Grass-fed beef production systems of Argentina's flooding pampas

Understanding ecosystem heterogeneity to improve livestock production

M.S. Cid, R.C. Fernández Grecco, M. Oesterheld, J.M. Paruelo, A.F. Cibils and M.A. Brizuela

Abstract: *The homogeneous topography of Argentina's flooding pampas conceals a substantial amount of spatial and temporal ecosystem heterogeneity. Differences in soils, grassland botanical composition and plant growth regimes that occur down to individual paddocks influence livestock grazing patterns and, predictably, affect the productivity of cattle ranches in the region. Over 40 years of ecological research have greatly improved understanding of the structural and functional heterogeneity of this ecosystem. This better understanding has led to the development of grazing management strategies that help ranchers optimize secondary production by achieving a more efficient use of vegetation. As a result, cattle ranches are rapidly increasing profitability by integrating grass-fed yearling finishing programmes with the traditional cow-calf operations of the region.*

Keywords: *native grassland; structural and functional heterogeneity; livestock grazing; ranching system productivity; Argentina*

M.S. Cid (corresponding author) is with the Facultad de Ciencias Agrarias, Universidad Nacional de Mar del Plata and the Instituto Nacional de Tecnología Agropecuaria, Ruta 226 km 73,5, 7620 Balcarce, Buenos Aires, Argentina, and the Comisión Nacional de Investigaciones Científicas y Técnicas, Argentina. E-mail: scid@balcarce.inta.gov.ar. R.C. Fernández Grecco is with the Instituto Nacional de Tecnología Agropecuaria, Buenos Aires, Argentina. M. Oesterheld and J.M. Paruelo are with the Comisión Nacional de Investigaciones Científicas y Técnicas and the Facultad de Agronomía, Universidad Nacional de Buenos Aires, Av San Martín 4453-1417 Buenos Aires, Argentina. A.F. Cibils is with the Department of Animal and Range Sciences, New Mexico State University, Las Cruces, NM 88003, USA. M.A. Brizuelan is with the Facultad de Ciencias Agrarias, Universidad Nacional de Mar del Plata, Buenos Aires, and the Comisión de Investigaciones Científicas de la Provincia de Buenos Aires, Buenos Aires, Argentina.

Argentina's flooding pampas

The flooding pampas cover approximately nine million hectares east of the Tandilia hills in the Argentine province of Buenos Aires and include the Salado River and Laprida Basins (Etchevehere, 1961; Vervoorst, 1967; see Figure 1). The region is extremely flat, with relative elevation differences that rarely exceed 4 m (Perelman *et al*, 2001) and exhibits a temperate–subhumid climate with mean annual temperatures ranging from 15.9ºC in the

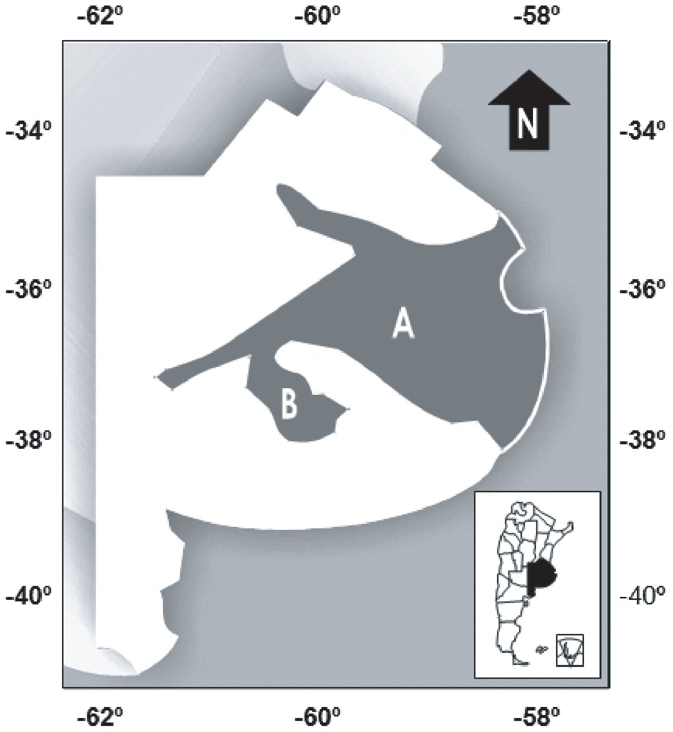

Figure 1. Location of the flooding pampas in Buenos Aires (dark area): A – Salado Basin; B – Laprida Basin.

north to 13.8ºC in the south, along with mean monthly temperatures from 6.8ºC in the winter to 21.8ºC in the summer. Average annual rainfall is approximately 900 mm, with no strong seasonality pattern. During the summer, areas of shallow soils are often subjected to drought due to high atmospheric demand, while the lack of a developed natural drainage network (due mainly to the lack of topographic relief of the region), on the other hand, is responsible for brief flooding events that occur in most years during autumn–spring in the lowland areas (Chanetón *et al*, 2002).

The flooding pampas constitute a heterogeneous ecosystem (Oesterheld *et al*, 2005a) comprising mostly native grasslands that are the main livestock forage resource of the region (approximately 80% of the total area). Management inputs aimed at improving rangeland condition and livestock production have increased dramatically in recent decades (Fernández Grecco, 1995). Historically, cow-calf ranching operations have accounted for most of the agricultural industry of the region. Cattle are typically raised in large paddocks (250–400 ha), with an estimated average stocking density of 0.7 animal units (AU) $ha^{-1} y^{-1}$ and a system production of 80–90 kg beef $ha^{-1} yr^{-1}$. Over the last decade, a large number of ranches have increased their secondary productivity by adding grass-fed yearling finishing programmes to their production system. The introduction of seeded pastures based on tall wheatgrass (*Thinopyrum ponticum*) and tall fescue (*Festuca arundinacea*) together with nitrogen (N) and phosphorus (P) fertilization of both seeded pastures and native rangelands has enabled these system changes. New beef production schemes have brought about a reduction in paddock size and an increase in stocking density and meat production to 1–1.1 AU $ha^{-1} y^{-1}$ and 110–120 kg beef $ha^{-1} yr^{-1}$ respectively.

A total of 2.4 million calves, mainly of British breeds (such as Aberdeen Angus and Hereford), are raised annually on Argentina's flooding pampas. A high percentage of these calves are sent to ranches for pasture-based finishing or to feedlots in different areas of the country, where they are later sold for slaughter once they reach a weight of approximately 440 kg (steers) or 320 kg (heifers). Currently, there are 8.8 million cattle on flooding pampas, accounting for 16% of the country's cattle population of 54 million (Rearte, 2006).

Structural heterogeneity of the flooding pampas

The heterogeneity of the vegetation of the flooding pampas was first described by Vervoorst (1967), and then analysed in detail in several phyto-sociological studies (León *et al*, 1975, 1979, 1985; Batista *et al*, 1988; Burkart *et al*, 1990, 1998) that described the botanical composition of plant communities in relation to environmental features such as topography, flooding regime and edaphic salinity and alkalinity. Perelman *et al* (2001), who synthesized these studies, found that heterogeneity was higher at the landscape *v* the regional scale, and reported that plant communities were associated with similar environmental heterogeneity across the region. Five vegetation units have been defined at the regional scale, which occur along gradients of humidity and salinity–alkalinity associated with small topographic differences: (1) mesophytic meadows (uplands); (2) humid mesophytic meadows (plains); (3) humid prairies (humid lowlands); (4) halophytic steppes (alkaline lowlands); and (5) humid halophytic steppes, which are associated with a relatively small area of poorly drained fluvial valleys (Figure 2). In addition, vegetated ponds (with, for example, *Typha* sp.) occur across most of the region. Because of their different botanical compositions and their associations with different soil types, the annual average carrying capacity of each community differs, and has been estimated as 1.00, 0.75, 0.60 and 0.30 UA $ha^{-1} y^{-1}$ for the uplands, plains, humid lowlands and alkaline lowlands respectively (see Figure 2). The regional proportions of the area represented by uplands (5%), plains (15%), humid lowlands (55%), alkaline lowlands (1%) and vegetated ponds (20%) that occur over scales of a few kilometres in different proportions and arrangements, were recently estimated from remotely sensed data (Aragón, 2007). However, the percentage of each community in a typical grazing paddock usually differs from regional average values: for example, the alkaline lowlands, when present, usually represent from 10 to 15% of the paddock area.

Climatic conditions across the flooding pampas allow the coexistence of C3 and C4 species, which vary in relative abundance along latitudinal and (mostly) topsoil pH gradients (Perelman *et al*, 2001, 2005). The ratio of C3:C4 grass cover decreases as topsoil pH increases; thus, the relative abundance of C3 *v* C4 species tends to be highest in uplands and lowest in alkaline lowlands where C4 rhizomatous grasses are dominant (Figure 2). Dallis grass (*Paspalum dilatatum*), annual ryegrass (*Lolium*

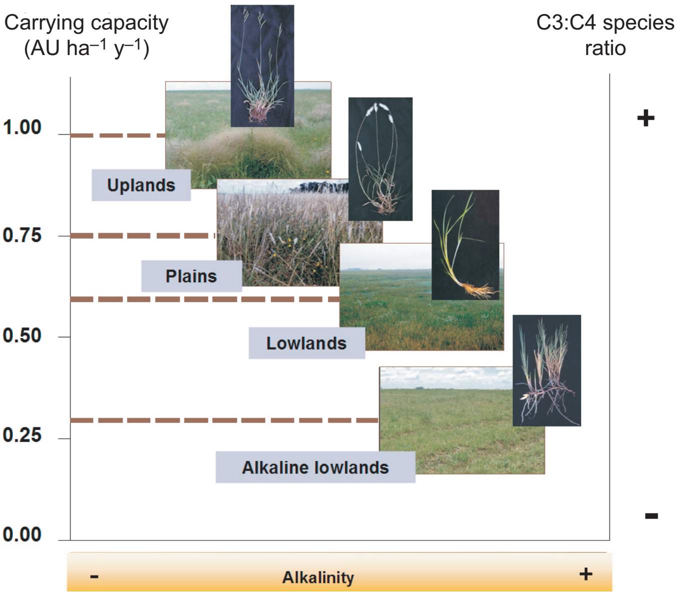

Figure 2. Plant communities of the flooding pampas according to gradients of soil alkalinity, carrying capacity, and C3:C4 species ratio. For each community, one of its characteristic plant species is included. Uplands – 'dallis grass' (*Paspalum dilatatum*); plains – 'cola de zorro' (*Bothriochloa laguroides*); humid lowlands – 'cebadilla de agua' (*Glyceria multiflora*); and alkaline lowlands – 'saltgrass' (*Distichlis spicata*).

multiflorum) and a needlegrass (*Stipa neesiana)* are typical of the uplands; foxtail (*Bothriochloa laguroides*) and the needlegrass *Stipa papposa* occur mainly in the plains plant communities; *Leersia hexandra* and *Glyceria multiflora* grow in the humid lowlands; and saltgrass (*Distichlis spicata*) dominates the alkaline lowlands (Berasategui and Barberis, 1982; Batista *et al*, 1985, 1988; Collantes *et al*, 1988; Agnusdei *et al*, 1989; Burkart *et al*, 1990; Oesterheld *et al*, 2005b; see Figure 2). *Paspalum quadrifarium* is a particularly conspicuous tussock-forming C4 grass, which occurs in uplands, plains and humid lowlands, giving these communities a characteristic physiognomy. South of the Salado River, 20% of the grassland area is dominated by this species (Herrera *et al*, 2005), which exhibits palatable regrowth (Brizuela *et al*, 2004; Sierra *et al*, 2005) following disturbances such as controlled burns; this causes its intake by cattle to increase (Laterra *et al*, 2003) and it can therefore meet the nutritional requirements of the cows during spring (Sacido *et al*, 1995).

Although native legumes are both scarce and have low nutritive value, the narrow-leaf trefoil *Lotus glaber* (= *L. tenuis*), introduced in the mid-1900s, has spread naturally into the plains and humid lowland plant communities (Miñón *et al*, 1990). Toxic plant species are frequent in all communities and, although there has not been a systematic evaluation of their impact on cattle production, toxic plant poisoning represents 28% of animal losses registered by the Diagnostic Service Laboratory of INTA Balcarce (E. Odriozola, personal communication). Toxic species of the greatest impact on animal production are *Solanum glaucophyllum*, *Wedelia glauca*, *Baccharis coridifolia*, *Cestrum parqui*, poison hemlock (*Conium maculatum*) and *Xanthium cavaniliesii*. The toxicity of some of these species, such as *C. maculatum*, can triple in regrowing plant tissues during dry periods (de la Torre *et al*, 2005). At present, there are protocols available that use microanalysis of digestive content to confirm livestock ingestion of some plant species that produce acute poisoning (Yagueddú *et al*, 1998; Cid *et al*, 2003; Indurain *et al*, 2006).

Functional heterogeneity of the flooding pampas

The coexistence of C3 and C4 species and mild winters ensures year-round productivity, which, nonetheless, tends to decline from late autumn through mid-winter. Sala *et al* (1981) and Hidalgo and Cahuépé (1991) reported that peaks of maximum productivity of uplands, plains and humid lowlands occurred between spring and early autumn, and concentrated between 60 and 70% of the annual biomass production, which until the late 1990s had been estimated at 5.0 to 5.8 ton DM ha^{-1} y^{-1}. Uplands reach their production peak in mid-spring, plains in late spring–early summer, and the lowlands in mid-summer (Figure 3). The maximum standing crop of alkaline lowlands (1.2 to 2 ton DM ha^{-1} y^{-1}) occurs at the end of the summer, when saltgrass, the dominant species of this community, becomes the peak standing crop (Sala *et al*, 1981; Ginzo *et al*, 1986; Brizuela *et al*, 1990). This temporal sequence in productivity agrees with the pattern of C3:C4 grass ratio at the landscape level reported by Perelman *et al* (2001), and partially supports the hypothesis that the flooding pampas experience two seasonal waves of primary production: a regional wave generated by variation in latitude, and a superimposed local wave generated by topography.

Recent studies using satellite images show two seasonal peaks in Normalized Difference Vegetation Index (NDVI), an estimator of above-ground productivity of native grasslands and seeded pastures of the region (Paruelo *et al*, 2000; Piñeiro *et al*, 2006; Grigera *et al*, 2007). The highest peak occurs during late spring, whereas a smaller peak is registered in the autumn. The mean

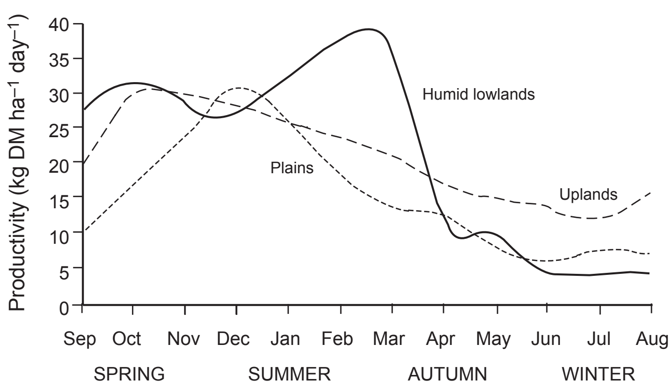

Figure 3. Seasonal productivity of plant communities of the flooding pampas.
Source: adapted from Hidalgo and Cahuépé, 1991.

seasonal productivity pattern exhibits high year-to-year variability; seasonal productivity patterns for any given year tend to deviate markedly from long-term (20 y) averages (Posse *et al*, 2005; see Figure 4). In some years, the spring peak moves towards the summer, whereas in other years the autumn peak becomes the most significant. On the other hand, the beginning of spring growth, particularly in the Laprida Basin, is highly variable and depends on the intensity and length of droughts that occur during the winter and beginning of the spring (Figure 5). These pronounced variations in seasonal forage productivity can cause either a considerable increase in the need for feed supplements or a sensible decrease in reproductive performance and weight gains of cattle herds, which can have carry-over effects on multiple annual production cycles (Grigera *et al*, 2007).

At the landscape scale, recent research has shown that seasonal NDVI patterns are predictably influenced by the relative area covered by each plant community (Posse *et al*, 2005; Grigera *et al*, 2007; see Figure 4**)**. However, the spatial and temporal variation in radiation use efficiency of the flooding pampas is still poorly understood, although progress is being made in establishing the influence of temperature/precipitation (Piñeiro *et al*, 2006) and soil/plant community (Grigera *et al*, 2007) interactions on radiation use efficiency across the region.

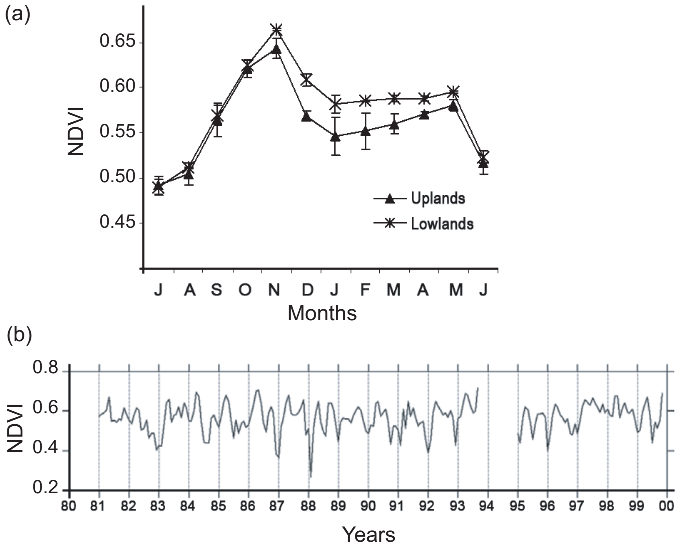

Figure 4. Seasonal pattern of the Normalized Difference Vegetation Index (NDVI) from two landscape units of the flooding pampas, one dominated by uplands, and the other by humid lowlands. (a) Average of 15 growing seasons. The error bars are spatial standard deviations across the pixels of the same landscape. (b) Seasonal values for the landscape dominated by uplands.
Source: from Posse *et al*, 2005.

Livestock grazing and grassland heterogeneity

The grasslands of the flooding pampas are subjected to the combined effects of grazing, floods and droughts. Grazing promotes a reduction in tussock size, modifies botanical composition by promoting forb invasion (Sala *et al*, 1986; Sala, 1988) and, when sufficient forage is available, generates vegetation patches that differ in structure and nutritive value (Siffredi *et al*, 1997; Cid and Brizuela, 1998; Cid *et al*, 2008). Grazing is associated with diminished spatial heterogeneity of vegetation at the landscape scale (Chanetón *et al*, 2002) due to the fact that it reduces cover of the most palatable grasses and favours the colonization of exotic and native forbs, which become co-dominant along with several sod grasses. This effect can be reversed either by animal exclusion or by floods that eliminate exotic forbs that, unlike the native species, are not adapted to waterlogged conditions (Chanetón *et al*, 1988; Insausti *et al*, 1999). Thus, floods tend to improve the quality and accessibility of forages.

Livestock recognize grassland heterogeneity at the landscape and plant community levels, and thus select communities within paddocks (Escobar, 1994; Siffredi *et al*, 1997) and species within communities (Brizuela *et al*, 1983, 1990; Miñón *et al*, 1984a; Cid and Brizuela, 1994; Vacarezza, 2000; Vacarezza and Cid, 2004). Cattle are frequently observed grazing in the humid and alkaline lowlands during the summer. This suggests that they select communities (that is, utilize them more than would be expected by chance) on the basis of plant growth rates and dominant species type (for example, cool-season [C3] or warm-season [C4] species). Thus, in a situation where cattle would select plant communities based solely on forage value, during autumn, winter and early spring, they would tend to select uplands and plains that had a

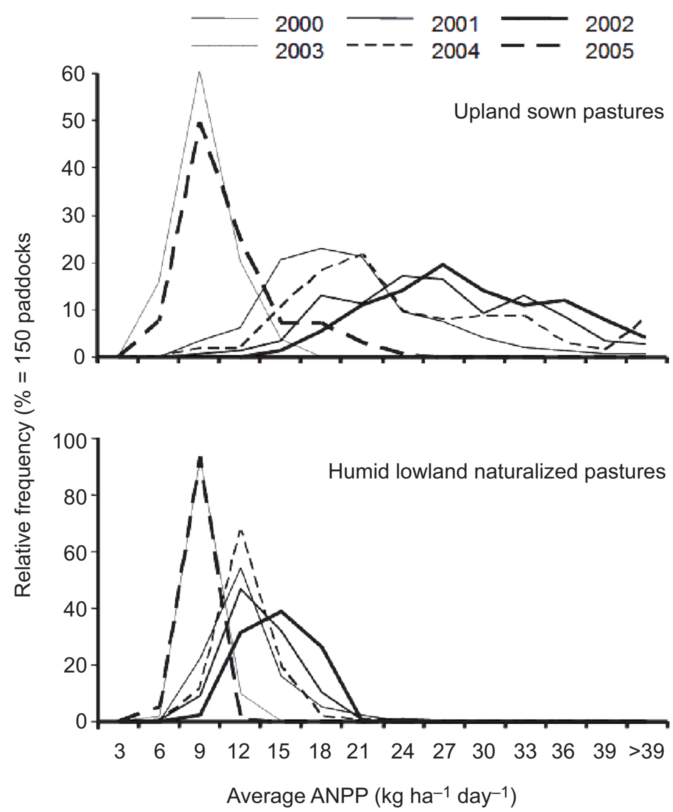

Figure 5. Frequency distribution of the above-ground net primary productivity (ANPP) of uplands and humid lowlands in October.
Source: from Grigera *et al*, 2007.

higher percentage of cool-season species than the lowlands. Conversely, from early spring to summer, livestock would select the lowlands, preferentially the humid ones (Fernández Grecco, 1995).

The studies cited above indicate that in most situations, selection of plant communities by cattle are influenced by topography, drinking water location and percentage of each plant community in a paddock (non-interactive factors, in the sense of Senft *et al*, 1987), which interact with the availability and quality of the forage in each plant community (interactive factors). Thus, total forage availability and percentage of upland and plains plant communities in a paddock (drinking water points are usually located in these communities) are the major factors that determine plant community selection by cattle throughout the year. If forage available in those communities remains above a given value (threshold), cattle will predominantly utilize them until the end of the spring; nevertheless, if forage available in the uplands and plains decreases below that threshold, cattle will preferentially utilize the lowlands. In this way, depending on the proportion of the different plant communities in a paddock, cattle may select the humid lowlands beginning in late winter or late spring (Vacarezza and Cid, 2004), or only during the summer (Escobar, 1994). On the other hand, the alkaline lowlands may also be selected in late spring (Vacarezza and Cid, 2004), summer (Brizuela *et al*, 1983, 1990) and even during winter (Escobar, 1994). Gradual reduction in the available forage in the uplands and plains, and animal requirements (according to their body size) suggest that, in cattle–sheep mixed grazing, cattle will be the first to use the lowlands (Vacarezza and Cid, 2004). On the other hand, populations of rheas (*Rhea americana*), which are frequently found on some ranches of the flooding pampas, are not affected by variations in forage availability, because they consistently select actively growing grasses as well as native and cultivated forbs (Vacarezza, 2000).

Studies conducted in mid- to small-sized paddocks with a strong predominance of one plant community, but with different forage availabilities (total and by species), have determined the plant species preferred by cattle. For example, in uplands and plains, annual ryegrass and *Bromus* spp. are selected during autumn and winter, with *B. laguroides* selected during spring and summer (Cauhépé and Fernández Grecco, 1981; Miñon *et al*, 1984a). In addition, in paddocks of seeded pastures where plains predominate with dispersed areas of alkaline lowlands, cattle and sheep select tall fescue over tall wheatgrass and saltgrass during the summer (Cid and Brizuela, 1994; Quintana *et al*, 2006). In these studies, sheep were more selective than cattle (Cid and Brizuela, 1994), and calves more selective than cows (Quintana *et al*, 2006). However, in late summer, when saltgrass biomass exceeds 10% of vegetation available, cattle select this species over tall wheatgrass (Brizuela *et al*, 1990). To date, no data on species selection in humid lowlands are available, although *L. hexandra*, *Panicum gounii* and *Paspalidium paludivagum* are frequently found in the diets of cattle and sheep that graze this community during late spring (Vacarezza, 2000).

Regardless of the specific mechanism of diet selection, cattle diets in the region are of higher quality than that provided by the average vegetation. Miñon *et al* (1984b) reported that in mid-winter, steers with oesophageal fistulas had diets with a higher percentage of green biomass (68 *v* 22%), were more digestible (46 *v* 31% DMD) and had a higher crude protein content (11 *v* 9% CP) than that provided by the average vegetation in paddocks with forage availabilities of 1.5 and 3.0 ton DM ha^{-1}.

Using grassland heterogeneity to enhance productivity of cattle ranching systems

Towards the end of the 1980s, a considerable amount of information regarding the structure and function of grasslands of the flooding pampas was available, in addition to data on rangeland survey methods (León *et al*, 1975, 1979, 1985; León and Bertiller, 1980; Arana and Mailland, 1981; Sala *et al*, 1981, 1986; Brizuela *et al*, 1982; Maceira and Verona, 1984; Cauhépé *et al*, 1985; Orbea *et al*, 1985; Insausti and Soriano, 1987; Batista *et al*, 1988). Despite this, information related to grassland utilization (Deregibus *et al*, 1986; Fernández Grecco *et al*, 1988) was insufficient to allow producers to develop efficient annual grazing management programmes. Beginning in the mid-90s, new strategies of grassland utilization were proposed to: (a) control grazing and resting periods in order to manage landscape heterogeneity; (b) increase winter forage production by fertilization; (c) promote the abundance of annual ryegrass, a species that is abundant in uplands and plains; and (d) evaluate the effect of continuous and rotational grazing systems on the vegetation of paddocks with predominance of plains or humid lowlands.

(a) Controlled grazing and resting periods for different plant community types

Fernández Grecco (1995) proposed and implemented a strategic management plan for cow-calf production systems, which consisted of establishing grazing and resting periods for each plant community aimed at meeting both plant and herd physiological needs. The planning process included considering the topographic position of the plant communities, periods in which plants experienced water excess or deficit, and the phenology and growth form of their species. In this grazing plan, paddocks are divided into grazing units that segregate the different plant communities (high *v* low-lying areas), maintaining a small area of uplands or plains in the humid lowland units to provide a dry place for animals to rest. The upland and plains grazing units are used during winter (calving season) and spring (breeding season), whereas the units that include only humid lowlands are used during summer and autumn, coinciding with the last month of the breeding season, weaning and dry cow stage.

Five years of applying this management scheme on a pilot 180 ha pasture at 'El Quemado' ranch produced an increase in biomass of some forage species such as *P. dilatatum*, *B. laguroides*, *L. hexandra* and annual ryegrass, and a decrease in the abundance of two of the main weeds, *Mentha pulegium* and *Ambrosia tenuifolia*. In addition, annual stocking density increased from 0.65 to 0.93 AU ha^{-1} y^{-1} and beef production increased from 65 to 132 kg ha^{-1} y^{-1}. Ranches associated with the 11 CREA

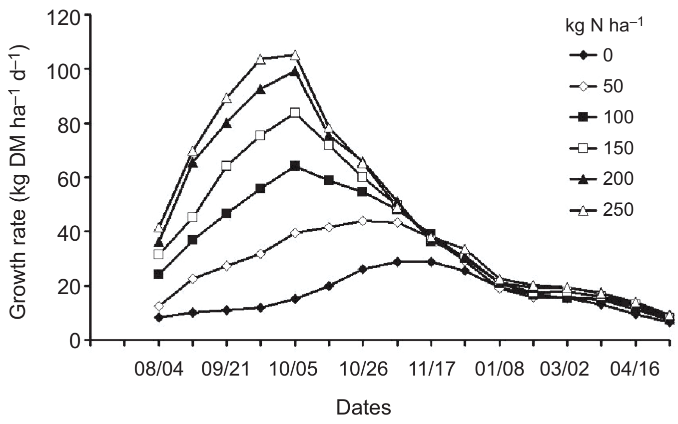

Figure 6. Seasonal forage growth of a plain plant community of the flooding pampas fertilized with different doses of nitrogen in winter (early August) in soils without water deficit and with adequate levels of phosphorus (20 kg P ha^{-1}).
Source: adapted from Fernández Grecco *et al*, 1995.

(Regional Consortia of Agricultural Experimentation) groups of the flooding pampas are using this management programme, and up until 2000, these groups included 90 ranches altogether covering more than 100,000 ha of the region.

(b) Fertilization

Although flooding pampas grasslands can sustain year-round growth, forage production during the spring–summer period is approximately 8 to 10 times higher than in winter, a phenomenon that undoubtedly affects livestock production. Because available soil N and P levels are low in most of the flooding pampas, growth of cool-season species, which can produce forage during low-temperature periods, is nutrient-limited. The addition of grass-fed yearling finishing programmes to the traditional cow-calf production systems mentioned above brought about the need to assess the response of plains plant communities to N + P fertilization (Fernández Grecco *et al*, 1995; Rodríguez Palma *et al*, 1999). Accordingly, Fernández Grecco *et al* (1995) found that winter (early August) fertilization of these plant communities using different levels of N and adequate levels of phosphorus (20 kg P ha^{-1}), with sufficient soil moisture, promoted: (a) late winter forage production, which began 25 to 30 days earlier; (b) an increase in forage production, with forage accumulations (8–10 ton DM ha^{-1} y^{-1}) four to five times higher than those obtained without fertilization (Figure 6); and (c) production of high-quality forage (2.5 to 3.0% N and 75% DMD), which enabled ranchers to establish grass-fed yearling finishing programmes (Rodríguez Palma *et al*, 1999). Currently, plant community-specific grassland fertilization is used by a large number of ranchers as a tool not only to increase forage production, but also to modify the pattern of annual forage distribution by extending the growth season of C3 grasses.

(c) Promoting annual ryegrass establishment

Annual ryegrass establishes early in autumn, has high winter growth rates, responds well to fertilization, and its nutritional value meets the requirements of yearlings undergoing rapid growth. Because of these characteristics, ranchers on the flooding pampas are now able to finish calves weaned in March with grass-fed diets that ensure animals reach slaughter weights in approximately nine months (December).

The use of glyphosate herbicides as a means of promoting ryegrass establishment to increase winter pasture productivity has been widely adopted in recent years. Natural vegetation is thus replaced by annual ryegrass, a strategy that has unfortunately led to a reduction in the abundance of the native cool- and warm-season grasses of high nutritive value, and has favoured perennial weed and annual grasses of low forage value. Consequently, at present, grasslands treated repeatedly with glyphosate exhibit a forage production peak during the winter–spring period at the expense of a decrease in summer grass production. Because of this, prescribed grazing is being proposed as an alternative to herbicides. This strategy consists of intense grazing during January–February to avoid the accumulation of summer growth, and thus facilitate the emergence and establishment of annual ryegrass without affecting warm-season species abundance. Fernández Grecco (2000) compared glyphosate and intense grazing treatments with (20 kg P ha^{-1} and 50 kg N ha^{-1} applied in early March) and without fertilization, and found that both strategies produced the same amount of winter annual ryegrass dry matter for a given fertilization level (Figure 7), but the intense grazing, as opposed to glyphosate, was able to maintain summer forage production (data not shown).

(d) Controlled grazing systems

Traditional year-round continuous grazing with fixed animal numbers has led to a reduction in cool-season grasses and an increase in weeds and bare soil, along with overall grassland degradation (Jacobo *et al*, 2006), which have resulted in decreased carrying capacity, poorer animal performance and lower profitability (Deregibus *et al*, 1995). More recently, many of the upland plant communities have been ploughed to grow crops, a phenomenon that has posed the challenge of maintaining the same number of livestock in a smaller area. This has given way to new management strategies that propose seasonal adjustments of the instantaneous stocking density (Deregibus *et al*, 1995; Fernández Grecco *et al*, 1995; Pueyo, 1996; Rodriguez Palma *et al*, 1999; Jacobo *et al*, 2000, 2006). A number of studies have shown that controlled grazing can double cool-season grass production, including annual ryegrass – which can account for as much as 77% of cool-season biomass increase (Jacobo *et al*, 2000). This increase in winter forage productivity allowed rotational systems to be stocked at almost twice the rate of traditional continuous systems (1.0 *v* 0.6 AU ha^{-1}). More recently, rotational systems in two plant communities have been shown not only to increase forage production, but to promote an increase in forage quality and a decrease in undesirable plants and bare soil (Jacobo *et al*, 2006). Thus, proposed controlled grazing systems can improve grassland condition and enhance the nutrition of grazing animals. Less intensive systems involving continuous grazing with variable stocking rates in fertilized pastures have also shown

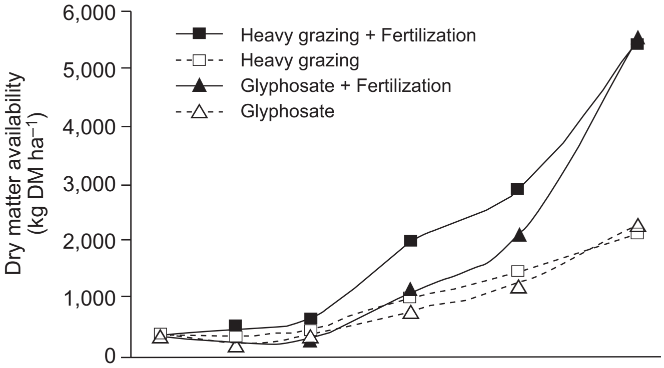

Figure 7. Effect of nitrogen and phosphorus fertilization (20 kg P ha^{-1} and 50 kg N ha^{-1} applied in early March) on the biomass accumulation of a plains plant community of the flooding pampas ‘promoted’ by either intense grazing or glyphosate. *Source:* adapted from Fernández Grecco, 2000.

promising results (Rodriguez Palma *et al*, 1999). Information on the morphogenesis of some grassland species, such as *Chaetotropis elongata*, *Hordeum stenotachys*, *Stipa neesiana*, *P. dilatatum*, *Sporobolus indicus* and annual ryegrass (Lemaire and Agnusdei, 2000), will be useful in tailoring grazing prescriptions that involve seasonal stocking density adjustments.

Conclusions

Argentina’s flooding pampas constitute a complex ecosystem that sustains a livestock industry that contributes heavily to the national economy. Significant progress in the knowledge of spatial and temporal dimensions of its structural and functional heterogeneity that has occurred over the last 40 years has allowed the development and implementation of management practices that increase and improve the seasonal distribution of primary production. Such knowledge has led to the development of livestock management strategies that, by improving vegetation utilization, have enhanced the productivity of cattle ranches that are rapidly integrating grass-fed yearling finishing programmes with the traditional cow-calf operations of the region.

Acknowledgments

An earlier version of this paper was presented at a Symposium on Rangelands of Argentina at the 60th Annual Meeting of the Society for Range Management in 2007. This symposium was sponsored by Dow Agro Sciences, the Society for Range Management, the Instituto Nacional de Tecnología Agropecuaria (Argentina) and the NSF-LTER Jornada Experimental Range.

References

Agnusdei, M. G., Collantes, M., and Anchorena, J. (1989), ‘Temperate native grassland evaluation through an integrated inventory of vegetation, soil and history of use (Argentina)’, *Proccedings of XIX International Grassland Congress, Nice (France)*, pp 1417–1418.

Aragón, R. (2007), ‘Variabilidad temporal del funcionamiento de la vegetación y heterogeneidad a escala de paisaje’, Tesis Doctorado, Escuela para Graduados Alberto Soriano, Facultad de Agronomía, UBA, Buenos Aires.

Arana, S., and Mailland, N. H. (1981), ‘Crecimiento y fenología de algunas especies de un pastizal natural de la EEA Balcarce’, Tesis de Ing. Agr., Facultad de Ciencias Agrarias, UNMdP, Balcarce.

Batista, W. B., León, R. J. C., and Perelman, S. B. (1985), ‘Relevamiento de las comunidades vegetales de un pastizal natural de la depresión de Laprida (provincia de Buenos Aires)’, *XII Reunión Argentina de Ecología, Resumen D-2, Buenos Aires*.

Batista, W. B., León, R. J. C., and Perelman, S. B. (1988), ‘Asociación entre comunidades vegetales y algunas propiedades del suelo en el centro de la Depresión del Salado’, *Ecología Austral*, Vol 2, pp 47–55.

Berasategui, L., and Barberis, L. (1982), ‘Relaciones entre unidades de suelo y vegetación en un área de la Depresión del Salado’, *Revista Facultad de Agronomía (UBA)*, Vol 3, pp 13–25.

Brizuela, M. A., Cauhépé, M. A., Cid, M. S., Viviani Rossi, E., Fernández Grecco, R. C., and Yagueddú, C. (1983), ‘Estimación de la composición botánica de la dieta de vacunos en un pastizal natural. II. Efecto de animal y período de muestreo’, *Producción Animal*, Vol 10, pp 395–403.

Brizuela, M. A., Cheppi, C., and Cauhépé, M. A. (1982), ‘Influencia de la forma y del tamaño de la unidad de muestreo en la estimación de la biomasa de un pastizal natural’, *Producción Animal*, Vol 9, pp 217–225.

Brizuela, M. A., Cid, M. S., Miñón, D. P., and Fernández Grecco, R. C. (1990), ‘Seasonal utilization of Saltgrass (*Distichlis* spp) by cattle’, *Animal Feed Science and Technology*, Vol 30, pp 321–325.

Brizuela, M. A., Cid, M. S., Sierra, P. V., and Cabria, F. (2004), ‘Pastizales serranos de Balcarce’, *Visión Rural*, Vol 53, pp 24–26.

Burkart, S. E., León, R. J. C., and Movia, C. P. (1990), ‘Inventario fitosociológico del pastizal de la Depresión del Salado (Prov. Bs. As.) en un área representativa de sus principales ambientes’, *Darwiniana*, Vol 30, pp 27–69.

Burkart, S. E., León, R. J. C., Perelman, S. B., and Agnusdei, M. G. (1998), ‘The grasslands of the Flooding Pampa (Argentina): floristic heterogeneity of natural communities of the southern río Salado basin’, *Coenosis*, Vol 13, pp 17–27.

Cahuépé, M. A., and Fernández Grecco, R. C. (1981), ‘Dieta de vacunos en pastoreo sobre un pastizal natural de la Depresión del Salado’, *Producción Animal*, Vol 8, pp 85–95.

Cauhépé, M. A., Hidalgo, L. G., and Galatoire, A. (1985), ‘Aplicación de un índice de valoración zootécnica en pastizales de la Depresión del Salado’, *Revista Argentina de Producción Animal*, Vol 5, pp 681–690.

Chanetón, E. J., Facelli, J. M., and León, R. J. C. (1988), ‘Floristic changes induced by flooding on grazed and ungrazed lowland grasslands in Argentina’, *Journal of Range Management*, Vol 41, pp 182–187.

Chanetón, E. J., Perelman, S. B., Omancini, M., and León, R. J. C. (2002), ‘Grazing, environmental heterogeneity, and alien plant invasions in temperate Pampa grasslands’, *Biological Invasions*, Vol 4, pp 7–24.

Cid, M. S., and Brizuela, M. A. (1994), ‘Respuesta animal en pastoreo mixto en relación a la estructura de la pastura y la selectividad animal’, *Revista Argentina de Producción Animal*, Vol 14, pp 161–173.

Cid, M. S., and Brizuela, M. A. (1998), ‘Heterogeneity in *Festuca arundinacea* pastures created and sustained by cattle grazing’, *Journal of Range Management*, Vol 51, pp 644–649.

Cid, M. S., Ferri, C. M., Brizuela, M. A., and Sala, O. (2008), ‘Structural heterogeneity and productivity of a tall fescue pasture grazed rotationally by cattle at four stocking densities’, *Grassland Science*, Vol 54, pp 9–16.

Cid, M. S., López, T. A., Yagueddú, C., and Brizuela, M. A. (2003), ‘Acute toxic plant estimation in grazing sheep ingesta and feces’, *Journal of Range Management*, Vol 56, pp 353–357.

Collantes, M. B., Kade, M., Miaczynski, C., and Santanatoglia, O. (1988), ‘Distribución de especies en función de factores edáficos

en un pastizal de la Depresión del Río Salado (provincia de Buenos Aires, Argentina)', *Studia Oecología*, Vol V, pp 77–93.
de la Torre, M. L., López, T. A., and Cid, M. S. (2005), 'Porcentajes de materia orgánica del suelo y de γ-coniceína en plantas de cicuta', *Revista Argentina de Producción Animal*, Vol 25 (Supl 1), pp 142–143.
Deregibus, V. A., Casal, J. J., and Simone, F. (1986), 'Efecto de pastoreo con altas cargas en pasturas invadidas por gramilla (*Cynodon dactylon*)', *Revista Argentina de Producción Animal*, Vol 6, pp 689–694.
Deregibus, V. A., Jacobo, E. J., and Rodríguez, A. M. (1995), 'Improvement in range condition of the Flooding Pampa of Argentina through controlled grazing', *African Journal of Range Forage Science*, Vol 12, pp 92–96.
Escobar, J. M. (1994), 'Descripción de la preferencia de bovinos por las comunidades vegetales en un pastizal de la Depresión del Salado', Tesis Magister Scientieae en Producción Animal, Facultad de Ciencias Agrarias, UNMdP – EEA, INTA Balcarce.
Etchevehere, P. (1961), 'Bosquejo de regiones geomorfológicos y del drenaje de la República Argentina', *IDIA*, Vol 162, pp 7–25.
Fernández Grecco, R. C. (1995), 'Principios de manejo de campo natural', INTA EEA, Balcarce.
Fernández Grecco, R. C. (2000), 'Promoción de raigrás anual en un pastizal natural de la Pampa Deprimida bonaerense', *Revista Argentina de Producción Animal*, Vol 20 (Supl 1), pp 165–167.
Fernández Grecco, R. C., Mazzanti, A., and Echeverría, H. E. (1995), 'Efecto de la fertilización nitrogenada sobre el crecimiento de forraje de un pastizal natural de la Pampa Deprimida bonaerense (Argentina)', *Revista Argentina de Producción Animal*, Vol 15, pp 173–176.
Fernández Grecco, R. C., Obregón, E., Doumecq, M., Olavarría, C., and Lucesoli, R. (1988), 'Efecto de períodos de pastoreo y descanso en un pastizal natural de la Depresión del Salado', *Revista Argentina de Producción Animal*, Vol 8 (Supl 1), pp 107–108.
Ginzo, H. D., Collantes, M. B., and Caso, O. H. (1986), 'Fertilization of a halophytic natural grassland in Argentina. Herbage dry matter, botanical composition, and mineral content', *Turrialba*, Vol 36, pp 453–460.
Grigera, G., Oesterheld, M., and Pacín, F. (2007), 'Monitoring forage production for farmers' decision making', *Agricultural Systems*, Vol 94, pp 637–648.
Herrera, L. P., Gómez Hermida, V., Martínez, G. A., Laterra, P., and Maceira, N. (2005), 'Remote sensing assessment of *Paspalum quadrifarium* grasslands in the Flooding Pampas, Argentina', *Rangeland Ecology and Management*, Vol 58, pp 406–412.
Hidalgo, L. G., and Cahuépé, M. A. (1991), 'Producción de forraje de comunidades forrajeras de la Pampa Deprimida', *Revista CREA*, Vol 149, pp 58–62.
Indurain, C., Cid, M. S., Odriozola, E., Brizuela, M. A., and Lauge, M. (2006), 'Confirmación por microanálisis de la ingestión de *Asclepias mellodora* St. Hil por ovinos', *Revista Argentina de Producción Animal*, Vol 26 (Supl 1), pp 366–367.
Insausti, P., Chanetón, E. J., and Soriano. A. (1999), 'Flooding reverted grazing effects on plant community structure in mesocosms of lowland grassland', *Oikos*, Vol 84, pp 266–276.
Insausti, P., and Soriano, A. (1987), 'Efecto del anegamiento prolongado en un pastizal de la Depresión del Salado (Provincia de Buenos Aires – Argentina): Dinámica del pastizal en conjunto y de *Ambrosia tenuifolia*', *Darwiniana*, Vol 28, pp 397–403.
Jacobo, E. J., Rodríguez, A. M., Bartoloni, N., and Deregibus, V. A. (2006), 'Rotational grazing effects on rangeland vegetation at farm scale', *Rangeland Ecology and Management*, Vol 59, pp 249–257.
Jacobo, E. J., Rodríguez, A. M., Rossi, J. L., Salgado L. P., and Deregibus, V. A. (2000), 'Rotational stocking and production of Italian ryegrass on Argentinean rangelands', *Journal of Range Management*, Vol 65, pp 483–488.
Laterra, P., Vignolio, O. R., Linares, M. P., Giaquinta, A., and Maceira, N. (2003), 'Cumulative effects of fire on a tussock pampa grassland', *Journal of Vegetable Science*, Vol 14, pp 43–54.
Lemaire, G., and Agnusdei, M. G. (2000), 'Leaf tissue turnover and efficiency of herbage utilization', in Lemaire, G., Hodgson, J., de Moraes, A., Nabinger, C., and de F. Carvalho, P. C., eds, *Grassland Ecophysiology and Grazing Ecology*, CABI Publishing, Wallingford, pp 265–287.
León, R. J. C., Agnusdei, M. G., Burkart, S. E., Fernández Grecco, R. C., Movia, C. P., Oesterheld, M., Perelman, S. E., and Rusch, G. (1985), 'Las comunidades herbáceas al sur de la Depresión del Salado', *Actas XII Reunión Argentina de Ecología*, A-45.
León, R. J. C., and Bertiller, M. (1980), 'Aspectos fenológicos de dos comunidades de un pastizal de la Depresión del Salado (provincia de Buenos Aires)', *Boletín de la Sociedad Argentina de Botánica*, Vol 20, pp 329–347.
León, R. J. C., Burkart, S. E., and Movia, C. P. (1979), 'Relevamiento fitosociológico del pastizal del norte de la Depresión del Salado (Partidos de Magdalena y Brandsen, pcia de Bs.As.)', *Monografías CIC*, Vol 5, pp 75–107.
León, R. J. C., Movia, C. P., and Valencia, R. F. J. (1975), 'Relación entre unidades de paisaje, suelo y vegetación en un área de la región Castelli-Pila', *Monografías CIC*, Vol 5, pp 109–132.
Maceira, N. O., and Verona, C. A. (1984), 'El pastoreo como factor organizador de la comunidad vegetal en un pastizal natural', *Revista Argentina de Producción Animal*, Vol 4, pp 1137–1148.
Miñón, D. P., Cauhépé, M.A., Lorenzo, M. S., Colombo, I., Brizuela, M. A., and Miquel, M. C. (1984a), 'Análisis comparativo de las dietas de dos razas vacunas en un pastizal de la depresión del Salado (Buenos aires). I – Composición botánica del alimento', *Revista Argentina de Producción Animal*, Vol 4, pp 789–801.
Miñón, D. P., Cauhépé, M. A., Lorenzo, M. S., Colombo, I., Brizuela, M. A., and Miquel, M. C. (1984b), 'Análisis comparativo de las dietas de dos razas vacunas en un pastizal de la depresión del Salado (Buenos aires). II – Composición química del alimento', *Revista Argentina de Producción Animal*, Vol 4, pp 803–814.
Miñón, D. P., Sevilla, G. H., Montes, L., and Fernández, O. (1990), '*Lotus tenuis*: leguminosa forrajera para la Pampa Deprimida', *Boletin Técnico*, No 98, EEA Balcarce, INTA.
Oesterheld, M., Aguiar, M. R., Ghersa, C. M., and Paruelo, J. M., eds (2005a), *La heterogeneidad de la vegetación de los agroecosistemas. Un homenaje a Rolando J.C. León*, Facultad de Agronomía, University of Buenos Aires.
Oesterheld, M., Aragón, R., Grigera, G., Oyarzábal, M., and Semmartín, M. (2005b), 'Cómo deben percibir la heterogeneidad quienes manejan la vegetación de los agroecosistemas? El caso de la Pampa Deprimida', in Oesterheld, M., Aguiar, M. R, Ghersa, C. M., and Paruelo, J. M., eds, *La heterogeneidad de la vegetación de los agroecosistemas. Un homenaje a Rolando J.C. León*, Facultad de Agronomía, University of Buenos Aires, pp 131–144.
Orbea, J., Agnusdei, M. G., and Cauhépé, M. A. (1985), 'Efecto de tres intensidades de corte en la productividad, vigor y persistencia de *Poa lanigera* Ness', *Revista Argentina de Producción Animal*, Vol 5, pp 441–450.
Paruelo, J. M., Oesterheld, M., Di Bella, C. N., Arzadum, M., Lafontaine, J., Cahuépé, M., and Rebella, C. M. (2000), 'Estimation of primary production of subhumid rangelands from remote sensing data', *Appl. Veg. Sc*, Vol 3, pp 189–195.
Perelman, S. B., Batista, W. B., and León, R. J. C. (2005), 'El estudio de la heterogeneidad de la vegetación. Fitosociología y técnicas relacionadas', in Oesterheld, M., Aguiar, M. R., Ghersa, C. M., and Paruelo, J. M., eds, *La heterogeneidad de la vegetación de los agroecosistemas. Un homenaje a Rolando J.C. León*, Facultad de Agronomía, University of Buenos Aires, pp 321–350.
Perelman, S. B., León, R. J. C., and Oesterheld, M. (2001), 'Cross scale vegetation patterns of Flooding Pampa grasslands', *Journal of Ecology*, Vol 89, pp 562–577.
Piñeiro, G., Oesterheld, M., and Paruelo, J. M. (2006), 'Seasonal variation in aboveground production and radiation-use efficiency of temperate rangelands estimated through remote sensing', *Ecosystems*, Vol 9, pp 357–373.
Posse, G., Oesterheld, M., and Di Bella, C. M. (2005), 'Landscape, soil and meteorological influences on canopy dynamics of

northern flooding Pampa grasslands, Argentina', *Appl. Veg. Sc*, Vol 8, pp 49–56.
Pueyo, D. J. (1996), 'Dinámica del crecimiento y la utilización de pastizales naturales de la Pampa Deprimida bonaerense', Tesis MSc, Facultad Ciencias Agrarias, Universidad Nacional de Mar del Plata, Argentina.
Quintana, J., Cid, M. S., Sierra, P., Brizuela, M. A., and Sciotti, A. (2006), 'Selección de especies por vacas y terneros en pasturas de agropiro-festuca', *Revista Argentina de Producción Animal*, Vol 26 (Supl 1), pp 231–232.
Rearte, D. (2006), 'Argentinean meat production. Meat production program, INTA', Documento del programa nacional de Producción de Carnes, INTA, Buenos Aires.
Rodríguez Palma, R., Mazzanti, A., Agnusdei, M. G., and Fernández Grecco, R. C. (1999), 'Fertilización nitrogenada y productividad animal en pastizales bajo pastoreo continuo', *Revista Argentina de Producción Animal*, Vol 19, pp 301–310.
Sacido, M., Hidalgo, M. G., and Cauhépé, M. A. (1995), 'Efecto del fuego y la defoliación sobre el valor nutritivo de matas de paja colorada (*Paspalum quadrifarium*)', *Revista Argentina de Producción Animal*, Vol 15, pp 142–146.
Sala, O. E. (1988), 'The effect of herbivory on vegetation structure', in Werger, M. J. A., Van der Aart, P. J. M., During, H. J., and Verboeven, J. T. A., eds, *Plant Form and Vegetation Structure*, SPB Academic Publishing, The Hague, pp 317–330.
Sala, O., Deregibus, V. A., Schlichter, T., and Alippe, H. (1981), 'Productivity dynamics of a native temperate grassland in Argentina', *Journal of Range Management*, Vol 34, pp 48–51.
Sala, O. E., Oesterheld, M., León, R. J. C., and Soriano, A. (1986), 'Grazing effects upon plant community structure in sub humid grasslands of Argentina', *Vegetatio*, Vol 67, pp 27–32.
Senft, R. L., Coughenour, M. B., Bailey, D. W., Rittenhouse, L. R., Sala, O. E., and Swift, D. M. (1987), 'Large herbivore foraging and ecological hierarchies', *BioScience*, Vol 11, pp 789–799.
Sierra, P. V., Cid, M. S., and Brizuela, M. A. (2005), 'Dieta de bovinos en pajonales serranos de paja colorada (*Paspalum quadrifarium*)', *Revista Argentina de Producción Animal*, Vol 25 (Supl 1), pp 143–144.
Siffredi, G. L., Brizuela, M. A., Cid, M. S., and Cangiano, C. (1997), 'Selective sheep grazing in an heterogeneous wheatgrass dominated pasture related to stocking rate', *Proceedings of XVIII International Grassland Congress, Saskatoon, Canada*, Sec 29, pp 159–160.
Vacarezza, G. (2000), 'Uso de la vegetación por el ñandú (*Rhea americana* L.) en la pampa deprimida bonaerense y sus relaciones con herbívoros domésticos', Tesis de Magister en Investigación Biológica Aplicada, Facultad de Agronomía, Univ Nac Centro Provincia, Buenos Aires.
Vacarezza, G., and Cid, M. S. (2004), 'Utilización de especies de bajos por bovinos y ovinos en pasturas naturalizadas de la Depresión del Salado', *Revista Argentina de Producción Animal*, Vol 24 (Supl 1), pp 198–199.
Vervoorst, F. B. (1967), 'Las comunidades vegetales de la Depresión del Salado', INTA, Buenos Aires.
Yagueddú, C., Cid, M. S., and López, T. (1998), 'Microanalysis of sheep gastrointestinal content to confirm poisonous plant ingestion', *Journal of Range Management*, Vol 51, No 6, pp 655–660.