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Mechanical control of shrubs in a semiarid region of Argentina and its effect on soil water content and grassland productivity

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Abstract

Mechanical shrub control with roller choppers can be an inexpensive and non contaminant system for increasing grassland production in rangelands dry regions. A field experiment was carried out between October 1997 and October 2001 in the "Caldenal-Jarillal" botanic district of Argentina, a natural rangeland ecosystem with a high water deficit throughout much of the year. The trial was conducted on a Typic Ustortent and consisted of the following treatments: a control, the undisturbed natural condition (N), and rolled with (I) and without (R) interseeding of *Panicum coloratum*. Results showed that I and R improved soil water content within the upper 100 cm, dry matter production of grasses, amount of litter and water use efficiency as compared to N. The positive effect of rolling on soil water content was detected only in autumn months when water balance was positive. In summer months, when a negative water balance occurred, soil water content of rolled treatments was not different from that of the unrolled one. Consumptive water use was similar in rolled and unrolled treatments, and equivalent to the rainfall, reflecting the low soil water-holding capacity. The higher efficiency of water use in rolled treatments indicated that grasses were more efficient in using the consumed water. The I and R treatments had similar values of soil water content within the upper 100 cm, grass dry matter production, amount of litter and water use efficiency. However, a higher grass dry matter production in R than in I was noticed in part of the last year of this study. Grass dry matter production increased at the same rate in all treatments after 4 years, but litter remained constant in the unrolled treatment and decreased in the rolled ones. Mechanical shrub control with a roller chopper decreased shrub competition, thereby increasing the productivity of the ecosystem.

Keywords: Rolling; Shrub control; Water balance; Natural grasses; Semiarid regions

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1. Introduction

The “Caldenal-Jarillal” district of Argentina is a natural ecosystem with very low forage potential productivity. The most limiting factor is water availability to plants due to the high water deficit existing throughout the year (297 mm). In this ecosystem, several shrub species and palatable natural grasses coexist and are the basis of cattle production (Table 1).

This ecosystem was degraded by sheep grazing during the early part of the twentieth century. This was followed by cattle overgrazing and the frequent occurrence of both natural and anthropogenic fires, which increased shrub population and decreased relative grass cover (INTA et al., 1980). Potential productivity of grasses in this ecosystem decreased mainly due to shrub competition for water. It has been demonstrated that shrub control or elimination increases soil water contents (Sturges, 1993; Troendle and King, 1985), improves secondary grass succession, and increases grass yield and quality (Hill and Rice, 1963; Martin and Morton, 1993). Sturges (1993) found that shrub control in a rangeland of Montana had a positive effect on grassland production after 17 years.

Mechanical shrub control had not been tested in the semiarid region of Argentina. However, the technique has been successfully used in other parts of the country where branches of a shrub were not thicker than 12 cm (Casas et al., 1978). The cutting operation produces large amounts of plant residues lying on the soil, which helps to increase soil water retention, as a consequence of reduced runoff and increased infiltration (Ruan et al., 2001). This effect lasts as long as residues remain on the soil, before their decomposition.

Interseeding of graminaceous species can be a good complement to the rolling operation, increasing grassland production (Huss et al., 1986). This technique had not been tested yet in the semiarid part of Argentina.

From previous results, it was hypothesised that rolling of shrubs and interseeding of grasses would increase grass production due to an increase in soil water storage.

Table 1
Main characteristics of the studied soil

Parent material	Holocene aeolian sands	
Horizons	AC	C_k
Depth (cm)	0–12	12–99
Bulk density (mg m^{-3})	1.38	1.26
Clay (%)	7.4	6.4
Silt (%)	18.7	19.7
Sand (%)	73.9	73.9
Pores >1000 μm (%)	32.3	41.4
Hydraulic conductivity (mm h^{-1})	53.8	79.6
Water content at −0.033 MPa (mm)[a]	21.5	147.5
Water content at −1.5 MPa (mm)[a]	12	77
Organic carbon (g kg^{-1})	5.9	3.6
Nitrogen (g kg^{-1})	0.7	0.5
Available phosphorus (mg kg^{-1})	9.53	1.11
pH in the paste	8.20	8.24

[a] Determined with the pressure plate and pressure membrane methods (Cassel and Nielsen, 1986).

The objective of this study was to evaluate the effect of mechanical shrub control and gramineous interseeding on water use efficiency and grass production in a natural semiarid region of Argentina.

2. Material and methods

This study was carried out in Chacharramendi, La Pampa, Argentina (37°22′S, 65°46′W), where mean annual temperature is 15.5 °C, winter mean temperature is 7.5 °C, and summer mean is 24 °C.

The region has a continental climate, with short winter days (10 h sunlight and a mean daily heliophany of 5 h), and long summer days (14.5 h sunlight and 9.5 h heliophany).

Annual precipitation averages 492 mm (1961–2000), with a high variation coefficient (30.8%, Roberto et al., 1994). Rainfall is more concentrated in spring and summer (74.3% of annual rainfall, see Fig. 1) and the maximum evapotranspiration rate also occurs during this period. Potential evapotranspiration (Thornthwaite) for the 1976–1996 period was 789 mm, and mean annual water defficit is 297 mm. The climate of this region has been classified as semiarid (Jacyszyn and Pittaluga, 1977).

Soil parent material are holocene aeolian sediments, with high content of soft powdery lime, volcanic ash and gravel. The soil in this study was a Typic Ustortent (Jacyszyn and Pittaluga, 1977), and the mean slope of the site was 2%.

The vegetation of the studied site consisted of a perennial shrub strata, and low and intermediate height herbaceous grass strata (INTA et al., 1980). The shrub strata was composed of 0.50–3 m high trees which covered 40 % of the soil surface (Camfield, 1941). The fol-

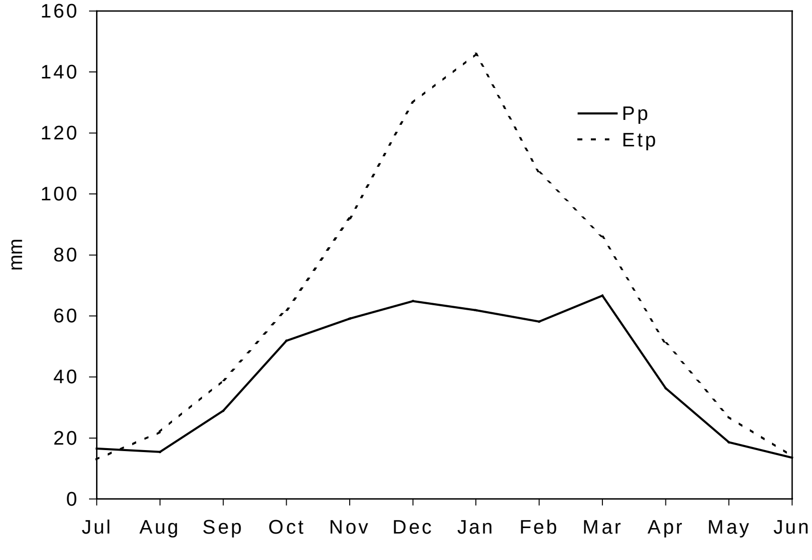

Fig. 1. Main climatic conditions of the studied region (Pp = rain Etp = potential evapotranspiration).

lowing shrub species were dominant: *Chuquiraga erinacea* Don, (370–1670 plants per ha), *Larrea divaricata* Cavanilles (430–2030 plants per ha), *Lycium chilense* (100–1970 plants per ha), and *Prosopis flexuosa* De Candolle (170–600 plants per ha). Other species such as *Condalia microphylla* Cavanilles, *Prosopidastrum globosum* Burkart, *Cassia aphylla* Cavanilles, *Ephedra ochreata* Miers and *Lycium gillesianum* Miers were scarcer.

The herbaceous strata was dominated by winter (62%) rather than by summer gramineous species (14%) or other type of herbs (24%). The dominant grasses were *Stipa tenuis* Philippi, *Poa ligularis* Nees ex Steudel, *Piptochaetium napostaense* Hackel, *Digitaria californica* Henrard, *Trichloris crinita* Parodi, *Acantholipia seriphioides* Moldenke, *Sphaeralcea crispa* Baker and *Baccharis ulicina* Hook et Arn.

A square 16-ha plot was isolated with a fence and grazed 1 month before the experiment started in October 1997. The amount of living green grass was equivalent to 500 kg of dry matter per ha.

Six months after the experiment started, the following treatments were carried out on 50 m × 400 m plots, arranged in a randomised complete block with four replicates: a natural condition (N), a rolled shrub (R) and a rolled shrub interseeded with *Panicum coloratum* cv. Klein Verde (I).

Treatment R was carried out as follows: shrub control was done on October 1997 with a 10 ton heavy roller chopper formed by a 1.5 m high and 3 m wide iron wheel, with fourteen 75 cm long and 12 cm high cutting knifes arranged along the wheel. The roller chopper was dragged by an articulated 180 HP tractor.

The I treatment consisted of shrub control with the roller chopper as in treatment R, but it included an interseeding of *P. coloratum*. With this purpose, a seeder was adapted to the roller chopper and *P. coloratum* was seeded simultaneously with shrub control at a rate of 2.5 kg ha^{-1}. This resulted in a final *P. coloratum* density of 1.2 plants m^{-2}. Plots were grazed by cattle for 25 days per year using a stocking rate of one cow per 8 ha.

Soil moisture was measured monthly in each plot, between October 1997 and October 2001, in triplicate, in the upper 100 cm soil depth using gravimetric methods. Soil water content was expressed on a soil volumetric basis using the bulk density of each soil horizon, which was determined using the core sample method (Schlichting et al., 1995).Precipitation during the experiment was measured with an automatic meteorological station. Consumptive water use (CWU) was calculated using the equation:

$$\mathrm{CWU} = \mathrm{Al} + \mathrm{P} - \mathrm{AF} \quad (1)$$

where AF is the soil water content at the end of the measuring period, Al is the soil water at the starting time of measuring period, and P is the rainfall during measuring period (López and Arrúe, 1997).

Water use efficiency (WUE) was determined using the equation:

$$\mathrm{WUE} = \frac{\mathrm{FA}}{\mathrm{CWU}} \quad (2)$$

where FA was the accumulated biomass in 1 year and CWU the consumptive water use in the same period.

Dry matter yield (DM) of the herbaceous strata was evaluated in each treatment before cattle grazing, in March, June, September and December of each year using the cutting and weigh method. With this purpose, plants were cut at soil surface height from eight random sampling sites of 0.25 m^2 each. Plant samples were then oven-dried at 60 °C.

The amount of litter or dead plant residues was determined in June 1998, 1999, 2000 and 2001 from eight random samples of 0.25 m^2 each.

Separate analyses of variance were used for each time of sampling, and comparisons of means were performed using orthogonal contrasts with a significance level of $P = 0.05$, if not specified otherwise. Additional analyses (not shown) were performed using a mixed model for repeated measures (Littell et al., 1996), for confirmatory purposes.

3. Results and discussion

Soil water content during the study was highly variable among years and seasons of the year (Fig. 2). Between October 1997 and April 1999, soil water content below the permanent wilting point (89 mm) existed in all treatments. In the period April 1999 to November 2000, a recharge of the profile occurred and soil water was above field capacity (169 mm). Such was the case in May and April 1999, when soil water content reached 206 and 211 mm, respectively. Within this period, some dry sub-periods occurred, as in February and May 2000, where soil water content averaged 81 and 102 mm, respectively. Since, April 2001, a new wet period occurred, and soil water content was above field capacity (May = 184 mm, September = 185 mm and October = 207 mm).

Although no relationship between rainfall and soil water content was found ($r = 0.35$), both variables showed similar trends in the study period. The lack of significance of this

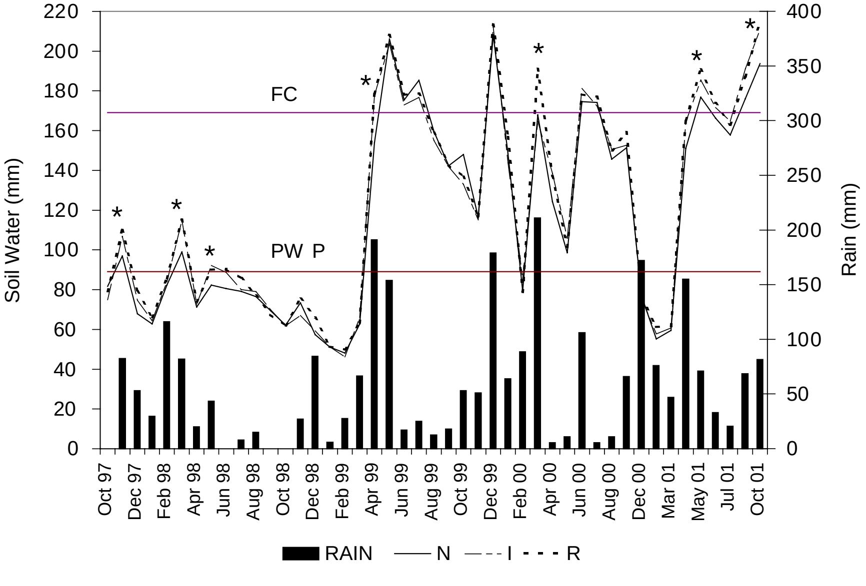

Fig. 2. Water contents of the first 100 cm soil depth in the natural (N), rolled (R), rolled plus interseeding (I) treatments and rains during the study period (FC = field capacity, PWP = permanent wilting point).

relationship was probably a consequence of plant consumption on soil water content. It must be considered that grass strata was dominated by species with different growing habits, i.e. summer and winter growth, making the water use rather variable during the year.

Soil water content during the study was lower in Summer than in Winter, although the higher rains occurred in December, January and February (185 mm). A lower evapotranspiration rate in winter allowed a relatively higher soil water content than in Summer (Fig. 2).

Even when soil water content was below the permanent wilting point (89 mm), grasses did not show wilting symptoms, which indicates that the vegetation absorbs water at soil water tensions lower than -1.5 MPa. Similar results were reported by Frasier and Cox (1994). Noy-Meir (1973) showed that vegetation of dry regions can absorb water retained by the soil at tensions of -7 to -10 MPa.

Treatments R and I showed higher soil water content than N in Autumn of all studied years, but there were no differences among treatments in the other seasons. One month after the experiment started, soil water content increased significantly in R and I in relation to N (Fig. 2). This difference existed in December 1997 and disappeared in January 1998. The effect of rolling was also detected in Autumn 1998, when R (90.3 mm), and I (88.6 mm), showed higher, but non-significant, soil water content than N (80.6 mm, $P = 0.07$). In spring and summer 1998, differences between treatments disappeared but they were detected again in autumn 1999. In April 1999, the recharge of the profile with water was significatively higher in R (178.6 mm) and I (177.7 mm) than in N (153.9 mm). Higher soil water contents of R and I than N were also in agreement with the greater soil cover with shrub residues in the rolled treatments, where the soil water evaporation was lower than in the unrolled treatment.

Grass dry matter (DM) is shown in Fig. 3. Average DM of all treatments varied between 1190 kg ha^{-1} in March 1998 and 3747 kg ha^{-1} in December 2000.

Average DM values of the 4-year study were similar between R (2950 kg ha^{-1}) and I (2886 kg ha^{-1}), but both were significatively higher than N (1530 kg ha^{-1}). These results indicate that DM of R and I were 58–140% higher than N. An exception to this general trend occurred in March and June 2001, when treatment I had higher DM values ($P = 0.05$) than R (504 and 324 kg ha^{-1}, respectively). Despite the general low proportion of *P. coloratum* in relation to the total herbaceous composition (5% at the experiment end), treatment I showed more phytomasse than R in the last 2 years.

Higher DM of rolled treatments compared to the non rolled one may be the result of a better soil water use by the herbaceous strata in the rolled treatments. These results are in agreement with those of Wight and Black (1979) who studied a semi-arid grassland in Montana USA. Sturges (1993), in a 17-year experiment, showed that shrub control doubled the productivity of the grasses in relation to treatments with no shrub control.

As shown in Fig. 4, rolling produced significative larger ($P = 0.01$) litter amounts in R (6114 kg ha^{-1}) and I (5991 kg ha^{-1}) than in N (1486 kg ha^{-1}). These larger amounts of litter in the rolled treatments may have produced their larger soil water content, due to lower evapotranspiration and higher water infiltration (Ruan et al., 2001).

Undisturbed natural condition had about the same amount of litter throughout the 4-year study (1515 kg ha^{-1}), while I and R showed a decrease (6658 to 4378 kg ha^{-1}), being 34% less at the end of the experiment. This reduction was a consequence of decomposition of the

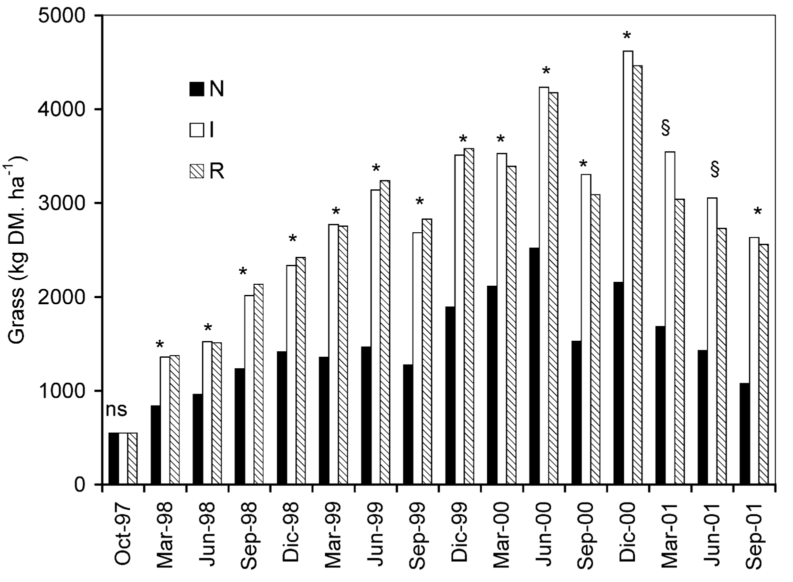

Fig. 3. Grass dry matter production (MS) in the natural (N), rolled (R) and rolled plus interseeding (I) treatments, during the study period. *Indicates significant differences between N and both I and R ($P < 0.05$), § Indicates significant differences between all treatments ($P < 0.05$).

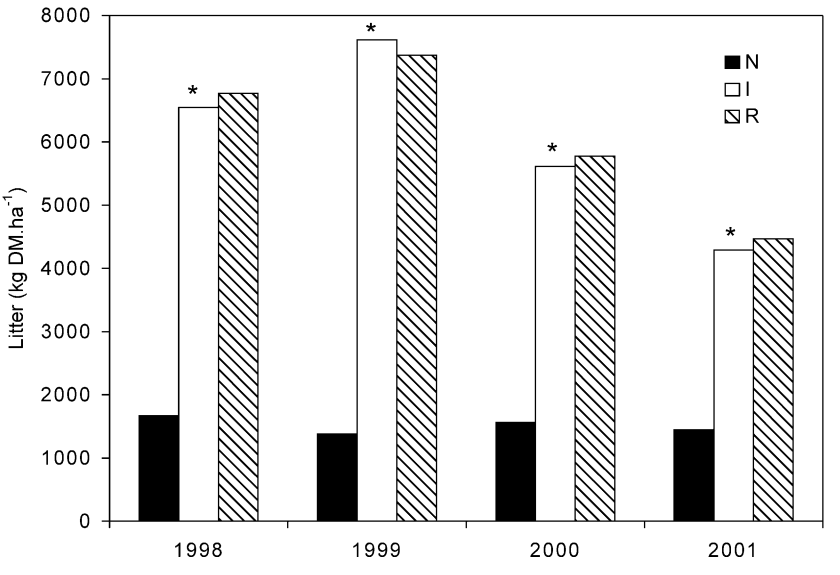

Fig. 4. Litter accumulation in the natural (N), rolled (R) and rolled plus interseeding (I) treatments in June 1998, 1999, 2000 and 2001.

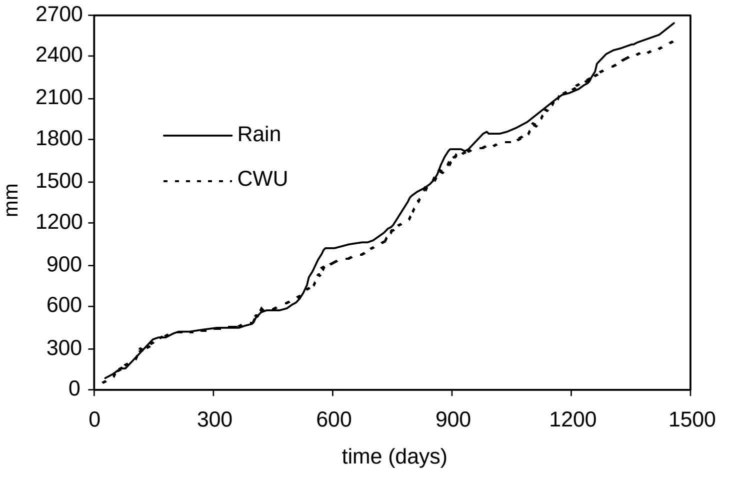

Fig. 5. Evolution of accumulated rains and consumptive water use (CWU) along the study period.

more labile plant residues (tree leaves and bark) after 4 years, since the more recalcitrant residues (mostly branches) remained almost undisturbed on the soil surface.

Monthly and annual CWU values were similar in all treatments during this 4-year study. The mean annual CWU (630 mm) was also similar to the mean annual precipitation (662 mm). Values of precipitation and CWU remained similar during the whole study period (Fig. 5). This indicates that vegetation growth was highly dependent on rainfall, which was expected in this soil with a low water storage capacity (Cable, 1980). Considering that WUE and rain are closely related, Wight and Black (1979) proposed the indistinct use of the terms water use efficiency and rain use efficiency.

The annual WUE was significantly higher in treatment R (4.22 ± 0.1 kg ha^{-1} mm^{-1}) and I (4.27 ± 0.2 kg ha^{-1} mm^{-1}) than in N (2.07 ± 0.2 kg ha^{-1} mm^{-1}). Dwyer and De Garmo (1970) showed that shrubs require more water than grasses to produce the same amount of biomass, and therefore they are less efficient in using water. This may be the cause of the lower WUE of N, where the proportion of shrubs was higher.

4. Conclusions

Mechanical shrub control with a roller chopper increased soil water content in the upper 100 cm only in autumn, and also grass dry matter production, amount of litter and water use efficiency.

Interseeding with *P. coloratum*, in addition to rolling, did not affect any of the above parameters compared to the rolling treatment alone, except that the amount of grass dry matter in part of the last years of the study was higher with rolling and interseeding.

The positive effect of rolling on soil water content was detected only in autumn months, when the hydrological balance was positive. In summer months, when a negative hydrological balance occurred, soil water content of rolled treatments was not different from that of the unrolled one.

The CWU was similar in rolled and unrolled treatments, and similar to the amount of rainfall, reflecting the low water holding capacity of the soil. On the other hand, water use efficiency, an index of the amount of water used in plant growth, was significantly higher in the rolled treatment than in the unrolled one, indicating that grasses were more efficient in using water.

Grass DM increased at the same rate in all treatments after 4 years, but litter remained constant in the non-rolled treatment and decreased in the rolled ones.

Shrub control with rolling decreased shrub competition for water, thereby increasing grass productivity.

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