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N and P fertilization on rangeland production in Midwest Argentina

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Abstract

Low soil nutrient status may be the major limiting factor to forage production in rangelands of the Mendoza plains 4 years out of 10. We studied vegetation responses to annual applications of N and P on such rangelands. Fertilizer application rates were 0 or 25 N and 0 or 11 P (kg ha^{-1}) in a factorial arrangement. Dry matter production of grasses and palatable shrubs and crude protein (CP) content of grasses were determined annually from 1996 to 1998. Experimental plots received rains of 189, 278, and 346 mm during the 3 study years compared to mean growing season rainfall of 258 mm. Forage production was increased by N+P fertilization only in 1998 (1,390 vs 980 kg ha^{-1}, $P < 0.05$), producing 16.5 kg forage kg^{-1} N applied. Crude protein concentration was increased by N fertilization in 1997 (6.3 vs 5.3%, $P < 0.05$) and N+P application increased in 1998 (6.8 vs 5.7%, $P < 0.05$). Nitrogen and P application increased seasonal rain-use efficiency when the rainfall exceeded 300 mm. In 1998, the increase of grass production per kg N applied with and without P was 18.4 and 12.4 kg, respectively. The break-even point between rain and nutrients as the main primary production determinant on sandy soils in the central Mendoza plains is around 400 mm year^{-1} instead of 300 mm in other arid lands of the world. The value of meat increment derived from the N fertilization, with and without P application (US\$ 0.07 ha^{-1} year^{-1} kg^{-1} N) was lower than the fertilizer cost (US\$ 0.87 kg^{-1} N). A 5-fold increase in forage yields would be required to offset the cost of fertilizer. Fertilizer application did not increase forage production enough to be profitable for cattle production at present fertilizer and meat prices.

Resumen

El contenido bajo de nutrientes del suelo puede ser el factor limitante principal de la producción de forraje en las pasturas naturales de la llanura de Mendoza en 4 años de 10. Se estudió la respuesta de la vegetación de esas pasturas a aplicaciones anuales de N y P. Las dosis aplicadas de fertilizantes fueron (kg ha^{-1}): 0 o 25 N y 0 u 11 P en un diseño factorial. Se determinó anualmente la producción de materia seca de las gramíneas y leñosas forrajeras y el contenido de proteína bruta (PB) de las primeras, desde 1996 a 1998. La lluvia media anual durante la estación de crecimiento en el sitio de estudio fue de 258 mm, mientras que las parcelas experimentales recibieron 189, 278 y 346 mm durante los tres años de estudio. La producción de forraje se incrementó como consecuencia de la aplicación de N+P sólo en 1998 (1.390 vs 980 kg ha^{-1}, $P < 0,05$), lo que correspondió a 16,5 kg de forraje por kg de N aplicado. La fertilización con N incrementó el contenido de PB de las gramíneas en 1997 (6,3 vs 5,3%, $P < 0,05$) y la aplicación de N+P la aumentó en 1998 (6,8 vs 5,7%, $P < 0,05$). La aplicación de N+P incrementó la eficiencia estacional de uso de las lluvias cuando éstas fueron mayores que 300 mm. En 1998, el incremento de la producción de gramíneas por kg de N aplicado, con y sin agregado de P, fue de 18,4 y 12,4 kg, respectivamente. El punto de quiebre entre la lluvia y los nutrientes, como determinante principal de la producción primaria en suelos arenosos de las llanuras centrales de Mendoza, está alrededor de 400 mm por año, en vez de 300 mm en otras zonas áridas del mundo. El valor del incremento de carne que derivaría de la aplicación de N, con y sin adición de P (US\$ 0,07 ha^{-1} año^{-1} kg^{-1} N) fue menor que el costo del fertilizante (US\$ 0,87 kg^{-1} N). Se requeriría que la producción de forraje se incrementara 5 veces para compensar el costo del fertilizante. La aplicación de fertilizantes no aumentó suficientemente la producción de forraje para que esta práctica sea rentable en la producción de carne bovina, dados los precios de fertilizantes y carne actuales.

Key Words: crude protein, seasonal rain-use efficiency, nutrient use efficiency, range fertilization economics

As aridity increases, the importance of rainfall as a limiting factor to primary production increases (Le Houérou 1983, Le Houérou et al. 1988). The break-even point between nutrients and rainfall as being the focal point and major determinant in arid land primary production is around a mean annual rainfall of 300 mm on coarse sandy soils, as was demonstrated by Tadmor et al. (1972) and Van Keulen (1975) for the Northern Negev and by Penning de Vries and Djiteye (1982) for the Sahel of Mali. This rainfall has a 40% probability of occurrence in the central Mendoza plains (Guevara et al. 1997).

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The rangelands of the Mendoza plains of Argentina occupy an area of 5.6 million ha. About two-thirds of the Mendoza cattle population (318 x 10^3 head) was concentrated in this area in 1998. Economic analyses for cow-calf operations of various size classes conclude that most operations are negative while a very small number are marginally positive (Guevara 1992, Guevara et al. 1996a). This suggests action is needed to increase the economic performance of animal production systems.

Range development programs designed to attain higher productivity include fertilization, among other practices (Le Houérou 1995, Guevara et al. 1997). In Argentina, fertilization experiments have been performed outside of the arid zones. Under arid conditions similar to the Mendoza plain, low levels of N+P fertilization (10–20 kg ha^{-1}) increased forage production by a factor of 3 to 5 in Israel and the Sahel of Mali (Van Keulen 1975, Penning de Vries and Djiteye 1982). In the Indian arid region, annual application of 20 kg N ha^{-1} more than doubled forage yields 7 years out of 10 (Rao et al. 1996).

The objective of this study was to determine the effects of annual, low-level N and P fertilization on forage production, crude protein content of grasses, seasonal rain use efficiency and nutrient use efficiency in mid-west Argentina. A brief economic analysis was also performed.

Materials and Methods

Study area

This study was conducted at El Divisadero Cattle and Range Experiment Station (33°45' S, 67° 41' W, elev. 520 m), in the north central Mendoza plain, mid-west Argentina. The climate is temperate-warm. Average maximum daily temperatures ranged from 32.4 in January to 14.9°C in July. Average minimum temperatures ranged from 16.0 in January to -0.9° C in July (Personal communication, Estrella et al.). Mean annual rainfall for 1987–98 was 303.4 mm (SD = 96.6) with nearly 85% occurring during the growing season.

Soils are Torripsamments with greater silt content in interdunal depressions. Some major soil characteristics include: pH, 6.4–7.6; organic matter (Walkley-Black method), 0.09–0.22 %; total N (Macro-Kjeldahl method), 360–420 ppm; extractable P (bicarbonate extraction, Arizona method), 9–20 ppm; extractable K (nitric acid extraction, Pratt method), 990–1,420 ppm; and EC of soil saturation extract, 0.17–0.38 mS cm^{-1} (Masotta and Berra 1994).

The vegetation is an open xerophytic savanna and shrubland of *Prosopis flexuosa* DC. (algarrobo dulce). Warm-season grasses dominate the herbaceous vegetation with *Panicum urvilleanum* Kunth (tupe) as the major species. The other grasses present include *Aristida mendocina* Phil. (flechilla crespa), *Aristida inversa* Haeck. (flechilla), *Chloris castilloniana* Lillo & Parodi (falso plumerito), *Digitaria californica* (Benth.) Henr. (pasto algodón), *Pappophorum philippianum* Roseng. (pasto blanco), *Setaria leucopila* (Scrib. & Merr.) Schum. (cola de zorro), and *Sporobolus cryptandrus* (Torr.) A. Gray (gramilla cuarentona). *Capparis atamisquea* Kuntze (atamisque) was the principal palatable woody species.

Experimental procedures

In October 1995 a 40 x 40-m study area was selected and treatments randomly assigned to 4 plots within each of 4 blocks. Each treatment plot was 7 x 7 m with a distance between plots of 1 meter. Treatments were repeated on the same plots for 3 years (1995, 1996, and 1997). Fertilizer application rates were 0 or 25 N and 0 or 11 P (kg ha^{-1}) in a factorial treatment arrangement. Ammonium nitrate (30% N) and triple superphosphate (39% P_2O_5, i.e. 17% P) were the N and P sources, respectively. Fertilizer was broadcast by hand and then buried by a rake without disturbing the vegetation. Half of the N and all of the P were applied at the beginning of the rainy season (mid-October). The remaining N was applied at the peak of the rains (January). The experimental area was excluded from grazing during the experiment.

Herbaceous vegetation was harvested annually within eight, 1.0-m^2 permanent quadrats located within each plot when grasses reached maturity. Vegetation was handclipped at ground level, separated into species, oven dried at 60°C, and weighed to determine dry matter production. Height, crown width and basal diameter of the stems of each woody species present in the plots were recorded at the beginning of the study and annually. Total dry biomass of woody species was calculated based on allometric relations between plant dimensions and dry weights as described by Braun et al. (1978). Aboveground annual productivity of palatable woody species was estimated via the assumption that biomass increment was equivalent to the deciduous production, which amounts to 14% of aboveground phytomass (Braun et al. 1978).

Crude protein (CP) of harvested grasses was determined using 1 composite sample of each species per single treatment plot by micro-Kjeldahl (N x 6.25), in 1997 and 1998.

Calculations and statistical analyses

Seasonal rain-use efficiency (S-RUE) was determined by dividing forage yield over total rainfall of the growing season. From data on fertilizer rate and forage production greater than the yield of no-fertilized plots, nutrient use efficiency was calculated as kg dry matter kg^{-1} fertilizer applied. The growing season rainfall probabilities at the study site were calculated assuming data were normally distributed.

Three-way Within-Subjects (Repeated Measures) ANOVA was performed for each response variable (forage production, crude protein content and seasonal rain use efficiency). The Tukey's HSD test was used to assess differences among treatment means ($P < 0.05$).

A brief economic analysis was conducted using April 1999 prices (US$ 0.87 kg^{-1} N, and US$ 0.8 kg^{-1} meat on the hoof). A conversion rate of 32 kg of consumable forage per kilogram of meat on the hoof in cow-calf operations (Guevara et al. 1996b) was assumed. It was also assumed that there were no residual effects of fertilizers applied.

Results and Discussion

Rainfall and forage production

The experimental plots received a total of 189 and 278 mm of rainfall during the 1995–1996 and 1996–1997 growing seasons, which were lower and slightly higher than normal, respectively (Table 1). In 1998 the growing season rainfall was greater than the long-term mean.

There was a significant yield response to N and years. Furthermore, there was a significant N by year interaction. Application of N, P, and N+P did not affect forage yields in 1996 and 1997 (Fig. 1). In 1998, yield from N+P application was higher than that from no-fertilization. If the average forage yield over the 3 study years are compared, the application of N, P, and N + P did not affect forage yields.

According to the rainfall probabilities in the growing season at the study site, rainfall of 335 mm, similar to that occurred in 1997–98, would occur 2 years out of 10. Thus we would expect rainfall adequate to obtain yield responses to N+P applications in at least 20% of the growing seasons. In this study, yield responses to N+P fertilization occurred 1 year out of 3. The difference is probably due to the limited sample size of this study.

Forage production from N+P application was around 40% above the yield from non-fertilized plots in 1998. The response to fertilization in this study was lower than that in the Sahel of Mali because the mean annual rainfall was 250 mm lower, while

Table 1. **Rainfall at El Divisadero Cattle and Range Experiment Station in 1995 to 1998, compared to the 11-year mean.**

Period	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Growing season total	Annual total (Aug–Jul)
	mm							
1995–96	6	76	28	42	17	20	189	281
1996–97	3	16	85	114	24	36	278	344
1997–98	7	23	62	107	90	57	346	414
Mean	24	42	55	64	42	31	258	303

Table 2. Mean annual aboveground primary productivity of palatable woody species on a Mendoza plain rangeland with different fertilizer application rates, 1995–98.

Fertilizer rate N–P	Year 1995	1996	1997	1998
(kg ha^{-1})	kg dry matter ha^{-1}			
0–0	140	160	160	180
25–0	100	100	100	100
0–11	50	50	50	50
25–11	150	140	150	130

the substrates and soils were almost identical in both sites. On the other hand, the probability of occurrence of 300 mm rains reaches 90% in the Sahel (Penning de Vries and Djiteye 1982, Le Houérou 1989) and, therefore, nutrients are more often the main limiting factor to primary production.

Forage production from N, P and N+P applications was higher in 1998 than those in the previous years. Average forage yield was different over years (380, 660, and 1,150 kg ha^{-1} during 1996, 1997, and 1998, respectively).

Fertilizer application or growing season rains did not affect aboveground primary production of palatable woody species (Table 2). The aboveground production estimated during the experiment strongly depended on the production levels that existed in 1995. The roots of atamisque, the main palatable woody species, usually reach water tables as deep as 20–30 m (Roig and Ruiz Leal 1959) and production, therefore, is little affected by rains. This result supports the role of browse species as stabilizers of the forage productivity in arid lands.

Crude protein content

Nitrogen fertilization affected the crude protein (CP) content of grasses. The CP content from N application in 1997 and from N + P application in 1998 was higher than that of the grasses from the plots without fertilization (Fig. 2). The CP content from each treatment did not differ between the 2 study years. If the average CP content over the 2 years is compared, the values from N and from N+P applications were higher than that from grasses without fertilization and did not differ from the P application. Increases of CP content due to N or N+P applications has been reported in numerous studies (Stephens and Whitford 1993, Rubio et al. 1996, Veneciano and Terenti 1997, Gillen and Berg 1998).

Seasonal rain-use efficiency

Nitrogen fertilization and years significantly affected seasonal rain-use efficiency (S-RUE). The S-RUE from N+P application was higher than P application in 1996, but fertilizers did not affect S-RUE in 1997 (Fig. 3). In 1998, S-RUE from N+P application was higher than that from no-fertilization and from P application.

In 1998, S-RUE from N application, with and without P, was higher than those in 1996 and 1997. Average S-RUE was higher in 1998 (3.3 kg ha^{-1} mm^{-1} year^{-1}) than in 1997 (2.4) and 1996 (2.0). This indicates that N application affected S-RUE only if rainfall through the growing season was higher than 300 mm.

The average efficiency over years from the control (2.4 kg ha^{-1} mm^{-1}) was lower than that previously estimated for the central Mendoza plain (Guevara et al. 1996b, 1997). The difference is probably due to the lower contribution of woody species at the current study site.

Nutrient use efficiency

Nutrient use efficiency increased as the growing season rainfall increased (Table 3). This agrees with the results of Rubio et al. (1996). In 1998 the ratio of kg herbage produced versus kg fertilizer applied was 18.4, and 12.4 kg for N applications with and without P, respectively. The N use

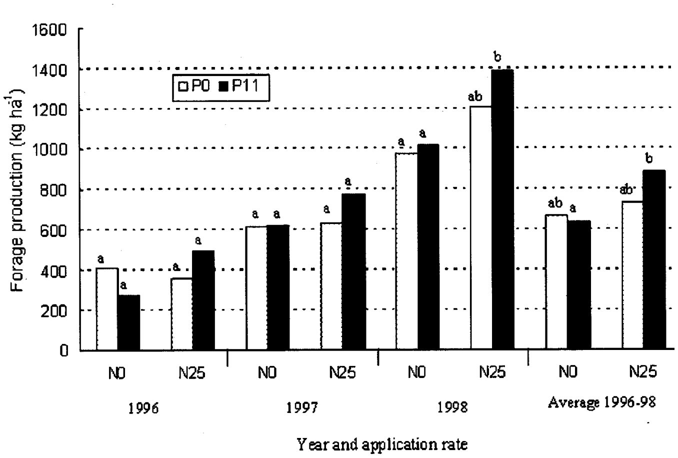

Fig. 1. Mean annual forage production on a Mendoza plain rangeland with different fertilizer application rates, 1996–98. Bars within years sharing a common letter are not significantly different (P > 0.05).

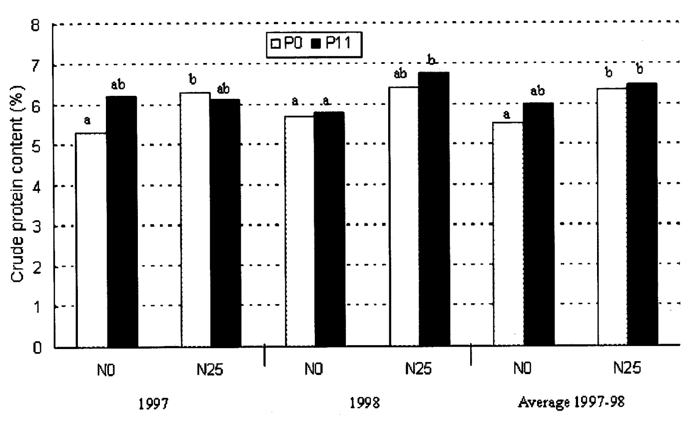

Fig. 2. Mean annual crude protein content of grasses on a Mendoza plain rangeland with different fertilizer application rates, 1997–98. Bars within years sharing a common letter are not significantly different (P > 0.05).

Table 3. Nutrient use efficiency on a Mendoza plain rangeland with different fertilizer applications, 1996–98.

Fertilizer	Nutrient use efficiency			Average
	1996	1997	1998	
($kg\ ha^{-1}$)-	- - - - - - - -	kg dry matter kg^{-1} fertilizer	- - - - - - - -	- - - - - - - -
N 25 (without P)	–	0.9	9.2	2.7
N 25 (with P)	3.4	6.6	16.5	8.8
P 11	–	0.8	3.7	–

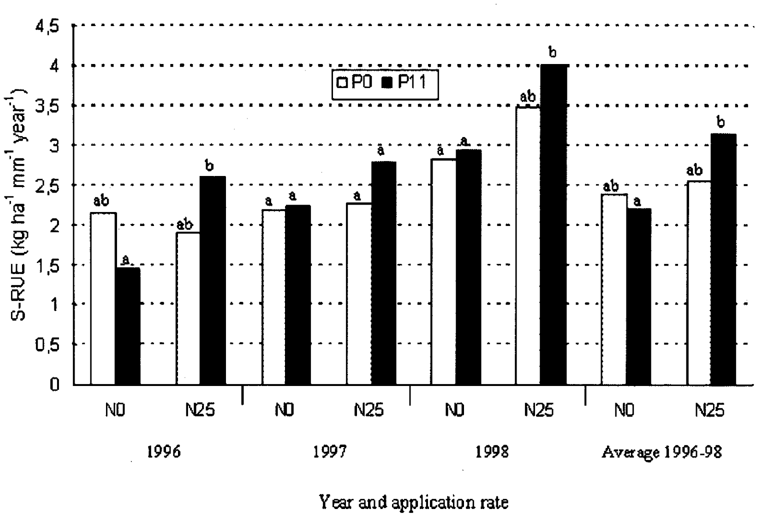

Fig. 3. Mean annual seasonal rain use efficiency (S-RUE) on a Mendoza plain rangeland with different fertilizer application rates, 1996–98. Bars within years sharing a common letter are not significantly different (P > 0.05).

efficiency without P application was lower than the range of 15 to 40 kg herbage production kg^{-1} N applied for warm-season grasses (Wilkinson and Langdale 1974, Tucker and Murdock 1984).

Economic analysis

Using the forage yields from 1998, the N fertilization yielded 322 kg (mean of production values from N fertilization with and without P application) above the non-fertilization treatment. This additional yield corresponds to about 73 kg of consumable forage ha^{-1} (Guevara et al. 1996b). This translates into meat production of 2.3 kg ha^{-1} $year^{-1}$ or 0.09 kg meat ha^{-1} $year^{-1}$ kg^{-1} N. The value of this meat increment was US$ 0.07, lower than the fertilizer cost (US$ 0.87 kg^{-1} N). A 5-fold increase in forage yields would be needed to offset the cost of fertilizers. This result agrees with findings in the Sahel, where the increase in primary production would have to be multiplied by a factor of almost 10 to make range fertilization economically feasible (Le Houérou 1983, 1989 p. 103). The ratio for the Sahel was estimated considering only the herbage yield while in this study the shrub production was also considered.

Conclusions

Application of N+P increased forage yield, crude protein content of grasses and seasonal rain-use efficiency when the growing season rains were higher than 300 mm. The break-even point between rain and nutrients as main primary production determinant on sandy soils in the central Mendoza plains is around 400 mm per year instead of 300 mm in other arid lands of the world. Rainfall greater than 400 mm has a 20% probability of occurrence and, therefore, rainfall is more often than nutrients the limiting factor to forage production. Our N+P fertilization rates did not increase forage production enough to be profitable for cattle production at present fertilizer and cattle prices.

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