TEXAS A&M UNIVERSITY
Department of Rangeland Ecology and Management
Room 225 Animal Industries Building
College Station, Texas 77843-2126
(409) 845-5579
FAX (409) 845-6430

12 de Diciembre de 1995

Estimados Oscar y Hugo,

Les acompaño una copia del manuscrito que acabo de enviar a publicar al Journal of Arid Environments. Es una revista inglesa y la dirección a la cual la mande es

Dr. G.E. Wickens
The Triangle
Buxton Road
Aylsham
Norfolk NR11 6JD
United Kingdom

En el manuscrito incluí la información que me enviaron por email y carta (n=50 en 1978). Disculpen que no les acompañe una copia en español pero por ahora no puedo hacerlo por los compromisos que tengo asumidos aqui; con mucho gusto haré una copia en español cuando regrese a Bahía Blanca el año próximo. Partiremos con mi familia de regreso a Argentina el 27 de feb. 1996 de manera que después de la primer semana de marzo ya voy a estar trabajando normalmente. Si les interesara podríamos volver a trabajar juntos a mi regreso con datos que tuvieran para analizar y que pudieran ser publicados, de la misma manera que lo hicimos con este trabajo. Tambien podríamos iniciar proyectos en asociación.

Reciban un fuerte abrazo y FELIZ NAVIDAD Y AÑO NUEVO!!!

Carlos

Carlos Busso
FAX= (409) 845-6430
email: CBUSSO@RLEM.TAMU.EDU

Al manuscrito lo hice revisar por un Profesor de este Departamento de Ecología y Manejo de Pastizales y le pareció 10 puntos.

Effects of various management treatments and precipitation on the herbaceous biomass of East-Central rangelands in semiarid Argentina

H. Giorgetti[1], O.A. Montenegro[1], G. Rodriguez[1], C.A. Busso[2,*], T. Montani[2], M.A. Burgos[2], A.C. Flemmer[2], M.B. Toribio[2] & S.S. Horvitz[2]

[1]Chacra Experimental de Patagones, Ministerio de la Produccion, C.C. 118, 8604 - Carmen de Patagones, Argentina.
[2]Departamento de Agronomia y Centro de Recursos Naturales Renovables de la Zona Semiarida (CERZOS), Universidad Nacional del Sur. Altos del Palihue. 8000 - Bahia Blanca, Argentina.
*To whom all correspondence should be addressed.

Impacts of six range treatments and precipitation on annual herbaceous biomass, taken when major forage species reached maturity, were measured in 1978 and during 1984-1992 in rangelands of East-Central, semiarid Argentina. Treatments included: (1) Untreated Control; (2) Burning; (3) Herbicide application (Chemical); (4) Mechanical 1 or (5) Mechanical 2 (areas previously exposed to different degrees of mechanical soil disturbance for 25 years); and (6) Overgrazing. Burning and Chemical treatments were applied between December 1977-

March 1978. Access of domestic herbivores was excluded thereafter from all treatments until 1993.

During 1984-1992, total annual herbaceous biomass was often greater in both Mechanical than in the other treatments; highest mean values were 2336 and 1640 kg/ha for the Mechanical 1 and Mechanical 2 treatments, respectively. Lowest total annual herbaceous biomasses in all treatments ($\bar{X}$= 296-475 kg/ha) occurred in 1989, the year with the lowest annual precipitation (257.5 mm). Desirable perennial grasses contributed most (44-100%) to total herbaceous biomass in all treatments during the study period. Most of this biomass was composed by the cool-season grasses *Stipa tenuis*, *S. clarazii*, *Poa ligularis*, *S. papposa* and *Piptochaetium napostaense*. Annual precipitation was closely related ($\underline{P}$<0.05) to total herbaceous and desirable perennial grass biomasses in most treatments, and appeared as the major factor accounting for most of the variation in herbage production between years. Further research is needed to obtain models to predict precipitation levels at a seasonal and interannual scale within this semiarid region. This information could be used by livestock producers early in the year to predict potential forage production for more efficient livestock and rangeland management.

Key words: perennial and annual grasses, annual dicotyledoneous, precipitation, biomass, burning, overgrazing, herbicides, mechanical control.

Introduction

Range inventory and assessment of primary production are important for planning range development (Le Houerou et al., 1988). One of the main factors affecting primary production in arid and semiarid rangelands is precipitation (White, 1985; Le Houerou et al., 1988). Although precipitation can be very variable in the East-Central rangelands of Argentina (Cabrera, 1976), quantitative measurement of its effect on herbage biomass is lacking. This information is important because it could serve as a basis for determining the long-term influence of precipitation 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 biomass can also occurr with removal of woody plants (Vallentine, 1990), control of woody vegetation using herbicides (Meyer & Bovey, 1985), burning (Wright & Bailey, 1982), mechanical disturbance of soil (Wight et al., 1978; White et al., 1981), and overgrazing (Vallentine, 1990). Moreover, the relative impacts of these treatments have been shown to vary temporally in concert with climatic variations and post-treatment management tactics (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 tillage, overgrazing and precipitation on herbage biomass 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^{o} 39'S, 62^{o} 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 by occasional individuals of *Prosopis caldenia*. The community is characterized by an open shrubby layer of *Condalia microphylla*, *Chuquiraga erinacea*, *Geoffroea decorticans*, *Schismus fasciculatus*, *Lycium chilensis* var. *minutifolia* and *Larrea divaricata* which include herbaceous layer species of different desirability for livestock production. In this study, annual or perennial grass and dicotyledoneous species of the herbaceous layer were classified according to their degree of acceptance by livestock in desirable, intermediate (grazed when desirable species are not available) or undesirable (only cut off when a better forage is not available). Herbaceous species were grouped in desirable perennial grasses (*Stipa tenuis*, *Pappophorum subbulbosum*, *Pappophorum caespitosum*, *Piptochaetium napostaense*, *Stipa clarazii*, *Poa lanuginosa*, *Poa ligularis*, *Stipa papposa*, *Bromus brevis*, *Sporobolus cryptandrus* and *Koeleria permollis*), intermediate perennial grasses (*Stipa speciosa*, *Aristida spegazzinii*, *Aristida subulata*, *Aristida pallens* and *Aristida trachyantha*), undesirable perennial grasses

(*Stipa ambigua*, *Stipa brachychaeta*, *Stipa trichotoma* and *Sporobolus rigens*), desirable annual grasses (*Bromus mollis*, *Vulpia megalura*, *Schismus barbatus*, *Hordeum murinun*, *Bromus catharticus* and *Lolium multiflorum*), and desirable annual dicotyledoneous (*Medicago minima* and *Erodium cicutarium*). Except for the *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. The desirable annual grass and dicotyledoneous 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 0.06 .

Long-term (1901-1950) annual precipitation is 331 mm, with a mean annual temperature of 14.6 ^{o}C, absolute minimum temperature of -7.6 ^{o}C (August), absolute maximum temperature of 43 ^{o}C (January), mean annual relative humidity of 60%, and mean annual wind speed of 13 km/h. Various climatic parameters obtained from 1984 to 1992 using a meteorological station located at 22 km from the study site are shown in Figure 1. During this period, absolute monthly maximum and minimum, and mean monthly temperatures (^{o}C) ranged from 13.9 (1984, July) to 40.0 (1987 and 1989, February); -9.9 (1988, July) to 9.0 (1984, January), and 4.2

(1984, June) to 23.0 (1984, January), respectively. Changes in mean monthly soil temperatures (^{o}C) were greater nearer the soil surface than at greater depths; i.e., values ranged from 3.5 (1988, July) to 28.4 (1989, December) at 0.05 m, and from 7.2 (1988, July) to 26.8 (1990, January) at 0.50 m soil depth. The absolute monthly minimum and mean monthly relative humidities (%) varied from 8.0 (1988, January) to 48.0 (1984, June), and 54.0 (1989, December) to 88.0 (1985, December), respectively. Mean monthly wind speed (km/h), saturation water vapor deficit (MPa) and pan evaporation (mm) ranged from 4.1 (1985, June) to 12.6 (1990, December); 1.5 (1991, June) to 13.9 (1984, January), and 0.5 (1984 and 1991, June) to 9.4 (1988, December), respectively. Annual precipitation (mm) ranged from 257.5 (1989) to 877.3 (1984), and 23.9 ± 2.9, 24.3 ± 1.7, 19.0 ± 2.7 and 32.8 ± 4.2% ($\overline{X} \pm 1$ S.E.) of it fell in fall, winter, spring and summer, respectively during 1984-1992.

Treatments and Field Sampling

Before treatments were imposed at the study site, the plant community was characterized (n=20 stands) on 1 Nov. 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* ($\overline{X}$=2.3), *Bacharis ulicina* ($\overline{X}$=1.2) and *Stipa tenuis* ($\overline{X}$=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 from trees and undergrowth, and cropped from 1951 until 1975. Previous to cultivation, half of this area (Mechanical 1) had been exposed to a more severe grazing than the other half (Mechanical 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), other site (37 ha) was burned (Burning), and herbicides (Chemical) were applied on the third site (24 ha) for shrub control. 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 ^{o}C, mean relative humidity was 49%, and wind speed and dry weight of fine fuel load were 22 km/h and 438 kg/ha, respectively. One year after burning, $\geq$ 50% of plants of *G. decorticans*, *C. microphylla*, *L. chilensis*, *Ch. erinacea*, *L. divaricata* and *S. 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) and 2,4,5-T (4 l/ha) 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 *Ch. 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*, *Ch. erinacea* and *L. divaricata* were less than 50% defoliated.

By mid-November 1978, percentage cover was determined per species within each treatment (n=50) by randomly distributing 20x50 cm quadrats following the canopy-cover method of Daubenmire (1959). Biomass was also estimated at the Control, Mechanical 1, Mechanical 2, Burning and Chemical treatment sites in 1978 (n=50), and at these and the overgrazed site from 1984-1992 by hand clipping standing crop of live-plus-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 economical constraints. At harvesting time during 1984-1992, 30 randomly-distributed, permanent plots (0.5x0.5 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 biomass was measured, and dried in a forced draft oven at 70^{o}C until constant weight. Vegetation biomass production was then expressed on a dry weight basis. Clipping by species permitted us to express species composition as a percent of total biomass production. Within the desirable annual grass or dicotyledoneous group, a species was separated from the remaining total biomass when its contribution to this biomass was substantial.

Precipitation-use efficiency is defined as kg of forage (ovendry) produced per mm of precipitation received and is based on the plant growth and precipitation that occurs between harvests (Wight & Black, 1972).

Data were analyzed using 2 factorial ANOVA (species x treatments within each year) and means were separated where appropiate using Fisher's Least Significant Difference ($P<0.05$). Simple linear regression analysis was developed to predict changes in annual biomass production of each species; desirable, intermediate or undesirable perennial grasses; desirable annual grasses or dicotyledeneous, or total herbage in response to variable annual precipitation 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 biomass, the biomass 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

Annual Herbaceous biomass

One year after treatments, the lowest and highest total herbaceous biomasses were obtained in the Burning ($\bar{X}$=967 kg/ha, 52% of control) and Mechanical 2 ($\bar{X}$=3804 kg/ha, 203% of control) treatments (data not shown). Similar to our results, total herbaceous production of several grassland communities has been lower on burned than on unburned sites one year following burning (Bartos et al., 1994; Cook et al., 1994; Pfeiffer & Steuter, 1994). Also, mechanical treatments have increased total forage production over the untreated control in rangelands of southeastern Wyoming (Griffith et al., 1985). The release of plant nutrients through soil weathering and decomposition of organic matter as a result of mechanical disturbances, and the subsequent effects on plant growth have been reported by Wight & White (1974).

Total herbaceous biomass during 1984-1992 ranged from 295 (Overgrazing, 1989) to 2335 (Mechanical 1, 1985) kg/ha (Fig. 2). These biomass values are within the range reported by Cano (1975, 1988), Lutz & Graff (1980), Digiuni (1983), Distel & Fernandez (1986), Fresnillo Fedorenko et al. (1991) and Vallati (1995) for rangelands at the Calden District, by Heitschmidt et al. (1995) for rangelands of the Northern

Great Plains where longterm precipitation averaged 338 mm, and by Perez Corona et al. (1995) for herbaceous communities of semiarid grasslands in Central-West Spain.

Total herbaceous biomass was lower (P<0.05) in the control than in the Mechanical 1 treatment in 1984-1988 and 1991, and than in the Mechanical 2 treatment in 1986-1988 and 1991 (Fig. 2). Mechanical disturbance of the soil surface has already been reported to increase herbage standing crop in Northern Great Plains rangelands (Haferkamp et al., 1993). Tillage treatments may increase weathering with a subsequent release of nutrients and plant growth enhancement (Wight & Siddoway, 1972). Although it has been reported that the fertility effects of mechanical treatment application would usually disappear within a few years (Wight & Siddoway, 1972), other researchers (Fisser et al., 1974; Wight & White, 1974; White et al., 1981) have estimated, however, that the beneficial effects of some mechanical treatments on plant growth could last from 15-25 years.

Except in 1989, the Control and Burning treatments had a similar (P>0.05) total herbaceous biomass during 1984-1992 (Fig. 2). This result is similar to that of Bartos et al. (1994) who found that total undergrowth production of *Populus tremuloides* communities was similar at burned and unburned sites 12 years after burning. The Control and Chemical treatments had a similar (P>0.05) total herbaceous biomass between 1984-1992, except in 1989 and 1992 when it was greater ($\underline{P}$<0.05) in the Control than in the Chemical 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 than that in untreated areas 4-17 months after treatment. With the exception in 1986 and 1987, total herbaceous biomass during the study period was greater in the Control than in the Overgrazing treatment although differences were only significant ($\underline{P}$<0.05) in 1989 and 1990 (Fig. 2). Archer and Smeins (1991) have already reported that increased grazing intensity may decrease herbaceous standing crop, reduce fire frequency and intensity, and enhance the dispersal and germination of woody plant seeds thereby contributing to shrub encroachment in several arid or semiarid ecosystems of North and South America, and Australia. The lower total herbaceous production on continuously, severely grazed rangelands could be attributed, at least in part, to the reducing effects of continuous, severe defoliation on tiller both density and size of grassland species (Briske & Richards, 1995). However, total herbaceous production may also be higher on overgrazed than on ungrazed semiarid rangelands because of the high contribution that annuals can make to total dry matter yields during years of well-distributed, normal or above-normal rainfall (Fresnillo Fedorenko et al., 1991).

Desirable perennial grasses constituted from 44 (1988, Mechanical 2) to 100% (1984 and 1985, Burning) of total herbaceous biomass in the different treatments during 1984-

1992 (Fig. 2). Fifty six (1985, Mechanical 2) to 99% (1992, Control) of this desirable perennial grass biomass was composed by *S. tenuis*, *S. clarazii*, *P. ligularis*, *S. papposa* and *P. napostaense* (Fig. 3). The biomass of desirable perennial grasses was > 1.2 times greater in the Control than in the Overgrazing treatment in 6 out of the 9 study years. Fresnillo Fedorenko et al. (1991) also reported a greater biomass for desirable perennial grasses on an ungrazed than on an overgrazed site in a temperate, semiarid region of Central Argentina. The combined contribution of *S. clarazii* and *P. ligularis* to total herbaceous biomass was < 24% or > 44% in the Overgrazing or Control treatment, respectively during 1984-1992 (Fig. 3). Boo et al. (1993) reported that these two grazing sensitive species are the most highly preferred by cattle in semiarid rangelands of Central Argentina, and tend to dissapear from the pastures with heavy grazing. After fifteen years of treatment application (i.e., 1992), however, the species composition of the Control and Overgrazing treatments was quite similar (Fig. 3). Milchunas et al. (1989) also reported that differences in species composition of ungrazed versus heavily grazed semiarid grasslands were still small after nearly 50 years from treatment. The Control and Burning treatments had a similar ($P>0.05$) desirable perennial grass biomass during the period of study. This result is similar to that obtained by Cook et al. (1994) at some sites after 1-3 years of burning mesic, high elevation *Artemisia* *tridentata* communities in southcentral Wyoming. Twelve years following burning of *Populus tremuloides* communities, grass dry matter production has also been reported to be lower or similar on burned sites which had been exposed to a moderate burn severity than on unburned sites (Bartos et al., 1994).

Intermediate perennial grasses were almost exclusively found in the Mechanical 2 treatment where they represented from 14 to 45% of total herbaceous biomass during 1984-1992 (Fig. 2); contribution of the intermediate perennial grasses to total herbaceous biomass in the other treatments was very low (<2% in the Control and Mechanical 1 treatments). These grasses included *Aristida* species (Fig. 3) which like *A. subulata* may be utilized as an indication of rangeland overuse (Cano, 1988). This suggests that previous to cultivation, the Mechanical 2 site may have been exposed to severe overgrazing.

Undesirable perennial grasses were mostly confined to the Mechanical 1 and Overgrazing treatment were they represented from 1 to 35% of total herbaceous biomass in 1984-1992 (Fig. 2). Species integrating this group, namely *S. ambigua*, *S. brachychaeta* and *S. trichotoma* (Fig. 3), are indicative of previous grazing mismanagement conducive to rangeland deterioration (Cano, 1988). A greater biomass of these species in the Mechanical 1 than in the Mechanical 2 site was probably due to the greater proximity of the Mechanical 1 site to a water source for cattle; this may have contributed to a more severe and continuous rangeland grazing at this site.

The species composition of the intermediate and undesirable perennial grass groups in the Control was different than that in both Mechanical treatments (Fig. 3); these treatments also had some differences in the species composition of the desirable perennial grass group. Wight & Siddoway (1972) also reported that throughout the Northern Plains, fields that had been cultivated during approximately 40 years and then abandoned were readily discernible by a distinct difference in species composition from that on an adjacent, undisturbed rangeland. In addition, changes in species composition resulting from surface modifications can be relatively permanent (Branson et al., 1966). Cultivation during 25 years must have eliminated the original vegetation in the open shrubland with a continuous herbaceous layer of Stipa tenuis. After abandonment, the successful seed germination and establishment from existing seeds that *S. tenuis* can show in areas with low interference from surrounding vegetation (Distel et al., 1992), and the very high daughter production reported for parent tillers of this species (Busso et al., 1993) may help to explain its persistence and high contribution to total herbaceous biomass in both Mechanical treatments.

The Burning treatment may have been severe enough as to negatively affect intermediate and undesirable perennial grasses; these two grass groups were absent in the Burning treatment during 1984-1992 (Fig. 2). Boo et al. (in press) reported very high mortality rates in *S. 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 accumulate abundant old growth which may in turn have determined the high temperatures measured during the controlled burns. 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 a better forage is not available (Cano, 1988), which would also allow for old growth accumulation. Species such as *S. tenuis*, *S. clarazii*, *P. ligularis* and *P. napostaense* 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 in the proximity of the growing points (Boo et al., in press).

Desirable annual grasses or dicotyledoneous were either absent in anyone treatment between 1984-1992 or their contribution to total herbaceous biomass was as high as 45% for desirable annual grasses (1989, Overgrazing) or 22% for desirable annual dicotyledoneous (1987, Mechanical 2) (Fig. 2). Biomasses contributed for these two desirable annual plant groups were usually higher in the Overgrazing or the Mechanical treatments than in the other treatments. Maximum biomass values in the Overgrazing and Mechanical treatments during 1984-1992 were 309 (1992) and 720 (1992, Mechanical 1) kg/ha, respectively for the desirable annual grasses, and 35 (1986) and 323 (1987, Mechanical 2) kg/ha, respectively for the desirable annual dicotyledoneous (Fig. 2). Annual grasses have been shown previously to increase with overgrazing in semiarid 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 *M. minima* and *E. cicutarium* during 1984-1992 in all treatments (Fig. 2) are lower than those reported for Fresnillo et al. (1991) on overgrazed and ungrazed sites of the Calden District in central Argentina. *M. 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 et al., 1991).

Relationship between annual herbaceous biomass and precipitation

Total herbaceous biomass and precipitation during the previous 12 months correlated highly ($P<0.05$) during 1984-1992 in all treatments, except for the Mechanical 2 treatment were the regression was significant only at $P<0.1$ (Table 1). Precipitation may thus account for most of the variation in total herbaceous biomass between years. Similar results were obtained in other grasslands exposed to various managements by Griffith et al. (1985), Robertson (1987), Wellard (1987), Lauenroth & Sala (1992), Milchunas et al. (1994) and Silvertown et al. (1994). It should be noted, however, that production of individual tillers might be expected to be more closely correlated than production per unit surface area to current-year precipitation; a dry year or a series of dry years may reduce basal cover, thereby constraining production in subsequent years even when conditions are favorable for growth (Milchunas et al., 1994). Increases in total herbaceous biomass in 1987, 1990 and 1992, when there were a concurrent increase in annual precipitation, with respect to previous-year values were similar or greater in the overgrazing than in the control treatment. This result is similar to that reported by Milchunas et al. (1994) in that it does not support the hypothesis of a decreasing capacity for response to wet years with increasing grazing intensity. Precipitation-use efficiency varied from 1.1 to 3.9 in all treatments during 1984-1992. These values are similar to those reported by Wight & Siddoway (1972), Robertson (1987), Wellard (1987) and Le Houerou et al. (1988) for other rangelands.

The lower correlation coefficient for the Mechanical 2 treatment may have been due in part that between 21 and 56 % of its total herbaceous biomass were intermediate perennial grasses and desirable annual grasses and dicotyledoneous (Fig. 2); these perennial grasses were warm-season *Aristida* species (Fig. 3) which biomass did not correlate with annual precipitation, except for *A. pallens* (Table 1). The biomass of desirable annual grasses or dicotyledoneous also did not correlate with annual precipitation (Table 1). This finding contrasts with results of other studies which have shown positive relationships between production of annual cool-season grasses and amounts of fall and spring precipitation (White, 1985; Smoliak, 1986; Whisenant, 1990). However, the increases in annual precipitation in 1987, 1990 or 1992 were greater than 40% with respect to values during the previous year (Fig. 1), and this may help to explain the greater contribution of annual species to total herbage biomass during these years in all treatments, especially during 1992 (Fig. 2). Wide yearly fluctuations in peak standing crop on California annual-type range were also partially explained by precipitation patterns (Pitt & Heady, 1978; George et al., 1985). Robertson (1987) reported that heavy rainfall was a major factor in determining changes in dominance between annuals and perennials for pastures at Menindee, Australia. Changes in species composition of *Astrabla* grassland associated with high rainfall in south-western Queensland led Orr (1981) to a similar conclusion.

Contribution of desirable perennial grasses to total herbaceous biomass in the control treatment was > 86% in 7 out of the 9 studied years (Fig. 2); this species group showed a highly significant correlation with precipitation (Table 1). This correlation was similar to that observed in the Mechanical 1 treatment where total herbaceous biomass was composed from 5 to 35% by undesirable perennial grasses (Fig. 2). These undesirable perennial grasses corresponded mainly to *S. ambigua* and *S. brachychaeta* (Fig. 3) which biomass correlated with precipitation at least at $P<0.1$ (Table 1).

Significant ($P<0.05$) positive relationships of biomass on precipitation in the different treatments occurred in 20 out of 50 comparisons in the desirable perennial grasses, 1 out of 5 comparisons in the intermediate perennial grasses, and 5 out of 8 comparisons in the undesirable perennial grasses (Table 1). However, slopes of the relationship between biomass and precipitation were similar ($P>0.05$) in all species within any given both treatment and species group; this indicates that changes in biomass were similar among species pertaining to the same group for any given change in precipitation. *Stipa tenuis*, however, has showed a greater growth response under irrigation than *S. clarazii* (Flemmer et al., 1995). Slopes were also similar ($P>0.05$) among treatments for any given species.

This study allowed the examination of different management activities (i.e., burning, chemical or mechanical treatment, overgrazing) on the herbaceous biomass production of East-Central rangelands in Argentina. Even though mechanical soil disturbance stimulated total biomass production of the herbaceous layer during several years after abandonment of cultivation, precipitation appeared to be the major factor in accounting for most of the variation in herbage production between years. The positive relationship between precipitation and herbage biomass, and the great year-to-year variations in precipitation which can occurr at the East-Central rangelands in Argentina continually pose a challenge for land managers. Large and rapid changes in forage production that can occurr in this region require special management skills for maintenance of a viable livestock industry. Further research is needed to develop, adjust and validate models to predict precipitation levels at a seasonal and interannual scale in this semiarid region. This information could then be used by livestock producers early in the year to predict or determine the potential forage production for that year. This would contribute to design and effect a more efficient livestock and rangeland management.

Acknowledgements

We thank R.W. Bovey for revising the manuscript.

References

Archer, S. & Smeins, F.E. (1991). Ecosystem-level processes. In: Heitschmidt, R.K. & Stuth, J.W. (Eds), *Grazing Management. An ecological perspective*, pp. 109-139. Portland: Timber Press, Inc. 259 pp.

Bartos, D.L., Brown, J.K. & Booth, G.D. (1994). Twelve years biomass response in aspen communities following fire. *Journal of Range Management*, 47: 79-83.

Boo, R.M., Lindstrom, L.I., Elia, O.R. & Mayor, M.D. (1993). Botanical composition and seasonal trends of cattle diets in central Argentina. *Journal of Range Management*, 46: 479-482.

Boo, R.M., Pelaez, D.V., Bunting, S.C., Elia, O.R. & Mayor, M.D. (in press). Fire effects on grasses in central semi-arid Argentina. *Journal of Arid Environments.*

Branson, F.A., Miller, R.F. & McQueen, I.S. (1966). Contour furrowing, pitting, and ripping on rangelands of the Western United States. *Journal of Range Management*, **19**: 182-190.

Briske, D.D. & Richards, J.H. (1995). Plant responses to defoliation: A physiological, morphological and demographic evaluation. In: Bedunah, D.J. & Sosebee, R.E. (Eds), *Wildland Plants: Physiological Ecology and Development Morphology*, pp. 635-710. Society for Range Management, Denver, Colorado.

Busso, C.A., Boo, R.M. & Pelaez, D.V. (1993). Fire effects on bud viability and growth of *Stipa tenuis* in semiarid Argentina. *Annals of Botany*, **71**: 377-381.

Cabrera, A.L. (1976). Regiones fitogeográficas Argentinas. Enciclopedia Argentina de Agricultura y Jardinería. Tomo II. Editorial ACME S.A.C.I., Buenos Aires, 85 pp.

Cano, E. (1975). Pastizales en la región central de la Provincia de La Pampa. *IDIA*, **331-335**: 1-15.

Cano, E. (1988). Pastizales Naturales de La Pampa. Descripción de las especies más importantes. Tomo I. Convenio AACREA-Provincia de La Pampa (in Spanish), 425 pp.

Cook, J.G., Hershey, T.J. & Irwin, L.L. (1994). Vegetative response to burning on Wyoming mountain-shrub big game ranges. *Journal of Range Management*, **47**: 296-302.

Daubenmire, R. (1959). A canopy-coverage method for vegetation analysis. *Northwestern Scientist*, 33: 43-64.

Digiuni, D. (1983). Métodos de desmonte y su impacto sobre el pastizal natural en el noroeste de Rio Negro. *Estación Experimental IDEVI, Serie Técnica*, 11: 1-73.

Distel, R.A. & Fernandez, O.A. (1986). Productivity of *Stipa tenuis* Phil. and *Piptochaetium napostaense* (Speg.) Hack in semiarid Argentina. *Journal of Arid Environments*, 11: 93-96.

Distel, R.A., Pelaez, D.V. & Fernandez, O.A. (1992). Germination of Piptochaetium napostaense (Speg.) Hackel and Stipa tenuis Phil. and seedling survival under field conditions. *Rangeland Journal*, 14: 49-55.

Flemmer, A.C., Busso, C.A., Montani, T., Fernandez, O.A., Vazquez, R. & Toribio, M. (1995). Crecimiento de *Stipa tenuis*, *Stipa clarazii* y *Stipa gynerioides* bajo distintos niveles hídricos del suelo durante la etapa reproductiva. *Resúmenes XVII Reunión Argentina de Ecología*, pp. 86-87.

Fresnillo Fedorenko, D.E., Fernandez, O.A. & Busso, C.A. (1991). Forage production of the annual legume Medicago minima in semiarid rangelands of Central Argentina. Proc. Symp. *Grazing, a challenge for development and environment*, IVth International Rangeland Congress, Montpellier, France, pp. 372-374.

Fisser, H.G., Mackey, M.H. & Nichols, J.T. (1974). Contour-furrowing and seeding on nuttall saltbush rangeland of Wyoming. *Journal of Range Management*, **27**: 459-462.

Gartner, F.R. (1988). Improvements practices that increase range efficiency. In: White, R.S. & Short, R.E. (Eds), *Achieving efficient use of rangeland resources*, pp. 86-91. Fort Keogh Res. Symp., September 1987, Miles City, Montana, Montana Agr. Exp. Sta.

Gartner, F.R., White, E.M. & Butterfield, R.I. (1986). Mechanical treatment and burning for high quality range forage. South Dakota Beef Report, Animal Range Science Dep., Agr. Exp. Sta., Coop. Ext. Serv., South Dakota State Univ., Brookings. pp. 135-140.

George, M.R., Clawson, W.J., Menke, J. & Bartolome, J. (1985). Annual range forage productivity. *Rangelands*, **7**: 17-19.

Griffith, L.W., Schuman, G.E., Rauzi, F. & Baumgartner, R.E. (1985). Mechanical renovation of shortgrass prairie for increased herbage production. *Journal of Range Management*, **38**: 7-10.

Haferkamp, M.R., Volesky, J.D., Borman, M.M., Heitschmidt, R.K. & Currie, P.O. (1993). Effects of mechanical treatments and climatic factors on the productivity of Northern Great Plains rangelands. *Journal of Range Management*, **46**: 346-350.

Heitschmidt, R.K., Grings, E.E., Haferkamp, M.R. & Karl, M.G. (1995). Herbage dynamics on 2 Northern Great Plains range sites. *Journal of Range Management*, **48**: 211-217.

Klemmedson, J.O. & Smith, J.G. (1964). Cheatgrass (*Bromus tectorum* L.). *Botanical Review*, 30: 226-262.

Lauenroth, W.K. & Sala, O.E. (1992). Long term forage production of North American shortgrass steppe. *Ecological Applications*, **2**: 397-403.

Le Houerou, H.N., Bingham, R.L. & Skerbek, W. (1988). Relationship between the variability of primary production and the variability of annual precipitation in world arid lands. *Journal of Arid Environments*, **15**: 1-18.

Lutz, E.E. & Graff, A. B. (1980). Efecto de la quema controlada sobre la pastura natural, en un monte de la región semiárida pampeana. *Revista de Investigaciones Agropecuarias, Buenos Aires, Serie 2*, 15: 1-15.

Meyer, R.E. & Bovey, R.W. (1985). Response of herbaceous vegetation in East-Central Texas to herbicides. *Weed Science*, 33: 81-90.

Milchunas, D.G., Forwood, J.R. & Lauenroth, W.K. (1994). Productivity of long-term grazing treatments in response to seasonal precipitation. *Journal of Range Management*, **47**: 133-139.

Milchunas, D.G., Lauenroth, W.K., Chapman, P.L. & Kazempour, M.K. (1989). Effects of grazing, topography, and precipitation on the structure of a semiarid grassland. *Vegetatio*, **80:** 11-23.

Mueller-Dombois, D. & Ellenberg, H. (1974). Aims and Methods of Vegetation Ecology. John Wiley & Sons, Inc., New York, USA. 547 pp.

Neter, J., Wasserman, W. & Kutner, M.H. (1985). Applied linear statistical models: regression, analysis of variance, and experimental designs. 2nd ed. R.D. Irwin, Homewood, Illinois, USA. 1127 pp.

Orr, D.M. (1981). Changes in the quantitative floristics in some Astrebla spp. (Mitchell grass) communities in south-western Queensland in relation to trends in seasonal rainfall. *Australian Journal of Botany*, **29:** 533-545.

Perez Corona, M.E., Garcia Ciudad, A., Garcia Criado, B. & Vazquez de Aldana, B.R. (1995). Patterns of aboveground herbage production and nutritional quality structure on semiarid grasslands. *Communications in Soil Science and Plant Analysis*, **26:** 1323-1341.

Pfeiffer, K.E. & Steuter, A.A. (1994). Preliminary response of Sandhills prairie to fire and bison grazing. *Journal of Range Management*, **47**: 395-397.

Pitt, M.D. & Heady, H.F. (1978). Responses of annual vegetation to temperature and rainfall patterns in California. *Ecology*, **59:** 336-350.

Robertson, G. (1987). Plant dynamics. In: Caughley, G., Shepherd, N. & Short, J. (Eds), *Kangaroos, their Ecology and Management in the Sheep Rangelands of Australia*, pp. 50-68. Cambridge: Cambridge University Press. 253 pp.

Silvertown, J., Dodd, M.E., McConway, K., Potts, J. & Crawley, M. (1994). Rainfall, biomass variation, and community composition in the park grass experiment. *Ecology*, **75:** 2430-2437.

Smoliak, S. (1986). Influence of climatic conditions on production of Stipa-Bouteloua prairie over a 50-year period. *Journal of Range Management*, **39:** 100-103.

Vallati, A.R. (1995). Dinámica de los nutrientes minerales de un pastizal en el Caldenal. Tesis de Magister, Universidad Nacional del Sur, Bahía Blanca, Argentina. 193 pp.

Vallentine, J.F. (1990). Grazing management. Academic Press, Inc., San Diego, California, USA. 331 pp.

Wellard, G. (1987). The effect of weather on soil moisture and plant growth in the arid zone. In: Caughley, G., Shepherd, N. & Short, J. (Eds), *Kangaroos, their Ecology and Management in the Sheep Rangelands of Australia*, pp. 35-49. Cambridge: Cambridge University Press. 253 pp.

Whisenant, S.G. (1990). Postfire population dynamics of Bromus japonicus. *American Midland Naturalist*, 123: 301-308.

White, L.M. (1985). Stand age, precipitation, and temperature effects on forage yield. *Journal of Range Management*, **38:** 39-43.

White, E.M., Gartner, F.R. & Butterfield, R. (1981). Range claypan soil improvement: Response from furrowing and ripping in Northwestern South Dakota. *Journal of Range Management*, **34:** 119-125.

Wight, J.R. & Black, A.L. (1972). Energy fixation and precipitation-use-efficiency in a fertilized rangeland ecosystem of the Northern Great Plains. *Journal of Range Management*, **25:** 371-375.

Wight, J.R., Neff, E.L. & Soiseth, R.J. (1978). Vegetation response to contour furrowing. *Journal of Range Management*, **31:** 97-101.

Wight, J.R. & Siddoway, F.H. (1972). Improving precipitation-use efficiency on rangeland by surface modification. *Journal of Soil and Water Conservation*, **27:** 170-174.

Wight, J.R. & White, L.M. (1974). Interseeding and pitting on a sandy range site in eastern Montana. *Journal of Range Management*, **27:** 206-210.

Wright, H.A. & Bailey, A.W. (1982). Fire Ecology. John Wiley and Sons, New York, USA. 501 pp.

Table legends

Table 1. Correlation coefficients (r) and predictive equations with significance levels (p) for biomass (B, kg/ha/yr) as a function of precipitation (P, mm/yr) in the Control, Burning, Chemical, Mechanical 1, Mechanical 2 or Overgrazing treatment. Linear regressions were developed for total herbaceous, species group (desirable, intermediate or undesirable perennial grasses, and desirable annual grasses or dicotyledoneous) and species biomasses within each treatment. Values for each year came from 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. *Data of all treatments were pooled because their individual regression lines were equal ($\underline{P}>0.05$).

Figure legends

Fig. 1. Absolute monthly maximum and minimum, and mean monthly temperatures (A); mean monthly soil temperatures at 0.05, 0.10, 0.20, 0.30, 0.40 and 0.50 cm depth (B); absolute monthly minimum and mean monthly relative humidities (C); mean monthly wind speed and saturation water vapour deficit (D), and mean monthly pan evaporation, monthly precipitation and long-term monthly precipitation (E) during 1984-1992 at a meteorological station located 22 km from the study site.

Fig. 2. Total herbaceous biomass as composed by desirable, intermediate and undesirable perennial grasses, and desirable annual grasses and dicotyledoneous in the Control, Burning, Chemical, Mechanical 1, Mechanical 2 or Overgrazing treatment during 1984-1992. Each histogram is a mean of n=30. Vertical bars represent 1 S.E.M. for total herbaceous biomass.

Fig. 3. Percentage contribution of each species to total herbaceous biomass in the Control, Burning, Chemical, Mechanical 1, Mechanical 2 or Overgrazing treatment within each species group (desirable, intermediate or undesirable perennial grasses, desirable annual grasses or dicotyledoneous) during 1984-1992. Each histogram is a mean of n=30.

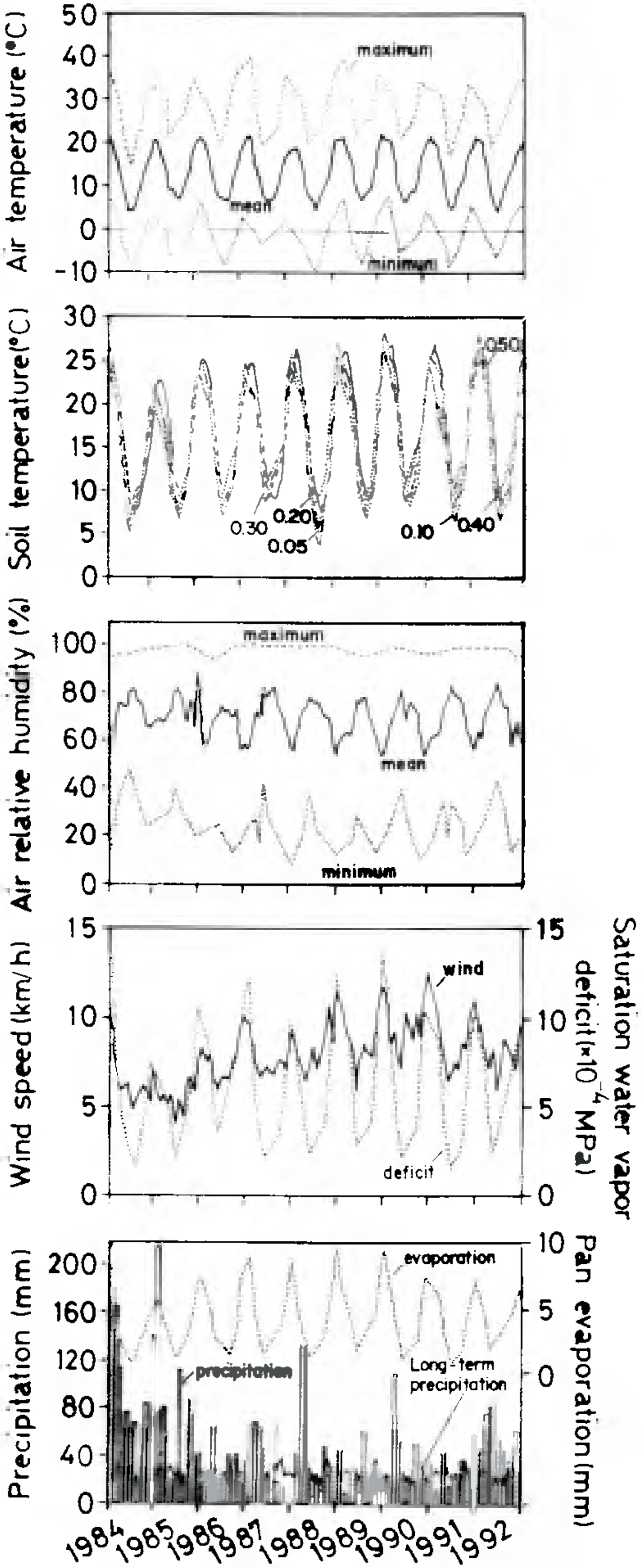
Table 1

		B=a+bP, 1984-1992			
		a	b	r	p<
Total					
	Control	133.300	1.7620	0.87	0.005
	Burning	164.520	1.5270	0.93	0.001
	Chemical	236.480	1.5230	0.88	0.005
	Mechanical 1	58.200	2.7720	0.88	0.005
	Mechanical 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
	Mechanical 2	288.800	0.0780	0.10	>0.5
Undesirable perennial grasses					
	Control	7.227	-0.0040	0.28	0.5
	Chemical	-11.468	0.0540	0.88	0.005
	Mechanical 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 dicotyledonous*		23.924	-0.0230	0.14	0.5
Species					
Stipa tenuis					
	Control	108.140	0.2210	0.73	0.025
	Burning	-41.480	0.3230	0.79	0.025
	Chemical	13.584	0.1240	0.56	0.5
	Mechanical 1	-12.040	1.0590	0.78	0.025
	Mechanical 2	115.040	0.6090	0.74	0.025
	Overgrazing	-115.872	0.4980	0.93	0.001
Stipa clarazii					
	Control	-65.160	0.7630	0.95	0.001
	Burning	-9.280	0.5770	0.90	0.001
	Chemical	-54.600	0.4780	0.91	0.001
	Mechanical 1	77.040	0.0490	0.18	>0.5
	Mechanical 2	72.440	0.0360	0.09	>0.5
	Overgrazing	-11.028	0.1180	0.95	0.001
Poa ligularis					
	Control	-0.504	0.3660	0.91	0.001
	Burning	11.640	0.2050	0.55	0.5
	Chemical	187.800	0.3010	0.55	0.5
	Mechanical 1	89.240	0.0210	0.06	>0.5
	Mechanical 2	2.400	0.0060	0.13	>0.5
	Overgrazing	34.892	-0.0240	0.33	0.5
Stipa papposa					
	Control	-26.236	0.1270	0.79	0.025
	Burning	-17.756	0.1870	0.79	0.025
	Chemical	-1.560	0.2720	0.76	0.025
	Mechanical 1	121.760	0.0160	0.05	>0.5
	Mechanical 2	16.932	-0.0100	0.27	0.5
	Overgrazing	-25.760	0.3320	0.66	0.1

continued

Table 1 Continued

		a	b	r	p<
Species					
Piptochaetium napostaense					
	Control	19.996	0.0790	0.77	0.025
	Burning	20.748	0.0820	0.80	0.01
	Chemical	3.204	0.0650	0.76	0.025
	Mechanical 1	0.116	0.0005	0.14	>0.5
	Mechanical 2	46.840	0.0880	0.28	0.5
	Overgrazing	105.800	0.2540	0.45	0.5
Pappophorum subbulbosum					
	Control	4.704	0.0200	0.29	0.5
	Burning	24.884	0.0070	0.12	>0.5
	Chemical	23.160	0.1290	0.51	0.5
	Mechanical 1	38.184	-0.0310	0.31	0.5
	Mechanical 2	36.332	-0.0110	0.14	>0.5
	Overgrazing	16.980	0.0860	0.42	0.5
Poa lanuginosa					
	Control	24.532	0.0150	0.25	>0.5
	Burning	7.312	0.0900	0.83	0.01
	Chemical	31.676	0.0120	0.22	>0.5
	Mechanical 1	0.349	-0.0003	0.12	>0.5
	Mechanical 2	1.248	-0.0010	0.42	0.5
	Overgrazing	24.432	0.0150	0.23	>0.5
Sporobolus cryptandrus					
	Chemical	0.663	-0.0006	0.15	>0.5
	Mechanical 2	-14.280	0.3320	0.42	0.5
	Overgrazing	0.284	0.0080	0.37	0.5
Bromus brevis					
	Chemical	-0.416	0.0010	0.73	0.025
	Mechanical 1	-69.400	0.2650	0.55	0.5
	Mechanical 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
Stipa speciosa					
	Control	1.276	0.0060	0.24	>0.5
Aristida spegazzinii					
	Mechanical 2	299.520	-0.2260	0.33	0.5
Aristida subulata					
	Mechanical 2	15.240	0.1200	0.44	0.5
Aristida pallens					
	Mechanical 2	-26.488	0.1900	0.71	0.05
Aristida trachyantha					
	Mechanical 2	6.344	-0.0070	0.23	>0.5
Stipa ambigua					
	Mechanical 1	-125.120	0.5860	0.88	0.005
	Mechanical 2	-0.941	0.0030	0.69	0.05
Stipa brachychaeta					
	Mechanical 1	-47.840	0.2900	0.59	0.1
Stipa trichotoma					
	Control	7.222	-0.0040	0.28	0.5
	Chemical	-10.064	0.0520	0.88	0.005
	Mechanical 1	0.929	-0.0010	0.31	0.5
	Overgrazing	-19.780	0.0770	0.78	0.025
Sporobolus rigens					
	Overgrazing	28.964	0.0760	0.75	0.025



Air temperature (°C)
maximum
mean
minimum
Soil temperature(°C)
0.50
0.30
0.20
0.05
0.10
0.40
Air relative humidity (%)
maximum
mean
minimum
Wind speed (km/h)
Saturation water vapor deficit(×10^-4 MPa)
wind
deficit
Precipitation (mm)
Pan evaporation (mm)
evaporation
precipitation
Long-term precipitation
1984
1985
1986
1987
1988
1989
1990
1991
1992

Fig. 1

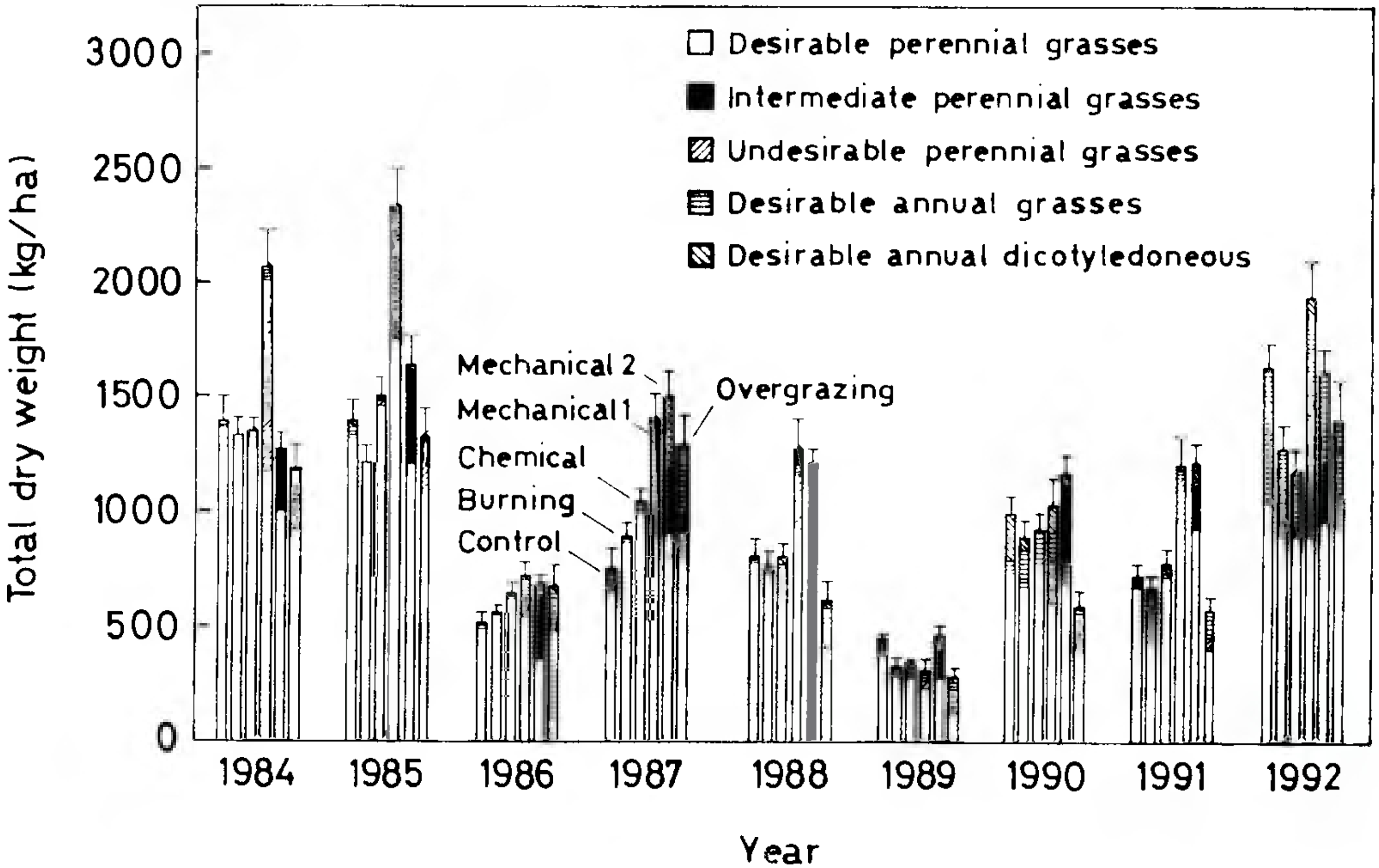
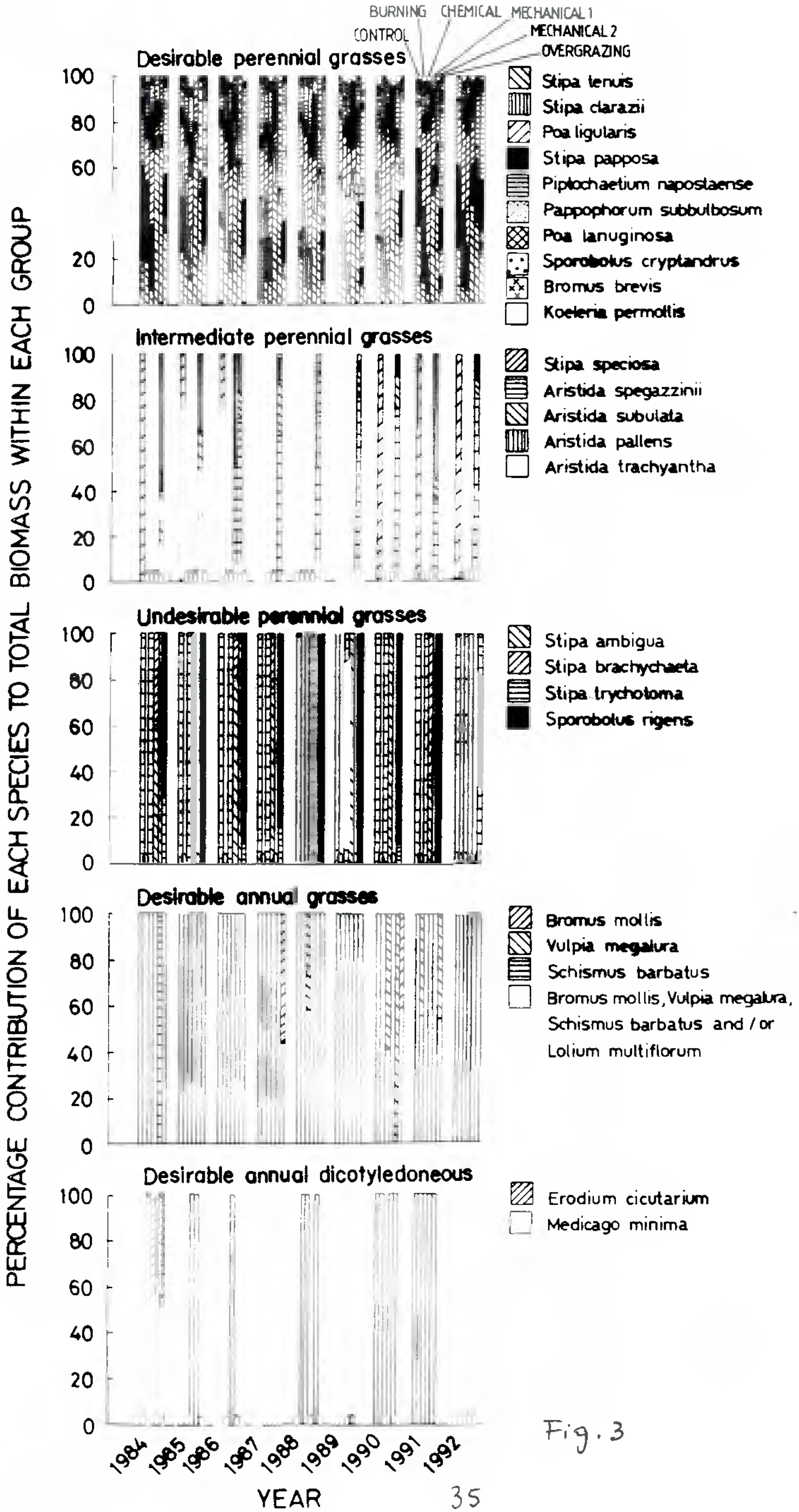

Total dry weight (kg/ha)
3000
2500
2000
1500
1000
500
0
Desirable perennial grasses
Intermediate perennial grasses
Undesirable perennial grasses
Desirable annual grasses
Desirable annual dicotyledoneous
Mechanical 2
Mechanical 1
Chemical
Burning
Control
Overgrazing
1984
1985
1986
1987
1988
1989
1990
1991
1992
Year

Fig. 2



BURNING
CHEMICAL
MECHANICAL 1
CONTROL
MECHANICAL 2
OVERGRAZING
Desirable perennial grasses
Stipa tenuis
Stipa clarazii
Poa ligularis
Stipa papposa
Piptochaetium napostaense
Pappophorum subbulbosum
Poa lanuginosa
Sporobolus cryptandrus
Bromus brevis
Koeleria permollis
Intermediate perennial grasses
Stipa speciosa
Aristida spegazzinii
Aristida subulata
Aristida pallens
Aristida trachyantha
Undesirable perennial grasses
Stipa ambigua
Stipa brachychaeta
Stipa trychotoma
Sporobolus rigens
Desirable annual grasses
Bromus mollis
Vulpia megalura
Schismus barbatus
Bromus mollis, Vulpia megalura, Schismus barbatus and / or Lolium multiflorum
Desirable annual dicotyledoneous
Erodium cicutarium
Medicago minima
PERCENTAGE CONTRIBUTION OF EACH SPECIES TO TOTAL BIOMASS WITHIN EACH GROUP
YEAR
1984
1985
1986
1987
1988
1989
1990
1991
1992

Fig. 3