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ORIGINAL ARTICLE

Structural heterogeneity and productivity of a tall fescue pasture grazed rotationally by cattle at four stocking densities

Maria Silvia Cid[1,2], Carlos M. Ferri[3], Miguel A. Brizuela[1,4] and Osvaldo Sala[5]

1 Faculty of Agricultural Science, Mar del Plata National University, Balcarce, Argentina
2 National Council of Scientific and Technical Investigations, Buenos Aires, Argentina
3 Faculty of Agronomy, La Pampa National University, La Pampa, Argentina
4 Scientific Research Commission of Buenos Aires Province, Argentina
5 Department of Ecology and Evolutionary Biology, Environmental Change Initiative, and Center for Environmental Studies, Brown University, Providence, USA

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Correspondence
Maria Silvia Cid, Faculty of Agricultural Science, Mar del Plata National University, 7620 Balcarce, Argentina.
Email: scid@balcarce.inta.gov.ar

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Abstract

The spatial heterogeneity in the structure and the productivity of the vegetation was examined in a tall fescue (*Festuca arundinacea* Schreb.) pasture rotationally grazed at four stocking densities in the Pampean region of Argentina. The examined pasture was grazed at the stocking densities of 3.6, 4.6, 5.6 and 6.6 animals ha^{-1} with a two-paddock 14-day rotational grazing system. Spatial distribution of plant height was examined as well as the percentages of short patch area (heavily utilized patches) or tall patch area (areas ungrazed or lightly defoliated). In addition, biomass, growth rate and relative growth rate were assessed for both short and tall patches. Grazing generated patchiness in vegetation structure and growth at all stocking densities. Increased stocking density caused an increase in the percentage of the short patch area in the paddocks. Short patches had relatively less live biomass than tall ones, but their relative growth rate was 31% higher than that of tall patches (0.021 ± 0.007 vs 0.016 ± 0.005 g DM g DM^{-1} day^{-1}). The increase in stocking density enlarged the proportion of short patch areas with higher relative growth rate. The relative growth rate (average between short and tall patches) of the two highest stocking densities was 61.7% higher than that of the low stocking density treatments (0.023 ± 0.006 vs 0.014 ± 0.004 g DM g DM^{-1} day^{-1}). Although the growth rate of the short patches did not exceed the value of the tall patches, the high value of relative growth rate appeared to indicate a higher photosynthetic capacity of the short patches. Moreover, live biomass did not decrease during the experimental period even in the short patch areas showing that, in the particular conditions of our study, overgrazing did not occur at the range of the stocking density examined.

Introduction

Cattle grazing generates vegetation mosaics in which heavily utilized patches alternate with lightly grazed ones, in continuous (Shiyomi *et al*. 1983; Gibb and Ridout 1986; Cid and Brizuela 1998) as well as in rotational (Hirata 2000; Ogura and Hirata 2001) grazing systems. It has been reported that these patches differ in several attributes such as vegetation structure and nutritive value. In pastures dominated by perennial ryegrass (*Lolium perenne* L.) (Illius *et al*. 1987) and by tall fescue (*Festuca arundinacea* Schreb.) (Cid and Brizuela 1998), heavily used patches have less biomass per unit area than lightly used patches, but their live biomass is denser, and their regrowth has higher nutritive value. Thus, the structural heterogeneity of grazed pastures (Shiyomi *et al*. 1983; Gibb and Ridout 1986; Cid and Brizuela 1998; Hirata 2000; Ogura and Hirata 2001) and grasslands (Kellner and Bosch 1992; Wallis de Vries and Daleboudt 1994) has been well documented, while the effect of the structural heterogeneity on pasture growth has not been examined yet.

In the Pampean region of Argentina, tall fescue pastures are widely used, being continuously or rotationally grazed with stocking rates varying seasonally from approximately 2–3 animals ha^{-1}. In the region, it is known that continuous grazing by cattle generates and sustains vegetation heterogeneity in the structure and the nutritive value of tall fescue pastures over the range of stocking densities conventionally used (Cid and Brizuela 1998). However, the structural heterogeneity of rotationally grazed tall fescue pastures has not been documented. Neither is it known whether structural changes in pasture structure affect pasture growth rate and relative growth rate. The aims of this study were to evaluate the structural patchiness in a tall fescue pasture rotationally grazed under four stocking densities of cattle with a two-paddock 14-day rotational grazing system, and to examine the effects of this patchiness on pasture productivity, as shown by growth rate and relative growth rate.

Materials and methods

Study area

This study was conducted March–December 1992 in the south-east of Buenos Aires Province, Argentina at Balcarce (37°45′S, 58°18′W), using a 12-ha pasture dominated by tall fescue, with orchardgrass (*Dactylis glomerata* L.) and dallisgrass (*Paspalum dilatatum* Poir.) as minor components. The pasture was fertilized neither previously and nor during the experimental period. The climate of the region is temperate–subhumid, without strong seasonal differences in precipitation. Long-term averaged mean annual temperatures and rainfall are 13.7°C and 952 mm, respectively (data from the last 30 years from the Balcarce Experimental Station, National Institute of Agricultural Technology). Annual precipitation during the study year was 1012 mm, and its seasonal distribution was similar to the long-term average.

The pasture was rested during the summer of 1991–1992, and mowed to a uniform canopy height of 15 cm at the beginning of fall (March) to erase previous grazing effects on the vegetation. The experimental area was divided into eight grazing units, and each one of them was divided into two paddocks of similar size to implement a two-paddock 14-day grazing rotational system. The units were grazed March–December at four stocking densities of 3.6, 4.6, 5.6 and 6.6 animals ha^{-1} in the paddocks. All stocking density treatments were implemented with four Aberdeen Angus steers (171 ± 16.8 kg live weight), using paddocks of 1.11, 0.87, 0.71 and 0.61 ha. Each stocking density was replicated twice.

Sampling methods

Vegetation sampling started on 1 August 1992, when patchiness created by grazing was clear at all stocking densities. Sampling was done approximately every 28 days from 1 August–18 December. Measurements were made in one randomly selected paddock of each grazing unit throughout the experiment. We estimated pasture heterogeneity (percentage of short vegetation area in each paddock) after each grazing event, and patch structure (height, and total and live biomass) both before and after each grazing event.

In continuously grazed pastures, heterogeneity arises when animal intake rate does not match vegetation growth, and height is the most practical cue to evaluate it. At moderate stocking densities, the frequency distribution of patch vegetation height is better described by a double normal distribution than by a normal distribution (Gibb and Ridout 1988; Cid *et al.* 1997). Moreover, even at high stocking densities, grazing generates vegetation heterogeneity because of animal rejection of the vegetation in dung or thistle areas, in continuously (Cid and Brizuela 1998) as well in rotationally grazed pastures (Ogura and Hirata 2001). Accordingly, in the present study we classified vegetation patches into two categories, short (heavily utilized patches) or tall (areas ungrazed or with signs of light defoliation) (Ring *et al.* 1985).

Sward heterogeneity

The percentages of paddock area represented by short or tall vegetation were estimated after grazing along three 10-m transects by paddock. First, using a 30-cm diameter Styrofoam-aluminum disc (pressure equal to 0.3 g cm^{-2}) that was gently lowered onto the vegetation along a metallic stick, we determined the canopy height of 30-cm diameter patches along each transect (33 patches, side-by-side). Simultaneously, we randomly selected five short patches and five tall patches in each paddock, measured their height with the disk previously described, and clipped the vegetation to ground level using a 0.1-m^2 frame (the biomass of these patches was clipped for further estimation of patch structural heterogeneity and growth). Finally, for each paddock and date, we classified grazing patches as short or tall on the basis of the height (mean and standard deviation) of the five tall and five short clipped patches. To do this, we first selected for each paddock a dividing point, which was a height value used to discriminate the patches on transects as short (sp.) or tall (tp.), minimizing the possibility of an error in that classification (classifying a short patch as tall or vice versa) (see Afifi and Clarck 1984). The samples of tall and short patches had different standard deviations (SD), so the dividing point (DP) was calculated in such a way that the differences between the sample means of both types of patch and the dividing point were the same proportion of their respective SD (see Table 1). Thus, the DP

Table 1 Heights (cm) used as dividing points† to discriminate grazing patches measured along transects as short (highly defoliated) or tall (lightly or not defoliated) in a tall fescue pasture rotationally grazed by steers at four stocking densities August–December, Balcarce, Argentina

		Months				
Stocking density (animals ha^{-1})	Replicates	August	September	October	November	December
3.6	1	6.7	11.6	21.3	18.9	18.6
	2	8.2	11.0	18.2	17.2	18.0
4.6	1	8.2	12.7	18.6	15.0	22.0
	2	8.9	11.3	12.8	12.3	11.7
5.6	1	7.2	7.3	10.0	9.0	8.0
	2	7.2	11.0	18.9	20.1	13.9
6.6	1	6.0	8.0	11.6	19.1	8.8
	2	6.5	9.3	12.2	17.4	9.6

† Refer to the text for the dividing points.

for each paddock was calculated as: $DP = x_{sp} + (a * SD_{sp})$, or $DP = x_{tp} - (a * SD_{tp})$, where $a = (x_{tp} - x_{sp})/(SD_{tp} + SD_{sp})$. Later, patches along transects were classified as tall and short areas according to these dividing points, and their percentages calculated.

Patch structure and growth

We estimated patch structure post-grazing (from the five short patches and five tall patches clipped as we mentioned before) and in pregrazing (in another five short and five tall patches randomly selected and clipped in each paddock before each grazing event). A previous study on the same pasture indicated that patches created and maintained by continuous grazing differed in biomass, live biomass density and nitrogen concentration (Cid and Brizuela 1998), but differences between tall and short patches in botanical composition were minor. Thus, in the present study we did not evaluate patch botanical composition. Total biomass was manually separated into live and dead biomass. Samples were dried at 60°C to constant weight in a forced-air oven, and weighed. Patch vegetation growth rate (g DM m^{-2} day^{-1}) was estimated from the difference in live biomass at the beginning and end of the 14-day rest period (Mannetje 2000). Patch relative growth rate (g DM g DM^{-1} day^{-1}) was computed from patch vegetation growth and live initial biomass. To understand the influence of vegetation patchiness on grassland productivity, we evaluated the following relationships: live mass–growth rate, live mass–relative growth rate, and growth rate–relative growth rate.

Statistical analysis

Characteristics of the spatial distribution of canopy height in each paddock were expressed by the mean, minimum, maximum, SD and coefficient of variation of data from the 99 locations along the transects.

Data obtained repeatedly at each sampling were analyzed with a split–split plot design in space and time (Steel and Torrie 1980) with stocking density as main plot, patch type as subplot (short patch percentage data analysis did not include patch type effect), and sampling time as subsub-plot. This design assumes that the variance structure of the repeated samples has a compound symmetry, that is, it assumes that samples repeated over time on the same spatial unit have a constant correlation and corrects for this effect (Gomez and Gomez 1984). The three-way interactions were not significant ($P > 0.05$) and were pooled with the residual error term. Changes in sward, and in patch structure and growth over time were analyzed using orthogonal polynomials (Steel and Torrie 1980). Before and after grazing, structure data were analyzed separately. Differences among stocking densities were evaluated by Ryan–Einot–Gabriel–Welsch multiple range test (Westfall *et al.* 1999). All the differences reported are significant at $\alpha = 0.05$ unless indicated. The relationships between live biomass and growth rate, live biomass and relative growth rate, and growth rate and relative growth rate were evaluated by correlation analysis. All the analyses were performed using the Proc Glm of SAS (SAS 2000).

Results

Rotational cattle grazing created patchiness at all the considered stocking densities, generating patches with different utilization levels that differed in structure and productivity. After grazing, canopy height was spatially heterogeneous (Figure 1). The percentage of short vegetation largely differed even between the two replications at each stocking density and at each sampling date. In August (late winter), the percentages

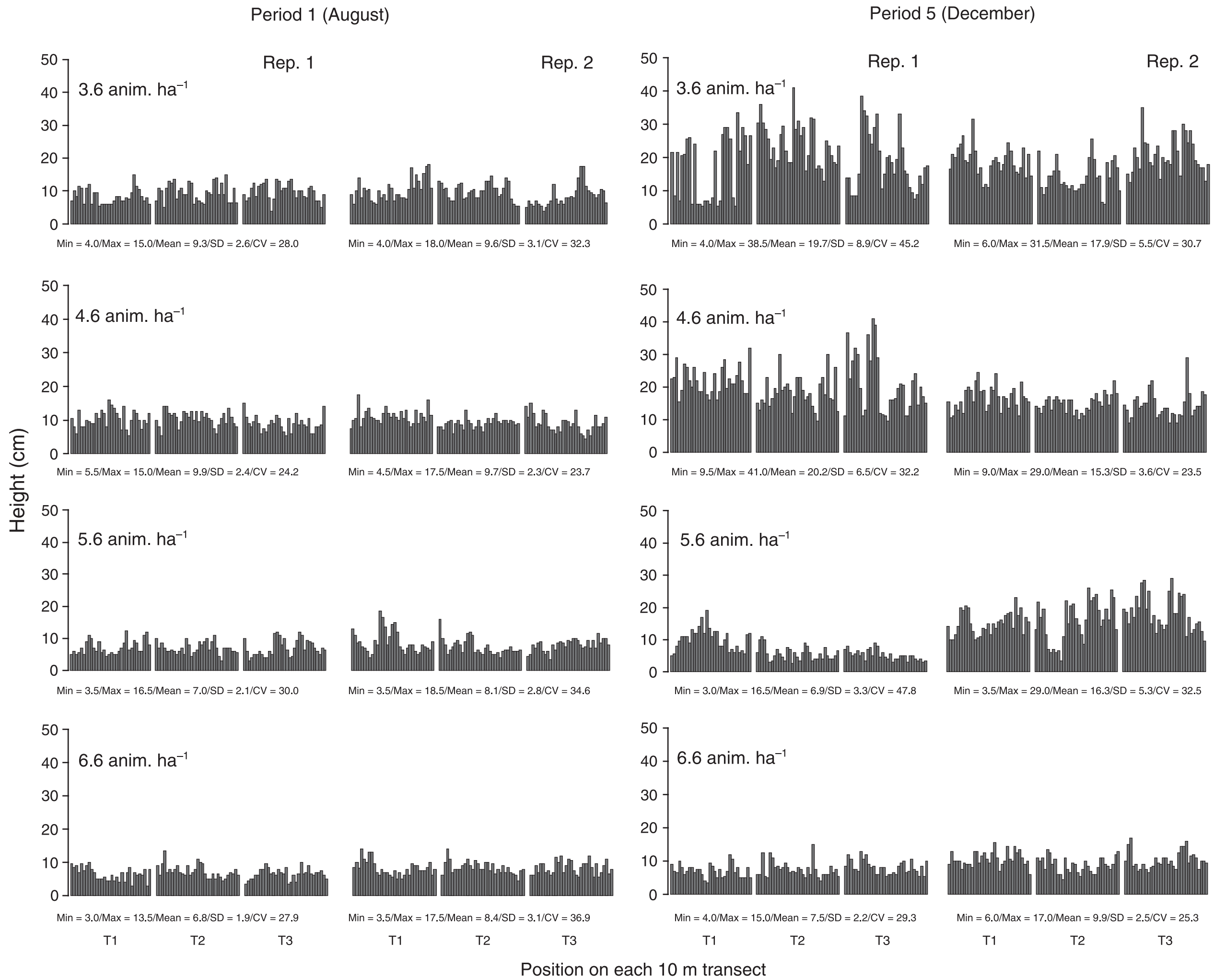

Figure 1 Post-grazing canopy height in paddocks of tall fescue grazed by cattle under a two-paddock 14-day rotational grazing system. The statistical parameters are minimum (Min), maximum (Max), mean, standard deviation (SD), and coefficient of variation coefficient (CV).

of short vegetation area ranged 30.1 ± 16.3% (4.6 animals ha^{-1}) to 43.4 ± 2.0% (5.6 animals ha^{-1}), averaging 36%. Then, it changed with different patterns depending on stocking density (stocking density–date interaction). Differences among stocking densities were significant only at the end of the experimental period. For each stocking density, the percentage of short patches did not differ between the two last sampling dates, averaging 97a, 77b, 52c, and 41c percentage for decreasing stockings (Figure 2).

There were significant differences in the changes of the height, and the total and live biomass through time between the short patches and the tall ones, both before and after grazing (patch type–date interactions), but these variables were not affected by stocking density. Short patches had less total and live biomass than tall patches both, before and after grazing events. Differences in height and live biomass between patches increased through time, because of live biomass accumulation in the tall patches (Figure 3). Largely, difference was observed in the patch growth rate between the short patches and the tall ones. Independently of stocking density and date, the tall patches produced more per unit surface area at the end of the growing season, and twice as much as the short patches (patch type effect, 3.23 ± 1.41 vs 1.46 ± 0.67 g DM m^{-2} day^{-1}) (Figure 4). Patch relative growth rate was strongly affected by grazing (patch type and stocking density effects) but not by time. On average, the relative growth rate of the short patches was 31% higher than that of the tall patches (patch type effect, 0.021 ± 0.007 vs 0.016 ± 0.005 g DM g DM^{-1} day^{-1}). In addition, an increase in stocking density improved the relative growth rate for both patch types. The relative growth rate averaged through patch types in the two highest stocking densities (0.023 ± 0.006 g DM g DM^{-1} day^{-1})

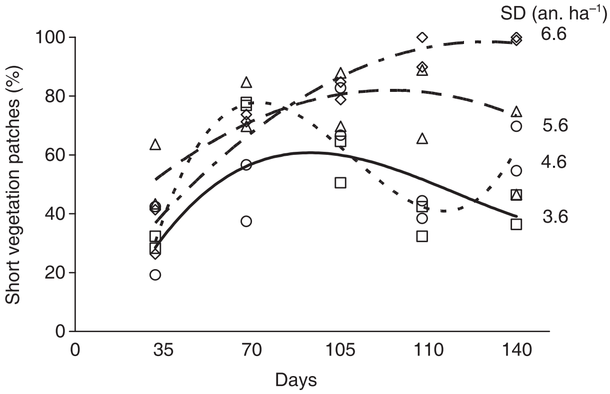

Figure 2 Percentage of short vegetation patches (%) as affected by stocking density (SD) and time in a tall fescue pasture under a two-paddock 14-day rotational grazing system (stocking density by date interaction; $P < 0.05$). The independent variable (x) is time in days from 1 August. Circles, 3.6; quadrates, 4.6; triangles, 5.6; diamonds, 6.6 animals ha^{-1}.

was 61% higher than that in the two lowest stocking densities (0.014 ± 0.004 g DM g DM^{-1} day^{-1}) (Figure 5).

The relationships between live biomass and growth rate ($r = 0.74$; $P < 0.01$); and between live biomass and relative growth rate ($r = -0.5$; $P < 0.01$) were inverted (Figure 6a,b). Between the growth rate and the relative growth rate, the relationship was not clear when all data was analyzed together ($r = -0.063$; $P > 0.05$). However, when the data were analyzed separately, for the short patches ($r = 0.50$; $P < 0.05$) and for the tall patches ($r = 0.55$; $P < 0.05$), a significant correlation was observed for both patch types (Figure 6c).

Discussion

The results in this study show that, in the two-paddock 14-day grazing system, cattle grazing generated vegetation patchiness in the tall fescue pasture at a wide range of stocking densities. In the previous study, the same tall fescue pasture was grazed continuously, and the grazing impacts on the vegetation

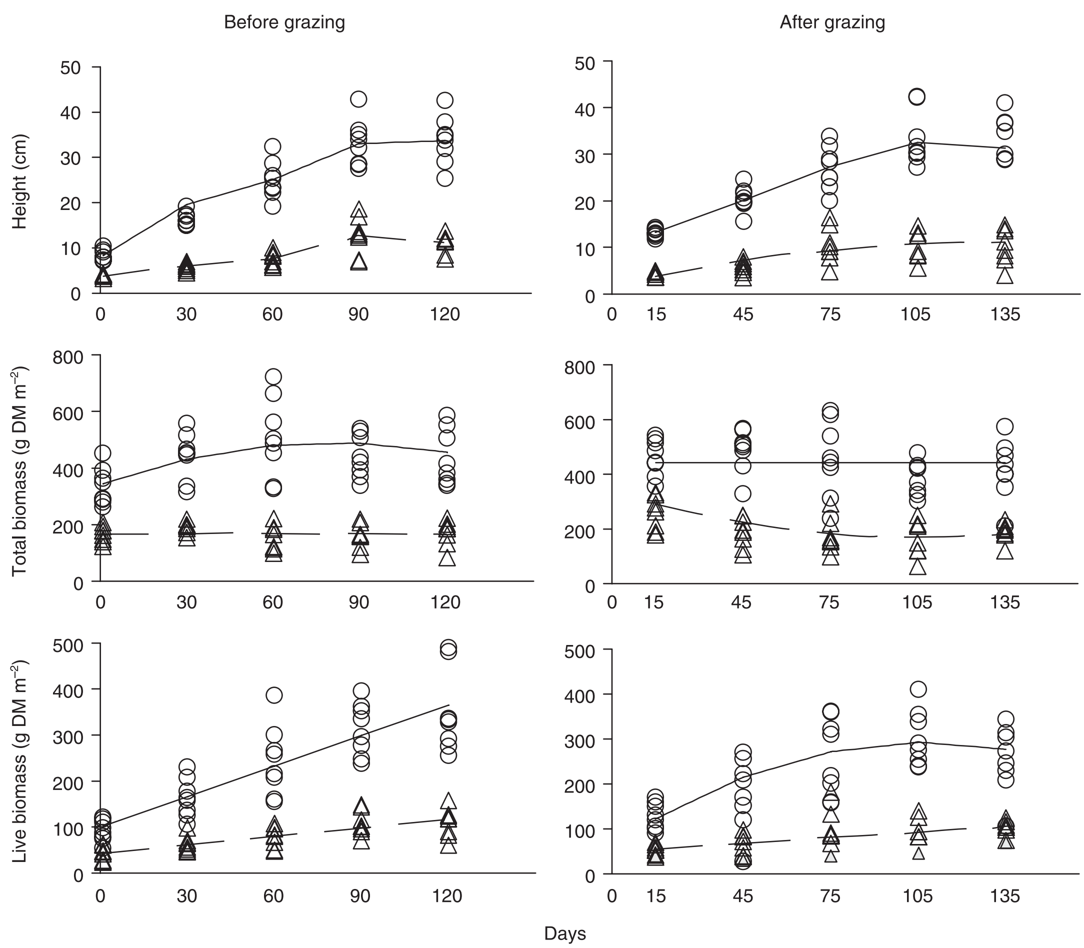

Figure 3 Structural characteristics of patch type over time in a tall fescue pasture under a two-paddock 14-day rotational grazing system. Circle and solid line, tall patches; triangle and dashed line, short patches. The independent variable (x) is time in days from 1 August. For all the variables, patch type–date interaction was significant ($P < 0.05$), but there was no effect on stocking density for patch type ($P > 0.05$).

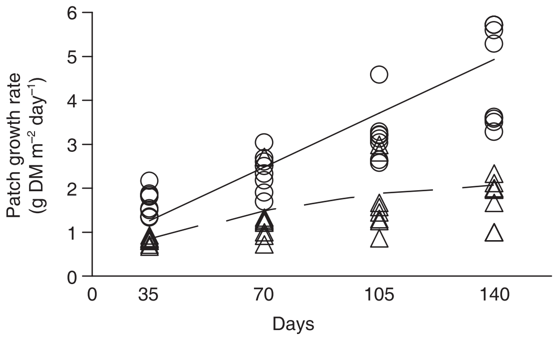

Figure 4 Patch growth rate in a tall fescue pasture grazed by cattle at four-stocking density under a two-paddock 14-day rotational grazing system. At each date, marks indicate the patch growth rate for a previous 15-day period. Circle and solid line, tall patches; triangle and dashed line, short patches (patch type effect; $P < 0.05$).

heterogeneity were examined. Comparing the results obtained in the two studies allows us to understand the difference in the impacts by these two grazing systems. The percentage of short patches was highly variable in both grazing systems, being highly related to stocking density. The structure of the highly grazed patches was not affected by grazing system, their height ranging 5–10 cm, and their live biomass ranging 50–100 g DM m^{-2}. On the other hand, the structure of the ungrazed and lightly grazed patches was affected by stocking density under continuous but not under rotational grazing.

An important purpose of the cattle grazing tactics is adjusting the proportion of short vegetation, for controlling pasture growth and intake rate by animals. By maintaining patches of vegetation short, animals will find forage of high quality (Cid and Brizuela 1998), and the proportion of intake to gross shoot production will increase (Parsons *et al.* 1983b). In addition, the lower bite size at the short vegetation could be partially compensated by a higher bite rate (Wallis de Vries and Daleboudt 1994).

In our study, the short patches had lower productivity per unit area but higher relative growth rate than the taller patches. The values of relative growth rate we obtained for short and tall patches are similar to those by Kemp *et al.* (2001) obtained in a controlled environment (21°C day, 15°C night, 12-h photoperiod). They found that a change in defoliation intensity induced a 10% increase in the relative growth rate of tall fescue individual plants (0.0176 and 0.0194 g DM g DM^{-1} day^{-1} for 4 and 0 fully expanded blades remaining, respectively).

Although in our study the relative growth rate of the short patches was higher than that of the tall ones, its effect was not sufficient for increasing the growth rate of the pasture. Our results indicate that the increase in the relative growth rate should have been approximately two-times higher (0.028) than that of actual data (0.016), in order for the growth rate of the short patches to be similar or higher than that of the tall ones.

The high relative growth rate of the short patches is one of indicators of high potential of productivity of the short patches. Grazing reduces total leaf area, but also alters the age structure of leaves within canopies. Because plant leaves generally exhibit the maximum photosynthetic rates at approximately the time of full expansion (Caldwell 1984), the young leaves of forage plants expanded after defoliation may display greater rates of photosynthesis than those of non-defoliated plants (Parsons *et al.* 1983a; Briske 1991). This is a reason why the relative growth rate of the short patches was higher than that of the tall patches. Moreover, in our study, the increase in stocking density improved the relative growth rate of the vegetation, enlarging the proportion of short patch area with the higher relative growth rate.

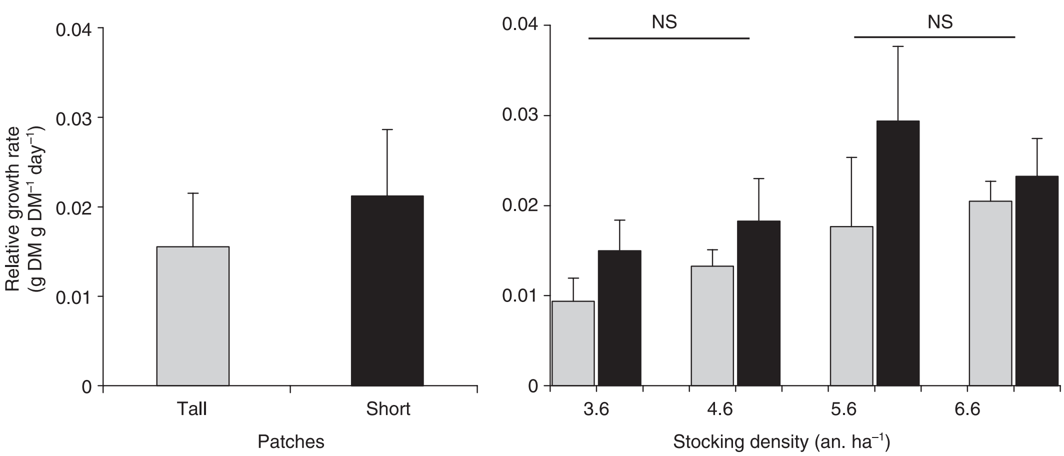

Figure 5 Patch relative growth rate in a tall fescue pasture grazed by cattle at four-stocking density under a two-paddock 14-day rotational grazing system. Gray, tall patches; black, short patches (patch type and stocking density effects; $P < 0.05$). Averaged through patch type, relative growth rate was higher at the two highest stocking densities (lowest SD, 0.014 ± 0.004; highest, 0.023 ± 0.006 g DM g DM^{-1} day^{-1}) (NS, not significant).

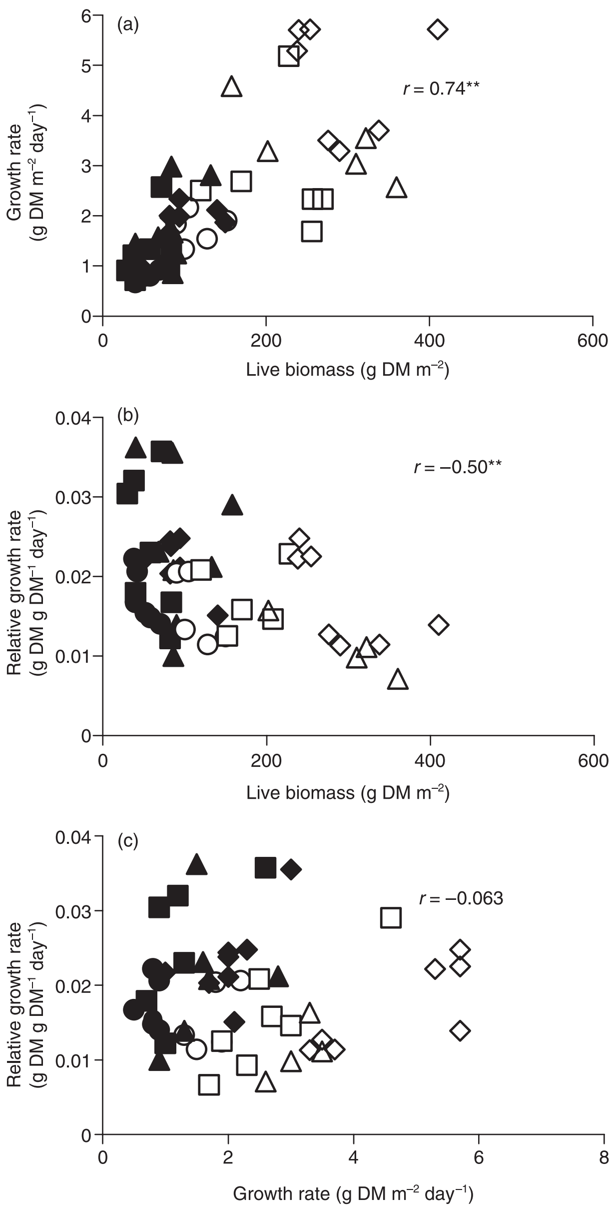

Figure 6 Relationship between herbage live mass and growth (a) and relative growth (b) rates, and between growth and relative growth rates (c) of grazing patches in a tall fescue pasture under a two-paddock 14-day rotational grazing system. When data were analyzed by patch type, the correlation coefficients between the growth rate and the relative growth rate were $r = 0.50^*$ for short patches, and $r = 0.55^*$ for tall patches. $^*P < 0.05$; $^{**}P < 0.01$. Shapes indicate dates: circles, September; quadrates, October; triangles, November; diamonds, December. Black, short patches; white, tall patches.

In plant regrowth, relative growth rate did not only reflect the photosynthetic capacity of the plants, but also the amount and mobility of the reserve substances from storage tissues. Nevertheless, in our study the relative growth rate of short patches did not decline throughout the experimental period, although it would occur if the high relative growth rate of short patches depended on below-ground reserves. This is indirect proof that the high relative growth rate is mainly related to their high photosynthetic capacity. The high rate of regrowth after defoliation can be interpreted as a mechanism which improves tolerance to grazing (Briske 1991). Therefore, improving relative growth rate of the short patches is a form of adaptation of tall fescue plants to sever grazing condition. However, in the Pampean region, overgrazing occasionally occurs in short patch areas of continuously grazed tall fescue pastures, resulting in the invasion of highly competitive thistles (Brizuela and Cid 1991). As a consequence, forage productivity of the tall fescue pastures declines. This means that although severe defoliation induces an increase of relative growth rate of short patches, pasture degradation will be caused at an excess level of defoliation. In our study, live biomass did not decrease during the experimental period even in the short patch areas showing that, in the particular conditions of our study, overgrazing did not occur at the range of the stocking density examined.

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