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The comparative influence of past management and rainfall on range herbaceous standing crop in east-central Argentina: 14 years of observations

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Impacts of six initial treatments and rainfall on maximum above-ground herbaceous standing crop were assessed in 1978 and annually from 1984 to 1992 in rangelands of east-central semi-arid Argentina. Treatments applied in 1977–1978 were: (1) untreated control; (2) burning; (3) herbicide application (shrub control); (4) Old Field 1 or (5) Old Field 2 (areas previously exposed to different degrees of mechanical soil disturbance for 25 years); and (6) overgrazing. Domestic herbivores were excluded thereafter from all treatments until 1993.

During 1984–1992, total above-ground herbaceous standing crop often remained greater in both Old Fields than in the other treatments; highest mean values were 2336 and 1640 kg ha^{-1} for Old Field 1 and Old Field 2 treatments, respectively. Lowest total above-ground standing crops in all treatments (M = 296–475 kg ha^{-1}) occurred in 1989, the year with the lowest annual rainfall (257·5 mm). Desirable perennial grasses contributed most (44–100%) to total herbaceous standing crop in all treatments during the study period. Most of this standing crop was made up of the cool-season grasses *Piptochaetium napostaense, Poa ligularis, Stipa clarazii, S. papposa* and *S. tenuis*. Annual rainfall was closely related ($p < 0·05$) to total herbaceous and desirable perennial grass standing crops in most treatments, and accounted for most of the variation in herbage production between years.

Keywords: perennial and annual grasses; annual forbs; rainfall; standing crop; burning; overgrazing; shrub control; soil furrow

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Introduction

Range inventory and assessment of primary production are important for planning range development (Le Houérou *et al.*, 1988). One of the main factors affecting primary production in arid and semi-arid rangelands is rainfall (White, 1985; Le Houérou *et al.*, 1988). Although rainfall can be very variable in the east-central rangelands of Argentina (Cabrera, 1976), quantitative measurement of its effect on herbage standing crop is lacking. This information is important because it could serve as a basis for determining the long-term influence of rainfall increases (e.g. cloud stimulation) or decreases (e.g. long-term droughts), and in formulating guidelines for proper stocking rate management. Dynamic shifts in herbage standing crop can also occur with removal of woody plants (Vallentine, 1990), control of woody vegetation using herbicides (Meyer & Bovey, 1985), burning (Wright & Bailey, 1982), mechanical disturbance of soil (White *et al.*, 1981), and overgrazing (Vallentine, 1990). Moreover, the relative impacts of these treatments have been shown to vary in concert with climatic variations and post-treatment management (Gartner, 1988). Increasing herbaceous production while controlling undesirable species through use of herbicides, fire or mechanical treatments would increase the value of the treated area. Therefore, this study sought to examine the effects of chemical shrub control, burning, soil furrow, overgrazing and rainfall on herbage standing crop of east-central rangelands in Argentina over several years.

Materials and methods

Study area

This study was conducted at the research field site of the experimental farm of Patagones (40° 39' S, 62° 54' W; 40 m a.s.l.) located 22 km north of Carmen de Patagones. The site is within the phytogeographical Province of the 'Monte' (Cabrera, 1976). The tree layer may be composed of occasional individuals of *Prosopis caldenia* (Table 1). The community is characterized by an open shrubby layer which includes herbaceous species of different desirability for livestock production. In this study, annual or perennial grass and forb species of the herbaceous layer were classified according to their degree of acceptance by livestock as desirable, intermediate (grazed when desirable species are not available) or undesirable (only cut off when a better forage is not available) (Table 1). Except for *Sporobolus, Aristida* and *Pappophorum* species which are warm-season grasses, all other perennial grass species regrow in fall, remain vegetative during winter, and flower and set seed in spring and early summer. Desirable annual grass and forb species complete their life cycle within the period from fall to spring. Regional topography is typically a plain; therefore neither runoff nor runon was very likely a contributing factor in this study. Soil texture ranges from loamy and loam-sandy to loam-clay-sandy. Average soil pH is 7·6, organic carbon is 0·6%, organic matter is 1% and total nitrogen is 0·006%.

Long-term (1901–1950) annual rainfall is 331 mm, with a mean annual temperature of 14·6°C, absolute minimum temperature of –7·6°C (August), absolute maximum temperature of 43°C (January), mean annual relative humidity of 60%, and mean annual wind speed of 13 km h^{-1}. Various climatic parameters obtained from 1984 to 1992 using a meteorological station located at the study site are shown in Fig. 1.

Treatments and field sampling

Before treatments were imposed at the study site, the plant community was

Table 1. *Major species composition of the community at the research field site, which is typical of east-central rangelands in Argentina within the phytogeographical Province of the Monte*

		Grasses				Forbs	
Trees	Shrubs	Desirable	Perennial intermediate	Undesirable	Annual desirable	Perennial undesirable	Annual desirable
Prosopis caldenia Burkart	*Chuquiraga erinacea* D. Don	*Bromus brevis* Nees	*Aristida pallens* Cav.	*Sporobolus rigens* (Trin.) Desv.	*Bromus catharticus* Vahl	*Bacharis ulicina* Hook. & Arn.	*Erodium cicutarium* (L.) L'Hér.
	Condalia microphylla Cav.	*Koelleria permollis* Nees	*A. spegazzinii* Arech.	*Stipa ambigua* Speg.	*B. mollis* L.		*Medicago minima* (L.) Grufberg
	Geoffroea decorticans (Gill. ex Hook. & Arn.) Burkart	*Pappophorum caespitosum* Fries	*A. subulata* Henrard	*S. brachychaeta* Godron	*Hordeum murinun* L		
	Larrea divaricata Cav.	*P. subbulbosum* Arech.	*A. trachyantha* Henrard	*S. trichotoma* Nees	*Lolium multiflorum* Lam.		
	Lycium chilensis Miers ex DC. var. *minutifolia*	*Piptochaetium napostaense* (Speg.) Hack.	*Stipa speciosa* Trin. & Rupr.		*Schismus barbatus* (L.) Thell.		
	Schinus fasciculatus (Gris.) I.M. Johnston	*Poa lanuginosa* Poir.			*Vulpia megalura* (Nutt.) Rydb.		
		P. ligularis Nees ex Steud.					
		Sporobolus cryptandrus (Torr.) A. Gray					
		Stipa clarazii Ball					
		S. papposa Nees					
		S. tenuis Phil.					

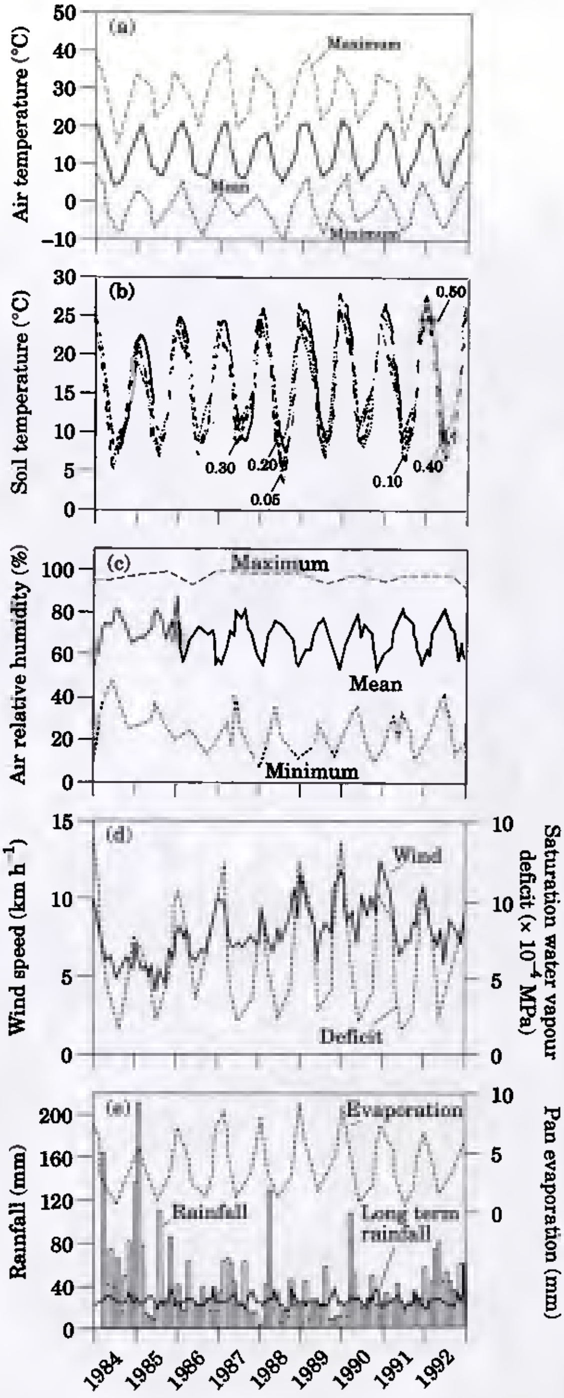

Figure 1. (a) Absolute monthly maximum and minimum, and mean monthly air temperatures, (b) mean monthly soil temperatures at 0·05, 0·10, 0·20, 0·30, 0·40 and 0·50 cm depth, (c) absolute monthly maximum and minimum, and mean monthly relative humidities, (d) mean monthly wind speed and saturation water vapour deficit, and (e) mean monthly pan evaporation, monthly rainfall and long-term monthly rainfall during 1984–1992 at a meteorological station located at the study site.

characterized ($N = 20$ stands) on 1 November 1977 by using the abundance-dominance/sociability index of Braun Blanquet (Mueller-Dombois & Ellenberg, 1974). Species with the highest index for the shrubby, forb and grass layers were *Chuquiraga erinacea* (M = 2·3), *Bacharis ulicina* (M = 1·2) and *Stipa tenuis* (M = 4·4), and the community was then classified as an open shrubland of *Ch. erinacea* and *Condalia microphylla* within a continuous herbaceous layer of *S. tenuis*. The study was initiated thereafter on areas which had been previously subjected to continuous grazing by cattle and sheep, and then exposed to different managements. One area (20 ha) was cleared of trees and undergrowth, and cropped from 1951 until 1975. Previous to cultivation, half of this area (Old Field 1) had been exposed to a more severe grazing than the other half (Old Field 2) because of its greater proximity to a water source for animals. During this period, an adjacent area (95 ha) which had not been cleared was grazed by cattle and sheep. Access of domestic herbivores was then excluded in both areas from 1975 to 1993. However, the 95 ha area was exposed to three different managements between December 1977 and March 1978: one site (34 ha) remained untreated (control), another site (37 ha) was burned (burned), and herbicides (shrub control) were applied on the third site (24 ha) for controlling shrubs. The last studied area was an adjacent site which had been severely overgrazed (overgrazing) until 1981, and then excluded from domestic herbivory grazing until 1993.

Burning was effected on 3 March 1978. At this time, maximum and mean air temperatures were 23·5 and 14·4°C, respectively, mean relative humidity was 49%, and wind speed and dry weight of fine fuel load were 22 km h^{-1} and 438 kg ha^{-1}, respectively. One year after burning ≥ 50% of plants of *Geoffroea decorticans*, *C. microphylla*, *Lycium chilensis*, *C. erinacea*, *Larrea divaricata* and *Schinus fasciculatus* had produced basal regrowth. Chemical shrub control for this study has already been reported by Digiuni (1983). Briefly, an aerial application of Tordon 213 (2 l ha^{-1}) and 2,4,5,-T (4 l ha^{-1}) was made on 29 December 1977, when mean air temperature and relative humidity were 18·7°C and 58·0%, respectively, rainfall was 108 mm during December, and shrubs were at the reproductive stage of development. Herbicides were very effective in producing death or total defoliation with no basal regrowth in *G. decorticans*, *C. microphylla*, *L. chilensis* and *L. divaricata*, and less than 50% defoliation in *C. erinacea* immediately after their application. Sixteen months later, however, 80–90% of *G. decorticans* and *C. microphylla* plants had not produced any regrowth, but the remaining plants and those of *L. chilensis*, *C. erinacea* and *L. divaricata* were less than 50% defoliated. Unfortunately, lack of enough manpower at the research station prevented from studying how shrubs recovered afterwards.

By mid-November 1978, percentage cover was determined per species within each treatment ($N = 50$) by randomly distributing 20 × 20 cm quadrats following the canopy-cover method of Daubenmire (1959). Maximum above-ground standing crop was also estimated at the control, Old Field 1, Old Field 2, burned and shrub control treatment sites in 1978 ($N = 50$), and at these and the overgrazed site from 1984–1992, by hand clipping live + recent dead herbage; harvesting began when major forage species reached maturity, usually late December or early January. No determinations were effected during 1979–1983 because of economic constraints. At harvesting time during 1984–1992, 30 randomly distributed, permanent plots (0·5 × 0·5 m) were clipped to 30–50 mm stubble height in each treatment. Herbage was separated by species, except in the 1978 sampling when only total herbaceous standing crop was measured, and dried in a forced draft oven at 70°C until constant weight. Vegetation standing crop production was then expressed on a dry weight basis. Clipping by species permitted us to express species composition as a percent of total herbaceous standing crop production. Within the desirable annual grass or forb group, a species was separated from the remaining total standing crop when its contribution to it was substantial.

Rainfall-use efficiency is defined as kg of forage (oven-dry) produced per mm of rainfall received, and is based on the plant growth and rainfall measured between harvests (Wight & Black, 1972).

Standing crop data were analysed using two factorial ANOVA (species × treatments within each year) and means were separated where appropriate using Fisher's Least Significant Difference ($p < 0·05$). The percentage contribution of each species to total standing crop within each species group is presented only with descriptive purposes. These compositional data cannot be analysed using the two factorial ANOVA described above and multivariate analysis of variance (MANOVA) should be used instead after breaking the structure of compositional data. This is out of the scope of this paper since major emphasis has been placed on standing crop data and their relationship to rainfall. Simple linear regression analysis was developed to predict changes in maximum standing crop production of each species; desirable, intermediate or undesirable perennial grasses; desirable annual grasses or forbs; or total herbaceous standing crop in response to variable annual rainfall for several land uses during 1984–1992. When there was no significant differences among regression lines of the different treatments within each species, species group or total herbaceous standing crop, the standing crop data of these treatments were pooled and just one regression line was obtained following Neter *et al.* (1985). The procedure outlined by these authors was also followed to test for equality of slopes when the regression lines were unequal.

Results and discussion

Maximum above-ground herbaceous standing crop

One year after treatments, the lowest and highest total herbaceous standing crops were obtained in the burned (M = 967 kg ha^{-1}, 52% of control) and Old Field 2(M = 3804 kg ha^{-1}, 203% of control) treatments, respectively (data not shown). Similar results were obtained by Bartos *et al.* (1994) and Cook *et al.* (1994). Again, mechanical treatments increased total forage production in rangelands (Griffith *et al.*, 1985), possibly due to the release of plant nutrients as a result of soil disturbance (Wight & Siddoway, 1972; Wight & White, 1974; Haferkamp *et al.*, 1993).

Total herbaceous standing crop during 1984–1992 ranged from 295 (overgrazing, 1989) to 2335 (Old Field 1, 1985) kg ha^{-1} (Fig. 2). These values are within the range reported by Digiuni (1983), Cano (1988) and Fresnillo Fedorenko *et al.* (1991) for rangelands in the Calden District. Total herbaceous standing crop was lower ($p < 0·05$) in the control than in the Old Field 1 treatment in 1984–1988 and 1991, and than in the Old Field 2 treatment in 1986–1988 and 1991 (Fig. 2).

Except in 1989, the control and burned treatments had a similar ($p > 0·05$) total herbaceous standing crop during 1984–1992 (Fig. 2). The control and shrub control treatments had a similar ($p > 0·05$) total herbaceous standing crop between 1984–1992, except in 1989 and 1992 when it was greater ($p < 0·05$) in the control than in the shrub control treatment (Fig. 2). Meyer & Bovey (1985) also found that dry weight of grasses on a rangeland pasture in east-central Texas treated with 2,4,5-T was not significantly different from that in untreated areas 4–17 months after treatment. With the exception in 1986 and 1987, total herbaceous standing crop during the study period was greater in the control than in the overgrazing treatment although differences were only significant ($p < 0·05$) in 1989 and 1990 (Fig. 2). Archer & Smeins (1991) have already reported that increased grazing intensity may decrease herbaceous standing crop in several arid or semi-arid ecosystems of North and South America, and Australia.

Desirable perennial grasses constituted from 44% (1988, Old Field 2) to 100% (1984 and 1985, burned) of total herbaceous standing crop in the different treatments

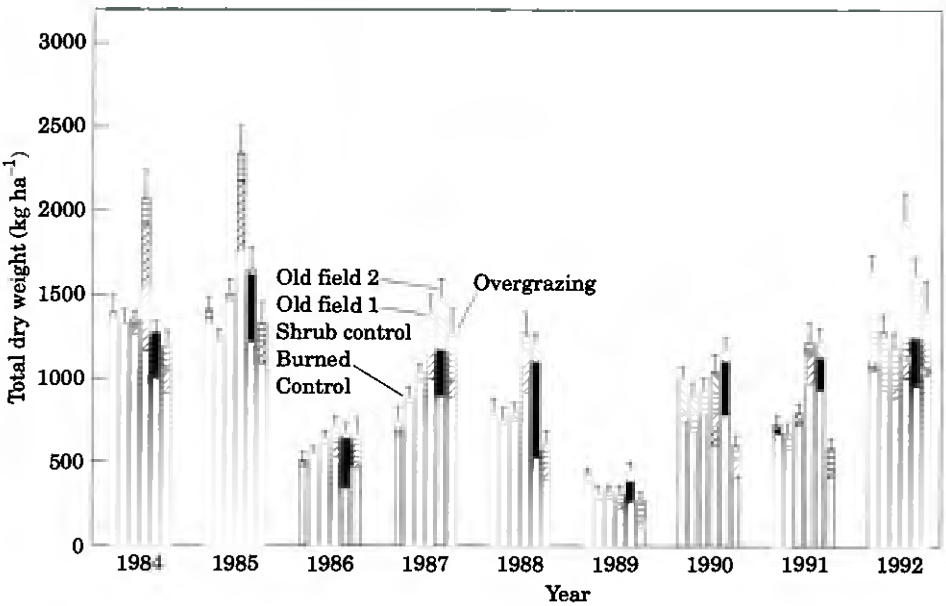

Figure 2. Total herbaceous standing crop is composed by desirable (□), intermediate (■) and undesirable (▨) perennial grasses, and desirable annual grasses (▤) and forbs (▧) in the control, burned, shrub control, Old Field 1, Old Field 2 and overgrazing treatments during 1984–1992. Each histogram is a mean of $N = 30$. Vertical bars represent 1 SEM for total herbaceous standing crop.

during 1984–1992 (Fig. 2). Fifty-six percent (1985, Old Field 2) to 99% (1992, control) of this standing crop was composed of *Piptochaetium napostaense, Poa ligularis, Stipa clarazii, S. papposa* and *S. tenuis* (Table 2). The standing crop of these grasses was more than 1·2 times greater in the control than in the overgrazing treatment in six out of the nine study years. Fresnillo Fedorenko *et al.* (1991) reported similar results. The combined contribution of *P. ligularis* and *S. clarazii* to total herbaceous standing crop was < 24% or > 44% in the overgrazing or control treatment, respectively, during 1984–1992 (Table 2). Bóo *et al.* (1993) reported that these two grazing-sensitive species are the most highly preferred by cattle in semi-arid rangelands of central Argentina, and tend to disappear from the pastures with heavy grazing. The control and burned treatments had a similar ($p > 0{\cdot}05$) desirable perennial grass standing crop during the period of study.

Intermediate perennial grasses were almost exclusively found in the Old Field 2 treatment where they represented from 14 to 45% of total herbaceous standing crop during 1984–1992 (Fig. 2); contribution of the intermediate perennial grasses to total herbaceous standing crop in the other treatments was very low (< 2% in the control and Old Field 1 treatments). These grasses included *Aristida* species (Table 2) which, like *A. subulata,* may indicate rangeland overuse (Cano, 1988). This suggests that previous to cultivation, the Old Field 2 site may have been exposed to severe overgrazing.

Undesirable perennial grasses were mostly confined to the Old Field 1 and overgrazing treatments where they represented from 1 to 35% of total herbaceous standing crop in 1984–1992 (Fig. 2). Species of this group, namely *Stipa ambigua, S. brachychaeta* and *S. trichotoma* (Table 2), are indicative of previous grazing mismanagement conducive to rangeland deterioration (Cano, 1988). A greater standing crop of these species in Old Field 1 than in Old Field 2 was probably due to

Table 2. *Percentage contribution of each species to total herbaceous standing crop within the desirable, intermediate or undesirable perennial grass species group in the control, burned, shrub control, Old Field 1, Old Field 2 or overgrazing treatment during 1984–1992. Each value is a mean ± 1 standard error of* N *= 30*

	1984						1985						1986					
Species	Control	Burned	Shrub control	Old Field 1	Old Field 2	Over-grazing	Control	Burned	Shrub control	Old Field 1	Old Field 2	Over-grazing	Control	Burned	Shrub control	Old Field 1	Old Field 2	Over-grazing
Desirable perennial grasses																		
Bromus brevis	0	8	8·1±0·1	21·2±7·7	0·4±0·4	0·4±0·4	0	0	8	22·4±6·2	1·0±1·8	8·4±0·3	0	0	0	12·4±5·6	0·1±0·1	0·1±0·1
Koeleria permollis	0	0	0	0	0	0	0	0	1·8±1·2	0	0	0	0	0·9±0·5	1·8±1·1	0	0	0
Pappophorum subbulbosum	1·4±0·7	2·5±1·3	9·4±3·5	1·9±1·8	1·7±0·9	7·6±2·4	2·2±1·2	3·3±1·8	13·6±4·3	3·6±3·3	2·6±1·5	8·0±3·3	2·3±1·1	5·7±3·4	11·6±3·6	3·5±2·3	4·2±2·1	7·6±3·4
Piptochaetium napostaense	6·4±2·2	5·7±1·4	4·4±1·6	0	12·6±4·5	30·4±3·8	5·9±1·9	6·5±1·8	3·7±1·4	0·04±0·04	8·4±3·5	38·5±5·9	7·2±2·1	6·8±1·5	4·4±1·5	0	10·1±3·6	42·7±6·4
Poa lanuginosa	1·9±0·7	7·3±1·7	2·4±0·6	0	0	2·8±0·8	4·5±1·2	7·1±1·5	3·8±0·8	0	0·1±0·1	3·5±0·9	4·7±1·4	7·4±1·1	3·6±0·9	0	0·1±0·1	3·5±0·9
Poa ligularis	24·4±3·9	17·5±3·3	34·8±4·4	3·4±1·5	0	1·5±1	16·3±3·8	13·8±2·9	24·4±3·4	4·0±2·3	0	0·6±0·5	19·9±3·6	19·9±3·6	28·0±3·9	7·8±3·4	0	1·5±1·5
Sporobolus cryptandrus	0	0	0	0	16·5±2·1	0·5±0·3	0	0	0	0	38·4±4·5	1·2±0·9	0	0	0·1±0·1	0	23·2±3·9	1·3±1·3
Stipa clarazii	37·7±4·4	33·9±3·7	26·8±4·0	5·8±1·8	4·4±1·9	8·2±1·7	37·9±4·4	35·6±3·7	23·8±3·4	5·4±2·0	3·6±1·3	5·6±1·7	26·7±3·2	27·7±3·5	18·1±2·8	9·1±2·8	8·4±2·8	5·2±2·2
Stipa papposa	6·9±1·5	11·4±3·0	14·8±2·9	12·0±3·7	1·0±0·7	15·1±3·6	7·1±2·0	12·0±3·2	16·9±3·1	6·6±2·6	0·5±0·5	15·8±5·1	6·1±1·8	9·4±2·6	19·3±3·2	12·8±4·7	1·3±0·8	18·5±6·6
Stipa tenuis	21·2±2·1	21·6±3·1	7·2±1·4	61·7±5·4	63·4±5·3	33·5±2·9	26·0±2·6	21·7±2·7	11·9±2·0	51·2±7·3	46·0±4·9	26·2±3·6	33·0±3·3	22·2±2·65	13·1±2·6	51·1±7·9	49·8±5·1	19·8±3·3
Intermediate perennial grasses																		
Aristida pallens	0	0	0	0	70·6±8·4	0	0	0	0	0	33·3±5·1	0	8	0	0	3·3±3·3	23·3±6·0	0
Aristida spegazzinii	0	0	0	0	0	0	0	0	0	0	52·2±6·1	0	0	0	0	3·3±3·3	59·5±7·7	0
Aristida subulata	0	0	0	0	6·1±4·3	0	0	0	0	8	11·0±5·3	0	0	0	0	0	13·8±5·8	0
Aristida trachyantha	0	0	8	0	0	0	0	0	0	0	00·2±0·2	0	0	0	0	0	0	0
Stipa speciosa	16·7±6·9	0	0	0	0	0	3·3±3·3	0	0	0	0	0	3·3±3·3	0	0	0	0	0
Undesirable perennial grasses																		
Sporobolus rigens	0	8	0	0	8	13·3±6·3	0	0	0	8	0	13·3±6·3	8	0	0	8	0	13·3±6·3
Stipa ambigua	0	0	0	71·8±7·0	3·3±3·3	0	0	0	0	53·5±8·30	0	0	0	8	0	42·8±8·7	3·3±3·3	0
Stipa brachychaeta	0	0	0	21·5±6·1	0	0	0	0	0	16·5±5·6	0	0	0	0	0	4·1±1·8	0	0
Stipa trichotoma	3·3±3·3	0	13·3±6·3	0	0	13·3±6·3	3·3±3·3	0	6·7±4·6	0	0	10·0±5·6	3·3±3·3	0	3·3±3·3	3·1±3·1	8	10·0±5·6

Table 2. *(Continued)*

Species	1987						1988						1989					
	Control	Burned	Shrub control	Old Field 1	Old Field 2	Over-grazing	Control	Burned	Shrub control	Old Field 1	Old Field 2	Over-grazing	Control	Burned	Shrub control	Old Field 1	Old Field 2	Over-grazing
Desirable perennial grasses																		
Bromus brevis	0	0	0	2·8±2·0	0·1±0·1	0·2±0·2	0	0	0	4·8±3·3	3·3±3·3	0	0	0	0	0	0	0
Koeleria permollis	0	0·4±0·3	0·9±0·6	0	0	0	0·6±0·6	0·4±0·4	0·5±0·5	0	0	0	0	0·2±0·2	0·2±0·2	0	0	0
Pappophorum subbulbosum	3·4±1·7	6·9±3·9	15·2±4·3	4·7±3·5	4·3±2·2	11·0±4·1	4·1±2·0	7·3±3·9	14·9±4·4	4·8±3·0	4·5±2·3	10·6±4·7	0·1±0·1	4·6±2·8	5·4±1·90	2·9±1·8	3·0±1·0	3·1±2·2
Piptochaetium napostaense	6·2±1·9	8·3±2·0	5·4±2·0	0·1±0·1	11·0±3·8	49·0±7·1	7·6±2·7	9·4±2·6	4·5±1·9	0	15·0±5·0	47·9±6·9	7·9±2·3	8·0±1·9	4·1±1·7	0	17·8±5·7	46·1±6·9
Poa lanuginosa	6·0±2·0	6·5±1·2	4·1±1·3	0	0·3±0·3	3·0±1·0	4·0±1·6	4·5±1·2	5·1±1·7	0	0·3±0·3	5·9±2·1	5·9±1·7	9·1±2·2	9·9±3·0	0	1·0±0·7	11·9±3·9
Poa ligularis	14·1±3·3	18·8±3·6	30·3±4·1	8·0±3·1	0	0·8±0·8	18·1±3·2	25·5±4·7	34·2±5·3	13·7±5·2	0	1·4±1·1	24·9±4·5	35·6±5·6	48·6±6·0	10·9±4·4	0	4·3±3·0
Sporobolus cryptandrus	0	0	0·2±0·2	0	34·6±4·4	1·3±1·0	0	0	0	0	23·6±3·7	0·6±0·6	0	0	0	0	0·9±0·4	0
Stipa clarazii	31·9±4·0	38·8±4·6	18·9±3·7	14·9±4·7	6·0±2·1	5·7±1·7	41·9±4·4	38·0±4·9	20·1±4·2	13·2±3·9	12·4±4·2	7·8±3·8	32·1±4·6	25·0±3·9	12·3±3·3	6·3±2·8	11·8±3·4	6·0±2·9
Stipa papposa	4·1±1·4	9·0±2·6	15·0±3·1	16·5±5·1	1·1±0·6	14·1±5·4	4·3±1·3	6·5±2·6	13·5±3·4	16·6±5·6	2·1±1·1	15·0±6·0	1·9±0·9	5·3±1·9	14·9±3·9	19·2±6·1	3·2±1·7	16·2±6·7
Stipa tenuis	34·1±4·0	11·3±1·5	10·0±2·5	44·9±7·3	39·3±5·0	15·0±3·5	19·4±3·2	8·3±1·3	7·1±2·0	46·8±7·5	38·8±5·9	10·8±2.6	27·1±3·3	12·2±2·4	4·7±1·5	54·0±8·0	62·2±6·4	9·0±3·5
Intermediate perennial grasses																		
Aristida pallens	0	0	0	0	11·2±4·2	0	0	0	0	0	10·5±4·9	0	0	0	0	0	1·9±1·1	0
Aristida spegazzinii	0	0	0	0	63·4±7·4	0	0	0	0	0	64·1±7·8	0	0	0	0	0	61·0±8·0	0
Aristida subulata	0	0	0	0	18·1±6·8	0	0	0	0	0	13·1±5·4	0	0	0	0	0	12·0±5·2	0
Aristida trachyantha	0	0	0	0	1·2±1·0	0	0	0	0	0	2·3±1·3	0	0	0	0	0	1·8±1·3	0
Stipa speciosa	0	0	0	0	0	0	6·7±4·6	0	0	0	0	0	0	0	0	0	0	0
Undesirable perennial grasses																		
Sporobolus rigens	0	0	0	0	0	16·7±6·9	0	0	0	0	0	16·7±6·9	0	0	0	0	0	16·7±6·9
Stipa ambigua	0	0	0	36·2±8·4	0	0	0	0	0	17·0±6·9	0	0	0	0	0	20·0±7·4	0	0
Stipa brachychaeta	0	0	0	7·1±3·6	0	0	0	0	0	19·6±7·3	0	0	0	0	0	0	0	0
Stipa trichotoma	3·3±3·3	0	6·7±4·6	0	0	3·3±3·3	3·3±3·3	0	6·7±4·6	0	0	3·3±3·3	3·3±3·3	0	13·3±6·3	0	0	0

Table 2. (*Continued*)

Species	1990						1991						1992					
	Cnntrol	Burned	Shrub control	Old Field 1	Old Field 2	Over-grazing	Control	Burned	Shrub control	Old Field 1	Old Field 2	Over-grazing	Control	Burned	Shrub control	Old Field 1	Old Field 2	Over-grazing
Desirable perennial grasses																		
Bromus brevis	0	0	0	0·3±0·3	0	0	0	0	0	3·7±3·3	0	0	0	0	0	0·8±0·6	1·0±0·5	0
Koeleria permollis	1·3±1·3	0·1±0·1	1·0±0·6	0	0	0	0	0·9±0·5	0·1±0·1	1·0±1·0	0	0	0	0·6±0·5	0·1±0·1	0	0	0
Pappophorum subbulbosum	0·1±0·1	4·0±2·2	5·9±2·1	2·6±1·8	4·5±1·7	7·6±4·1	0·3±0·2	4·4±2·3	7·3±2·0	3·9±2·5	2·6±0·9	7·7±4·0	0	3·5±1·8	7·9±2·3	2·2±1·8	2·3±1·0	8·5±4·4
Piptochaetium napostaense	8·5±3·1	8·2±2·2	2·4±1·0	0	16·8±4·9	44·7±7·6	5·1±1·5	6·5±2·0	2·7±1·3	0	16·5±5·1	45.9±7·7	10·8±3·0	6·7±2·1	3·4±1·5	0	22.5±5·5	48·2±7·7
Poa lanuginosa	4·7±2·0	6·0±2·1	7·7±3·0	0·1±0·1	0	12·6±4·7	5·2±2·1	6·8±1·6	8·3±3·3	0	0	11·4±4·9	2·6±0·8	4·9±1·8	5·6±2·4	0	0	7·2±2·7
Poa ligularis	24·7±4·9	39·3±5·3	51·9±6·1	11·8±4·6	0·7±0·6	4·8±2·9	22·7±4·0	34·3±5·3	51·0±5·9	14·5±5·1	1·4±1·0	5·0±3·2	23·4±4·3	37·9±5·6	46·2±6·1	15·6±5·1	3·4±2·4	3·7±2·6
Sporobolus cryptandrus	0	0	0	0	5·5±1·9	0	0	0	0	0	8·1±1·8	1·5±1·5	0	0	0	0	4·4±1·4	0
Stipa clarazii	33·1±4·3	26·6±4·3	13·7±3·1	9·4±3·0	9·1±2·8	3·9±2·3	35·7±4·3	32·3±4·2	16·6±3·9	12·7±3·9	18·1±4·5	4·2±2·1	37·7±4·9	34·0±4·5	18·7±4·2	14·9±4·3	23·8±5·7	6·7±3·0
Stipa papposa	0·7±0·4	7·6±2·7	12·6±3·6	19·9±5·9	2·7±1·7	17·4±6·6	0·6±0·4	7·0±2·7	9·2±2·9	10·2±4·2	3·8±2·1	19·1±6·6	0·9±0·6	5·7±2·6	12·0±3·7	12·5±4·5	1·0±0·7	11·8±5·4
Stipa tenuis	27·1±3·6	8·1±2·0	4·9±1·7	52·6±7·7	60·6±6·0	8·9±3·6	30·5±3·6	7·8±2·1	4·9±1·3	48·3±7·7	49·4±5·6	5·1±2·0	24·6±3·5	6·6±2·4	5·9±2·3	47·2±7·1	41·6±6·2	13·8±4·8
Intermediate perennial grasses																		
Aristida pallens	0	0	0	0	4·4±2·7	0	0	0	0	0	34·3±7·9	0	0	0	0	0	8·7±5·0	0
Aristida spegazzinii	0	0	0	0	51·8±8·4	0	0	0	0	0	17·8±6·3	0	0	0	0	0	50·3±9·0	0
Aristida subulata	0	0	0	0	13·8±5·7	0	0	0	0	0	7·9±4·5	0	0	0	0	0	10·9±5·6	0
Aristida trachyantha	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Stipa speciosa	3·3±3·3	0	0	0	0	0	6·7±4·6	0	0	0	0	0	3·3±3·3	0	0	0	0	0
Undesirable perennial grasses																		
Sporobolus rigens	0	0	0	0	0	13·3±6·3	0	0	0	0	0	13·3±6·3	0	0	0	0	0	13·3±6·3
Stipa ambigua	0	0	0	36·7±8·9	0	0	0	0	0	13·3±6·3	0	0	0	0	0	26·7±8·2	0	0
Stipa brachychaeta	0	0	0	0	0	0	0	0	0	16·7±6·9	0	0	0	0	0	0	0	0
Stipa trichotoma	3·3±3·3	0	6·7±4·6	0	0	3·3±3·3	6·7±4·6	0	6·7±4·6	0	0	3·3±3·3	3·3±3·3	0	6·7±4·6	0	0	6·7±4·6

the greater proximity of the Old Field 1 site to a water source for cattle, causing more severe and continuous grazing.

Species composition of the intermediate and undesirable perennial grass groups in the control was different from that in both Old Field treatments (Table 2); these treatments also showed some differences in the species composition of the desirable perennial grass group. Cultivation over 25 years must have eliminated the original vegetation in the open shrubland with a continuous herbaceous layer of *S. tenuis*. After abandonment, successful seed germination and establishment from existing seeds of *S. tenuis* in areas with low interference from surrounding vegetation (Distel *et al.*, 1992), and the very high vegetative reproduction reported for this species (Busso *et al.*, 1993), may help to explain its persistence and high contribution to total herbaceous standing crop in both Old Field treatments.

The burned treatment may have been severe enough to negatively affect intermediate and undesirable perennial grasses which were absent during 1984–1992 (Fig. 2). Bóo *et al.* (1996) reported very high mortality rates in *Stipa speciosa* after a very severe wildfire during summer time. These authors attributed this response to the fact that *S. speciosa* is not readily consumed by cattle, and accumulates old growth which may explain the high burning temperatures. Following this line of reasoning, a similar response might be expected with the other grass species of these groups because they may only be grazed when better forage is not available (Cano, 1988), which would also allow for old growth accumulation. Species such as *P. napostaense, P. ligularis, S. clarazii* and *S. tenuis* have had lower mortality rates than *S. speciosa* after a severe wildfire partly because they are readily grazed by cattle and do not accumulate as much old growth around the growing points (Bóo *et al.*, 1996).

Desirable annual grasses or forbs were either absent or contributed up to 45% of herbaceous standing crop for grasses in 1989 (overgrazing) or 22% for forbs in 1987 (Old Field 2) (Fig. 2). The contribution of these two groups was usually higher in the overgrazing or Old Field treatments than in others (Fig. 2). Annual grasses have been shown previously to increase with overgrazing in semi-arid rangelands of central Argentina (Cano, 1988), and with soil disturbance in the Great Basin (Klemmedson & Smith, 1964) and South Dakota (Gartner *et al.*, 1986). Our biomass values for *Medicago minima* and *Erodium cicutarium* during 1984–1992 in all treatments (Fig. 2) are lower than those reported by Fresnillo Fedorenko *et al.* (1991) on overgrazed and ungrazed sites of the Calden District in central Argentina. *Medicago minima*, and to a lesser extent *E. cicutarium*, however, can become major forages and an important complement of the herbivorous diet under conditions of aridity and overgrazing (Fresnillo Fedorenko *et al.*, 1991).

Relationship between maximum herbaceous standing crop and rainfall

Correlation between total herbaceous standing crop and prior year's rainfall was high ($p < 0{\cdot}05$) from 1984–1992 for all treatments (Table 3), except the Old Field 2 whose crop contained over 21% of desirable annuals and the intermediate warm season perennial *Aristida* spp. (Fig. 2). The standing crop of desirable annuals did not correlate with annual rainfall (Table 3), contrasting with other reports (White, 1985; Whisenant, 1990). Standing crop of *Aristida* spp. also did not correlate with annual rainfall, except for *A. pallens* (Table 3). It is clear that rainfall drives production variation (Griffith *et al.*, 1985; Robertson, 1987; Wellard, 1987; Milchunas *et al.*, 1994), and also that the overgrazed treatment is particularly sensitive to rainfall variation (Table 3). We thus agree with Milchunas *et al.* (1994) that the capacity to respond to wet years has not been lost through overgrazing. Precipitation-use efficiency varied from 1·1 to 3·9 throughout the observations, similar to other reports

Table 3. *Correlation coefficients (r) and predictive equations with significance levels (p) for standing crop (SC, kg ha^{-1} year^{-1}) as a function of rainfall (R, mm year^{-1}) in the control, burned, shrub control, Old Field 1, Old Field 2 or overgrazing treatement (SC=a+bR; 1984–1992). Linear regressions were developed for total herbaceous, species group (desirable, intermediate or undesirable perennial grasses, and desirable annual grasses or forbs) and species standing crops within each treatment. Values for each year came form* N=*30. Unless otherwise indicated, absence of a treatment under any species group or species means lack of that species group or species in that treatment*

	Treatment	a	b	*r*	*p*<
Total	Control	133·300	1·7620	0·87	0·005
	Burned	164·520	1·5270	0·93	0·001
	Shrub control	236·480	1·5230	0·88	0·005
	Old Field 1	58·200	2·7720	0·88	0·005
	Old Field 2	641·560	1·1800	0·62	0·1
	Overgrazing	162·680	1·5400	0·78	0·025
Species group					
Desirable perennial grasses*		147·360	1·3880	0·79	0·001
Intermediate perennial grasses					
	Control	0·360	0·0070	0·27	0·5
	Old Field 2	288·800	0·0780	0·10	>0·5
Undesirable perennial grasses					
	Control	7·227	–0·0040	0·28	0·5
	Shrub control	–11·468	0·0540	0·88	0·005
	Old Field 1	162·160	0·8590	0·83	0·01
	Overgrazing	16·416	0·1220	0·58	0·1
Desirable annual grasses*		40·120	0·1570	0·22	0·5
Desirable annual forbs*		23·924	–0·0230	0·14	0·5
Species					
Aristida pallens	Old Field 2	–26·488	0·1900	0·71	0·05
Aristida spegazzinii	Old Field 2	299·520	–0·2260	0·33	0·5
Aristida subulata	Old Field 2	15·240	0·1200	0·44	0·5
Aristida trachyantha	Old Field 2	6·344	–0·0070	0·23	>0·5
Bromus brevis	Shrub control	–0·416	0·0010	0·73	0·025
	Old Field 1	–69·400	0·2650	0·55	0·5
	Old Field 2	–6·067	0·0210	0·73	0·025
	Overgrazing	–2·762	0·0090	0·78	0·025
*Koeleria permollis**		3·142	0·0010	0·04	>0·5
Pappophorum subbulbosum	Control	4·704	0·0200	0·29	0·5
	Burned	24·884	0·0070	0·12	>0·5
	Shrub control	23·160	0·1290	0·51	0·5
	Old Field 1	38·184	–0·0310	0·31	0·5
	Old Field 2	36·332	–0·0110	0·14	>0·5
	Overgrazing	16·980	0·0860	0·42	0·5
Piptochaetium napostaense	Control	19·996	0·0790	0·77	0·025
	Burned	20·748	0·0820	0·80	0·01
	Shrub control	3·204	0·0650	0·76	0·025
	Old Field 1	0·116	0·0005	0·14	>0·5
	Old Field 2	46·840	0·0880	0·28	0·5
	Overgrazing	105·800	0·2540	0·45	0·5

Table 3. (*Continued*)

	Treatment	a	b	*r*	*p*<
Poa lanuginosa	Control	24·532	0·0150	0·25	>0·5
	Burned	7·312	0·0900	0·83	0·01
	Shrub control	31·676	0·0120	0·22	>0·5
	Old Field 1	0·349	−0·0003	0·12	>0·5
	Old Field 2	1·248	−0·0010	0·42	0·5
	Overgrazing	24·432	0·0150	0·23	>0·5
Poa ligularis	Control	−0·504	0·3660	0·91	0·001
	Burned	11·640	0·2050	0·55	0·5
	Shrub control	187·800	0·3010	0·55	0·5
	Old Field 1	89·240	0·0210	0·06	>0·5
	Old Field 2	2·400	0·0060	0·13	>0·5
	Overgrazing	34·892	−0·0240	0·33	0·5
Sporobolus cryptandrus	Shrub control	0·663	−0·0006	0·15	>0·5
	Old Field 2	−14·280	0·3320	0·42	0·5
	Overgrazing	0·284	0·0080	0·37	0·5
Sporobolus rigens	Overgrazing	28·964	0·0760	0·75	0·025
Stipa ambigua	Old Field 1	−125·120	0·5860	0·88	0·005
	Old Field 2	−0·941	0·0030	0·69	0·05
Stipa brachychaeta	Old Field 1	−47·840	0·2900	0·59	0·1
Stipa clarazii	Control	−65·160	0·7630	0·95	0·001
	Burned	−9·280	0·5770	0·90	0·001
	Shrub control	−54·600	0·4780	0·91	0·001
	Old Field 1	77·040	0·0490	0·18	>0·5
	Old Field 2	72·440	0·0360	0·09	>0·5
	Overgrazing	−11·028	0·1180	0·95	0·001
Stipa papposa	Control	−26·236	0·1270	0·79	0·025
	Burned	−17·756	0·1870	0·79	0·025
	Shrub control	−1·560	0·2720	0·76	0·025
	Old Field 1	121·760	0·0160	0·05	>0·5
	Old Field 2	16·932	−0·0100	0·27	0·5
	Overgrazing	−25·760	0·3320	0·66	0·1
Stipa speciosa	Control	1·276	0·0060	0·24	>0·5
Stipa tenuis	Control	108·140	0·2210	0·73	0·025
	Burned	−41·480	0·3230	0·79	0·025
	Shrub control	13·584	0·1240	0·56	0·5
	Old Field 1	−12·040	1·0590	0·78	0·025
	Old Field 2	115·040	0·6090	0·74	0·025
	Overgrazing	−115·872	0·4980	0·93	0·001
Stipa trichotoma	Control	7·222	−0·0040	0·28	0·5
	Shrub control	−10·064	0·0520	0·88	0·005
	Old Field 1	0·929	−0·0010	0·31	0·5
	Overgrazing	−19·780	0·0770	0·78	0·025

*Data of all treatments were pooled because their individual regeression lines were equal (p>005).

(Wight & Siddoway, 1972; Robertson, 1987; Wellard, 1987; Le Houérou *et al.*, 1988).

Contribution of desirable perennial grasses to total herbaceous standing crop in the control treatment was > 86% in seven out of the nine studied years (Fig. 2) and was significantly correlated with rainfall (Table 3). This correlation was similar to that observed in the Old Field 1 treatment where total herbaceous standing crop was composed from 5 to 35% by undesirable perennial grasses (Fig. 2), mainly *S. ambigua* and *S. brachychaeta* (Table 2).

Significant ($p < 0{\cdot}05$) positive relationships of standing crop on rainfall in the different treatments occurred in 20 out of 50 comparisons in the desirable perennial grasses, one out of five comparisons in the intermediate perennial grasses, and five out of eight comparisons in the undesirable perennial grasses (Table 3). However, slopes of the relationship between standing crop and rainfall were similar ($p > 0{\cdot}05$) in all species within any given treatment and species group; this indicates that changes in standing crop were similar among species pertaining to the same group for any given change in rainfall. *Stipa tenuis*, however, has showed a greater growth response under irrigation than *S. clarazii* (Flemmer *et al.*, 1995). Slopes were also similar ($p > 0{\cdot}05$) among treatments for any given species.

This study allowed the examination of different past management activities (i.e. burning, shrub control, soil furrow, overgrazing) on the herbaceous standing crop production of east-central rangelands in Argentina. Even though mechanical soil disturbance stimulated total standing crop production of the herbaceous layer during several years after abandonment of cultivation, rainfall appeared to be the major factor in accounting for most of the variation in herbage production between years. The positive relationship between rainfall and herbage standing crop, and the great year-to-year variations in rainfall which can occur at the east-central rangelands in Argentina continually pose a challenge for land managers. Large and rapid changes in forage production that can occur in this region require special management skills for maintenance of a viable livestock industry.

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