higher than that for cacti US$ 0·08 shrub^{-1}). It ranged from 0·10 for 50 goats to 0·07 for 200 goats.

The total cost of establishment of cactus + saltbush plantations (US$ farm^{-1}) corresponding to three selected rainfall probabilities (Fig. 5) ranges from (US$ 1166 (50 goats; $p_{0\cdot1}$) to 4095 (200 goats; $p_{0\cdot9}$). These costs appear to be high and not all stockmen could afford such investments. A reduction of the cost of fence installation could probably make the total investment affordable by stockmen. A live, defensive thorn-hedge made of a double row of spiny cactus could be established for only 40% of the cost of metal fence, but it should be established at least two years before planting the fodder shrubs (Le Houérou, 1989). This type of hedge is considered a goat-proof fence (Le Houérou, 1998*a*). Another possible alternative for diminishing the cost of fencing is the use of a solar electric fence (one post every 10 m and 9 strands up to 1·2 m). The cost of this fence is lower than that for the metal fence included in our model only for plantations higher than 1·6 ha because of the decreasing importance of the cost of the solar electrifier set as plantation size

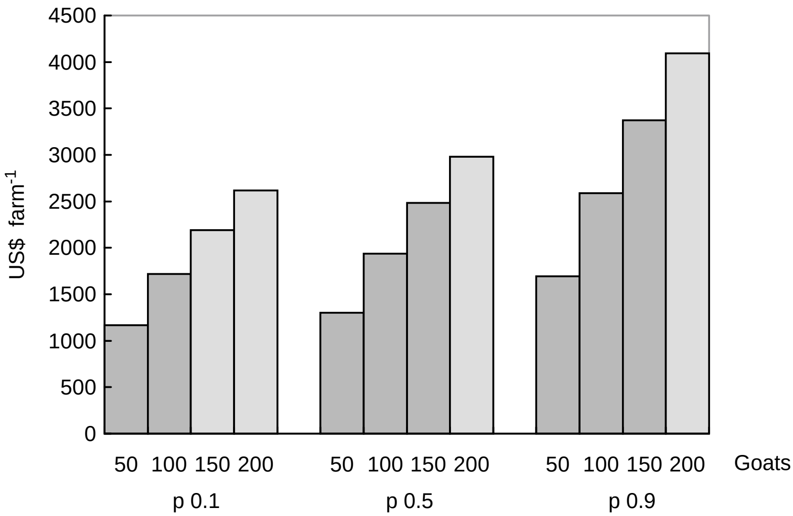

Figure 5. Cost of establishment of *Atriplex nummularia* and spineless cactus plantations for different goat herd sizes and three selected annual rainfall probabilities.

Table 3. *Nutrient content and nutrient cost for shrubs and alfalfa hay*

	Alfalfa hay	Atriplex+cactus
Nutrient content		
ME ($MJ\,kg^{-1}$ DM)	9·2	7·5
DP ($g\,kg^{-1}$ DM)	120	72·3
Nutrient cost*		
ME (US$ MJ^{-1})	0·016	0·008
DP (US$ kg^{-1})	1·25	0·83

*Nutrient cost for shrubs corresponds to shrub production cost of US$ 0·06 kg^{-1} DM.

increases. The cost of this type of fence would represent about 72% and 81% of the cost of the metal fence for the largest cactus (8·02 ha) and saltbush (4·11 ha) plantations, respectively.

Cost of shrub browse dry matter production

The cost of shrub browse production (US$ kg^{-1} DM) depends on the goat herd size and the annual rainfall probability. It ranges from 0·06 (50 goats; $p_{0 \cdot 9}$) to 0·03 (200 goats; $p_{0 \cdot 1}$). The cost of alfalfa hay at farm gate was US$ 0·15 kg^{-1} DM in 2001 currency. The nutrient costs for shrub browse were lower than those for alfalfa hay (Table 3).

Internal rate of return and annual additional number of kids per goat

The IRR corresponding to 0·3 annual additional kids per goat increases as the annual rainfall probability decreases, i.e. as cactus DM production per hectare increases, and as the goat herd size increases (Fig. 6). The threshold of 12% IRR is reached in the 50-head goat herd at $p_{0 \cdot 1}$–$p_{0 \cdot 2}$. The same threshold is attained at $p_{0 \cdot 7}$–$p_{0 \cdot 8}$ in a 100-head

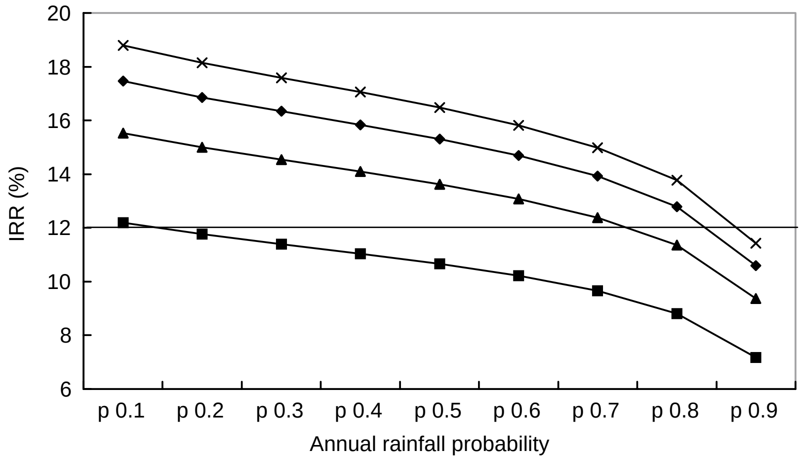

Figure 6. Effect of the goat herd size and the annual rainfall probability on the internal rate of return (IRR) of shrub plantations (see Fig. 4 for keys).

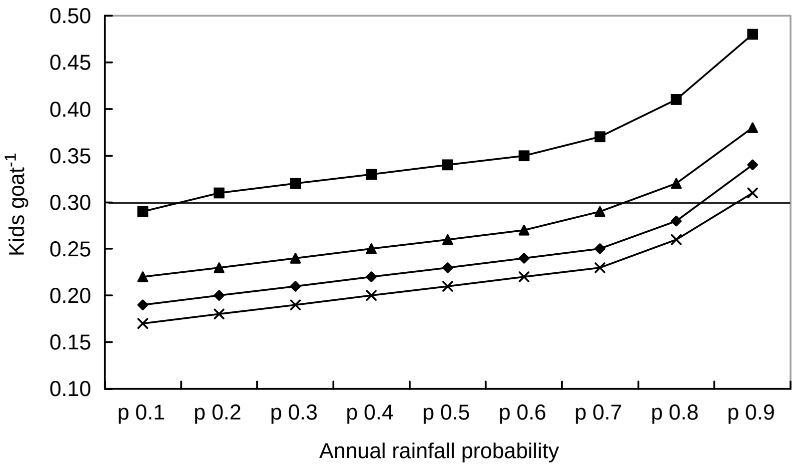

Figure 7. Annual additional number of kids per goat required to reach 12% IRR for different goat herd sizes and annual rainfall probabilities (see Fig. 4 for keys).

goat herd and at $p_{0\cdot8}$–$p_{0\cdot9}$ in 150- and 200-head goat herd. Shrub production appears not to be economically feasible at an annual rainfall probability of 0·9 for all goat herd sizes.

The annual amounts of additional kids per goat necessary to reach an IRR of 12% are presented in Fig. 7. These amounts increase as annual rainfall probability increases, i.e. as cactus yields decrease, and as goat herd size decreases. An annual number of kids per goat lower than 0·3 would be necessary to reach an IRR of 12% in the following scenarios: 200 and 150 goats at $p_{0\cdot1}$–$p_{0\cdot8}$, 100 goats at $p_{0\cdot1}$–$p_{0\cdot7}$ and 50 goats at $p_{0\cdot1}$. At an annual rainfall probability of 0·9, the additional numbers of kids per goat necessary to attain an IRR of 12% would be 0·31, 0·34, 0·38, and 0·48 for 200, 150, 100 and 50 goats, respectively.

In conclusion, our results have demonstrated that a decrease in annual doe mortality from 10% to 2% and an annual additional amount of kids per goat ranges from 0·17 to 0·32 would economically justify shrub plantations for stockmen having more than 50 goats at annual rainfall probabilities range from $p_{0\cdot1}$ to $p_{0\cdot8}$.

Limitations of the modelling effort derived from the fact that part of the experimental bases and assumptions included in the simulation model was based on data from zones of the world other than the study area. Research in progress will provide more information on the shrub productivity in the Mendoza plain. On the other hand, further studies are needed to establish, at field conditions, the daily amount of shrubs consumed by goats and the additional amount of kids per goat that might be obtained as a consequence of supplementing goats with shrubs during the fall–winter period.

The basic issue of profitability of shrub plantations has been addressed on several occasions for various areas of the world. There seems to be no overall yes or no answer: shrub plantations may be profitable or unprofitable according to circumstances (Le Houérou, 1991). Economic feasibility of shrub plantations depends on two main groups of factors: cost of establishment, including cost of fencing and yield/management. Thus, the feasibility of using our modelling framework for evaluating the economic feasibility of fodder shrubs in other areas of the world is subjected to the use of data referred to the groups of factors mentioned above adapted to the ecological and economic conditions of those areas. To allow the readers to examine their own scenarios, the spread sheets with its embedded formulas are available for the model potential users.

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