Institute of Agricultural Sciences in the Tropics (Hans-Ruthenberg-Institute)
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"Management of excess standing biomass in Argentinean grasslands to increase grass and livestock productivity"

Dissertation

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Preface

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Summary

Grasslands are the main source of feed for cattle in Argentina. Standing dead biomass (SDB) accumulation threatens efficient resource use. To reduce dead biomass pools, high impact grazing (HIG) was proposed as an alternative to mechanical elimination or the use of fire in Northern Argentinean rangelands. However its effects on grasslands' biomass accumulation, diversity and forage quality are unknown. The effect and timing of HIG by cattle was therefore studied in grasslands of North Eastern Argentina. We introduced HIG monthly, on adjacent paddocks over the course of the year and its effects were studied for 12 months following the treatment. Dynamics of biomass re-growth, accumulation of green and standing dead biomass were studied. Additionally, the effects of HIG on plant species composition and the forage quality parameters were monitored and evaluated. The immediate effect of HIG was the reduction of the standing biomass by more than 95%. HIG generally improved the green to total biomass ratio and reduced the overall biomass in the paddocks. All sub-plots subjected to HIG showed a growth pattern anti-cyclic to control, with an active growth phase during autumn when the biomass in the control sub-plots decreased. Best results in terms of SDB reduction and dead to green biomass ratios were achieved after HIG in winter. HIG in autumn, however, reduced fodder availability and reduced next year's grassland's productivity. Irrespectively of the season HIG was applied, the grassland recovered completely with regard to species richness and diversity, the Shannon-Wiener diversity index (H) and the Shannon's equitability index (E) did not reveal any difference within 12-month period after HIG. Our results suggest that HIG is not shifting plant species composition to a more ruderal strategy based plant community, but instead promotes previously established rather competitive and higher value fodder species. Our results indicate that HIG HIG normally improves the nutritive value of GB due to increased CP, DOM, and ME, but if applied in summer it has no evidently positive effect. On an area basis grassland subjected to HIG provided enough monthly ME and CP, to meet the requirements of the current stocking density in Corrientes. HIG could be an alternative management practice towards sustainable intensification. However, we are aware that long-term observations with repeated HIG should be analysed to detect possible delayed effects and interactions especially with seasonal variability.

Keywords: Corrientes, biomass, diversity, forage, management.

Deutsche Zusammenfassung

Natürliche Grasländer bilden die Futtergrundlage für die Rinderhaltung in Argentinien. Insbesondere in nordargentinischen Grasländern gefährdet ein hoher Anteil toter Biomasse jedoch die effiziente Nutzung dieser Futterressourcen. Um die Vorräte abgestorbener Biomasse auf den Weiden zu reduzieren, wird eine kurzzeitige Beweidung (im vorliegenden Fall 2 Tage) mit sehr hoher Besatzdichte (hier 150 Vieheinheiten / ha, "High Impact Grazing" HIG) als Alternative zur mechanischen Behandlung oder Verbrennung der Biomasse vorgeschlagen. Die Auswirkungen von HIG auf die weitere Entwicklung der Biomassenvorräte, Diversität und Futterqualität des Auswuchses sind jedoch unbekannt. Der HIG-Effekt an sich, als auch der Zeitpunkt der Maßnahme im Verlauf eines Jahres wurden in einem Feldversuch in Nordost-Argentinien untersucht. HIG wurde monatlich für den Zeitraum von eines Jahres auf jeweils anderen, benachbarten Weiden angewendet. Die Effekte des HIG wurden für insgesamt ein weiteres Jahr nach der Maßnahme beobachtet und gemessen. Hierbei wurden die Dynamik des Wiederaufwuchses und die Akkumulation von grüner als auch toter Biomasse erfasst. Zusätzlich wurde die Zusammensetzung der Pflanzenarten und Parameter für die Bewertung der Futterqualität aufgenommen. Der unmittelbare Effekt von HIG war die Reduzierung der stehenden Biomasse um mehr als 95%. HIG steigerte generell den Anteil grüner Biomasse an der gesamten Biomasse, wobei die gesamte Biomasse auf den Weiden reduziert wurde. Im Gegensatz zu der Kontrolle zeigten alle Flächen mit HIG eine aktive Wachstumsphase während des Herbstes und somit ein antizyklisches Wachstumsmuster, da zu diesem Zeitpunkt die Biomassen in den Kontrollflächen bereits zurückgingen. HIG im Winter erzielte die besten Ergebnisse bei der Verminderung der toten Biomasse und der Erhöhung von Anteilen grüner Biomasse. HIG durchgeführt im Herbst reduziert hingegen die Futterverfügbarkeit und die Produktivität des Graslandes im nächsten Jahr. Unabhängig von dem saisonalen Zeitpunkt des HIG konnte Diversität und Artenreichtum vollständig regenerieren. Der Shannon-Wiener Diversitäts-Index (H) und Shannon’s equitability index (E) zeigten keine Abweichung zur Kontrolle innerhalb von 12 Monaten nach HIG. Unsere Ergebnisse legen nahe, dass HIG die Artzusammensetzung des Graslandes nicht zu einer mehr durch ruderal Strategen basierten Pflanzengesellschaft verschiebt, sondern die zuvor etablierten, eher kompetitiven und qualitative höherwertigen Arten fördert. Unsere Ergebnisse zeigen weiter, dass HIG generell den Nährwert der grünen Biomasse aufgrund von höheren Werten von Rohprotein, Verdaulichkeit der organischen Substanz und der bereitgestellten Erhaltungsenergie (ME) verbessert. HIG im Sommer hatte allerdings keine positiven Effekte auf die Futterqualität. In den ersten Monaten nach einer HIG Behandlung stellt das untersuchte Grasland flächenbasiert weniger als die benötigte Erhaltungsenergie zur Verfügung, jedoch sind 100% der notwendigen Rohproteine verfügbar, um die Bedürfnisse der üblichen Bestockungsdichten für Corrientes zu erfüllen. Im Sinne einer nachhaltigen Intensivierung der Landnutzung besitzt HIG das Potenzial sich als eine alternative Maßnahme zu etablieren. Allerdings sollten Langzeit-Studien mit wiederholtem HIG analysiert werden, um mögliche verzögerte Auswirkungen und Interaktionen, insbesondere mit saisonaler Klimavariabilität zu prüfen.

1 General Introduction

1.1 Grasslands

The term “grassland” often also referred as rangelands, defines a vegetation cover type dominated by grasses, which has little or no trees (Di Gregorio and Jansen 2005). Grasslands constitute the largest and most diverse terrestrial ecosystem influencing through its productivity the livelihood of many million people globally, accounting around 40% of the terrestrial area (Suttie et al. 2005). At a broad scale, according to Dixon et al. (2014) grassland is represented by at least 49 biogeographical types (Fig. 1.1). Tropical and sub-tropical grassland comprise around 11% of the terrestrial land surface of the world (Alkemade et al. 2013; Di Gregorio and Jansen 2005; Dixon et al. 2014; Lund 2007). According to Bilenca & Miarro (2004) the grassland biome occupies approximately 3500000 km^2 in South America i.e. 25% of the whole area. In Argentina grasslands are quite widespread; they cover approximately 75% of continental Argentina, ranging from cold grassland steppes in the South, intensively managed and modified temperate grasslands in the central area, to relatively less modified sub-tropical grasslands in the North.

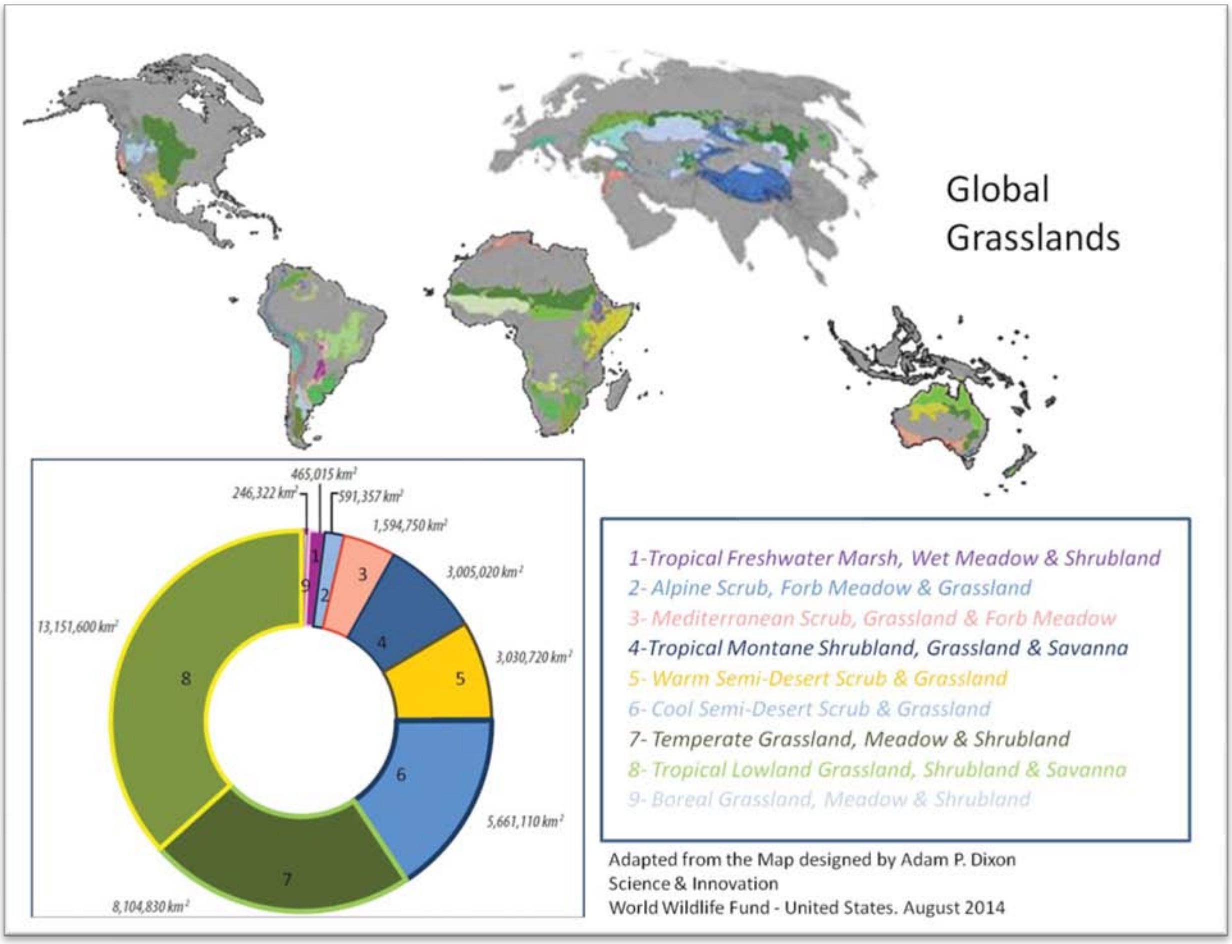

Figure 1.1. Global grassland classification, area and distribution.

The Argentinean sub-tropical grasslands are concentrated in the North, there the Corrientes Province has nearly 52% of its area (approx. 46550 km^2) covered by grasslands (Fig. 1.2). Livestock keeping is in turn the most important agricultural activity in the province, it concentrates an estimated of 5000000 heads, the third largest cattle herd in Argentina, which despite the lack of sustainable management, contributes significantly to farmers income and food security as millions of inhabitants in Argentina consume beef, around 55 kg $year^{-1}$.

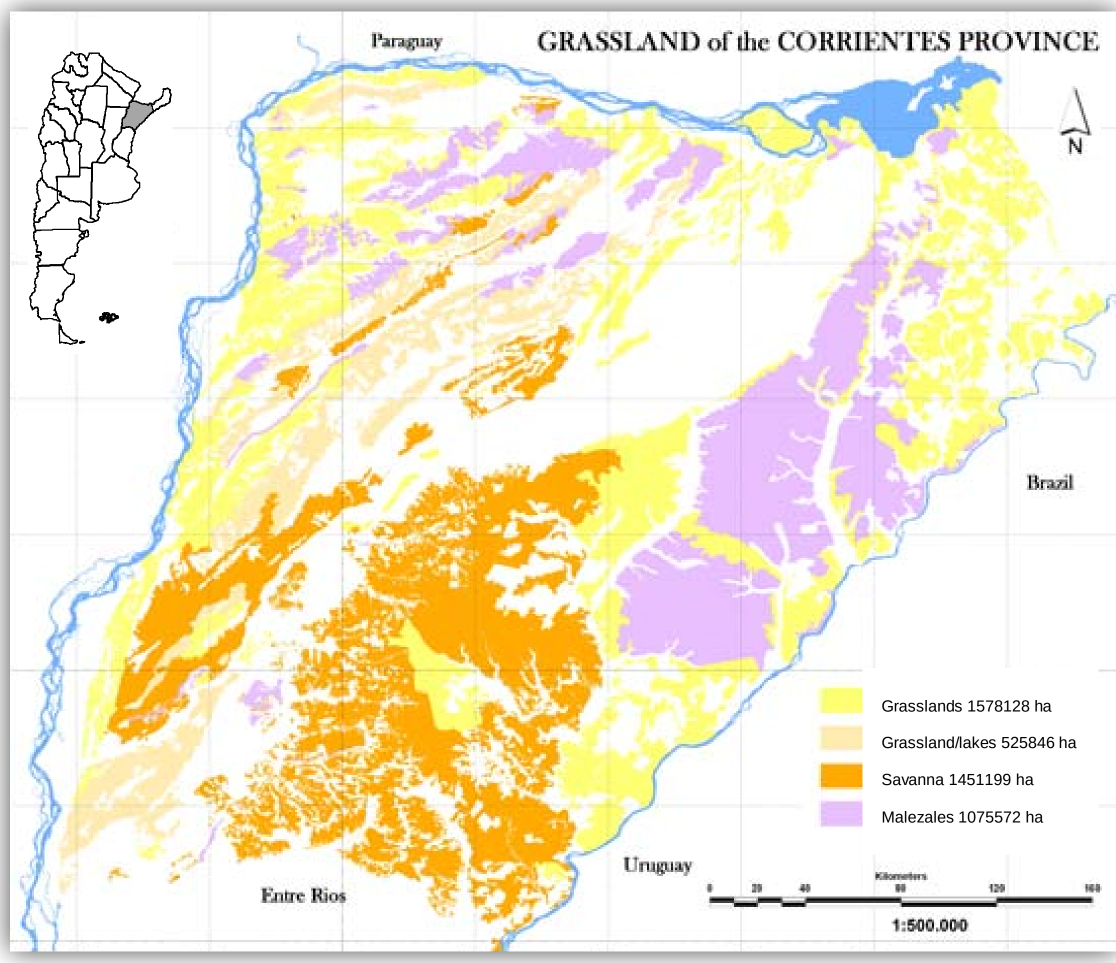

Fig. 1.2. Grassland types and distribution in the Corrientes Province – Argentina, where the total grassland cover reaches approximately 46550 km^2. Grasslands includes open grasslands and areas with < than 5% tree cover; Grassland/lakes is a grass dominated area scattered with lakes and lagoons of different size; Savannas includes a grass dominated area with not more than 15% tree cover and, malezales; which includes waterlogged grasslands (Navarro de Rau and Matteio 2009). Cobertura de Suelos de la Ecorregión Mesopotamia. Informe técnico. www.inta.gob.ar/personas/navarroderau

1.2 Grassland management

In Europe and in Asia the intensive use of grasses by people started about 10,000 years ago (van der Merwe et al. 1999). In America and particularly in Argentina a more intensive grasslands use started after the 14^{th} century with the introduction of cattle by European settlers. Regular disturbances such as continuous grazing and fire shaped Argentina's grassland structure (Carnevali 1994). Nowadays, the expected human population increase triggered the land use intensification and it also challenges the scientific community to develop novel and sustainable grasslands utilization, imbibed in a strong debate on how the anthropogenic climate change began to threaten natural grasslands (Briske 2013). Sustainable grassland management is a challenging issue, especially in sub-tropical regions, where high primary production (based on C_4 grasses) is achieved during the periods of high temperatures and high solar radiation, but where growth is reduced during those of low temperature and less solar radiation. This issue is especially evident in Northern Argentina where livestock production is based on traditionally managed grasslands. In Corrientes sub-tropical grasslands, most farmers stock their rangelands to the fodder availability of winter, which in turn results in very low stocking rates. Due to the low stocking rates, the system accumulates large amounts of dead plant material from the vigorous growth of C_4 grasses during the main growing period (Fidelis et al. 2013; Heckathorn et al. 1999).

1.3 Effects of current grassland management

As a result of the lack of appropriate management, standing dead material (SDM) accumulates form season to season and year after year, SDM constitutes therefore a major factor attempting better grassland utilization. First of all, the shadow produced by SDM interferes with photosynthesis (Heckathorn et al., 1999; McMillan et al., 2011; Ötztürk et al., 1981), which in turn interferes with grass growth. Second, it acts as grazing deterrent for the cows (Balph and Malecheck, 1985; Moisey et al., 2006), which attempts with cows consumption and therefore with proper nutrition. Recently published data indicated that over the last 60 years cattle live weight gains neither not changed in the Northern-Argentinean Province of Corrientes (Calvi, 2010), suggesting that the production potential is still to be achieved.

1.4 Current grassland management in Northern Argentina

In Northern Argentina, particularly in the province of Corrientes, with a strong tradition of cattle ranching, paddocks are large and stocking rates are relatively low, SDM accumulates form season to season, rendering the management of paddock quality quite difficult. There is a wide range of alternative treatments to diminish SDM (Fig. 1.3); from mechanical elimination e.g. with knife-rollers, choppers, mowers and plows (Adema et al., 2004) to the use of fire (Bernardis et al., 2008; Fernández et al., 2011;Toledo et al., 2014). On one hand, however, the mechanical options may produce soil compaction (Hamza and Anderson, 2005; Jung et al., 2010; Schrama et al., 2013) and reduced water infiltration (Chyba et al., 2014). While on the other hand, fire also could lead to disadvantages, namely increased burning risk of facilities and infrastructure (Fidelis et al., 2013; Thomas, 2006), biodiversity loss (Azpiroz et al., 2012; Podgaiski et al., 2014) and last but not least, it contributes to the release of CO_2 to the atmosphere. Nevertheless, very often livestock keepers decide to use fire to get read of the undesirably, low digestive SDM. Therefore prescribed burns represent a significant tool; not only for that but also against bush encroachment. Fire is the most frequent management tool in tropical grasslands and savannas (Oesterheld et al., 1999; Pausas and Ribeiro, 2013). Besides that option, also mechanical removal of SDM became to be more frequently used. Recently, however, burning has been forbidden in Argentina (Argentina, 2009). Both methods, keep on try to palliate the systems' inefficiency and also contribute to increase greenhouse gas emissions. As a result, sustainable alternatives for grassland utilization urge.

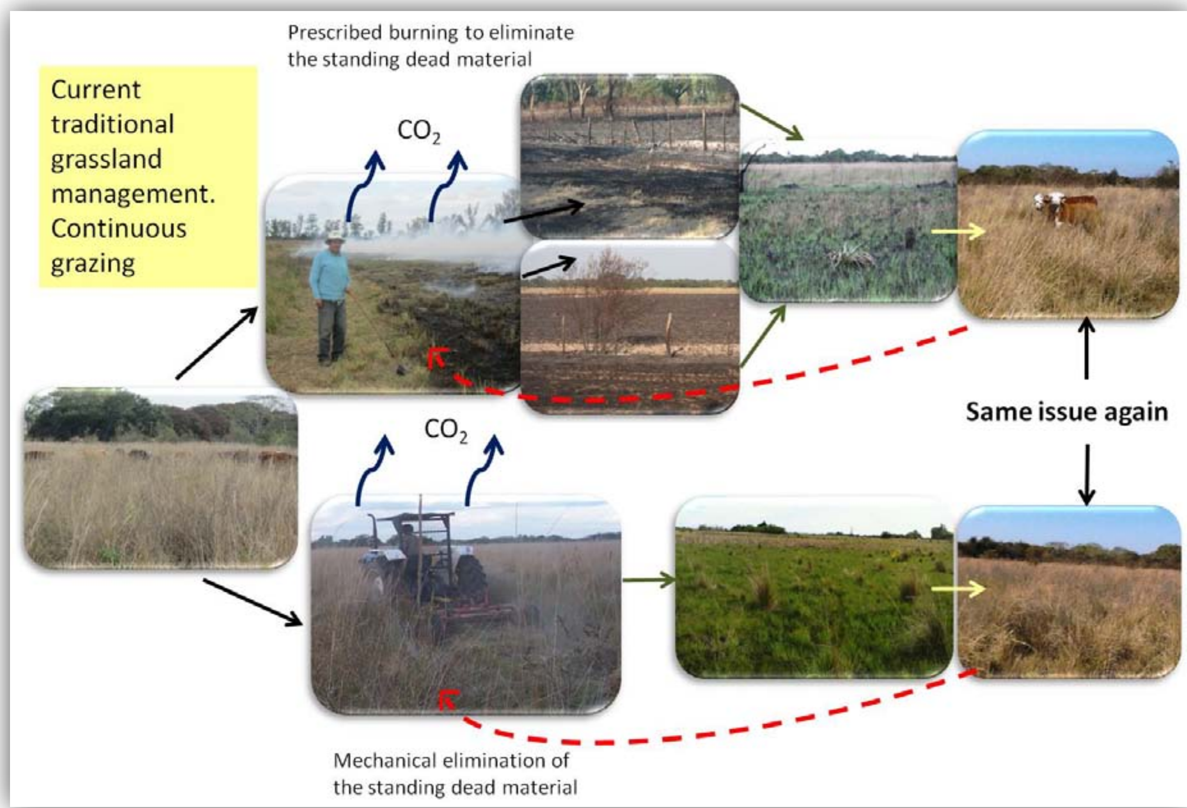

Fig. 1.3. Current management strategies to reduce standing dead material in the Northern Province of Corrientes, Argentina.

1.5 Alternative grassland management

Although sometimes controversially discussed (Briske et al., 2013; 2014; Carter et al., 2014; Teague et al., 2011), high impact grazing (HIG) was proposed as a management option to stimulate grass growth (McMillan et al., 2011; Savory and Parsons, 1980), for restoring and maintaining grassland ecosystem services, like biodiversity (Savory, 1983, 2005; Savory and Parsons, 1980) and by creating grazing lawns, it has also been reported to produce high fodder quality (Cromsigt and Olff, 2008; Hempson et al., 2014; McNaughton, 1984). HIG uses the herd effect, mimicking the behaviour grazing animals in natural grasslands (Cromsigt and Olff 2008; Hempson et al. 2014; McNaughton 1984; Savory 1983) to trample all vegetation down. Different to mechanical or fire, HIG could be an option to reduce SDM, which has no additional costs and could thus increase ranchers' profit, and which is safer than the use of fire (Thomas 2006). Up to now, most of the research on the effects of HIG was done in Africa, Australia and in the United States of America (Sherren et al., 2012; Savory 1983; 2005) but are missing in Argentina.

Common to most studies and particularly all studies done in Argentina, is that the impact of short but high intensity grazing was rarely considered and that the effects are unknown with regard to plant species composition and diversity (Pizzio et al., 2016), biomass production and fodder quality.

1.6 Objectives

Up to date it has not been investigated if HIG could be an alternative grassland management for Northern Argentinean to control standing dead biomass and promote plant growth. Besides that, to understand the effects HIG produces in Northern Argentinean grasslands and the possible interactions with climate conditions in relation to the specific objectives:

- to investigate HIG as a living tool to remove the excess standing dead material, and the effects of HIG timing (i.e. HIG in spring, summer, autumn, or winter) on biomass productivity following HIG,
- to analyse the effects of HIG on grassland floristic composition, diversity and plant functional groups,
- to address to what extent HIG changes the quality of the vegetation over time, with regard to nutritional values and digestibility.

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2 High Impact Grazing as a Management Tool to Optimize Biomass Growth in Northern Argentinean Grassland

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Keywords: cattle; grazing management; herd effect; standing dead biomass; trampling.

Abstract

Grasslands are the main source of feed for cattle in Argentina. Standing dead biomass accumulation threatens efficient resource use. The effect and timing of high impact grazing by cattle as a management tool to remove excess standing dead biomass was studied in grasslands of North Eastern Argentina. High impact grazing (HIG) was introduced monthly on adjacent paddocks over the course of the year and its effects were studied for 12 months following the treatment. Dynamics of biomass re-growth and accumulation of green and standing dead biomass were studied. HIG generally improved the green to total biomass ratio and reduced the overall biomass in the paddocks. Strong seasonal dynamics in the biomass growth rates strongly influenced the effects of timing of the HIG. All sub-plots subjected to HIG showed a growth pattern anti-cyclic to control, with an active growth phase during autumn when the biomass in the control sub-plots decreased. Best results in terms of standing dead biomass reduction and dead to green biomass ratios were achieved after HIG in winter. HIG in autumn, however, reduced fodder availability and reduced next year's grassland's productivity. We propose strategically (carefully) timed HIG not only as an alternative method to reduce standing dead biomass, but also as a pathway to sustainable intensification by providing green forage at levels equal or even higher than those achieved under continuous traditional grazing.

2.1 Introduction

Regular disturbances such as fire and continuous grazing have shaped Argentina's grassland structure (Carnevali 1994). In the northern province of Corrientes, having a strong tradition of cattle ranching, net primary productivity (NPP) of C_4 grasses is high in summer but relatively low in winter (Bernardis et al. 2005b; Martín et al. 2011; Royo Pallarés et al. 2005). Therefore, farmers stock their rangelands adjusted to the availability of winter fodder, which in turn results in very low stocking rates (Calvi et al. 2010). As a consequence, high standing dead biomass pools build up in large grassland areas in north-western Corrientes (Kurtz et al. 2010). Standing biomass decreases net photosynthesis and energy capture decreasing net production; nevertheless it accumulates annually, independent of the season (Fidelis et al. 2013) and acts not only as a grazing deterrent (Balph and Malecheck, 1985; Moisey et al. 2006) but also reduces live weight gain of large herbivores through decreased palatability and low overall forage quality (Mingo and Oesterheld, 2009). Due to these reasons, the overall animal production for northern Argentinean grasslands is low (Royo Pallarés et al. 2005). Recently published data indicated that over the last 60 years cattle live weight gain neither not change in Corrientes (Calvi et al. 2010) nor or in Argentina (Elizalde and Riffel, 2014; Hidalgo and Cauhépé, 1991), suggesting that a considerable production potential of these rangelands remains unutilised.

There is a wide range of possible treatments to reduce unproductive and low quality standing dead material. It comprises from mechanical elimination e.g. with knife-rollers, choppers, mowers and plows (Adema et al. 2004), targeted weed grazing (Frost et al. 2012), goat grazing (Lovreglio et al. 2014), and very often the use of fire (Bernardis et al. 2008; Fernández et al. 2011; Toledo et al. 2014). However, both fire and mechanical options have their disadvantages, namely increased burning risk (Fidelis et al. 2013; Thomas, 2006), bush encroachment (Dudinszky and Ghermandi, 2013), reduced species recruitment and weed germination (Franzese and Ghermandi, 2012), biodiversity loss (Azpiroz et al. 2012; Podgaiski et al. 2014), soil compaction (Hamza and Anderson, 2005; Jung et al. 2010; Schrama et al. 2013) and reduced water infiltration (Chyba et al. 2014). Nevertheless, fire is the most frequent and easy-to-use management tool in tropical grasslands and savannas (Oesterheld et al. 1999; Pausas et al. 2013). Recently, burning has been forbidden both in Argentina (Argentina, 2009) and in the Corrientes Province (Corrientes, 2004).

High impact grazing (HIG) or the “herd effect” was proposed as a management option for restoring and maintaining grassland ecosystem functions (Savory 1983; 2005) and as a means of improving the plant productivity (Savory and Parsons, 1980). Although sometimes controversially discussed (Briske et al. 2013; Teague et al. 2011), HIG has been shown to stimulate plant growth in some grassland ecosystems (McMillan et al. 2011) and create productive grazing lawns with high fodder quality (Cromsigt and Olff, 2008; Hempson et al. 2014; McNaughton, 1984).

HIG has multiple effects; it removes shading by dead biomass, including plant defoliation, nutrient removal and re-distribution through excreta, enhancing nutrient cycling and the mechanical effect of trampling. Although most of the aforementioned effects and issues are known, information of HIG effects on above ground biomass dynamics is surprisingly scarce and for some grassland ecosystems not considered so far. Up to date, the herd effect method generated a strong controversy in the scientific community (Briske et al. 2008; 2011; 2013; Dunne et al. 2011; Joseph et al. 2002). Only few studies analyzed the effects of HIG on the above ground biomass; Jacobo et al. (2000; 2006) found positive effects of rotational grazing to control standing dead material; Striker et al. (2011) found for flooded grasslands that the Graminiods share was increased after HIG, while the aboveground net primary productivity (ANPP) was not significantly affected. Since most grassland ecosystems are characterized by pronounced climate seasonality, the timing (i.e. HIG in spring, summer, autumn, or winter) will likely affect biomass growth dynamics during the months following HIG. If properly timed, we assume considerable shifts in green to dead biomass ratio and rangeland productivity and thus positive effects on animal production as well.

It has not been investigated to date if HIG could be a serious alternative management practice for Northern Argentinean grasslands to control standing dead biomass and promote plant growth. The results will be relevant for developing strategies within the concept of sustainable land use intensification with regards to both environmental stability and raising productivity of agro-ecosystems (Garnett et al. 2013).

2.2 Materials and methods

2.2.1 Study area

The study was carried out at the Corrientes INTA Research Station (lat 27°40’01’’S, long 58°47’11’’W), in the Empedrado Department, 30 km South of Corrientes city, Capital of the Corrientes Province, Argentina. Mean elevation at the site is 69 meters above sea level, and slopes are less than 0.1%. Local mean annual precipitation is about 1300 mm. There is a slight seasonality of rains; most of precipitation occurs in autumn (33% from March to May) and summer (30% from December to February) and less in spring (24% from September to November) and winter (13% from June to August). The average annual temperature is 21°C. The annual temperature amplitude of monthly means ranges from 25.6°C in January to 15.5°C in July. The mean temperature during the experiment was similar to the average mean temperature. Precipitation amount during the experimental period varied only slightly between years, from June 2012 to May 2013, total precipitation was 1345 mm, and evapo-transpiration 1150 mm. From June 2013 – May 2014, precipitation was 1233 mm and evapo-transpiration 1107 mm (Fig. 2.1). Soils have a sandy-loam texture and belong to the Treviño series (Aquic Ariudoll, Escobar et al. 1996) which covers approximately 37,250 hectares in north-western Corrientes. Soils remained humid or very humid for most of the time every year, mostly due to both, the high precipitation and the clay layer located at approx 40-90 cm depth (Bt horizon). The pH varied from 5.6 to 6.0, up to 7.0 to 7.4 below the Bt layer. Soil organic matter varied from 1.2 to 1.7% in the upper part, being as low as 0.3% at 90 cm (Escobar et al. 1996).

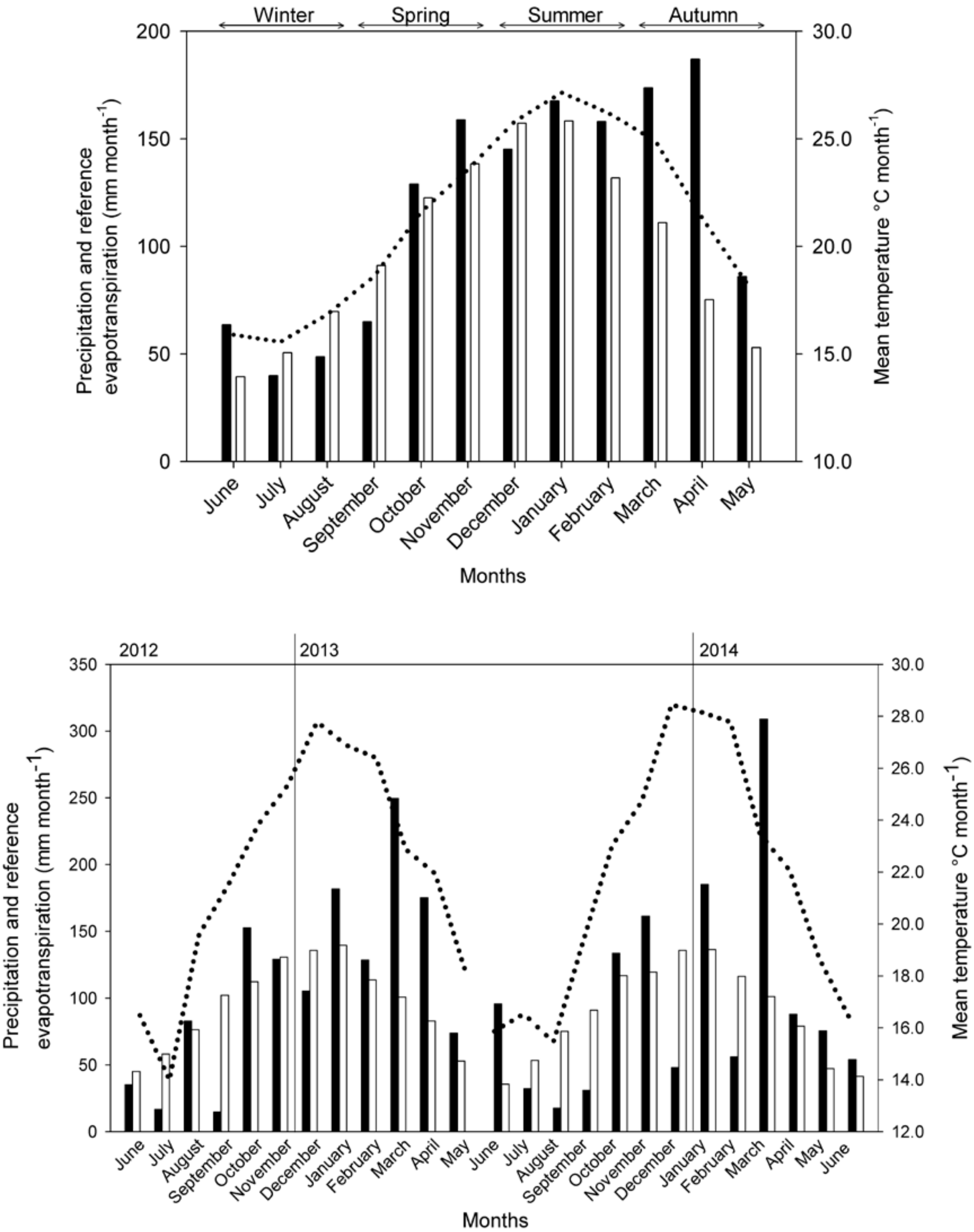

Figure 2.1. Monthly climate patterns and seasons from INTA Corrientes meteorological data, period 1968 to 1998 (upper right) and during the experiment from 2012 to 2014 (bottom right). The dotted line indicates mean air temperature (°C). White bars indicate reference monthly evapo-transpiration and black bars depict monthly precipitation (mm).

2.2.2 The dominant vegetation

Dominant tussock species were paja colorada (*Andropogon lateralis* Nees), paja amarilla *Sorghastrum setosum* (Griseb.) Hitchc. (ex *S. agrostoides* Speg. Hitchc.) and *Paspalum plicatulum* Michx. Among grass bunches, other short grasses develop, pasto horqueta (*Paspalum notatum* Flügge), *Axonopus affinis* Chase, *Eleocharis nodulosa* (Roth) Schult., *E. viridans* Kük. ex. Osten. and *Leersia hexandra* Sw. are the most frequent grass and grass-like species. Legumes are rather infrequent, with *Desmodium incanum* DC. being the most widely spread perennial legume and *Vicia epetiolaris* Burk. being the annual most frequent species growing and flowering in late winter and spring (Vanni and Kurtz, 2005).

2.2.3 Experimental layout

The experiment was established on a 24 ha natural grassland area which is part of the research facility of the Institute of Technical Agriculture (INTA) Corrientes. Before, the area was traditionally managed with continuous grazing at an intensity of 0.5 animal units per ha. Four adjacent paddocks of 6 ha each were separated with permanent electric fences. Three of them were used as replicates (R1 - R3) for the HIG treatment experiment, and the fourth paddock was defined as control with continuous grazing with no HIG. The HIG treatment followed a monthly sequence; therefore each replicate paddock was divided into 12 sub-plots of 0.5 ha each, used for monthly HIG. The experiment started in July 2012, when the first sub-plot (50 m width, 100 m length) was enclosed with mobile/temporal electric fences and subjected to three days of HIG. For that purpose a mixed 75-animal herd of Braford, Hereford, and Brahman cattle breeds was used, representing an instantaneous grazing intensity of 150 animals ha^{-1} (approximately 30000 kg of animal biomass ha^{-1}). During the first day the herd was allowed to graze *ad libitum* and the second day the cows were moved/driven around within the sub-plot to ensure an impact as homogeneous as possible until all vegetation was trampled down. After HIG, the mobile sub-plot fences were removed and the HIG herd was driven to the remaining two 6 ha paddocks to carry out the HIG at the particular sub-plots. All four 6 ha paddocks were continuously grazed throughout the experiment with 3 non lactating cows each, to resemble the average stocking rate of 0.5 animal unit ha^{-1} in Corrientes Province (Calvi 2010; Kurtz and Ligier, 2007). These cows were also crossbreeds Braford, Hereford, and Brahman. According to mean temperature, monthly precipitation, daily reference evapo-transpiration and relative humidity the impact month were classified to represent an annual season namely spring (September, October, November), summer (December, January, February), autumn (March, April, May), and winter (June, July, August) (Table 2.1, Fig. 2.1).

Table 2.1. Monthly climate variables which define the seasons in the study area, calculated from INTA Corrientes meteorological data, period 1968 to 1998.

Season Months	Monthly mean temperature (°C)	Monthly Precipitation (mm)	Daily evapo-transpiration (mm)	Monthly relative humidity (%)
Winter				
June, July and August	16.1 (0.7)	50.8 (14)	1.7 (0.5)	41.9 (3.2)
Spring				
September, October and November	21.3 (2.5)	104.7 (41.3)	3.9 (0.8)	47.2 (4.4)
Summer				
December, January and February	26.4 (0.7)	138 (24.7)	5 (0.2)	52.3 (3.2)
Autumn				
March, April and May	21.4 (3.4)	150.4 (44.2)	2.6 (0.9)	47.1 (0.7)

2.2.4 Biomass sampling

Aboveground biomass was harvested completely at two 1 m^2 sampling areas per sub-plot near the ground level. Aboveground biomass was sampled every month between February 2013 and June 2014 and separated into green and dead material. Monthly biomass re-growth was measured using two protective cages per sub-plot. The cages were placed onto the freshly cut m^2 of the particular sub-plot and harvested the next month. The plant material was oven-dried at 75° until constant weight.

2.2.5 Statistic analysis

We analysed the effects of HIG applied every month compared to the control areas without treatment. The experiment was set up as a randomized block design with three repetitions (R1 - R3). For biomass comparison, a linear mixed model for repeated measures using maximum likelihood (REML) in time with independent heteroscedastic errors was used for biomass. Months of harvest were considered as the fixed effects. For the random effects, sub-plots were declared as the stratification criteria, so that it was explicitly stated the correlation of measured data coming from the same sub-plot. The model takes into account the month of data acquisition order, as harvest time was equidistant, the structure corAR1 was applied (Piepho et al. 2004). Different biomass fractions were analyzed, monthly biomass re-growth

(BRG), standing green biomass (SGB), standing dead biomass (SDB) and standing total biomass (STB) as dependent variables. The comparison of means was tested when a significant F-value was achieved; then the least significant difference (LSD) post hoc analysis was applied. To explore how the time after seasonal impact influenced the biomass pools accumulation, we used a set of models using the different biomass fractions (BRG, SGB, SDB and STB) as dependent variable and months after high impact grazing (MAI) as independent variable. Statistical significance of all tests was $p < 0.05$, if not stated differently. We used the software InfoStat (v.2014) for the statistical analyses. The cows where weighed before and after the experiment. Analysis of variance (ANOVA) was used to analyse the treatment effects on live weight gain.

2.3 Results

2.3.1 Biomass dynamics

Compared with the control area, HIG had no effect on monthly biomass re-growth (BRG) (Fig. 2.2). There was no interaction between the harvest season and the HIG treatment ($p = 0.2898$).

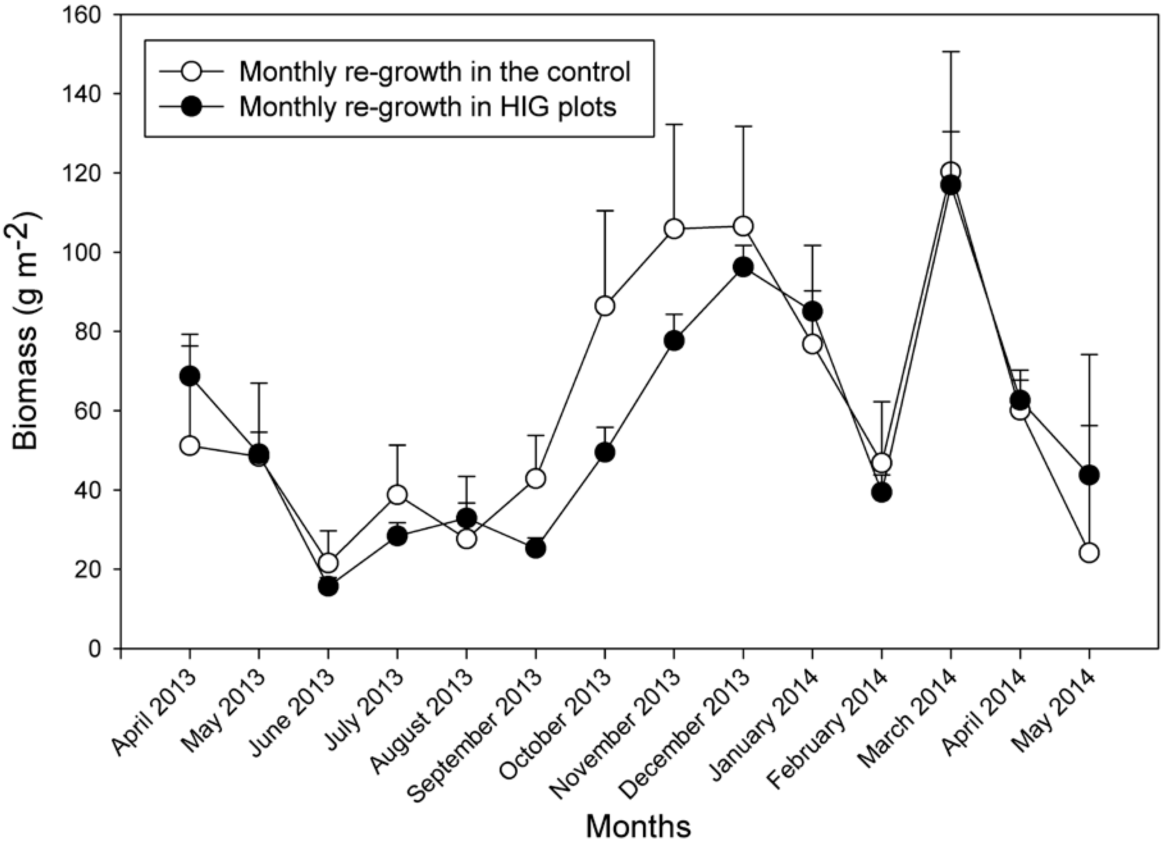

Figure 2.2. Grassland dynamics, monthly re-growth in control and in the high impact grazing (HIG) sub-plots. Al variables expressed in g m^{-2}. Error bars indicate the standard error of the means ($p < 0.05$).

However, season significantly influenced BRG ($p < 0.0001$), i.e. winter showed the lowest monthly re-growth (30 g m^{-2}), while growth rates in summer (73 g m^{-2}), autumn (64 g m^{-2}) and spring (60 g m^{-2}) were significantly higher.

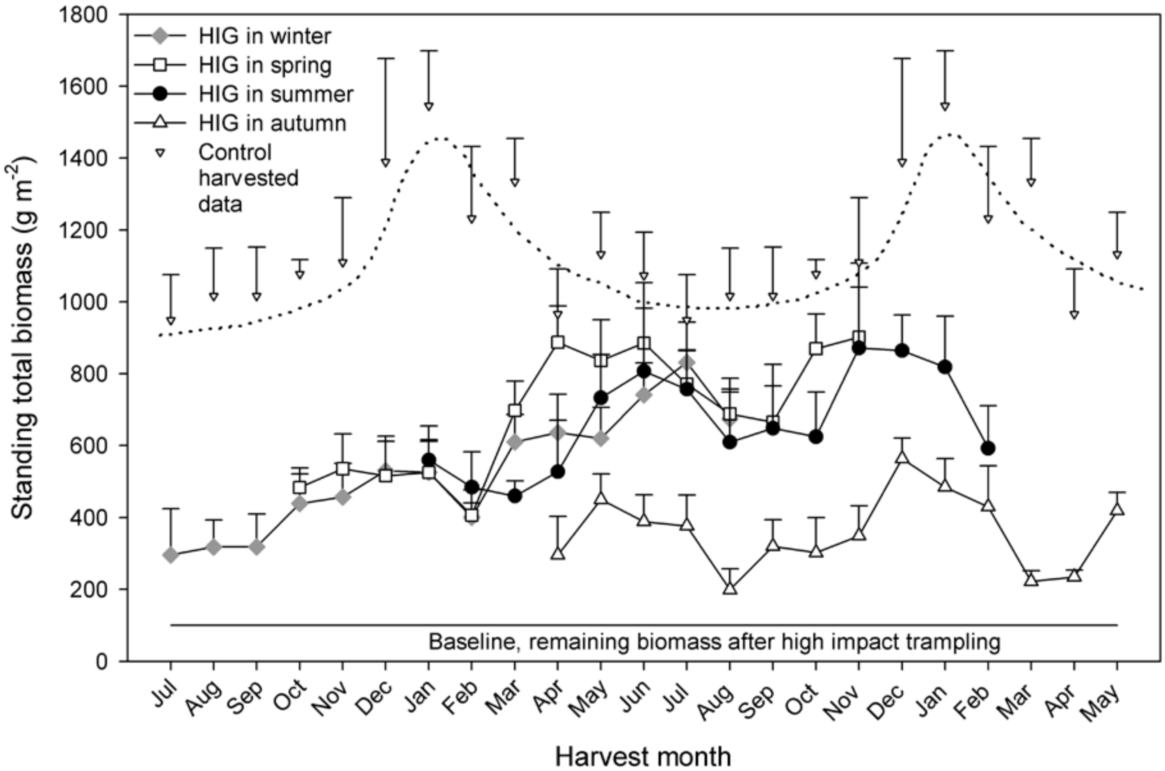

Figure 2.3. Standing total biomass (STB) after the high impact grazing (HIG) in winter, spring, summer and autumn compared to STB harvested in the control. STB of every impact season is the average STB of the impact months classified accordingly. For example winter HIG is the average STB of the months classified and treated by HIG in winter (e.g. June, July and August) measured at the particular month. For better comprehension biomass dynamics of control was eye fitted (dotted line).

Figure 2.3 shows the standing biomass (STB) dynamics of HIG treated sub-plots subdivided by impact timing (winter, spring, summer, autumn) and control sub-plots harvested during the whole 23-month sampling period. We found no seasonal effects on the residual biomass after trampling (Fig. 2.3). Our calculations indicate that on average the instantaneous effect of HIG reduced the standing green and dead biomass by 95% (+-1%), measured STB before and after HIG showed that it was reduced from 1970 g m^{-1} in spring, from 1680 g m^{-1} in summer, from 1770 g m^{-1} in autumn and from 2370 g m^{-1} in winter to approximately 100 g m^{-1}. Over the entire experimental period STB was significantly lower at the different HIG treatments (Fig. 2.3).

STB dynamics at the control sub-plot followed a seasonal pattern with clear maxima in November and December and minima from April to August but always above 1000 g DM m^{-2}. HIG sites showed a STB between 200 - 800 g DM m^{-2}. Active growth phases for both control and HIG were observed from September to January (spring and summer); thereafter total biomass of the control sub-plots decreased by about

40% in the period from February to August (autumn and winter). In contrast, sub-plots under HIG independent of the impact timing, showed an extended growth period in autumn, from February to June. With exception of the HIG in autumn the STB increased by 850 g m^{-2}, while the control lost biomass or stagnated at roughly 1000 g m^{-2}.

2.3.2 Impact timing

Figure 2.4 shows the biomass dynamics after HIG in spring, summer, autumn and winter. The figure shows total and standing dead biomass of HIG treated and control sub-plots over a period of 13 months; where the difference between the two curves, represents the amount of green biomass in the respective sub-plots.

HIG_{winter} resulted in two growth phases with one strong biomass increase in spring and the other one in autumn (Fig. 2.4a). In contrast we found only one active growth phase in spring for the control site. The STB accumulation in spring was faster after HIG_{winter} compared to the control (slope b = 258 g m^{-2} vs. 196 g m^{-2} month), as shown by the slope of the regression of STB over time, representing the growth rate (Fig. 2.4a). While the second growth phase at HIG_{winter} increased the aboveground biomass by around 500 g m^{-2}, the control sub-plots lost dry matter between 300-400 g m^{-2}.

HIG_{spring} triggered an extended active growth phase into autumn with increasing aboveground biomass (up to 1000 g DM m^{-2}) until seven months after impact (Fig. 2.4b). During the same time the control sub-plot showed decreasing biomass from 1500 to 1000 g m^{-2}. 10-12 months after the impact both control and HIG_{spring} resumed growth again during the following spring. Through the year the largest share of the biomass in the control was of very low quality with SDB varying from 62 to 84% compared to 34 to 74% in the HIG sub-plots. Moreover, SGB was not significantly different (277 g m^{-2} vs. 252 g m^{-2}) between control and HIG sub-plots, respectively.

HIG_{summer} also promoted growth, the first growth phase during the autumn (this phase was again absent in the control sub-plots where STB showed a negative trend) and a second one in spring. The autumn growth phase resulted in a sharp increase in STB (b = 137.1 g m^{-2} month), which peaked at about 800 g m^{-2} (Fig. 2.4c). The second growth phase, in spring, started in September and occurred in both, HIG and control sub-plots.

The HIG_{autumn} did not trigger a second active growth of biomass in the year but resulted in an extended growth phase from September to March in parallel with the control sub-plots. During this period, STB accumulated from about 1000 g m^{-2} to about 1400 g m^{-2} in the control sub-plots and from about 300 g m^{-2} to about 700 g m^{-2} in the HIG_{autumn} sub-plots (Fig. 2.4d).

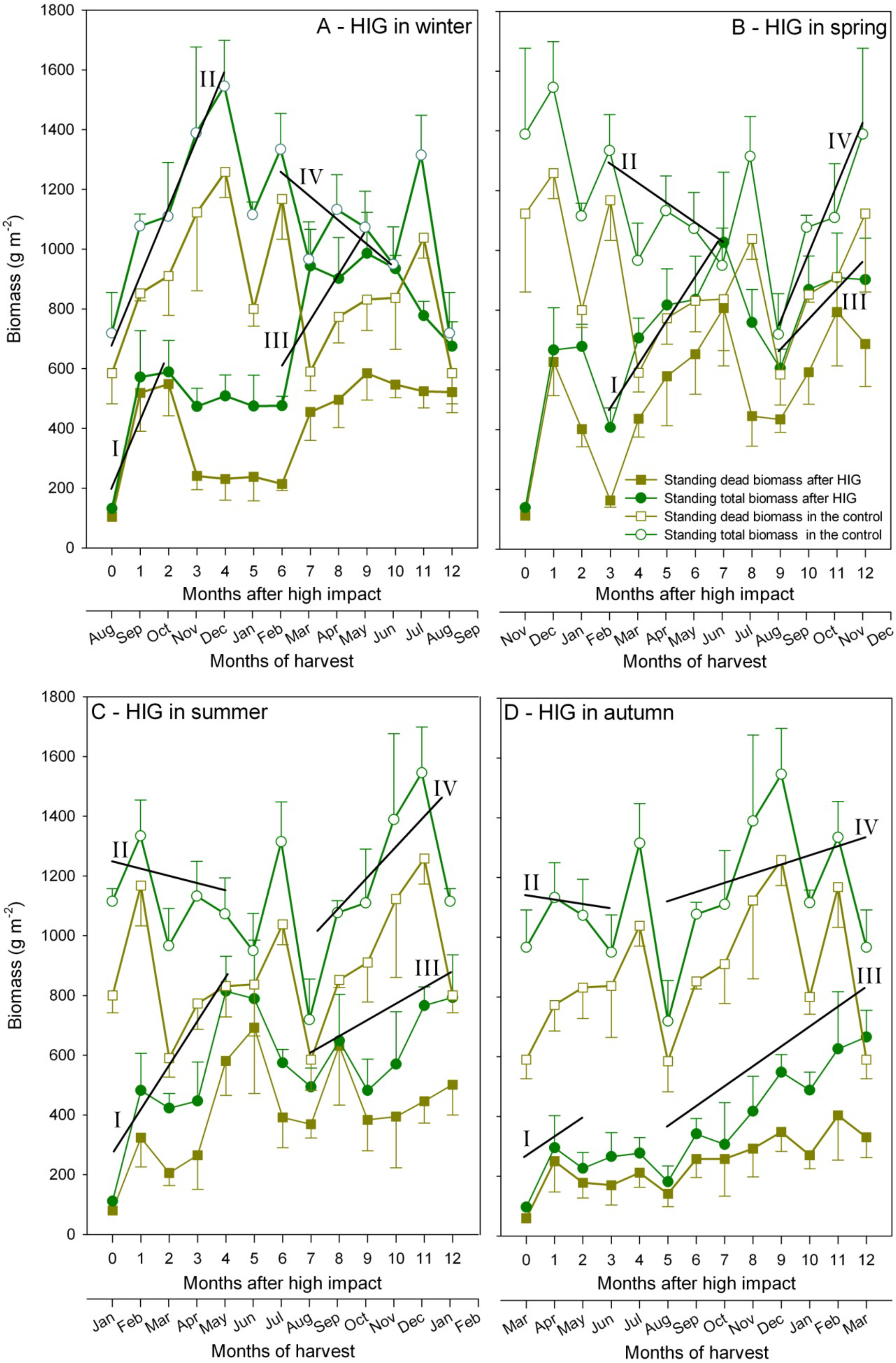

Figure 2.4. Total and dead biomass dynamics after high impact grazing (HIG) applied in four different seasons. Exemplary shown for August, HIG_{winter} (A), for November HIG_{spring} (B), for January HIG_{summer} (C) and for March HIG_{autumn} (D). The difference between curves indicates the green biomass. For

each HIG season the regressions were calculated considering the STB, one month after HIG and at the time the maximum achievable STB was harvested; while in the control and for comparativeness the regression was calculated considering the STB during that same period of time. The rate of biomass accumulation changed with the month of HIG occurrence as follows, AII. y = 258.4 x + 152.3 (r^2 = 0.775); AII. y = 196.5 x + 578.4 (r^2 = 0.954); AIII. y = 148.9 x + 603.5 (r^2 = 0.661); AIV. y = -66.2 x + 1289.9 (r^2 = 0.452). BI. y = 92.9 x + 681.9 (r^2 = 0.686); BII. y = 196.5 x + 484.9 (r^2 = 0.902); BIII. HIG, y = 136.9 x + 603.5 (r^2 = 0.661); BIV. y = -66.2 x + 1289.9 (r^2 = 0.452). CI. y = 55.4 x + 487.1 (r^2 = 0.6); CII. y = 104.8 x + 792.6 (r^2 = 0.472); CIII. y = 137.1 x + 181.3 (r^2 = 0.755); CIV. y = -28.5 x + 1209.9 (r^2 = 0.113). DI. y = 88.9 x + 504.6 (r^2 = 0.908); DII. y = 37.9 x + 986.2 (r^2 = 0.1273); DIII. y = 65.4 x + 218.1 (r^2 = 0.924); DIV. y = -10.9 x + 1057.6 (r^2 = 0.026).

Across all seasons the absolute amount of green standing biomass in the HIG sub-plots matched in most cases the amount of green biomass in the control sub-plots. In addition, due to a much higher accumulation of SDB in the control sub-plots the share of green biomass was higher in the HIG sub-plots for as at least as long that one year after the HIG (Fig. 2.5).

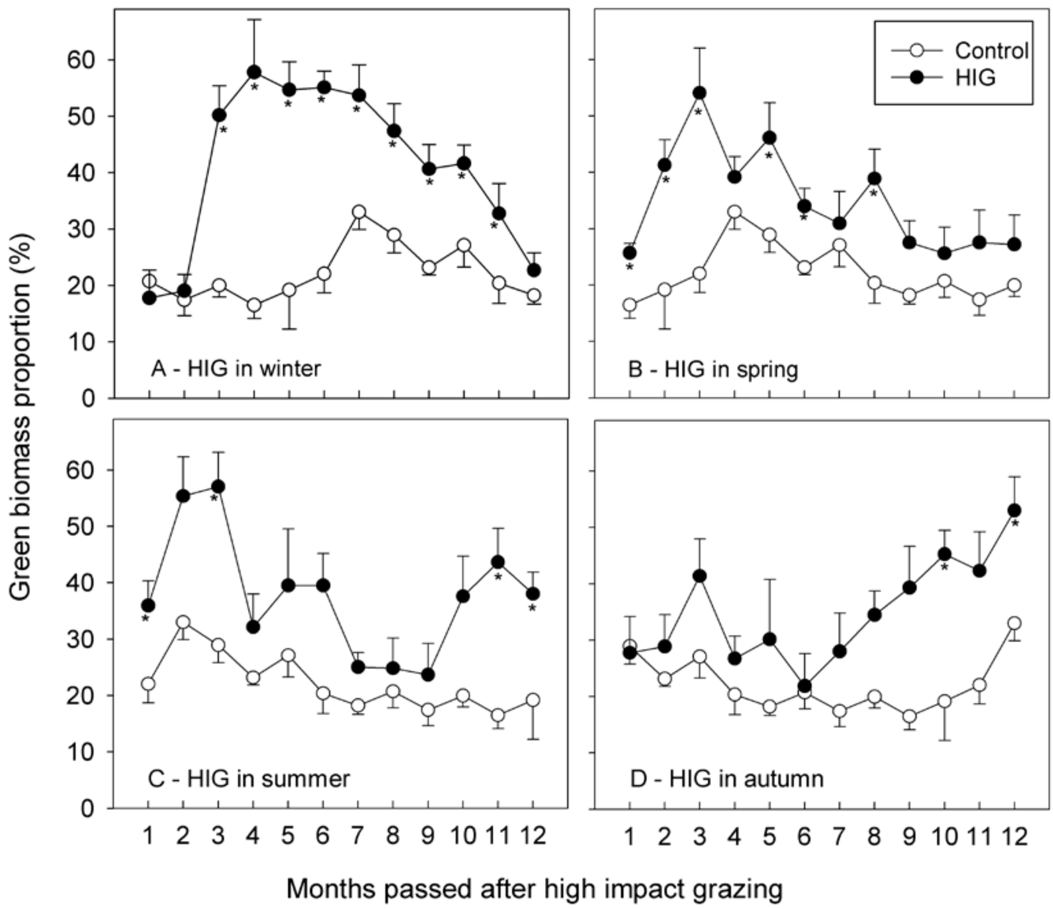

Figure 2.5. Green proportion of the grassland biomass and time passed after HIG, which was applied in four different seasons. Exemplary months are shown, August for HIG in winter (A), November for HIG in spring (B), January for HIG in summer (C) and March for HIG in autumn (D). Error bars indicate the standard error of the means ($p < 0.05$).

Green biomass share of the control sub-plots was highest during summer with a peak value of around 30% of the total biomass. For most parts of the year, the share of green biomass was lower and fluctuating roughly between 20 to 25%. In the HIG sub-plots the share of green biomass peaked once or twice depending of the HIG season and reached values of up to 60% of the total biomass. Throughout the year the proportion of green biomass in the HIG sub-plots was on average 20% higher than in the control sub-plots. In combination with the generally lower amounts of total biomass in the HIG sub-plots, the available biomass was better more palatable and more easily accessible to the cows in the HIG sub-plots.

2.4 Discussion

2.4.1 The effect of high impact grazing on grassland dynamics

The monthly vegetation re-growth showed a clear seasonal pattern, which is typical for C_4 dominated grasslands, where low growth rates coincide with periods of low temperature and low radiation (Knapp and Medina, 1999; Martín et al. 2011; Ötztürk et al. 1981; Royo Pallarés et al. 2005). The accumulated biomass re-growth was barely 8% higher in the control sub-plot (857 g m^{-2}) compared to the HIG sub-plots (791 g m^{-2}). Neither over-compensatory growth as reported by McNaughton (1979; 1983) nor a reduced productivity following the impact was observed in this study as growth rates remained similar between HIG and control sub-plots indicating a rather resilient rangeland in response to grazing disturbance. This could have been due to three factors, i) relatively more of the biomass was trampled down instead of grazed or, (ii) the nutrient cycles were not accelerated by the additional faeces deposition, and last but not least (iii), the intercalary and protected apical meristems were not lost by HIG and could recover easily after shoot removal (Heckathorn et al. 1999).

On the other hand, we found that HIG reduced the standing total (STB) and standing dead biomass (SDB). We can confirm that the effects on grassland biomass dynamics depend strongly on the season when HIG was applied (McNaughton 1983). HIG showed a different growth pattern anti-cyclic compared to that of the control, with an active growth phase during autumn when the biomass in the control sub-plots decreased. The declining trend of STB in the control sub-plots was indeed negative in autumn due to strong SDB biomass decay, whereas the response to HIG was active tillering that built up new biomass as most of the biomass was previously removed or trampled down.

In the untreated control sub-plots as a result of the seasonal growth, STB accumulated from spring to summer and decreased approaching the end of the growing season in late autumn until the end of the winter in August. The negative rate of STB accumulation was not only directly related to the climatic conditions, particularly to the low temperature (Long, 1999), but also, we assume likely due to less light interception due to the shade produced by the biomass. It is well documented that an open canopy and low light interception (shadow) is essential for high photosynthetic rates in C_4 plants (Heckathorn et al. 1999; McMillan et al. 2011; Ötztürk et al. 1981) and consequentially for biomass production (Heckathorn et al. 1999; Pearcy et al. 1981). During autumn and winter control sub-plots suffered from a combination of high amounts of STB shading the lower canopy leaves and decreasing temperatures. As the decreasing temperatures affect both the HIG and the control sub-plots equally, it is likely that the better light penetration in the HIG sub-plots induced the active growth observed in autumn in the HIG sub-plots improving the ratio between SGB and SDB. This is supported by the biomass re-growth results showing a similar growth potential of control and HIG sites throughout the year after biomass was removed (Fig. 2.2).

Compared to HIG in winter, summer or spring (STB accumulation between ~400 to 800 g m^{-2}), HIG in autumn produced exceptionally low STB (~200 to 600 g m^{-2}) (Fig. 2.4d). Two major effects may have been the cause of this. On one hand, seasonal variations in temperature induce C_4 plants to allocate resources to below-ground organs before grasses senesce when temperatures decrease towards winter. It is highly likely that the HIG towards the end of the growing season in autumn impeded the allocation of photosynthates to roots (Knapp and Medina, 1999). Therefore, the HIG in autumn, by destroying all present biomass, interfered with root resources allocation which translated into low growth on the following growing season. HIG_{autumn} could have been amplified by water logging resulting in soft water saturated soil horizons (Striker et al. 2011). High rainfall and low potential evapo-transpiration during autumn indeed resulted in water-logging during HIG on our experimental sites. Therefore HIG mainly due to trampling during times of water-logging has likely triggered stalks injury and serious root damage (Dunne et al. 2011; Striker et al. 2006), responsible for the reduced growth during the next spring and even summer.

Clearly the grasses are more sensitive to HIG in autumn, when soils were and normally are waterlogged, but if it had been applied in a less damaging manner at this time of year damage would likely have been considerably less. Also in a management system only a small part of the whole management would be receiving HIG treatment at this time of year. So if different areas of the grazing whole were subjected to HIG each year this would not be a problem.

In general, the control sub-plots offered a mixed bunch of green and huge amounts of deterrent standing dead grass hardly accessible for the cows (Balph and Malecheck, 1985; Moisey et al. 2006). Green proportion in control sub-plots barely reached 30% in autumn; they had, on average, only 22% green biomass (of ~800 to 1600 g m^{-2} STB) through the year. In contrast, the proportion of green biomass was higher in HIG sub-plots. For example, the share of green biomass was on average above 38% and 42% after HIG in winter and summer, respectively (Fig. 2.5). Moreover, it seems that by removing SDB and preventing shading we also prolonged leaf longevity (McNaughton 1983), as was shown by the share of green biomass in

HIG and control sub-plots (Fig. 2.5). HIG reduced STB by around 95%; nevertheless, seasonality and variable weather such as wet or dry conditions altered grassland STB incorporation to the soil. HIG under muddy conditions with water logging, led to more biomass incorporation into the soil compared to dry conditions, where biomass was trampled to the soil surface. However, several months after HIG we did not observe any significant effects on biomass dynamics. Finally, there was a clear trade-off; in general less forage was harvested in HIG sub-plots compared to the control, nevertheless after HIG the grassland produced a more stable availability of palatable green biomass throughout the year (Fig. 2.5). Independently of when HIG was done and compared to the control, the senesced grassland biomass was rejuvenated (McNaughton, 1983). Moreover, the results of the present study suggest better foraging conditions for grazers resulting from the reduction of SDB.

The proportion of SGB (SGB/SDB ratio) should be further explored to function as indicator for the positive effects of HIG. Although the amount of SGB produced was less when HIG was applied in summer or autumn compared to the winter or spring impact, the positive effects for the winter and spring period (the most difficult period for animal nutrition) are of higher relevance for the overall productivity of the land use system. HIG at any time of the year increased the SGB/SDB ratio which consequentially enhanced energy capturing during winter and early spring periods when grass growth is normally light limited by the SDB.

2.4.2 Implications for range management and meat production

Despite the fact that overall biomass was reduced, the amount of palatable biomass (SGB) in the HIG sub-plots was still sufficient to feed cows throughout the year. For example, during the first three months after HIG in winter, grassland had enough green biomass (~170 kg biomass ha^{-1}) to feed 0.5 A.U. which is the normal stocking rate in the Province (considering a theoretical daily feed intake of 12 kg dry matter or 3% of life weight of a 400 kg cow). Nevertheless after HIG in spring, summer or autumn, the available SGB was between 2 and 6 times more than needed at that stocking rate. On the other hand, control sub-plot produced 4 to 10 times the amount of green biomass at that stocking rate, but was barely accessible due to the huge volume of deterrent SDB. Even though not conclusive, our results clearly show that cows' weight increased significantly more on the grasslands subjected to HIG than on the control sub-plots. All sub-plots were constantly grazed by cows which at the beginning had the same live weight (232.8 kg, sd = 18.3 kg). Weighed again, about a year later, at the end of the experiment cows on control sub-plots weighted 282.3 kg (sd = 19.1 kg) whereas those in HIG sub-plots gained 30% more live weight (400.9 kg, sd = 86.7, Fig. 2.6).

Grazing was less efficient in the control since cows probably spent more time and energy searching for forage (Abdel-Magid et al 1987; Heckathorn et al. 1999). Our calculations indicate that cows could have consumed at least 20% more biomass after HIG than in the control (data not shown). The HIG, with monthly time intervals and on adjacent areas, produced a combination of areas of low, but high quality biomass and areas of high bulk but low quality biomass, which enhanced ruminant resources utilization (Hempson et al. 2014) and could have determined the higher live weight gain.

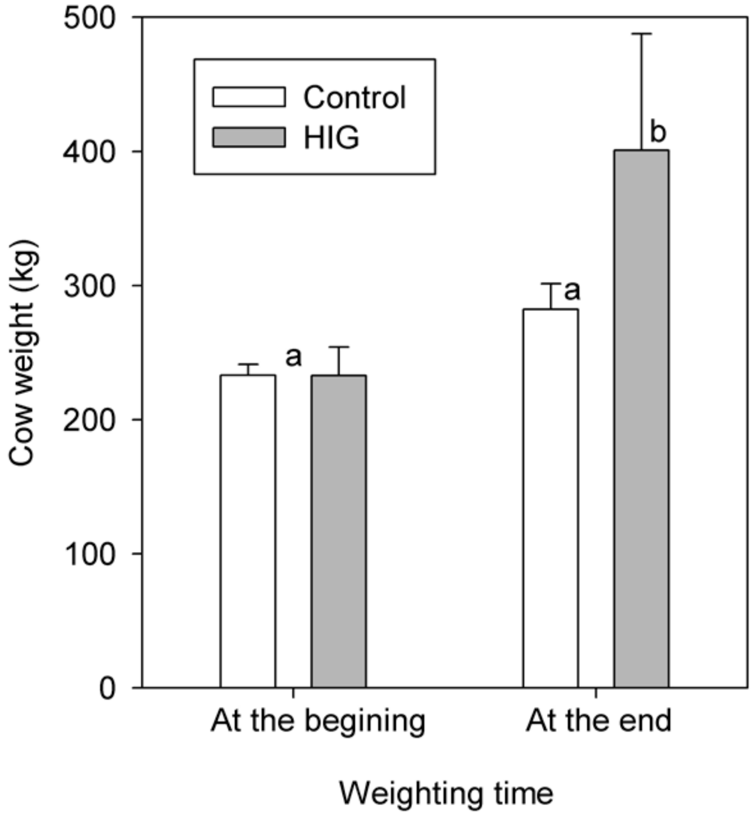

Figure 2.6. Live weight (kg) of the cows at the beginning and at the end of the 2013-2014 period, in both control and treated sub-plots. The figure shows the weight means and the vertical bars indicate the standard deviation. Means with a common letter are not significantly different ($p > 0.05$).

Reasons remain speculative, but the results are suggesting either a better availability due to the less proportions of deterrent SDB as a result of HIG, or an improved nutritious quality of the sward or both. Prior research in the region showed that the chemical composition of different grass species was most nutritious up to two months after clipping (Casco and Bernardis, 1992; 1993; 1994; Bernardis et al. 1997). Fodder quality analysis will reveal whether HIG was able to improve the nutrient content of the grasses or not. Our results suggest that impact grazing in (late) winter would result in most beneficial rangeland properties with regard to biomass re-growth dynamics, green to dead proportions and extended growth periods. An impact during autumn, however, could i) significantly reduce the fodder availability during the winter and ii) jeopardize the next years productivity due to the threat of serious root destruction in water logged soils unless management mitigates this impact as mentioned earlier. Our results confirm that strong disturbances towards the end of the winter, such as fire for example, maximally increase the share of green biomass in the grassland (Bernardis et al. 2005a; 2008; Fernández et al. 2011; Martín et al. 2011).

We are aware that, further in depth studies of HIG as a management tool are needed to improve our understanding of the plant-animal interactions and to use this potentially beneficial quasi-natural disturbance mechanism (Cromsigt and Olff, 2008; Hempson et al. 2014; McNaughton, 1984) to increase resource use efficiency and productivity of rangeland ecosystems.

2.5 Conclusions

We provide first hand evidence of a HIG management alternative for Argentinean ranchers in order to reduce the unproductive and grazing deterrent standing dead biomass. HIG effect on the biomass pools lasted for several months thereby increasing the green to dead biomass ratio. Timing of the HIG is most important and should consider the natural seasonal dynamics of the grassland ecosystem. Best results in terms of standing dead biomass reduction and dead to green ratios were achieved with HIG in winter. HIG in autumn, however, could reduce fodder availability and reduce next year's grassland's productivity. Irrespectively of the season applied HIG produced an extended growth phase which lasted until the next autumn. This growth response has not been observed or reported up to now for the region, and should be explored for the potential to improve the fodder availability for cattle right at the beginning of the winter. Dead to green biomass ratios as a result of HIG should be further analysed to function as an indicator for improved pasture management.

In addition our results contribute to a better understanding of ecosystem disturbance mechanisms with potential to be used for enhanced rangeland management. HIG could be a valuable alternative for range managers seeking not only for a different method to reduce dead biomass pools, but also working towards a sustainable intensification providing green forage at levels equal or even higher than those achieved under continuous traditional grazing.

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3 Effects of high impact grazing on species diversity and plant functional groups in grasslands of Northern Argentina

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Abstract

High impact grazing (HIG) was proposed to reduce dead biomass pools in Northern Argentinean rangelands. However, effects of HIG on grasslands' diversity and shifts in plant functional groups are largely unknown but essential analysing the systems' response to disturbance. During a two years grazing experiment carried out in the Chaco Corrientes grasslands, the effects of HIG on plant species composition were monitored. HIG was applied every month at different sites in order to analyse seasonal effects. The immediate effect of HIG was the reduction of the standing biomass by more than 95%. Irrespective of the season HIG was applied, the grassland showed high resistance with regard to diversity parameters. Species richness, Shannon-Wiener diversity index (*H*) and the Shannon's equitability index (*E*) did not differ from the control within a 12-month period after HIG. Notably, plant functional groups of dicotyledonous and annual species could not benefit from the HIG disturbance, but C_3-, C_4-monocotyledonous and perennials increased their absolute and relative cover. Our results suggest that HIG is neither altering diversity nor shifting plant species composition of Chaco grassland to a more ruderal strategy based plant community, but instead it promotes previously established rather competitive and higher value fodder species. HIG could therefore have the potential to contribute as alternative management practice towards sustainable land use intensification of Chaco grassland ecosystem and even counteract the encroachment of "low value" species. However, we are aware that long-term trials should be analysed to detect possible legacy effects and interactions especially with seasonal climate variability.

3.1 Introduction

Tropical grassland ecosystems comprise natural and semi-natural grass dominated areas of in total around 11% of the terrestrial land surface (Alkemade et al. 2013; Di Gregorio and Jansen 2005; Dixon et al. 2014; Lund 2007). These ecosystems provide multifunctional services for livestock farming and floral and faunal biodiversity, among others (Frame 2011). Plant diversity in grasslands depends on several environmental factors such as soil fertility, water availability, landscape heterogeneity, temperature, or grazing intensity (Cingolani et al. 2014; Hendricks et al. 2005; Milchunas and Lauenroth, 1993; Pucheta et al. 1998). In Argentina, the Chaco rangeland region hosts a very large semi-natural grassland and forest habitats (Grau et al. 2014), of which the Corrientes province in Northern Argentina belongs to species richest grassland ecosystems considered as diversity hot spots (Carnevali 1994; Rosengurtt 1979). Therefore, a sustainable land use balancing livestock production with a potential for intensification and grassland diversity protection are of major concern (Rockström et al. 2009; Rodriguez & Jacobo, 2010; West 1993).

Due to low stocking rates in Northern Argentina adapting the limited fodder availability during the winter, the system accumulates large amounts of dead plant material resulting from the vigorous growth of C_4 grasses during the summer growing season (Fidelis et al. 2013; Heckathorn et al. 1999). This surplus standing dead biomass (SDB) is considered to decrease fodder resource quality with regard to forage accessibility and nutritional value. As compared to traditional methods to reduce SDB such as burning, ploughing and mowing, high impact grazing (HIG) was analysed as an alternative management option (Kurtz et al. 2016). This method makes use of the natural destructive impact of large and dense herds of large herbivores found in natural grasslands (Cromsigt and Olff 2008; Hempson et al. 2014; McNaughton 1984; Savory 1983). Although being successful in reducing SDB the effects on diversity and floristic composition of the grassland are still unclear.

In general, the effects of different grazing intensities on plant species composition and diversity are comparably well documented for most of the world's grassland ecosystems. However, these studies often report contrasting results of reduced, unaffected or even increased diversity or shifts in plant functional groups. These different responses to herbivory were mainly explained by environmental gradients of available resources such as nutrient and water availability or energy budgets to compensate for the losses due to grazing (Milchunas and Lauenroth 1993, Milchunas et. al 1988; Borer et al. 2014). On top of these environmental fertility gradients, the anthropogenic impact via the grazing management composes a wide range of different land use practices strongly intervening with natural processes such as nutrient cycles or the water balance affecting the plant communities (Borer et al. 2014). In ecological theory HIG grazing can be considered as a strong ecosystem disturbance which in general promotes plant species following a ruderal strategy (r-strategy) (sensu Grime 1977). Therefore, possible shifts in species composition in response to HIG might counteract the positive effects of SDB reduction. This in particular because the higher quality fodder species found in the Chaco grassland mainly belong to the functional group following a more competitive strategy; which is considered as relatively sensitive to a strong disturbance. HIG could therefore negatively affect their abundance and productivity.

However, despite these more theoretical ecological assumptions most of the previous studies analysing plant-animal interactions in grasslands consider a permanent grazing pressure throughout the growing season, rather than short-term HIG effects (Adler et al. 2004; Anderson and Hoffmann 2007). There are just few studies analysing effects of grazing intensity in the sub-humid tropical grasslands such as Altesor (2005) who found that areas excluded from grazing had lower species richness and diversity than grazed areas, where grazing additionally produced a shift form tussock grasses to more prostrate species. On humid areas of Central Argentina, Jacobo et al. (2006) found that on midslopes, the rotational grazing increased the cover of C_3 grasses, while in lowlands, the plant functional groups remained unaffected by the grazing system. For the Corrientes province, it was found that species diversity and evenness decreased while species richness remained unaffected after 8 years of continuous high stocking rate. However, common to all studies is that the impact of short but high intensity grazing was rarely considered and that the effects are unknown with regard to plant species composition and diversity (Pizzio et al. 2016).

Therefore, this study aims to analyse the effects of HIG on grassland floristic composition, diversity and plant functional groups. The results will contribute to an improved understanding of HIG with regard to i) contra-productive or complimentary effects to common goals of grassland diversity conservation and ii) a sustainable management option in order to maintain and promote plant growth and valuable fodder species respectively.

3.2 Materials and methods

3.2.1 Study area

The study was conducted on the Corrientes INTA (National Institute of Agriculture) Research Station (1175 ha) in the province of Corrientes situated in northeast Argentina. The station is located in the Chaqueño Oriental phyto-geographic district (Cabrera 1971), 30 km South (lat. 27° 40’ 23.27’’S, long. 58° 44’ 12.94’’W, 69 m.a.s.l.) from the Corrientes capital city. The annual mean temperature is 21.3°C, with an average temperature for the coldest month July of 15.6°C, based on mean daily minimum of 9.9ºC and a mean daily maximum of 21.6ºC. Absolute maximum recorded for July was 32.7ºC and the absolute minimum -3.3ºC. The monthly average of the warmest month January is 27.1°C with a daily average minimum of 20.9ºC and a maximum of 33.2ºC, an absolute maximum of 41.2ºC and an absolute minimum of 2.1ºC. Local mean annual precipitation is ~1300 mm. There is a slight seasonality of rains; most of precipitation occurs in autumn (33% from March to May) and summer (30% from December to February), and less in spring (24% from September to November) and winter (13% from June to August). Sandy-loam texture soils (*Aquic Argiudol*) dominate in the study area (Escobar et al. 1996). Soils remain moist or very moist for most of the year, due to the high precipitation and the clay layer at approximately 40 cm depth (Bt horizon). The pH varies between 5.6 and 6.0 and soil organic matter from 1.2 to 1.7% in the upper soil layer.

In pristine grasslands or at very low stocking rates, grass canopy reaches 180 to 200 cm in height with an annual net dry matter primary productivity of up to 15 t ha^{-1}, which is dominated by *Andropogon lateralis* Nees and *Sorghastrum nutans* (L.) Nash interspersed with small shrubs and trees (Carnevali 1994). C_4 *Poaceae* species (grasses) is the most dominant plant functional group of northern Argentina grasslands, comprising bunch and short grasses with medium to moderate nutritional quality for ruminants (Schinini et al. 2004). Beside the productive C_4 grasses, mainly *Cyperaceae* species (sedges) with medium to low nutritional value and C_3 *Fabaceae* species (legumes) with higher protein content (Rosengurtt 1979) contribute to the total aboveground biomass. Forage growth is strongly seasonal, with maximum standing green biomass during summer (December - February) and minimum during winter, between July - September (Sampedro et al. 2004). Cattle graze freely at medium to relatively low stocking rates (~0.5 animal unit ha^{-1}) all year round (Calvi 2010).

3.2.2 Experimental layout

The experiment was established on a 24 ha natural grassland area which is part of the research facility of the INTA Corrientes. The area was previously managed with continuous grazing at an intensity of 0.5 animal units per ha^{-1} $year^{-1}$. Four adjacent paddocks of 6 ha each were separated with permanent electric fences. Three of them were used as replicates (R1–R3) for the HIG treatment experiment, and the fourth paddock was defined as control with no HIG. The HIG treatment followed a monthly sequence; therefore each replicate paddock was divided into 12 sub-plots of 0.5 ha each, used for monthly HIG. The experiment started in July 2012, when the first sub-plot (50 m width, 100 m length) was enclosed with mobile/temporal electric fences and subjected to three days of HIG. For that purpose a mixed 75-animal herd of Braford, Hereford, and Brahman cattle breeds was used, representing an instantaneous grazing intensity of 150 animal units' ha^{-1}. During the first day the herd was allowed to graze *ad libitum* and from the second day on, the cows were moved/driven around within the sub-plot to ensure an impact as homogeneous as possible until all vegetation was trampled down. After HIG, the mobile sub-plot fences were removed and the HIG herd was driven to the other two remaining replicates to carry out the HIG at the particular sub-plots. All four 6 ha paddocks were continuously grazed throughout the experiment with 3 non lactating cows each, to resemble the average yearly stocking rate of 0.5 animal unit ha^{-1} in Corrientes Province (Calvi, 2010; Kurtz and Ligier, 2007). These cows were also crossbreeds Braford, Hereford, and Brahman. According to mean temperature, monthly precipitation, daily reference evapotranspiration and relative humidity the impact months were classified to represent an annual season namely spring (September, October, November), summer (December, January, February), autumn (March, April, May), and winter (June, July, August) (For more details see Kurtz et al. 2016).

A detailed species inventory was performed at biomass peak time in the summer during February 2014. The least area size that was sufficiently representing the species richness was defined to be 8 m^2 ($p \leq 0.05$). During this inventory and at five randomly chosen positions within each of the 36 HIG sub-plots, we visually estimated the total ground cover of the standing dead biomass (SDB) and the green biomass ground cover (GB) of each individual species as well, also the share of litter and bare soil. For the control sub-plots, as there was no HIG disturbance, only twenty samplings were analysed at randomly selected positions. The sampled sub-plots represented the status of the grassland between 1 and 12 month after HIG. In total 200 sub-plots of 8 m^2 size were analysed. Additionally, for the offset analysis, from July 2013 to July 2014 we sampled 5, 25 x 25 cm quadrates (20 each month). We ranked the individual grassland species according to their ground cover in the month of impact of the four adjacent paddocks.

3.2.3 Grassland species composition, diversity and plant functional groups

This study defined and measured species richness (*S*) as the total number of plant species within the sampling plots. The Shannon-Wiener diversity index (*H*) was calculated considering *S* and evenness of individual (plant) species (Laurila-Pant et al. 2015; Spellerberg and Fedor 2003). The Shannon's equitability (*E*) index was used to indicate how evenly different species are distributed. All plant species were also categorized to their botanical families and to their plant functional groups (PFGs): monocotyledons and dicocotyledons, photosynthesis pathway (C_3 - C_4) and life cycle (perennial and annual).

3.2.4 Statistical Analysis

We analysed the effects of HIG applied every month, compared to the control areas without treatment. The experiment was set up as a randomized block design with three repetitions (R1–R3). A linear mixed model for repeated measures using maximum likelihood (REML) in time with independent heteroscedastic errors was used to fit serial and spatial variance covariance structure to compensate for autocorrelation using a spherical covariance structure (Piepho et al. 2004). The standing green plant material (%), *H*, *E*, *S* and PFGs were analysed as dependent variables in the regression analysis. The comparison of means was tested when a significant F-value was achieved; then the least significant difference (LSD) post hoc analysis was applied. Principal component analysis was also used. The significance levels was set at alpha = 0.05.

3.3 Results

3.3.1 The effects of HIG on grassland vegetation

In total, we identified 166 different plant species belonging to 37 families on the HIG sub-plots and the control area (Table 3.S1). Most species belong to *Poaceae* (62%), *Cyperaceae* (21%), and *Asteraceae* (3%) families. Besides that, 60% of all species were dicots and the rest monocots. Perennial species dominate (82%) over annuals (18%). C_4 species represented 54%, C_3 species 41% and CAM species the rest (5%).

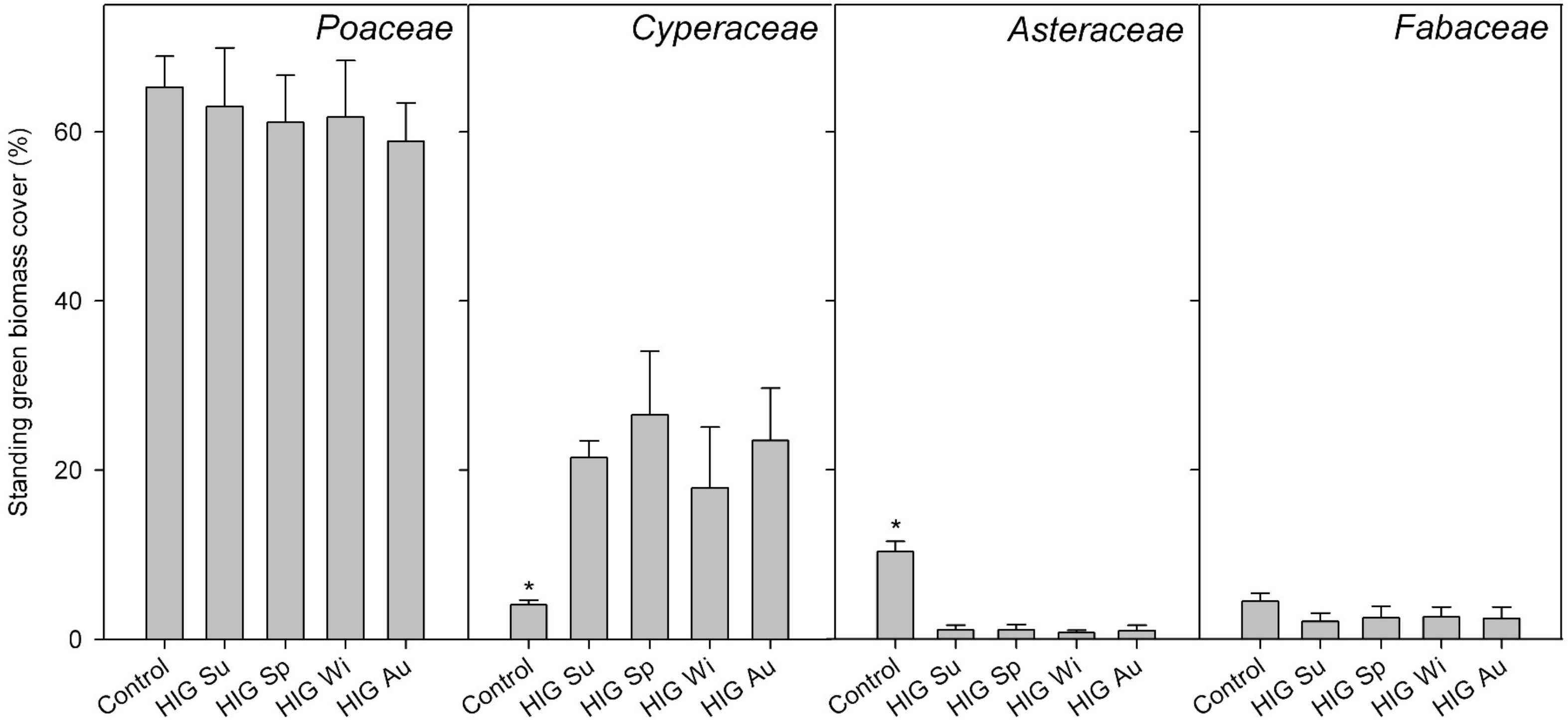
Species richness (*S*) measured at peak biomass time in February was not affected by HIG and its seasonal timing. Not even the most recent impact, around 3 weeks before sampling, showed less species (42 ± 5.4 sd.) compared to the control (48 ± 6.9 sd.) site (Table 3.1). For all other treatment sub-plots which received HIG up to one year ago the species richness was not significant different from the control. It varied from to 42 to 52 compared to 48 species (sd. = 6.9) in the control sub-plot. The Shannon-Wiener diversity index (*H*) did not reveal any difference in response to HIG compared to the control (p = 0.95). *H* varied from 1.8 to 2.9 among the HIG sub-plots, and it was 2.6 (sd. = 0.46) in the control (Table 3.1). The Shannon's equitability index (*E*) did not reveal any difference due to HIG compared to the control (p = 0.59). *E* varied between 0.58 and 0.75 in HIG sub-plots, while it was 0.66 (sd. = 0.084) in the control (Table 3.1).

The standing green and dead biomass shares based on ground cover (%) differed increasingly between the HIG sites and the control with time after the impact (Table 3.1). Within one year after HIG, the green biomass cover increases until around 80%, while the control site shows less than 30% green biomass cover. On the other hand, the standing dead decreases to less than 8% ground cover, at sites with more than 300 days since the last HIG compared to more than 65% standing dead ground cover in the control.

Table 3.1: Mean values (± sd.) of standing green (SGB) and standing dead biomass (SDB) in % of ground cover. Means (± sd.) for plant species richness (*S*), diversity (*H*) and equitability (*E*). Average values (± sd.) of plant functional groups: C_3, C_4 species, monocots, dicots, annual and perennial species based on their % of standing green ground cover. Measurements taken at peak biomass time in February 2014 between 19 and 357 days after high impact grazing (HIG) and in the control sub-plots. Means with different letters are different with p ≤ 0.05.

Impact Season	Impact Month	Days after HIG	SGB (%)		SDB (%)		C_3 (%)		C_4 (%)		Monocots (%)		Dicots (%)		Annual species (%)		Perennial species (%)		*S*		*H*		*E*	
	Control	-	25.0 ± 8.3	d	66.7 ± 13.0	a	12.3 ± 4.6	ab	12.7 ± 4.6	a	17.4 ± 1.7	a	7.6 ± 1.7	ns	1.1 ± 1.0	ns	23.9 ± 1.0	a	48.0 ± 6.9	ns	2.6 ± 0.4	ns	0.66 ± 0.06	ns
summer	February	19	18.8 ± 5.9	d	45.1 ± 4.6	b	8.0 ± 5.4	a	10.7 ± 5.5	a	17.9 ± 0.6	a	0.9 ± 0.6	ns	0.0005 ± 0.001	ns	18.8 ± 0.0009	a	42.3 ± 5.4	ns	1.8 ± 0.3	ns	0.58 ± 0.07	ns
	January	52	67.4 ± 7.8	ac	16.2 ± 6.1	ce	23.3 ± 5.9	bcd	43.6 ± 6.6	bcd	60.7 ± 4.6	bcd	6.7 ± 4.6	ns	0.7 ± 0.2	ns	66.7 ± 0.2	d	42.0 ± 5.4	ns	2.5 ± 0.1	ns	0.67 ± 0.02	ns
	December	54	62.8 ± 9.7	bc	18.5 ± 8.0	cd	32.1 ± 18.5	d	30.6 ± 18.6	b	45.8 ± 18.7	b	17.0 ± 18.7	ns	2.1 ± 1.5	ns	60.7 ± 1.5	bc	43.0 ± 6.0	ns	2.4 ± 0.1	ns	0.63 ± 0.05	ns
spring	November	87	67.8 ± 6.5	ac	10.3 ± 5.2	cf	16.8 ± 8.6	abc	50.9 ± 8.8	cd	57.1 ± 9.1	bcd	10.7 ± 9.1	ns	2.3 ± 3.3	ns	65.5 ± 3.3	cd	43.0 ± 6.1	ns	2.6 ± 0.2	ns	0.70 ± 0.04	ns
	October	116	59.8 ± 4.0	c	4.4 ± 0.8	f	11.4 ± 7.0	ab	48.4 ± 7.0	cd	53.6 ± 2.3	bc	6.2 ± 2.3	ns	0.8 ± 0.8	ns	59.0 ± 0.8	b	36.3 ± 5.3	ns	2.5 ± 0.2	ns	0.69 ± 0.03	ns
	September	146	71.6 ± 16.1	ac	8.4 ± 3.4	def	21.6 ± 3.9	abcd	49.8 ± 3.9	cd	64.6 ± 2.3	cd	7.0 ± 2.3	ns	1.0 ± 1.2	ns	70.6 ± 1.2	de	36.3 ± 5.3	ns	2.4 ± 0.1	ns	0.66 ± 0.08	ns
winter	August	176	78.2 ± 9.6	a	11.2 ± 5.9	def	31.7 ± 15.0	cd	46.1 ± 14.4	cd	57.9 ± 20.3	bcd	20.3 ± 20.3	ns	1.7 ± 2.1	ns	76.5 ± 2.1	fg	40.7 ± 7.2	ns	2.5 ± 0.2	ns	0.66 ± 0.06	ns
	July	206	67.8 ± 4.0	ac	20.1 ± 7.3	c	27.5 ± 3.4	cd	40.2 ± 3.4	bc	56.9 ± 10.4	cd	10.9 ± 10.4	ns	2.3 ± 2.7	ns	65.5 ± 2.7	cd	44.3 ± 7.2	ns	2.5 ± 0.3	ns	0.67 ± 0.06	ns
	June	253	78.3 ± 1.5	a	5.1 ± 1.5	ef	20.5 ± 7.5	abcd	57.8 ± 7.4	d	64.6 ± 4.4	cd	13.7 ± 4.4	ns	5.9 ± 7.2	ns	72.4 ± 7.2	ef	51.7 ± 7.7	ns	2.9 ± 0.1	ns	0.73 ± 0.01	ns
autumn	May	285	77.6 ± 2.9	ab	7.0 ± 1.2	def	22.9 ± 6.5	abcd	54.6 ± 6.5	cd	62.1 ± 12.9	bcd	15.5 ± 12.9	ns	2.5 ± 3.4	ns	75.1 ± 3.4	efg	45.7 ± 7.8	ns	2.9 ± 0.3	ns	0.75 ± 0.03	ns
	April	317	77.9 ± 4.1	a	7.8 ± 3.3	def	26.7 ± 10.6	cd	51.0 ± 10.8	cd	62.5 ± 13.9	bcd	15.4 ± 13.9	ns	4.0 ± 7.0	ns	73.9 ± 7.0	efg	44.0 ± 7.7	ns	2.7 ± 0.3	ns	0.71 ± 0.03	ns
	March	357	80.4 ± 3.2	a	7.2 ± 0.4	def	25.7 ± 10.3	cd	54.5 ± 10.3	cd	73.4 ± 4.7	d	7.0 ± 4.7	ns	1.5 ± 1.6	ns	78.9 ± 1.6	g	50.0 ± 6.5	ns	2.7 ± 0.2	ns	0.69 ± 0.05	ns

Fig. 3.1: Standing green biomass cover, at peak biomass time during February 2014, of the four most important botanical families *Cyperaceae*, *Asteraceae*, *Fabaceae* and *Poaceae* sampled in the experimental area at the Corrientes National Institute of Agriculture Research Station. The figure compares the families cover share on the control sub-plots and high impact grazing (HIG) sub-plots according to the time when HIG was applied (HIG Su = HIG applied in Summer; HIG Sp = HIG applied in Spring; HIG Wi = HIG applied in Winter and HIG Au, HIG applied in Autumn. Error bars indicate the standard error (se) of the means ($p \leq 0.05$).



More than 99% of the green biomass ground cover was composed of species belonging to the families of *Poaceae*, *Cyperaceae*, *Fabaceae,* and *Asteraceae*. The remaining 26 families represented less than 1% cover. To illustrate relative shifts of the dominant plant families' cover, Fig. 3.1 shows the impact of HIG and its seasonal timing on the green biomass cover of the four dominant plant families in comparison to the control site. The results show that seasonal impact timing had no effect on the main plant family composition (Fig. 3.1). Looking at the dominant families, relative green cover of *Poaceae* was unaffected by HIG accounting for 65% of total green cover in the control sub-plots and between 59-63% in HIG sub-plots (Fig. 3.1). In contrast, *Cyperaceae* species relative green biomass cover was strongly increased after HIG, as we measured 4% (sd. = 1.13) cover in control sub-plots and 18 to 27% in HIG sub-plots. *Fabaceaes'* relative cover decreased after HIG and ranged from 2 to 2.6% in HIG sub-plots and averaged 4.4% (sd. = 1.99) in the control sub-plots. The relative green biomass cover of *Asteraceae* species was 10.3% in the control sub-plots and this was reduced significantly to 0.8 - 1.1% after HIG.

3.3.2 Green biomass ground cover of plant functional groups

Relative shares of monocotyledonous, C_3 and C_4 plant species and perennial plant species were significantly affected by HIG (Table 3.1). C_4 species relative green biomass ground cover strongly increased to an average of 45% on HIG sub-plots (ranging from 10.7 to 57.8%) while for the control it was significant lower with 12.7% (sd. = 4.6). Remarkable was that the green ground cover of C_3 species which increased after HIG from 8.0% (sd. = 5.4) to max. 32.1% (sd. = 18.5), while in the control it averaged 12.3% (sd. = 4.6). HIG applied in winter and autumn, at least doubled the cover of C_3 species compared to the control sub-plots, while if applied in summer and spring it produced a similar C_3 cover as in the control (Table 3.1).

Monocotyledonous plant species relative cover strongly increased by around 200% after HIG compared to the control (Table 3.1). At the same time HIG did not reduced or increased the dicots species cover. Similarly, perennial species cover strongly increased after HIG compared to the control (Table 3.1). HIG did not affect annual species cover, which represented less than 6% throughout all analysed plots.

3.3.3 Principal component analysis (PCA)

The PCA axes can explain 90% of the total variation in the data set (Fig. 3.2, Table 3.2). The plant functional groups of dicots and monocots, C_4 and C_3 species as well as perennials and annuals showed an antagonistic relation. Green biomass and standing dead ground cover are naturally antagonistic as well. The diversity parameters species richness (*S*), Shannon index (*H*), and evenness (*E*) are much more related to appearance of annuals and dicots rather than perennials and monocots. Summer, autumn and winter HIG are placed close to the appearance of perennials and monocots, while spring closer to annuals and dicots (Fig. 3.2). Surprisingly the spring HIG was related closer to the diversity parameters *E* and *H* compared to all other treatments. The control area was mostly related to dicots, standing dead ground cover and C_3 species, however also the species richness *S* and annual species were positively correlated. In turn the control is negatively correlated with the appearance of monocots, green biomass cover, and C_4 species.

Table 3.2: Principal components analysis: eigenvectors for the analysed variables. PC1 is the first principal component and PC2 is the second principal component, both components explained 90% of the data set variation (PC1 53% and PC2 37%).

Variables	PC 1	PC 2
Dicots cover (%)	0.95	0.01
Monocots cover (%)	-0.95	-0.01
C_3 species cover (%)	0.67	-0.73
C_4 species cover (%)	-0.66	0.75
Annual species cover (%)	0.81	0.58
Perennial species cover (%)	-0.81	-0.58
H	0.61	0.79
E	0.28	0.94
S	0.92	0.36
Bare ground (&)	-0.37	0.37
Green material cover (%)	-0.61	0.71
Standing dead cover (%)	0.74	-0.64

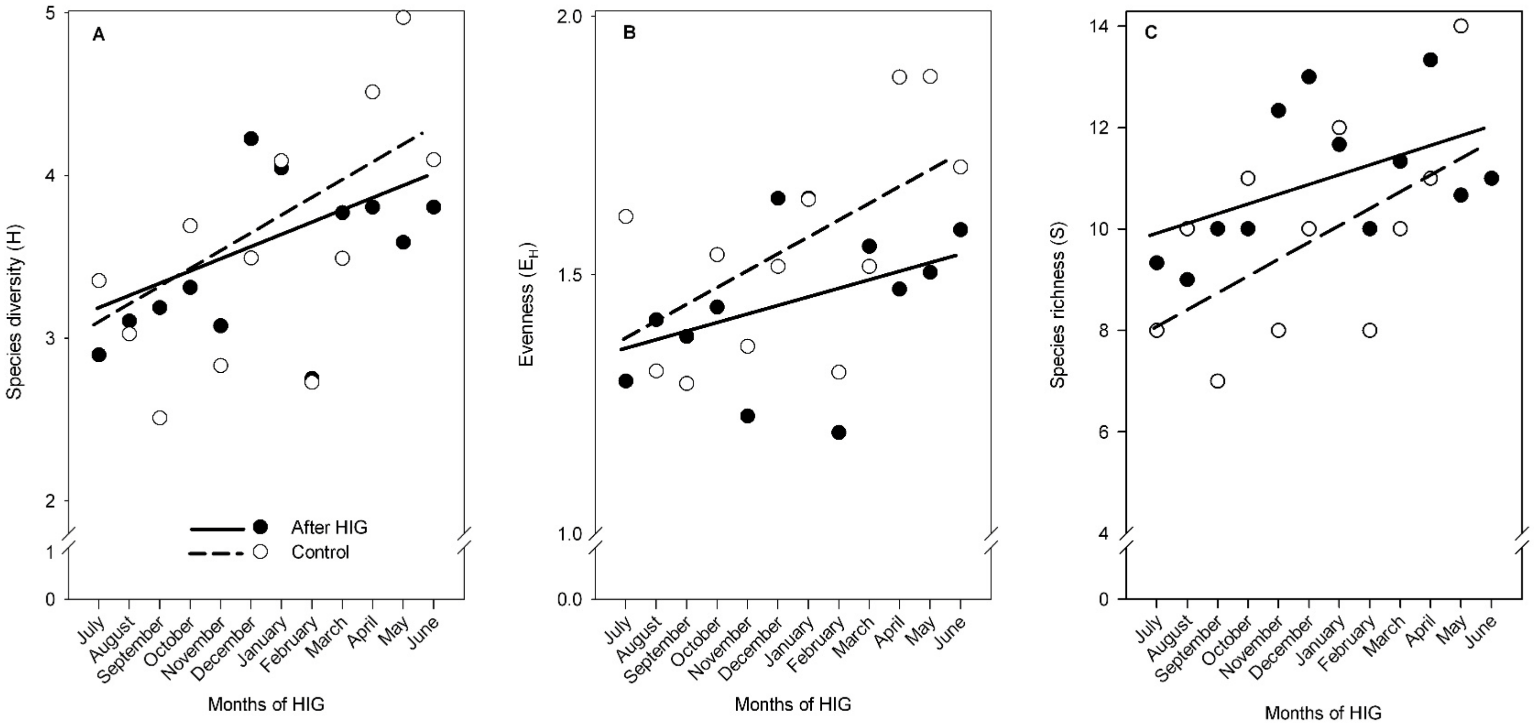
3.3.4 Grassland recovery analysis

Calculating *H*, *E* and *S* based on measurements taken monthly exactly one year after HIG, we found that *H*, *E* and *S* for HIG and control sub-plots showed a similar increasing general trend (Fig. 3.3, A, B and C). In the scatter plot figures, all analysed variables were not consistently higher or lower in control sub-plots than after HIG for any given month. The regression analysis indicated that the slopes are not different ($p < 0.05$).

3.4 Discussion

Corrientes rangelands have a grazing history of more than 500 years (Carnevali 1994). These grasslands are well adapted to eventual but intensive defoliation (Fidelis et al. 2013) as induced for example by natural or anthropogenic fires (Kurtz et al. 2010). Even though the nutrient status of the Corrientes soils is low (Escobar et al. 1996), the disturbances by defoliation are likely to be compensated by favourable climate conditions, with high temperatures and sufficient precipitation during most parts of the year. Due to both, the high primary productivity and the usually low stocking rates, the effects of grazing on vegetation, ecosystem functions and processes should therefore relatively small according to a general understanding of grassland response to herbivory (Cingolani et al. 2005; Milchunas et al. 1988, Milchunas and Lauenroth 1993). However, since the impact of a HIG is substantially different compared to a continuous grazing pressure, effects might considerably deviate. The idea using HIG as a management tool generated a controversial debate about benefits and risks in the literature (Briske et al. 2013; Teague et al. 2011) but also among farmers and rangers (*personal communication*). Our previous results showed that HIG in this particular tropical grassland had positive effects reducing standing dead biomass, improving the green biomass proportion and promoting grass growth (Kurtz et al. 2016). On the other hand, Pizzio et al. (2016) showed that permanent high stocking rates in Corrientes grasslands decrease evenness and the Shannon-Wiener diversity index, while species richness was less affected. The same study suggested that increasing grazing pressure would lead to reduced forage quality because of the loss of palatable grasses and the increase of forbs. However, our results show that the diversity parameters species richness, *H*, *E* and *S* did not differ between HIG sites and the control. Diversity analysis over the course of one year is showing an increasing trend for both HIG sites and the control simultaneously (Fig. 3.3) suggesting that other factors than HIG, e.g. natural fluctuations of plant species composition, are affecting diversity dynamics in this grassland. To avoid snap judgements with potential implications for land use policy this findings are certainly indicating the need for long term observations in order to improve our understanding related to effects of land use management vs. climate variability or change and natural diversity dynamics in this grassland system. Our concerns about a shift to more plant species following a ruderal strategy in response to HIG disturbance were not confirmed, either. HIG disturbance did not alter the green cover dominance of rather competitive *Poaceae* species and also did not reduce the *Fabaceae* species cover. However, we found a clear increase of *Cyperacea*, while cover of *Asteraceae* species decreased, which are considered as non palatable or even toxic for cattle. Example for invasive species are *Prosopis* sp. (Grau et al. 2014) or most frequently *Vernonia* species both belonging to the *Asteraceae* family (Kurtz et al. 2010). Therefore, HIG could have the potential contributing to a progressive de-encroachment of the natural grasslands. Encroachment with small trees, forbs or shrubs is a major threat to both grasslands productivity and diversity in the Chaco region (Carnevali 1994; Grau et al. 2014). Most of the single species (close to 80%) showed to react positively as increasers (or were indifferent) to HIG (Table 3.3). Most probably due to resistant bud belowground structures, like xylopodia (Fidelis et al. 2014), dicotyledonous species had less increaser (67%) and more decreaser (17%) compared to monocotyledonous species (mostly *Poaceae*) with 80% increasers and only 3% decreaser (Table 3.3). Grass tolerates trampling more than forbs (Striker el al. 2011).

Fig. 3.3. Species diversity *H*, Eveness E_H and Richness S for HIG and the control sites sampled in the course of one year, exactly one year after HIG. A - **Species diversity** (*H*). Regressions for control sub-plots, y = 0.097x + 2.9 ($r^2 = 0.22$) and after HIG y = 0.047x + 3.16 ($r^2 = 0.12$); B - **Species evenness** (E_H). Regressions for control sub-plots, y = 0.02x + 1.4 ($r^2 = 0.15$) and after HIG y = 0.006x + 1.4 ($r^2 = 0.02$) and C - **Species richness** (*S*). Regressions for control sub-plots, y = 0.33x + 7.86 ($r^2 = 0.35$) and after HIG y = 0.19x + 9.7 ($r^2 = 0.24$). The regression analysis indicated that the slopes are not different ($p < 0.05$). In this case, every month from July 2013 to July 2014, the individual grassland species were ranked according to their biomass ground cover in each sub-plot, we sampled 5, 25 x 25 cm quadrates (20 each month). Fig. 3. Species diversity *H*, Eveness E_H and Richness S for HIG and the control sites sampled in the course of one year, exactly one year after HIG. A - **Species diversity** (*H*). Regressions for control sub-plots, y = 0.097x + 2.9 ($r^2 = 0.22$) and after HIG y = 0.047x + 3.16 ($r^2 = 0.12$); B - **Species evenness** (E_H). Regressions for control sub-plots, y = 0.02x + 1.4 ($r^2 = 0.15$) and after HIG y = 0.006x + 1.4 ($r^2 = 0.02$) and C - **Species richness** (*S*). Regressions for control sub-plots, y = 0.33x + 7.86 ($r^2 = 0.35$) and after HIG y = 0.19x + 9.7 ($r^2 = 0.24$). The regression analysis indicated that the slopes are not different ($p < 0.05$). In this case, every month from July 2013 to July 2014, the individual grassland species were ranked according to their biomass ground cover in each sub-plot, we sampled 5, 25 x 25 cm quadrates (20 each month).



The removal of dead plant material resulted in an increased green biomass cover due to a combination of both, the high tiller density (Fidelis et al. 2014; Striker et al. 2011) and the better light transmission (Heckathorn et al. 1999; McMillan et al. 2011; Ötztürk et al. 1981). After HIG disturbance, resistant species regenerate form existing meristems and the existing soil seed bank. This finding opens an interesting option to introduce HIG in order to take advantage of the nutritious quality of C_3 green biomass species (Jacobo et al. 2006), like for example the trampling tolerant *Fabaceae* species *Desmodium incanum* Vog. Further analyses of HIG effects on fodder quality are therefore highly interesting for the livestock production. Nevertheless, not all C_3 species are palatable, particularly non-desirable is the perennial C_3 species *Eringium horridum* Malme, which possesses trampling resistant rosettes, which grow in summer (see December, fig. 3.3 A). The *E. horridum* individuals show a great capacity to resprout after plant damage (Fidelis et al. 2008). By opening the canopy, HIG favoured an increase of C_4 plants cover, which profit from less standing dead biomass and more light transmission (Heckathorn et al. 1999; McMillan et al. 2011; Ötztürk et al. 1981) compared to the control sub-plots (Table 3.3). However, with regard to fodder quality, the C_4 grasses have lower digestibility than C_3 species (Bayer and Waters-Bayer 2013). Complementarily, C_3 species represent only 5 - 8% cover in sub-tropical Argentina (Feldman et al. 2008) and less than 5% before HIG (this study). HIG favoured C_3 species as 88% of species increased their cover. Up to date, there was no previous report of such a management-induced increase of grassland C_3 species (Feldman et al. 2008).

In a previous research, we have shown that HIG has a rejuvenating effect and favours a high green/standing dead ratio. Cows grazing on plots treated with HIG before, gained more weight compared to those in the control area, which suggested higher forage consumption on HIG sub-plots (Kurtz et al. 2016). We showed that increasing green biomass cover consisting of higher value plant functional groups following the HIG treatment is indicating a more efficient foraging/grazing system as cows probably spent less time and energy searching for forage (Abdel-Magid et al. 1987; Heckathorn et al. 1999). Although HIG as a management tool needs to be analysed in more detail in order to get a more comprehensive picture of possible feedback and side effects. Our results indicated that HIG has the potential for implementation as an alternative grassland management tool towards sustainable intensification as it increases the green biomass proportion of most of the recorded grassland species of the analysed Chaco grassland, considered as being representative for in total almost 300,000 km^2 (Dixon et al. 2014).

Table 3.3: Plant functional groups in response to HIG (High impact grazing). The response was calculated according to the individual relative green cover measured at peak biomass time in February 2014 in relation to a control plot.

	Number of species and its response to HIG					
Plant functional groups	Indifferent	%	Decreasers	%	Increasers	%
Dicotyledonous	16	17	16	17	64	67
Monocotyledonous	11	17	2	3	52	80
Perennials	24	18	13	10	95	72
Annuals	3	10	6	19	22	71
C_3	10	15	10	15	48	71
C_4	16	18	9	10	64	72
CAM	1	13		-	7	88

Our results suggest that HIG has only a limited impact on the natural grassland diversity. Nevertheless, we are aware that HIG could eventually produce delayed responses affecting diversity, not captured during our two-years of observation. More bare ground patches and the altered competition resulting from to the removal of perennials biomass (Milchunas et al. 1988) could affect diversity on HIG sub-plots. Diversity could also change due to the strong biomass reduction, in turn affecting light transmission and so the energy budgets. The trampling impact on the topsoil could also change the nutrient dynamics and cycling as well as physical soil properties. Therefore, due to the lack of long-term studies, with repeated HIG and possible interactions with climate variability, our results should be carefully considered. Open questions still exist with regard to fodder quality and its possible interactions with seasonal variability. Moreover, the effects on the feed quality need to be analysed in order to assess the changes on the nutritious forage value. These results suggest that we need to intensify our research efforts to improve our understanding of ecological processes induced by HIG in order to get a more complete picture of this promising management option, in the context of sustainable land use intensification.

3.5 Conclusions

High impact grazing (HIG) did not alter diversity of in the Chaco Corrientes grasslands indicating this ecosystem as very resilient against HIG disturbance. Shifts in plant functional groups towards less dicotyledonous and annual plants and more C4 and C3 grasses as a result of HIG may contribute to increase forage quality and counteract negative processes of “low value” species encroachment. HIG could be a management option towards sustainable intensification, however, further field studies are needed to analyse long-term or legacy effects and the interaction with climate variability or the dynamics of other natural processes.

3.6 Main findings

1. Irrespectively of the season high impact grazing (HIG) was applied, the grassland showed a high resistance with regard to diversity parameters. Species richness, Shannon-Wiener diversity index (*H*) and the Shannon’s equitability index (*E*) was at the same level as compared to the control within 12-month period after HIG.
2. Plant functional groups of dicotyledonous and annual species, often contributing to the encroachment of unpalatable plants, could not benefit from the HIG disturbance, but C_3 and C_4 monocotyledonous and perennials increased their absolute and relative cover.
3. HIG could therefore have the potential to contribute as an alternative management practice towards sustainable land use intensification and the

reduction of “low value” species encroachment of the Chaco grassland ecosystem.

4. Long term observations are needed to detect legacy effects of HIG or interactions with climate variability.

3.7 Acknowledgements

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Table 3.S1 (supplemental material): Detailed list of all grassland plant species sampled in the experimental area at the Corrientes National Institute of Agriculture Research Station, at peak biomass time during February 2014.

Species	Familiy	[1]Number of cotyledons	[2]Life cycle	[3]Photosynthesis pathw ay	[4]Response to HIG
Justicia laevilinguis (Nees) Lindau	*Acanthaceae*	2	Pe	C_4	i
Ruellia sp. L.	*Acanthaceae*	2	An	C_4	i
Alternanthera philoxeroides (Mart.) Griseb.	*Amaranthaceae*	2	Pe	C_4	in
Amaranthus sp. L.	*Amaranthaceae*	2	An	C_4	i
Gomphrena celocioides Mart.	*Amaranthaceae*	2	An	C_4	d
Zepyranthes sp. Herb.	*Amaryllidaceae*	1	Pe	C_3	i
Eryngium coronatum Hook. & Arn.	*Apiaceae*	2	Pe	C_3	i
Eryngium ebracteatum Lam.	*Apiaceae*	2	Pe	C_3	i
Eryngium horridum Urb. ex H. Wolff, Malme	*Apiaceae*	2	Pe	C_3	i
Ammis majus L.	*Apiaceae*	2	An	CAM	i
Apium leptophyllum (Pers) F. Muell. Ex Benth	*Apiaceae*	2	Pe	CAM	i
Aristolochia fimbriata Cham.	*Aristolochiaceae*	2	Pe	C_3	i
Asceplias curassavica L.	*Asclepiadaceae*	2	Pe	C_3	i
Acmella sp. R.K. Jansen	*Asteraceae*	2	An	C_4	i
Baccharis coridifolia DC.	*Asteraceae*	2	Pe	C_4	i
Baccharis notorsegila Griseb.	*Asteraceae*	2	Pe	C_4	d
Baccharis punctulata DC.	*Asteraceae*	2	Pe	C_4	in
Baccharis sp. DC.	*Asteraceae*	2	Pe	C_4	i
Bidens pilosa L.	*Asteraceae*	2	An	C_4	in
Chaptalia nutans (L.) Polák	*Asteraceae*	2	Pe	C_4	i
Conyza bonariensis (L.) Cronquist	*Asteraceae*	2	An	C_4	i
Eupatorium candolleanum Hook. & Arn.	*Asteraceae*	2	Pe	C_4	i
Eupatorium macrocephalum Less.	*Asteraceae*	2	Pe	C_4	d
Eupatorium clematideum Griseb.	*Asteraceae*	2	Pe	C_4	in
Eupatorium subhastatum Hock. & Arn.	*Asteraceae*	2	Pe	C_4	i

Eupatorium sp. Hock. & Arn.	*Asteraceae*	2	Pe	C_4	in
Mikania coridifolia (L.f.) Willd.	*Asteraceae*	2	Pe	C_4	in
Orthoppapus angustifolius (Sw.)	*Asteraceae*	2	Pe	C_4	d
Pterocaulon lorentzii Malme	*Asteraceae*	2	An	C_4	in
Pterocaulon pycnostachyum (Michx.) Elliott	*Asteraceae*	2	Pe	C_4	in
Pterocaulon sp. DC.	*Asteraceae*	2	Pe	C_4	d
Senecio grisebachii Baker	*Asteraceae*	2	Pe	C_4	i
Solidago chilensis Meyen	*Asteraceae*	2	Pe	C_4	i
Vernonia incana (Less.) DC.	*Asteraceae*	2	Pe	C_4	i
Vernonia chamaedrys Lees.	*Asteraceae*	2	Pe	C_4	i
Vernonia rubricaulis Hum. & Bonpl.	*Asteraceae*	2	Pe	C_4	d
Chenopodium nigra L.	*Chenopodiaceae*	2	An	C_4	i
Commelina erecta L.	*Commelinaceae*	1	Pe	CAM	i
Tripogandra radiata (C.B. Clarke) Bacigalupo	*Commelinaceae*	1	Pe	CAM	i
Dichondra repens J.R. Forst. & G. Forst.	*Convolvulaceae*	2	Pe	C_4	i
Evolvulus sericeus Sw.	*Convolvulaceae*	2	Pe	C_4	d
Ascolepsis brasiliensis (Kunth) Benth. Ex Clarke.	*Cyperaceae*	1	Pe	C_4	i
Carex sororia Kunth	*Cyperaceae*	1	Pe	C_4	i
Cyperus aggregatus (Willd.) Endl.	*Cyperaceae*	1	Pe	C_3	in
Cyperus entrerrianus Boeckeler	*Cyperaceae*	1	Pe	C_4	i
Cyperus haspan ssp. *Juncoides*	*Cyperaceae*	1	Pe	C_3	i
Cyperus iria L.	*Cyperaceae*	1	Pe	C_4	in
Cyperus obtusatus (J. Presl & C. Presl) Mattf. & Kük.	*Cyperaceae*	1	Pe	C_4	i
Cyperus rigens C. Presl	*Cyperaceae*	1	Pe	C_4	i
Cyperus virens Michx.	*Cyperaceae*	1	Pe	C_4	i

Eleocharis nodulosa (Roth) Schult.	*Cyperaceae*	1	Pe	C_4	i
Eleocharis viridans Kük ex. Osten	*Cyperaceae*	1	Pe	C_4	i
Fimbristylis dichotoma (L.) Vahl	*Cyperaceae*	1	Pe	C_4	i
Rhynchospora corymbosa (L.) Britton	*Cyperaceae*	1	Pe	C_4	in
Rhynchospora scutellata Griseb.	*Cyperaceae*	1	Pe	C_4	i
Rhynchospora tenuis Link	*Cyperaceae*	1	Pe	C_4	i
Scleria sellowiana Kunth	*Cyperaceae*	1	Pe	C_4	d
Pteridium aquilinum (L.) Kuhn	*Dennstaedtiaceae*	-	Pe	C_3	d
Scoparia dulcis L.	*Escrofulariaceae*	2	An	C_3	i
Scoparia muricata L.	*Escrofulariaceae*	2	An	C_3	in
Phyllanthus stipulatus (Raf.) G.L. Webster	*Euphorbiaceae*	2	An	C_4	i
Euphorbia prostrata Aiton	*Euphorbiaceae*	2	An	C_4	d
Tragia geraniifolia Klotzsch ex Müll.Arg.	*Euphorbiaceae*	2	Pe	C_4	i
Aeschynomene americana L.	*Fabaceae*	2	Pe	C_3	i
Chamaecrista rotundifolia (Pers.) Greene	*Fabaceae*	2	Pe	C_3	d
Desmanthus virgatus (L.) Wild.	*Fabaceae*	2	Pe	C_3	i
Desmodium pachyrizum Vogel	*Fabaceae*	2	Pe	C_3	i
Rhynchosia laterita Burkart	*Fabaceae*	2	Pe	C_3	in
Desmanthus depressus Willd.	*Fabaceae*	2	Pe	C_3	in
Desmodium incanum DC.	*Fabaceae*	2	Pe	C_3	i
Discolobium sp. Benth.	*Fabaceae*	2	Pe	C_3	in
Galactia marginali s Benth.	*Fabaceae*	2	An	C_3	i
Indigofera asperifolia Benth.	*Fabaceae*	2	Pe	C_3	i
Leucaena leucocephala (Lam.) de Wit	*Fabaceae*	2	Pe	C_3	i
Macroptilium lathyroides (L.) Urb.	*Fabaceae*	2	Pe	C_3	d

Macroptilium postratum Benth. (Urb.)	*Fabaceae*	2	An	C_3	d
Phaseolus sp. Benth.	*Fabaceae*	2	Pe	C_3	in
Rhynchosia edulis Griseb.	*Fabaceae*	2	Pe	C_3	i
Rhynchosia sp. Lour.	*Fabaceae*	2	Pe	C_3	in
Stylosanthes hippocampoides Mohlenbr.	*Fabaceae*	2	Pe	C_3	i
Stylosanthes montevidensis Vogel	*Fabaceae*	2	Pe	C_3	in
Hydrolea spinosa L.	*Hydrophyllaceae*	2	An	C_3	i
Sisyrinchium sp. Baker	*Iridaceae*	1	Pe	C_3	d
Juncus microcephalu s Kunth	*Juncaceae*	1	Pe	C_3	i
Hyptis lappacea Benth.	*Labiadae*	2	An	C_3	i
Nothoscordum inodorum (Aiton) G. Nicholson	*Liliaceae*	1	Pe	C_3	in
Selaginella sp. Spring	*Lycopdiopsida*	-	Pe	C_3	i
Cuphea carthagenensis (Jacq.) J. F. Macbr.	*Lythraceae*	2	Pe	C_3	i
Cuphea lysimachioides Cham. & Schltdl.	*Lythraceae*	2	Pe	C_3	i
Cuphea sp. Koehne	*Lythraceae*	2	Pe	C_3	i
Heymia salicifolia (Kunth) Link & Otto	*Lythraceae*	2	Pe	C_3	i
Krapovickasia sp. Fryxell	*Malvaceae*	2	An	C_3	i
Malvastrum coromandelianum (L.) Garcke	*Malvaceae*	2	An	C_3	i
Melochia hernannioides A. St. Hil.	*Malvaceae*	2	Pe	C3	i
Sida rhombifolia L.	*Malvaceae*	2	Pe	C_3	i
Sida tuberculata R.E.Fr.	*Malvaceae*	2	Pe	C_3	i
Marsilea consinea Mirb.	*Marsiliaceae*	-	Pe	C_3	i
Cissampelos sp. Kunth	*Menispermaceae*	2	Pe	C_3	i
Ludwigia major (Micheli) Ramamoorthy	*Onagraceae*	2	Pe	C_3	i
Orchidia sp. Juss.	*Orchidaceae*	1	Pe	CAM	in

Oxalis sp. L.	*Oxalidaceae*	2	Pe	CAM	i
Passiflora coerulea L.	*Passifloraceae*	2	Pe	CAM	i
Plantago officinalis Crantz	*Plantaginaceae*	2	Pe	CAM	i
Andropogon lateralis Ness	*Poaceae*	1	Pe	C_4	i
Axonopus affinis Chase	*Poaceae*	1	Pe	C_4	in
Axonopus compressus (Sw.) P. Beauv.	*Poaceae*	1	Pe	C_4	i
Axonopus fissifolius (Raddi) Kuhlm.	*Poaceae*	1	Pe	C_4	i
Bothriochloa laguroides DC.	*Poaceae*	1	Pe	C_4	i
Bothriochloa saccharoides Sw.	*Poaceae*	1	Pe	C_4	i
Briza uniolae (Nees) Steud.	*Poaceae*	1	An	C_4	i
Chloris distichophylla Lag.	*Poaceae*	1	Pe	C_4	i
Cynodon dactylon (L.) Pers.	*Poaceae*	1	Pe	C_4	i
Digitaria insularis (L.) Mez ex Ekman	*Poaceae*	1	Pe	C_4	in
Digitaria phaeotrix (Trin.) Parodi	*Poaceae*	1	Pe	C_4	i
Digitaria sp. Haller	*Poaceae*	1	An	C_4	i
Eleusine indica (L.) Gaertn.	*Poaceae*	1	Pe	C_4	i
Eleusine tristachya Lam	*Poaceae*	1	Pe	C_4	i
Elyonurus muticus (Spreng.) Kuntze	*Poaceae*	1	An	C_4	i
Eragrostis airoides Nees	*Poaceae*	1	Pe	C_4	i
Eragrostis bahiensis Roem. & Schult.	*Poaceae*	1	Pe	C_4	i
Hemarthria altissima (Poir) Stapf & C.E. Hubb.	*Poaceae*	1	Pe	C_4	i
Leersia hexandra Sw.	*Poaceae*	1	Pe	C_3	i
Panicum miliaceum L.	*Poaceae*	1	Pe	C_4	i
Panicum milioides Ness. Ex Trin.	*Poaceae*	1	Pe	C_4	i
Panicum prionitis Nees	*Poaceae*	1	Pe	C_4	-

Panicum sp. L.	*Poaceae*	1	Pe	C_4	in
Paspalum acuminatum Raddi	*Poaceae*	1	Pe	C_4	i
Paspalum almun Chase	*Poaceae*	1	Pe	C_4	i
Paspalum notatum Flügé	*Poaceae*	1	Pe	C_4	i
Paspalum plicatulum Michx.	*Poaceae*	1	Pe	C_4	i
Paspalum simplex Morong	*Poaceae*	1	Pe	C_4	i
Paspalum urvillei Steud.	*Poaceae*	1	Pe	C_4	i
Phalaris sp. Jansen & Wacht.	*Poaceae*	1	An	C_4	i
Piptochaetium montevidense (Spreng.) Parodi	*Poaceae*	1	Pe	C_4	in
Rotboellia selloana L.F.	*Poaceae*	1	Pe	C_4	i
Schizachyrium microstachyum (Desv.) Roseng.	*Poaceae*	1	Pe	C_4	i
Setaria geniculata P.Beauv.	*Poaceae*	1	Pe	C_4	i
Sorghastrum pellitum (Hack.) Parodi	*Poaceae*	1	Pe	C_4	in
Sorghastrum setosum (Griseb.) Hitchc.	*Poaceae*	1	Pe	C_4	i
Sporobolus indicus (L.) R. Br.	*Poaceae*	1	Pe	C_4	i
Sporobolus monandrus Roseng., B.R. Arrill. & Izag.	*Poaceae*	1	Pe	C_4	in
Sporobolus poiretii (Roem. & Schult.) Hitchs.	*Poaceae*	1	Pe	C_4	i
Sporobolus sp. R. Br.	*Poaceae*	1	Pe	C_4	i
Steinchisma hians (Elliott) Nash	*Poaceae*	1	Pe	C_4	i
Steinchisma laxa Sw.	*Poaceae*	1	Pe	C_4	i
Tridens brasiliensis (Steud.) Parodi	*Poaceae*	1	Pe	C_3	i
Polygala molluginifolia A. St. Hil.	*Polygalaceae*	2	An	C_3	i
Polygala obovata A. St. Hil. & Moq.	*Polygalaceae*	2	An	C_3	i
Polygala sp. DC.	*Polygalaceae*	2	An	C_3	i
Muehlenbeckia sagittifolia (Ortega) Meisn.	*Polygonaceae*	2	Pe	C_4	i

Poligonum punctatum Elliot	*Polygonaceae*	2	Pe	C_3	i
Clematis bonariensis Juss. Ex DC.	*Ranunculaceae*	2	Pe	C_3	i
Relbunium richardianum (Gillies ex Hook. & Arn.) Hicken	*Rubiaceae*	2	An	C_3	d
Rubiacea Juss.	*Rubiaceae*	2	An	C_3	d
Bouchetia anomale (Miers) Britton & Ruby	*Solanaceae*	2	Pe	C_3	i
Petunia sp. Juss.	*Solanaceae*	2	An	C_3	i
Phisalis viscosa L.	*Solanaceae*	2	Pe	C_3	i
Solanum granulosum-leprosum Dunal	*Solanaceae*	2	Pe	C_3	in
Turnera sidoides DC.	*Turneraceae*	2	An	C_3	d
Lantana sp. Moldenke	*Verbenaceae*	2	Pe	C_3	d
Lippia sp. Moldenke	*Verbenaceae*	2	Pe	C_3	d
Glandularia peruviana (L.) Small	*Verbenaceae*	2	Pe	C_3	i
Glandularia rigida Sprengel	*Verbenaceae*	2	Pe	C_3	i
Verbena litoralis Kunth	*Verbenaceae*	2	Pe	C_3	i
Verbena rigida Spreng.	*Verbenaceae*	2	Pe	C_3	i

[1] Number of cotyledons: 1 = Monocotyledons, 2 = Dicotyledons; [2]Life cycle: An = Annual, Pe = Perennial; [3]Photosynthesis pathway: CAM = Crassulacean acid metabolism, C_3 or C_4 species; and, [4]Response to HIG (high impact grazing) reported here as, “in” = increasers, “d“ = decreasers and “in” = indifferent, response to HIG was calculated based on the green ground cover of each individual species.

4 The effects of high impact grazing on fodder quality

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Abstract

Natural grasslands represent the major feed source for ruminants in northern Argentina. Traditional management on large farms and the relatively low stocking rate, lead to the accumulation of low quality, grazing deterrent standing dead biomass (SDB), which reduces plant re-growth and accessibility of high quality green biomass (GB) for grazers. Currently, range managers and farmers use one of several conventional options to eliminate SDB, of these fire being the most important management tool. High impact grazing (HIG) was proposed as an alternative tool to address this problem. However, the consequences of HIG on forage nutritional quality are unknown. Hence, the aim of the current study was to evaluate the effects of HIG on fodder plant’s concentrations of crude protein (CP), metabolisable energy (ME), and digestible organic matter (DOM). Quality parameters were analysed up to one year after HIG and compared to control sub-plots under standard grazing regime. Our results indicate that HIG applied in winter, autumn or spring increases the nutritive value of the grassland, but if applied in summer it has no evidently positive effect. The proportion of palatable species remains unaffected, but grass availability was enhanced do to the reduced SDB. On an area basis grassland subjected to HIG provided enough ME and CP, to meet the requirements at the current stocking density in Corrientes.

4.1 *Introduction*

Cattle livestock production is the main agricultural activity in the Province of Corrientes, located in the subtropical north-eastern corner of Argentina (Calvi 2010; Carnevali 1994), where ruminants feed mainly on semi-natural grassland (SIGSA-

SENASA 2013). Although grasslands are highly productive with annual net primary production between 15–20 t dry matter (DM) ha^{-1} (Bernardis et al 2005; Royo Pallarés et al. 2005), constant stocking densities of only ~0.5 cattle animal units ha^{-1} $year^{-1}$ are applied, because of the low plant growth rate during winter and the annual accumulation of standing dead biomass (SDB) of very low nutritional quality for the ruminants (Kurtz et al. 2010; 2016). This grassland management does not seem to make efficient use of the existing grazing resources. Hence, green biomass (GB) is hardly accessible to the animals due to the grazing deterrent SDB and is therefore wasted (Balph and Malecheck, 1985; Moisey et al. 2006; Mingo and Oesterheld, 2009). Traditionally, prescribed or occasional fires have been used to reduce the above-ground SDB and to promote re-growth (Oesterheld et al. 1999; Pausas et al. 2013). Recently, burning has been out-lawed in the Corrientes Province or is allowed only under specific conditions (Corrientes, 2004). Among the varied range of options to reduce SDB, high impact grazing (HIG) was proposed as a management option within the holistic management of grasslands (Savory 1983; 2005) which uses the herd effect as a means to create grazing lawns with high fodder quality (Cromsigt and Olff, 2008; Hempson et al. 2014; McNaughton, 1984). Recently, we demonstrated that HIG is an alternative management option to reduce SDB which reduces the dead to GB ratio (Kurtz et al. 2016). Most studies on alternative grazing systems, however, focused on animal performance and not directly on forage quality (Dickhoefer et al. 2014). As such, there is no research dealing with the effects of HIG on forage quality in Northern Argentinean grasslands.

Hence, the present study aimed at analysing to what extent HIG changes the nutritional value of the grassland vegetation for grazing ruminants. More specifically, the objectives of this study were i) to understand how grassland forage quality changes after HIG and ii) to find the best time of the year to apply HIG in order to increase the nutritional value of the forage on grasslands in North-eastern Argentina. Due to HIG, we would first expect that, i) younger plant material is more available for cows, ii) that fertilization by urine and faeces increases N uptake by plants, and iii) as a result there might be an overall forage quality increase.

4.2 *Materials and methods*

4.2.1 *Study area description*

This field study was located in the wettest part of the Chaco phyto-geographical province (Cabrera 1971) and placed at the Corrientes INTA Research Station (27°40’01’’S, 58°47’11’’W, 62 m above sea level) in the Empedrado Department, Corrientes Province, Argentina (Fig. 4.1). Details on climatic conditions, soil characteristics and the vegetation of natural grasslands in the study region are given in Kurtz et al. (2016).

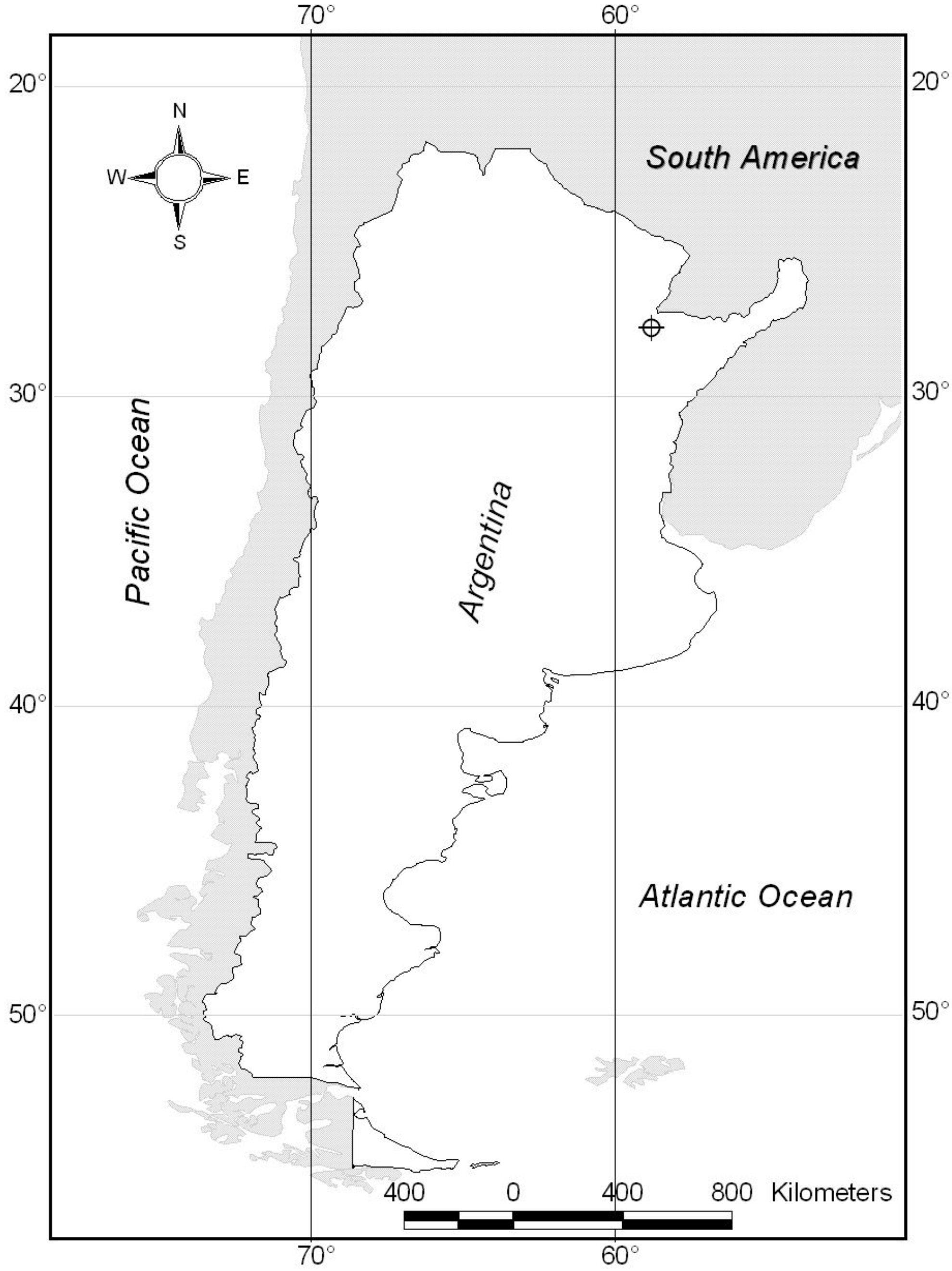

Figure 4.1. Location of the study site in sub-tropical north-eastern Argentina, province of Corrientes. The map is displayed in standard geographic coordinates, the system and the coordinate units are shown in decimal degrees (Geographic projection).

4.2.2 *Experimental layout*

The experiment was established on 24 ha of natural grassland that were divided into four adjacent paddocks of 6 ha each by permanent electric fences. Three of the paddocks were used as replicates (R1 - R3) for the HIG treatment, whereas the fourth paddock was not subjected to HIG and thus treated as a control area. All four 6-ha paddocks were continuously grazed throughout the experiment with three non-lactating cows each (Braford, Hereford, and Brahman crossbreed cows averaging 232.8 kg, sd = 18.3 kg) to achieve a stocking rate of 0.5 animal units ha^{-1} $year^{-1}$ which is similar to the average stocking rate on natural grasslands in Corrientes Province. The HIG treatment followed a monthly sequence; therefore each paddock was divided into 12 plots of 0.5 ha each (50 m x 100 m) which were sequentially subjected to HIG once every month. The experiment started in July 2012, when the first sub-plot was enclosed with mobile electric fences and subjected to three days of HIG until all vegetation was trampled down. For that purpose a herd of a total of 75 Braford, Hereford, and Brahman crossbreed cows was used, representing a stocking density of approximately 150 animals ha^{-1}. The animals were driven around within the specific sub-plot to ensure that the trampling impacts were distributed as homogeneously as possible. After HIG, the mobile sub-plot fences were removed and the HIG herd was driven to another paddock to carry out the HIG on the respective sub-plot for that month. Sub-plots of the control paddock were not subjected to HIG, but grazed at 0.5 animal unit ha^{-1} $year^{-1}$ throughout the experiment. For further details on the experiment layout, see Kurtz et al. (2016).

4.2.3 *Sample collection, processing, and analysis*

To determine HIG effects on the nutritional quality of the available forage and its seasonal changes, aboveground plant biomass was hand cut with scissors. Every month, in two 1 m^2 areas per sub-plot that were randomly chosen, between February 2013 and June 2014, the aboveground biomass was harvested near to the ground level. Besides that, the monthly biomass re-growth was also measured using two protective cages per sub-plot. The cages were placed onto the freshly cut m^2 of the particular sub-plot and harvested the next month. Immediately after harvest, biomass samples were transferred into plastic bags that were sealed and weighed with an Ohaus Scout pro 2001 Balance (2000g Capacity - 0.1g Readability). After that, a representative and homogeneous quarter of the sample was separated by hand into green and dead material. The two sub-samples were then oven-dried at 75°C and then, before laboratory analysis at 105°C, until constant weight to determine DM content. Thereafter, the rough samples were ground with a Retsch mill (1mm mesh) (Retsch SM2, Retsch Technology GmbH, Haan). After that, the same samples were ground again with a Culatti mill (also 1 mm mesh) (micro - mill (Culatti , Culatti AG, Zurich) to ensure a more fine and homogeneous sample suitable for spectrum reading (the Culatti mill is not suitable for large coarse samples). Only the GB fraction was analysed, as we assumed that the SDB had no nutritive value. After HIG the accumulated biomass was harvested monthly in every sub-plot, but not every sample was sent to the laboratory for analysis. We selected a set of samples to cover every HIG season; June and July were selected for HIG_{winter}, September for

HIG_{spring}; December for HIG_{summer} and March for HIG_{autumn}. Likewise, the control samples were also chosen at the same months. In order to evaluate how grassland quality changed after HIG, we analysed the GB from the sub-plots of all paddocks corresponding to 1, 2, 4, 5, 7, 8, 10, and 11 months after HIG performed in the different seasons, corresponding to a particular month, as was already explained (i.e., winter, spring, summer and autumn) were analysed for their nutritional value. Based on the amount of harvested biomass in each square (i.e. its contribution) the two samples of each sub-plot were pooled to one composite sample of 25g, as a result we had three pooled sample for each HIG analysed sub-plot. As the control paddock received no HIG disturbance, the control samples were not pooled, so we end up also with 3 samples for each sampling month. In total 195 samples were analysed, 168 corresponding to HIG sub-plots and 27 for the control paddock. These samples were analysed using near-infrared reflectance spectroscopy (NIRS) for crude ash (CA; in g 100 g^{-1} DM), crude protein (CP; in g 100 g^{-1} DM), and net gas production (GP; ml 200 mg^{-1} DM) during *in vitro* fermentation (in ml/200mg DM). Samples were packed into a soda-lime glass petri dish (35mm diameter × 12mm height) and compressed with a metal weight to cover all the surface of the petri dish. Material of each sample was placed in four different petri dishes and was scanned consecutively with a NIRFlex N-500 instrument (Büchi Labortechnik AG, Flawil, Switzerland), resulting in four spectra per sample. Samples were analysed at room temperature at wavelengths between 800 and 2500 nm. Each day, a system suitability test was performed before starting the spectrometric analysis (Stuth et al. 2003). Data analyses were done with the NIRCal software version 5.5 of Büchi Labortechnik AG (Flawil, Switzerland). For NIRS calibration, a sub-set of 45 randomly chosen samples were analysed by standard chemical procedures. The samples were analysed for DM concentrations by drying at 105ºC till constant weight. The nitrogen concentrations were determined following the Dumas procedure. The CP concentration was then calculated from the nitrogen concentration in a sample by multiplying the nitrogen concentration by 6.25. The GP during 24 h of in vitro fermentation was determined using the Hohenheimer gas test (Menke et al. 1979). For this, samples were incubated in triplicate on separate days. Partial Least Square regression method was used to develop the NIRS calibrations for DM, CA, CP, and GP. Additionally, concentrations of apparent total tract digestible organic matter (DOM; in g 100 g^{-1} DM) and metabolisable energy (ME; in MJ kg^{-1} DM) were estimated from crude nutrient concentrations and *in vitro* gas production using the equations of Menke and Steingass (1987) as follows:

where DOM is the apparent total tract organic matter digestibility (g 100 g^{-1} DM), GP is the net gas production during *in vitro* fermentation (ml 200 mg^{-1} DM), CP refers to the crude protein concentration (g 100 g^{-1} DM), CA refers to crude ash concentration (g 100 g^{-1} DM), ME is the metabolisable energy concentration (in MJ kg^{-1} DM), and CL refers to the crude lipid concentration (g 100 g^{-1} DM).

A standard crude lipid concentration of 2.4% was used for a typical grassland species in Corrientes grasslands (*P. notatum. http://www.feedipedia.org/search/node/paspalum%20notatum*). Finally we also multiplied the CP concentration by the GB to estimate the total nutrients offer per hectare.

4.2.4 *Palatability assessments*

In this case, every month from July 2013 to July 2014, the individual grassland species were ranked according to their biomass ground cover in each sub-plot, we sampled 5, 25 x 25 cm quadrates (20 each month). After that, individual species were classified according to their palatability in five categories, fine = highly palatable species; tender = palatable species; ordinary = barely palatable; hard = poorly palatable, and weeds = not palatable (palatability scale proposed by Rosengurtt 1979). Data collection took place monthly from July 2012 until July 2014.

4.2.5 *Canopy height*

To evaluate grassland recovery, the canopy height was measured monthly with a rule on a pre-established grid of then geo-referenced points in the control and on HIG sub-plots.

4.2.6 *Statistical analysis*

We analysed the quality variables of the GB performed in the different seasons (4 i.e., HIG_{winter}, HIG_{spring}, HIG_{summer} and HIG_{autumn}), of all paddocks (4), from the sub-plots between 1 to 11 months after HIG. InfoStat (v.2014) software was used for statistical analysis (developed by the Agricultural College of the National University of Córdoba, Argentine). Analysis of variance was used to analyse the nutritional quality of plant biomass changes due to HIG (i.e. we tested for the effects of the treatment), the changes after HIG, the impact season, and their interactions. The least significant difference (LSD) post hoc analysis was applied for comparisons of the means. The palatability assessment was evaluated by paired t-test analysis based on monthly green cover estimations before HIG and on the same sub-plots one year after HIG. Statistical significance of all tests was considered at $p < 0.05$.

4.3 ***Results***

4.3.1 *Green and dead biomass canopy height*

Due to the combined effects of forage consumption and trampling, total aboveground on HIG sub-plots was lower, compared to the control (Fig. 4.2a, b, c, d). Nevertheless, approximately three months after HIG_{winter} (Fig. 4.2a), HIG_{spring} (Fig. 4.2b), or HIG_{summer} (Fig. 4.2c), the GB was similar to the GB on the respective control sub-plots. Moreover after HIG, the GB was on average above 35% after HIG_{autumn} and HIG_{spring}, 38% after HIG_{summer} and 42% after HIG_{winter}. Most important was that HIG markedly not only reduced the deterrent SDB but also and consequently, the canopy height. The mean canopy height varied between 100 and 144 cm in the control sub-plots, whereas in the HIG sub-plots, canopy height increased from 22 cm directly after HIG to only 95 cm within 12 months after HIG_{winter}, from 25 cm to only 84 cm within 10 months after HIG_{spring}, from 34 cm to only 109 cm within 10 months after HIG_{summer}, and from 16 cm to only 101 cm within 11 months after HIG_{autumn} (data not shown).

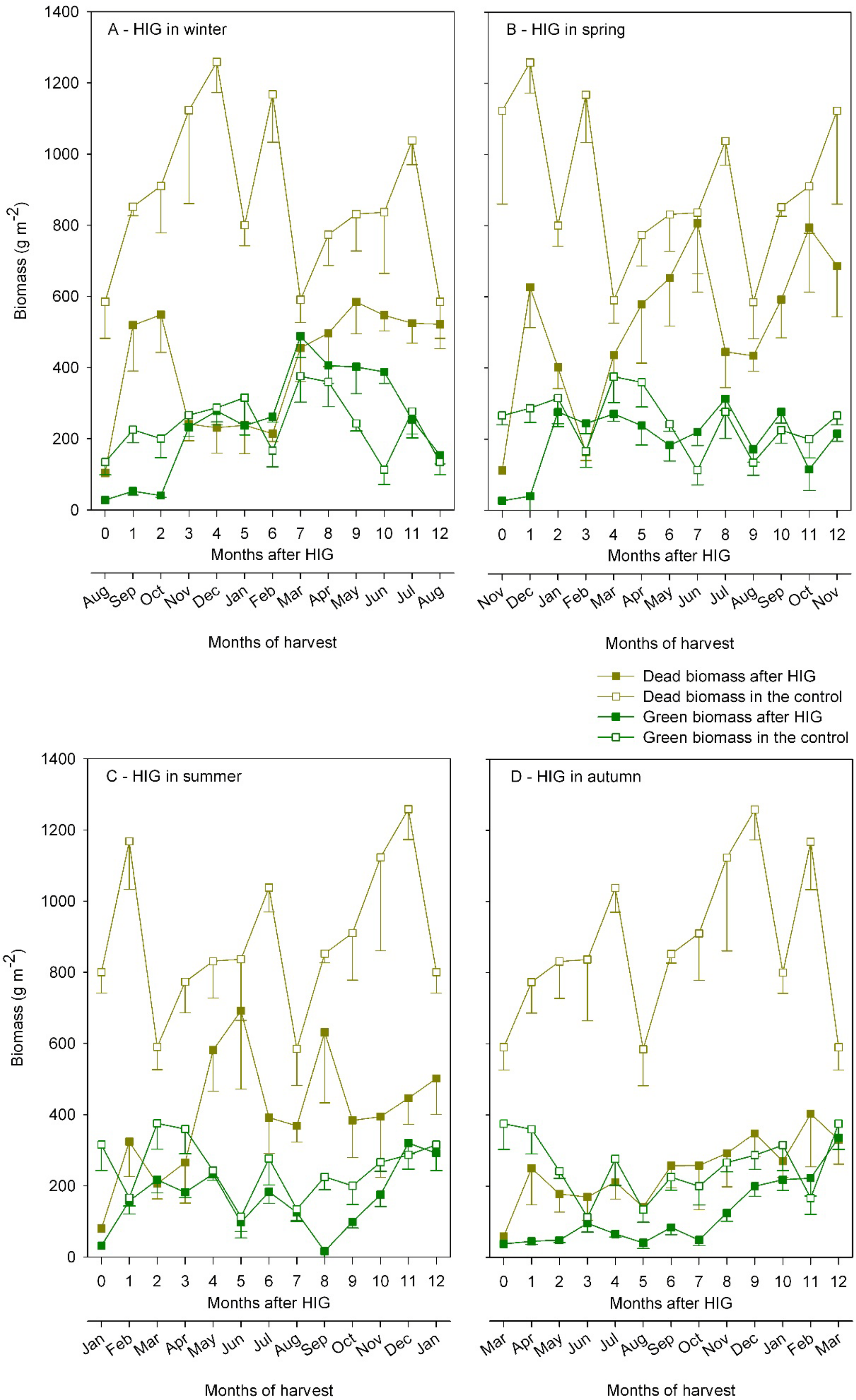

Figure 4.2. Above-ground green and dead plant biomass of the herbaceous vegetation on grasslands grazed by cattle at low stocking densities in Corrientes, north-eastern Argentina, after high impact

grazing (HIG) applied in four different seasons. The open and solid squares represent the arithmetic means for the control (open) and HIG sub-plots (close), calculated on dry matter basis, the error bars indicate the standard error of the means (only shown down for aesthetic reason).

4.3.2 *Nutritional value of above-ground green plant biomass on High Impact Grazing and traditionally managed grasslands*

The effects of HIG on the measured quality parameters compared to traditionally managed grasslands (control) are presented in Table 4.1. The HIG did not affect CA and OM (p=0.228), but it did affect all other parameters which were high on HIG su-plots compared to the control, CP 5.8 (0.17) vs. 4.8 (0.3) (p=0.0041), GP 18.9 (0.28) (p=0.0217), ME 4.9 (0.04) (p=0.198) vs. 4.8 (0.07) (p=0.0198) and DOM 39 (0.29) vs. 37 (0.49) (p=0.0096), but only those samples collected outside the exclosures. Moreover, the IS affected only GP, ME and DOM (<0.0001). Interactions between months after HIG (MAI) and IS did occur for all quality parameters indicating that the effects of HIG are different depending on IS and that quality parameters change as the time passes after HIG (Table 4.1). On the opposite, HIG had no effect on the quality parameters harvested from inside the exclosures, i.e. the grassland monthly regrowth (Table 4.2). The IS did not affect forage quality but the CP content, which was only higher in the control (p=0.0252).

Table 4.1. Effect of the HIG treatment *per se*, the impact season (IS) and their interaction, on grassland quality outside exlosures. Crude ash (g 100 g^{-1} DM), organic matter (g 100 g^{-1} DM), crude protein (g 100 g^{-1} DM), net gas production (ml 200 mg^{-1} DM), metabolizable energy (g 100 g^{-1} DM) and organic matter digestibility (g kg^{-1} DM). Different letters indicate means difference at P < 0.05.

					p-value			
	HIG		Control		Treatment effect	Impact season	MAI	ISxMAI
Crude ash	7.2		6.8		0.2288	0.1731	0.0126	0.0388
SE	0.15		0.27					
Organic matter	92.85		93.22		0.2288	0.1731	0.0126	0.0388
SE	0.15		0.27					
Crude protein	5.79	a	4.8	b	0.0041	0.4166	0.013	0.0082
SE	0.17		0.3					
Gas production	18.94	a	17.62	b	0.0217	<0.0001	0.0003	0.0004
SE	0.28		0.49					
Metabolizable energy	4.97	a	4.78	b	0.0198	<0.0001	0.0003	0.0005
SE	0.038		0.068					
Organic matter digestibility	39.09	a	37.13	b	0.0096	<0.0001	0.0003	0.0005
SE	0.29		0.49					

Table 4.2. Effect of the HIG treatment *per se* and the impact season (IS) on grassland the quality of grassland monthly regrowth, inside the exlosures. Crude ash (g 100 g^{-1} DM), organic matter (g 100 g^{-1} DM), crude protein (g 100 g^{-1} DM), net gas production (ml 200 mg^{-1} DM) and organic matter digestibility (g 100 g^{-1} DM). Different letters indicate means difference at P < 0.05.

	exclosures		p-value	
	HIG	Control	Treatment effect	Impact season
Crude ash	9.8	10.2	0.2221	0.87
SE	0.14	0.27		
Organic matter	90.17	89.79	0.2221	0.87
SE	0.14	0.27		
Crude protein	9.71	10.11	0.3971	0.0252
SE	0.22	0.42		
Gas production	21.87	21.81	0.9377	0.6442
SE	0.34	0.65		
Metabolizable energy	5.57	5.61	0.7708	0.0008
SE	0.11	0.11		
Organic matter digestibility	45.09	45.47	0.6612	0.369
SE	0.4	0.76		

4.3.3 *High impact grazing timing*

The effects of HIG_{winter} on the measured quality parameters compared to traditionally managed grasslands (control), as time passed after HIG (MAI) and their interaction on the quality of grassland outside the exclosures are presented in Table 4.3. The HIG_{winter} did not affect CA and OM (p=0.9914), but it did affect CP (p=0.0043), GP (<0.0001), ME (p<0.0001) and DOM (p=0.0002). Moreover, MAI affected only GP (p=0.0247) and ME (p=0.0339). Interactions between months after HIG_{winter} and MAI did not occur (Table 4.3). The effects of HIG_{spring} on the measured quality parameters compared to traditionally managed grasslands (control), as time passed after HIG (MAI) and their interaction on the quality of grassland outside the exlosures are presented in Table 4.4. The HIG_{spring} did affect the parameters, CP (p=0.05), GP (p=0.03), ME (p=0.0284) and DOM (p=0.0173). Moreover, MAI affected only the GP (p=0.0261) and ME (p=0.0278). Interactions between months after HIG_{spring} and MAI did not occur (Table 4.4). The HIG_{summer} did not affect the quality parameters (Table 4.5). Moreover, MAI affected only the GP (p=0.002) and ME (p=0.003). Interactions between months after HIG_{summer} and MAI did not occur. The HIG_{autumn} did affect CP (p=0.0026), GP (p=0.0006), ME (p=0.0003) and DOM (p=0.0021) (Table 4.6). Moreover, MAI affected all evaluated parameters, CA (p=0.0458), OM (p=0.0458), CP (0.0009), GP (p=0.0086), ME (p=0.006) and DOM (p=0.0021). Interactions between months after HIG_{spring} and MAI did also occur for ME (p=0.0447) and DOM (p=0.0453). When HIG affected the different parameters, it resulted in better quality, so HIG either did not produce effects on quality or it enhanced it, but the quality was never reduced.

Table 4.3. Effect of the HIG_{winter} treatment *per se* and as time passed after HIG (MAI) on grassland and their interaction on the quality of grassland outside the exlosures. Crude ash (g 100 g^{-1} DM), organic matter (g 100 g^{-1} DM), crude protein (g 100 g^{-1} DM), net gas production (ml 200 mg^{-1} DM) and organic matter digestibility (g 100 g^{-1} DM). Different letters indicate means difference at P < 0.05.

	HIG Winter		Control		p-value Treatment	MAI	Interaction
Crude ash	6.9		6.9		0.9914	0.1143	0.7946
SE	0.32		0.29				
Organic matter	93.09		93.1		0.9914	0.1143	0.7946
SE	0.32		0.29				
Crude protein	5.99	a	4.87	b	0.0043	0.0679	0.1562
SE	0.27		0.25				
Gas production	20.49	a	17.53	b	<0.0001	0.0247	0.2005
SE	0.44		0.41				
Metabolizable energy	5.19	a	4.68	b	<0.0001	0.0339	0.1205
SE	0.075		0.07				
Organic matter digestibility	40.3	a	37.16	b	0.0002	0.0699	0.1085
SE	0.56		0.51				

Table 4.4. Effect of the HIG_{spring} treatment *per se* and as time passed after HIG (MAI) on grassland and their interaction on the quality of grassland outside the exlosures. Crude ash (g 100 g^{-1} DM), organic matter (g 100 g^{-1} DM), crude protein (g 100 g^{-1} DM), net gas production (ml 200 mg^{-1} DM) and organic matter digestibility (g 100 g^{-1} DM). Different letters indicate means difference at $P < 0.05$.

	HIG Spring		Control		p-value Treatment	p-value MAI	p-value Interaction
Crude ash	7.62		6.91		0.1133	0.1301	0.6395
SE	0.32		0.3				
Organic matter	92.38		93.09		0.1133	0.1301	0.6395
SE	0.32		0.3				
Crude protein	5.59	a	4.84	b	0.0624	0.3312	0.1698
SE	0.29		0.27				
Gas production	18.73	a	17.59	b	0.03	0.0261	0.2036
SE	0.37		0.35				
Metabolizable energy	4.99	a	4.78	b	0.0284	0.0278	0.1908
SE	0.051		0.047				
Organic matter digestibility	39.02	a	37.2	b	0.0173	0.1054	0.1421
SE	0.53		0.5				

Table 4.5. Effect of the HIG_{summer} treatment *per se* and as time passed after HIG (MAI) on grassland and their interaction on the quality of grassland outside the exlosures. Crude ash (g 100 g^{-1} DM), organic matter (g 100 g^{-1} DM), crude protein (g 100 g^{-1} DM), net gas production (ml 200 mg^{-1} DM) and organic matter digestibility (g 100 g^{-1} DM). Different letters indicate means difference at P < 0.05.

	HIG Summer	Control	p-value Treatment	MAI	Interaction
Crude ash	7.21	6.99	0.5841	0.2082	0.7113
SE	0.29	0.27			
Organic matter	92.79	93.01	0.5841	0.2082	0.7113
SE	0.29	0.27			
Crude protein	5.45	5.01	0.3004	0.9615	0.565
SE	0.31	0.29			
Gas production	16.77	17.46	0.2518	0.0022	0.2555
SE	0.43	0.41			
Metabolizable energy	4.67	4.76	0.2741	0.003	0.2584
SE	0.059	0.56			
Organic matter digestibility	36.94	37.21	0.745	0.4836	0.4135
SE	0.61	0.57			

Table 4.6. Effect of the HIG_{autumn} treatment *per se* and as time passed after HIG (MAI) on grassland and their interaction on the quality of grassland outside the exlosures. Crude ash (g 100 g^{-1} DM), organic matter (g 100 g^{-1} DM), crude protein (g 100 g^{-1} DM), net gas production (ml 200 mg^{-1} DM) and organic matter digestibility (g 100 g^{-1} DM). Different letters indicate means difference at P < 0.05.

	HIG Autumn		Control		p-value: Treatment	p-value: MAI	p-value: Interaction
Crude ash	6.86		6.81		0.9121	0.0458	0.3239
SE	0.33		0.29				
Organic matter	93.14		93.19		0.9121	0.0458	0.3239
SE	0.33		0.29				
Crude protein	6.15	a	4.89	b	0.0026	0.0009	0.0588
SE	0.29		0.25				
Gas production	19.67	a	17.63	b	0.0006	0.0086	0.063
SE	0.41		0.35				
Metabolizable energy	5.08	a	4.69	b	0.0003	0.006	0.0447
SE	0.072		0.062				
Organic matter digestibility	39.61	a	37.2	b	0.0021	0.0059	0.0453
SE	0.55		0.47				

4.3.4 *Months after high impact grazing*

Figures 4.3, 4.4 and 4.5 show the CP, ME and DOM for control sub-plots and sub-plots subjected to HIG within the course of a year. Quality mean parameters in GB changed, decreased as the time passed after HIG (MAI). Nevertheless, compared to the control sub-plots, CP concentrations were higher at least during the first 2-4 months after HIG_{winter} (Fig. 4.3a), HIG_{spring} (Fig. 4.3b), and HIG_{autumn} (Fig. 4.3d), the exception was HIG_{summer} (Fig. 4.3c) respectively. GP, ME and DOM also decreased as the time passed after HIG (MAI), but compared to the control sub-plots, they were higher at least during the first 2-5 months after HIG_{winter} (Fig. 4.4a-4.5a), HIG_{spring} (Fig. 4.4b-4.5b), and HIG_{autumn} (Fig. 4.4d-4.5d), the exception was HIG_{summer} (Fig. 4.4c-4.5c) (the figures for GP are not shown).

4.3.5 *Shifts in the species composition and its different palatability*

Seasonal averages of the GB ranked according to their palatability showed that HIG timing had only limited effect on grassland species palatability (Table 4.7). Our results showed that $HIG_{summer\ and}$ HIG_{autumn} increased fine species GB cover (p=0.006); while HIG_{summer} reduced tender species cover (p=0.01), reduces ordinary species cover (p=0.06) and decreases hard species cover (p=0.02). Timing had no effect on weeds (irrespective of the season). HIG_{winter} and HIG_{spring} had no effect on species palatability. The most evident effect of HIG was the reduction of the proportion of SDB and consequently the increase in the proportion of the GB (Fig. 4.6). According to their palatability classified monthly, the proportion of tender species was higher after high impact grazing in September (p=0.0211), November (p=0.0115) and February (p=0.0143). The proportion of ordinary species was higher after high impact grazing November (p=0.0228). The proportions of all the other species did not change sinfificantly one year after high impact grazing (Fig. 4.6).

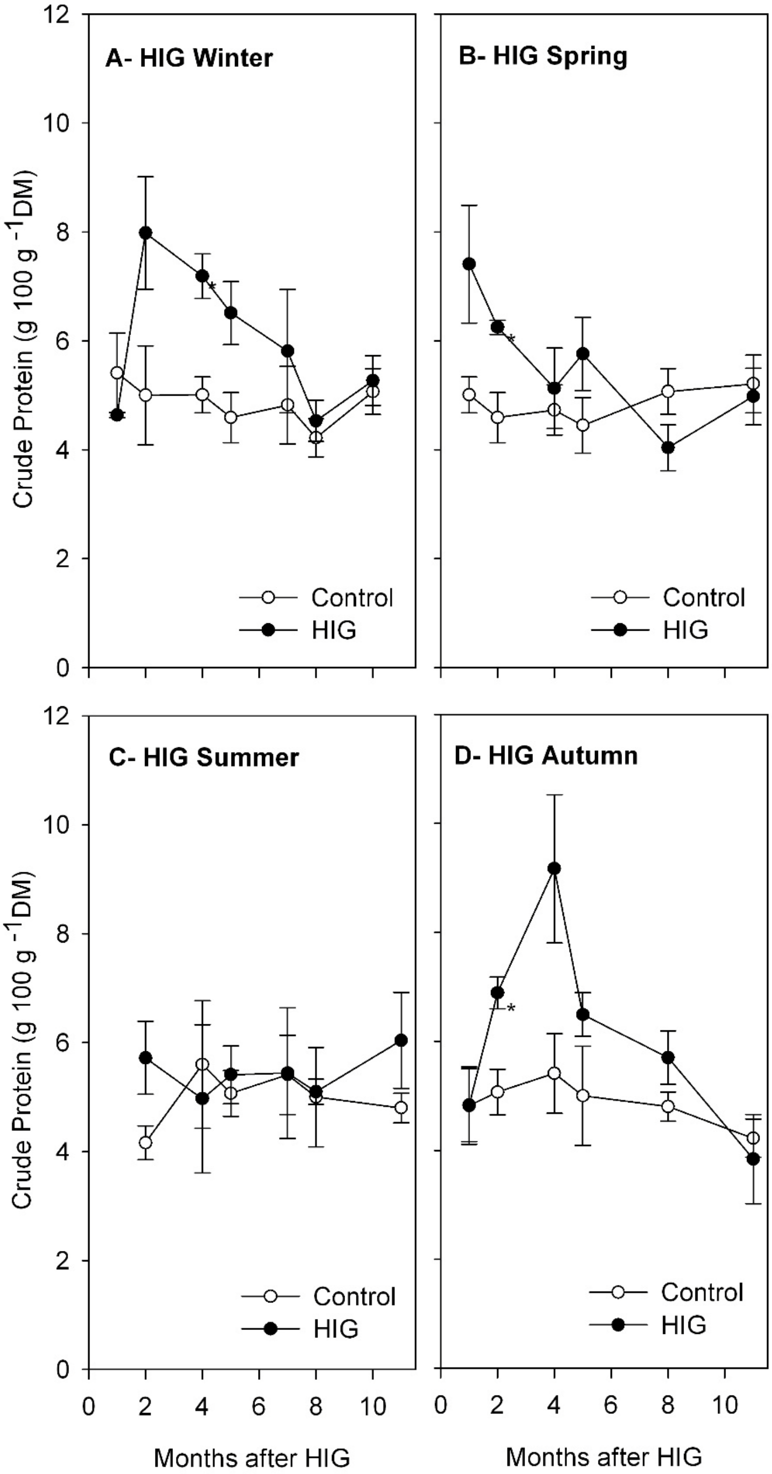

Figure 4.3. Crude protein (g 100 g^{-1} DM) concentrations of the aboveground green plant biomass of the herbaceous vegetation on grasslands grazed by cattle at low stocking densities in Corrientes, north-eastern Argentina, after high impact grazing (HIG) applied in four different seasons. The open and solid circles represent the arithmetic means for the control (open) and HIG sub-plots (close), calculated on dry matter basis (DM); the error bars indicate the standard errors of the means.

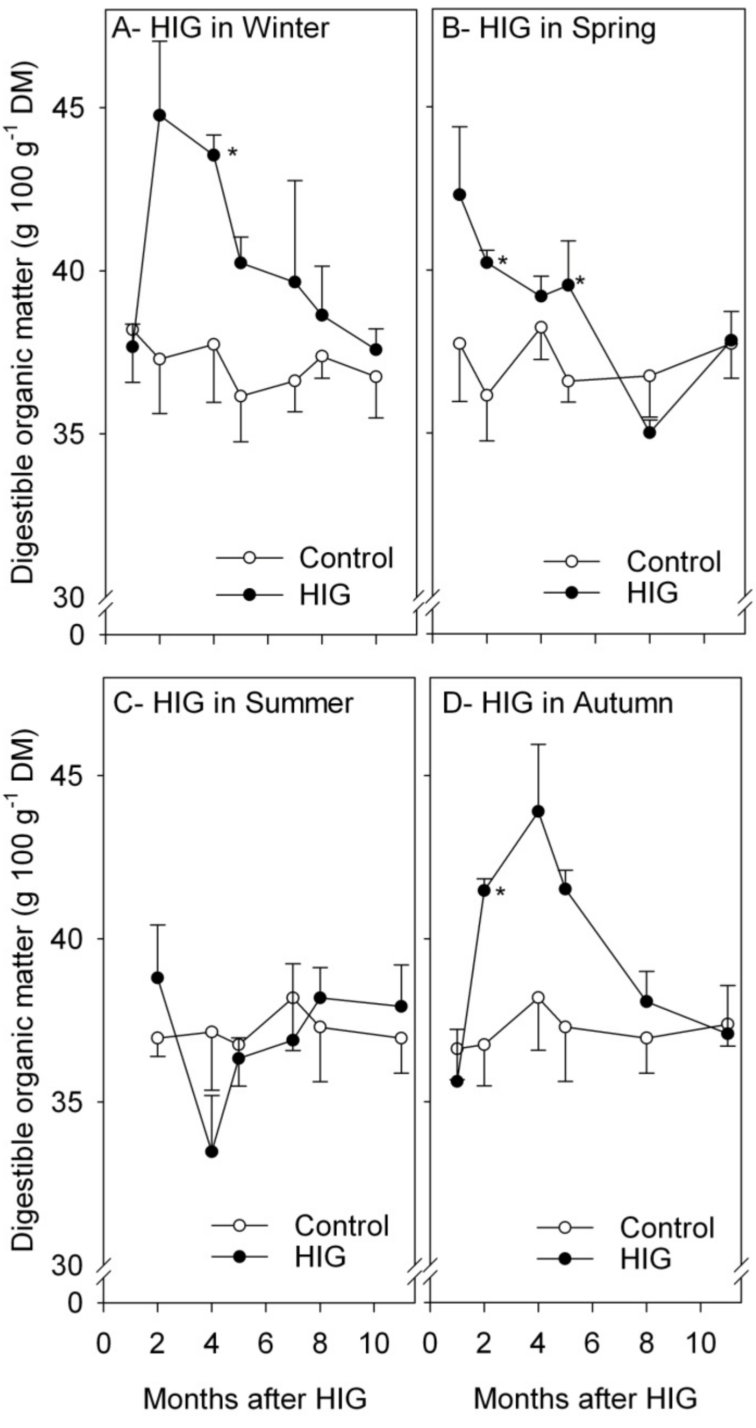

Figure 4.4. Digestible organic matter concentrations (g 100 g^{-1} DM) of the aboveground green plant biomass of the herbaceous vegetation on grasslands grazed by cattle at low stocking densities in Corrientes, north-eastern Argentina, after high impact grazing (HIG) applied in four different seasons. The open and solid circles represent the arithmetic means for the control (open) and HIG sub-plots (close).-Error bars indicate the standard errors of the means.

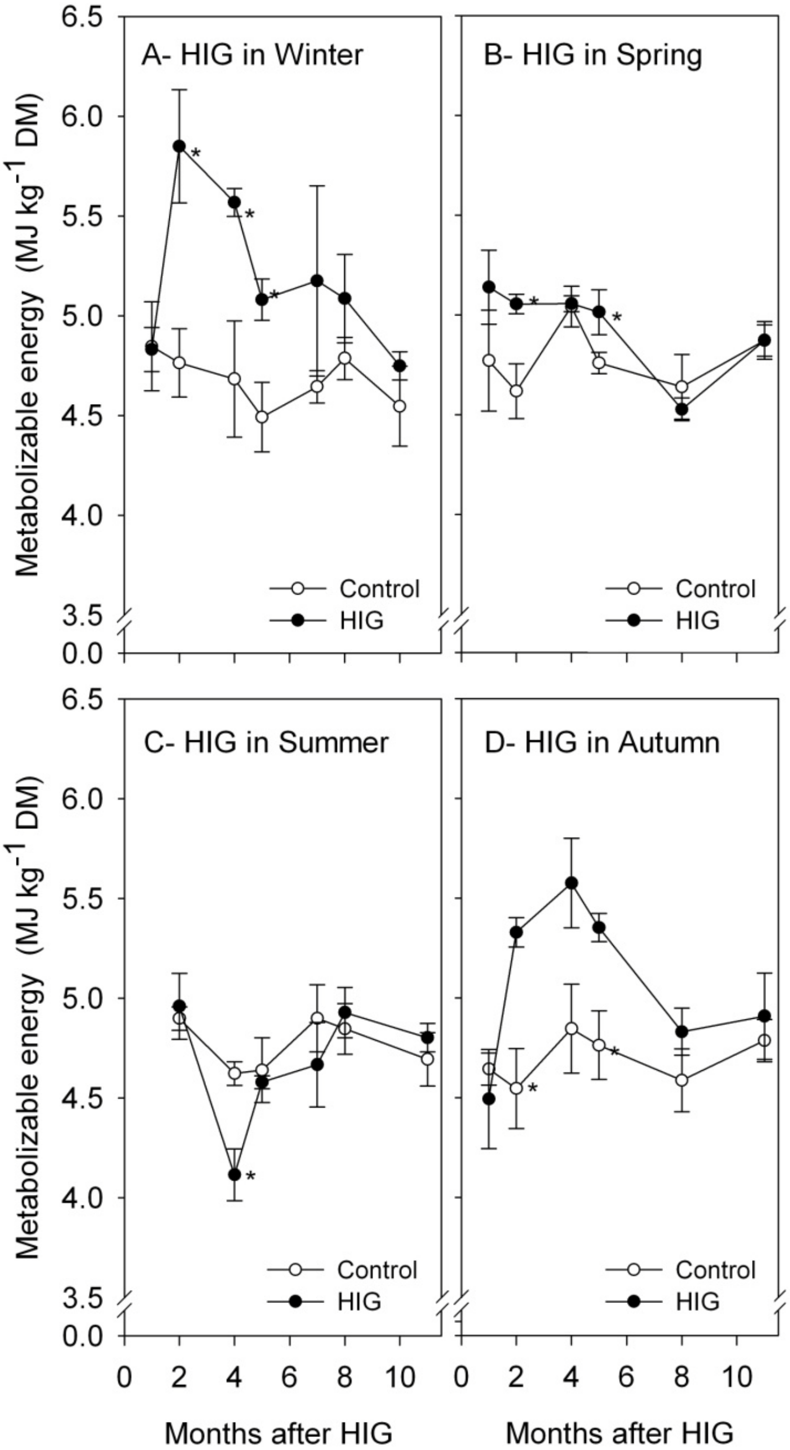

Figure 4.5. Metabolizable energy (MJ kg^{-1} DM) of the aboveground green plant biomass of the herbaceous vegetation on grasslands grazed by cattle at low stocking densities in Corrientes, north-eastern Argentina, after high impact grazing (HIG) applied in four different seasons. The open and solid circles represent the arithmetic means for the control (open) and HIG sub-plots (close). Error bars indicate the standard errors of the means.

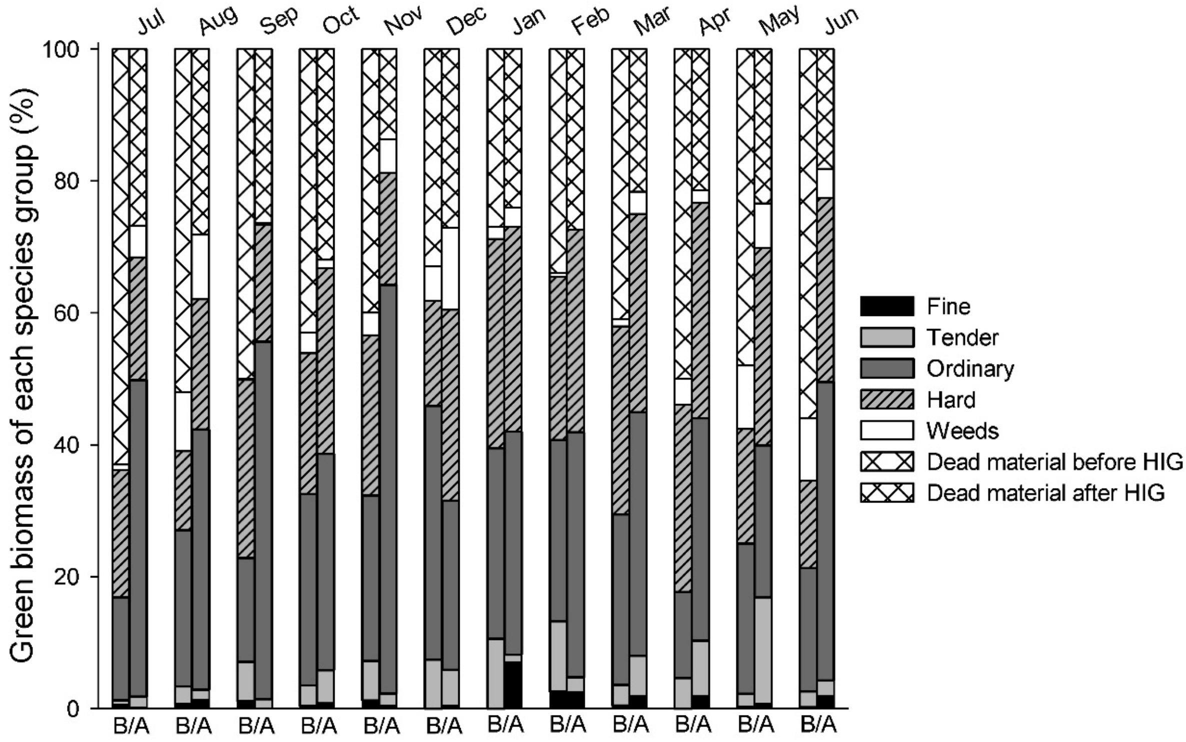

Figure 4.6. Proportion of aboveground green plant biomass of the herbaceous vegetation on grasslands in Corrientes, north-eastern Argentina, belonging to different plant species of different palatability (classified according to Rosengurt (1979). The figure shows the green biomass for every month in the year before (B) high impact grazing and in the same sub-plot, but one year after HIG (A) high impact grazing for each palatability group.The percentage share of total standing dead material is included. The proportion of tender species was higher after high impact grazing in September (p=0.0211), November (p=0.0115) and February (p=0.0143). The proportion of ordinary species was higher after high impact grazing (p=0.0228). The proportions of all the other species did not change sinfificantly one year after high impact grazing.

Table 4.7. Means and the p values of the palatability assessment based on seasonally green cover estimations before high impact grazing and on the same sub-plots, but one year after high impact grazing. Aboveground plant cover of the species belonging to different palatability classes (classified according to Rosengurt 1979).

	Fine species GB cover (%)		p value	Tender species GB cover (%)		p value	Ordinary species GB cover (%)		p value	Hard species GB cover (%)		p value	Weeds GB cover (%)		p value
Season	Before HIG	After HIG		Before HIG	After HIG		Before HIG	After HIG		Before HIG	After HIG		Before HIG	After HIG	
Winter	0.45	1.02	0.40	3.20	2.67	0.72	49.36	45.54	0.59	40.99	38.74	0.69	8.25	9.78	0.55
sd	0.7	1.6		3.8	2.2		20.0	22.5		25.4	21.0		14.4	15.8	
Spring	0.85	0.73	0.85	8.67	5.40	0.23	42.36	50.48	0.38	41.75	44.84	0.67	3.28	1.64	0.15
sd	1.2	1.1		4.8	6.2		22.6	26.6		24.6	20.7		5.0	2.8	
Summer	0.46	4.18	0.06	14.15	4.61	0.01	46.78	32.09	0.06	50.71	35.45	0.02	3.35	8.23	0.17
sd	1.4	5.1		9.5	5.9		17.2	23.3		23.1	14.4		7.1	11.3	
Autumn	0.17	1.64	0.06	6.30	10.62	0.25	39.35	32.77	0.33	50.09	47.57	0.71	6.61	4.87	0.47
sd	0.3	1.9		5.6	9.9		26.1	13.7		21.4	29.5		12.8	7.8	

Table 4.8. P values of the palatability assessment based on monthly green cover estimations before high impact grazing and on the same sub-plots, but one year after high impact grazing. Aboveground plant cover of the species belonging to different palatability classes (classified according to Rosengurt 1979). The proportion of tender species was higher after high impact grazing in September (p=0.0211), November (p=0.0115) and February (p=0.0143). The

proportion of ordinary species was higher after high impact grazing (p=0.0228). The proportions of all the other species did not change sinfificantly one year after high impact grazing.

Month	Fine species	Tender species	Ordinary species	Hard species	Weeds
June	0.3930	0.6894	0.3820	0.1988	0.7792
July	0.4967	0.3068	0.3373	0.9573	0.6869
August	0.7501	0.6841	0.4018	0.1249	0.2438
September	0.2449	**0.0211**	0.3786	0.2830	0.1912
October	0.6666	0.1951	0.2087	0.3283	0.2717
November	0.5175	**0.0115**	**0.0228**	0.1249	0.2169
December	0.4226	0.4866	0.1491	0.2104	0.3265
January	0.1938	0.1477	0.1730	0.9438	0.2893
February	0.9227	**0.0143**	0.1506	0.3971	0.1850
March	0.6031	0.3655	0.8409	0.8471	0.5668
April	0.2672	0.3387	0.1841	0.5095	0.6928
May	0.6499	0.5729	0.1763	**0.0273**	0.3967

4.3.6 *Total crude protein and metabolizable energy availability in green biomass*

The HIG had positive effects on the total amount of CP available in GB (kg ha^{-1}). Already 2 months after HIG_{winter}, total CP available in GB was similar to the total CP in GB of the control sub-plots. Thereafter, it was on average more than 25% higher than the amount of CP in GB of the control sub-plots (Fig. 4.7a). Similarly, 2 months after HIG_{spring} and HIG_{summer}, the amount of CP in GB reached a similar value to that in control sub-plots (Figs. 4.7b-4.7c). In contrast, CP in GB after HIG_{autumn} was lower compared to the amount of CP in GB of the control sub-plots for up to 4 months after HIG and remained similar to the control values thereafter (Fig. 4.7d). On an area basis, HIG also had a positive effect on the total available ME in GB (MJ ha^{-1}). Already 2 months after HIG_{winter}, ME availability already equalled the total ME offered in the control sub-plots. Moreover, 8 months after HIG_{winter}, the total amount of ME in GB was on average at least 40% higher than in the control sub-plots (Fig. 4.8a). Similarly, total ME equalled that in control sub-plots already 2 months after HIG_{spring} and HIG_{summer} (Figs. 4.8b-4.8c). On the opposite, up to 6 months after HIG_{autumn}, amount of ME available in GB was lower compared to the control sub-plots and was similar to that in the control sub-plots thereafter (Fig. 4.8d).

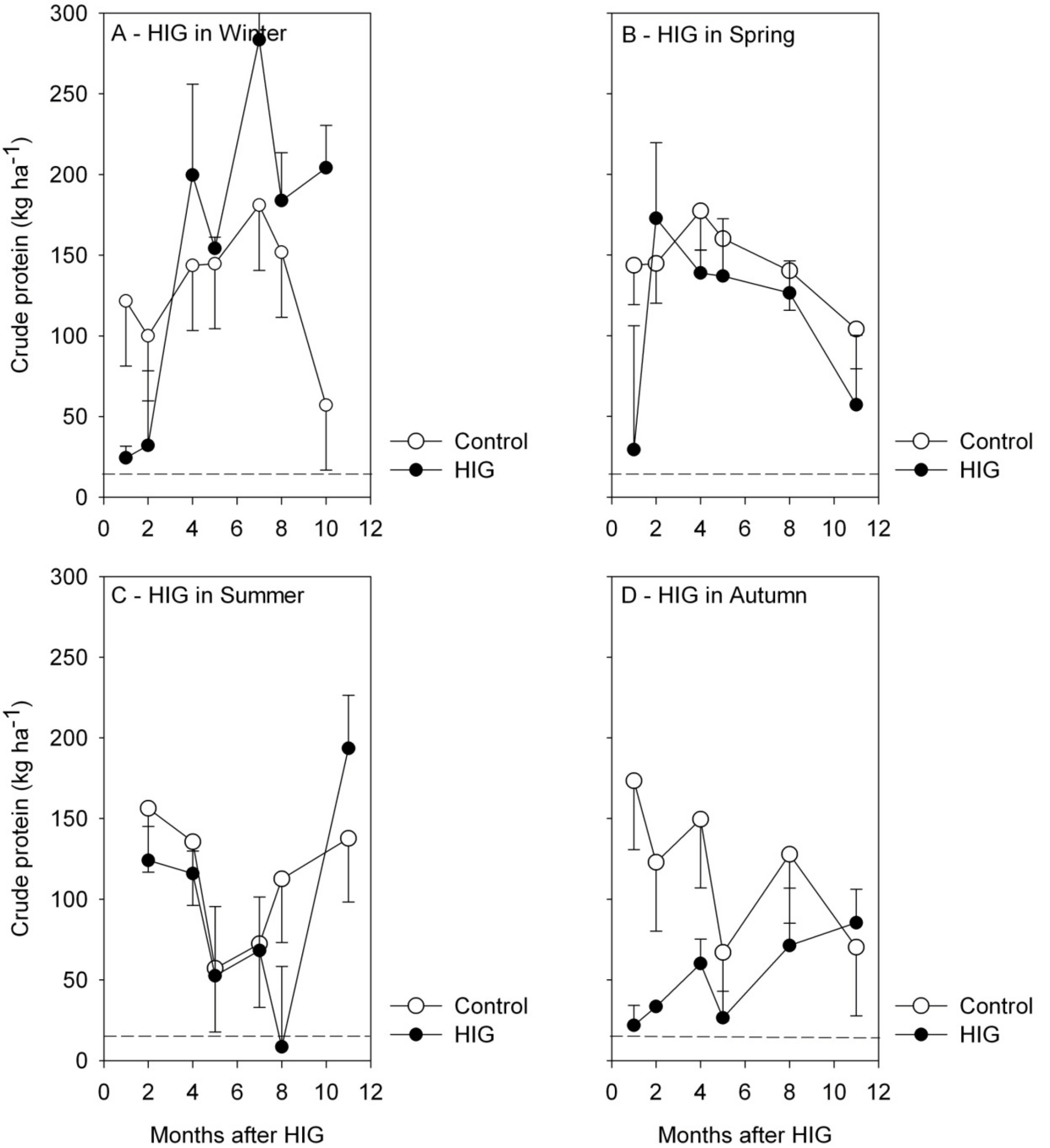

Figure 4.7. Available crude protein (CP in kg ha^{-1} DM) in the aboveground green plant biomass of the herbaceous vegetation on grasslands grazed by cattle at low stocking densities in Corrientes, north-eastern Argentina, after high impact grazing (HIG) applied in four different seasons. The open and solid circles represent the arithmetic means for the control (open) and HIG sub-plots (close). Error bars indicate the standard errors of the means. The slashed line indicates the average monthly CP requirement (13 kg $month^{-1}$) for maintenance and growth of a 250 kg cow (Hidalgo and Cauhépé 2009), equivalent to the average stocking rate of 0.5 animal unit ha^{-1} $year^{-1}$ in Corrientes, north-eastern Argentina.

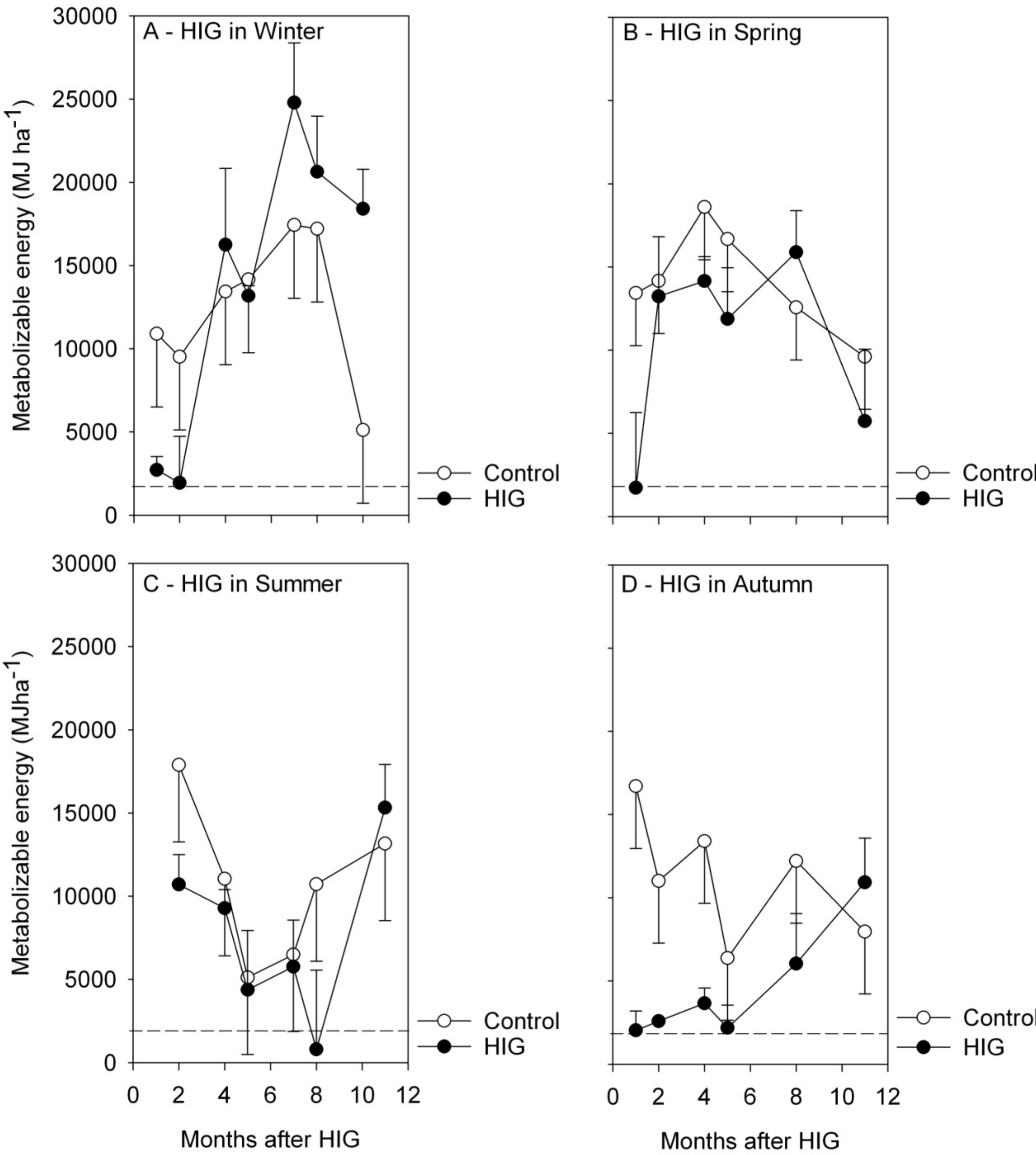

Figure 4.8. Available metabolizable energy (ME in MJ ha^{-1} DM) in the aboveground green plant biomass of the herbaceous vegetation on grasslands grazed by cattle at low stocking densities in Corrientes, north-eastern Argentina, after high impact grazing (HIG) applied in four different seasons. The open and solid circles represent the arithmetic means for the control (open) and HIG sub-plots (close). Error bars indicate the standard errors of the means. The slashed line indicates the average monthly ME requirement (1500 MJ month^{-1}) maintenance and growth of a 250 kg cow (Hidalgo and Cauhépé 2009), equivalent to the average stocking rate of 0.5 animal unit ha^{-1} year^{-1} in Corrientes, north-eastern Argentina.

4.4 ***Discussion***

From our previous research (Kurtz et al. 2016) we know that in general, total aboveground biomass in the control sub-plots was always above 1000 g DM m^{-2}.

The largest proportion of aboveground plant biomass in the control sub-plots was SDB, it accounted for approximately 800 g m^{-2} DM which is equivalent to 78% of total plant biomass throughout the year (Fig. 4.2a, 4.2b, 4.2c, 4.2d).

4.4.1 *Forage nutritional value*

Results of this research confirmed former findings that plant biomass of the herbaceous vegetation on traditionally managed natural grasslands in Corrientes is characterized by low CP concentrations (Bernardis et al. 1997; 2005; Casco and Bernardis 1992; 1993; 1994) which limit rumen fermentation and nutrient digestibility by ruminants (Crowder 1985; Golding 1985; McDowell 1985). However, HIG increased CP concentrations in GB in the present study. Similarly, Bernardis et al. (1997; 2005) and Casco and Bernardis (1992; 1993; 1994) found that the CP was at the maximum between one or two months after levelling harvest due to an enhanced plant regrowth. Contrarily, we found that after HIG_{winter} the enhanced CP lasted up to 4 MAI. Different to mechanical harvest, the urine and faeces depositions by HIG contribute to this extended and enhanced higher CP proportion (Cromsigt and Olff, 2008; Savory 2005). Hence, after any HIG, but HIG_{summer} CP concentrations, EM and DOM increased compared to the control. From our previous research we know that cows' weight increased significantly on the grasslands subjected to HIG than on the control. The deterrent SDB was reduced do to HIG, so grazing accessibility improved. Moreover, high amounts of SDB on grazing plots might have hampered forage harvest by the animals (Kurtz et al. 2016); SDB was reported to be the greatest impediment to grazing (Moisey et al. 2006). Now we confirm that after any HIG, but HIG_{summer}, the nutritious grassland quality was enhanced. The combination of more CP, enhanced DOM and more available ME of the GB, constitutes additional evidence to confirm the reasons of 30% more cow liveweight gain on HIG sub-plots compared to the control.

The effects of HIG in GB quality are scarce in sub-tropical regions (Hempson et al. 2014) and are particularly missing for sub-tropical Argentina (Kurtz et al. 2016). Our results contribute to better understanding the implications of HIG as a management tool. As we showed, HIG can improve overall grassland quality. Nevertheless, these positive effects may be even stronger and last longer depending on HIG timing. In general, herbage quality was enhanced by HIG_{winter}, HIG_{autumn}, HIG_{winter}, but not HIG_{summer}, particularly resulting in more CP and ME contents and better DOM. Logically, these quality parameters decreased as the grazing season advanced. We found that CP, DOM and ME declined after HIG, most probably as a result of plant ageing (Greenwood et al. 1990; Lemaire et al. 2007). On the opposite, grassland quality in the control remained stable but at lower values compared to HIG subplots, (excluding HIG_{summer}). CP, DOM and ME are closely linked to the vegetative state and they decline increases with heading. When HIG_{summer} is applied most grasses where probably already mature and had already lost its quality, specifically CP, DOM and ME (Royo Pallarés et al. 2005). Therefore HIG_{summer} was probably less efficient to produce the “rejuvenating” effect (Kurtz et al. 2016). The pasture quality after HIG_{summer} resulted in similar grass quality as in the control. Our results suggest that, HIG_{spring} by favouring CP and ME contents and better DOM, could directly improve the forage quality during the winter (3-6 MAI), with potential positive impacts on livestock performance. On the other hand low GB production and high quality grass after HIG_{autumn} may constitute an important constraint for the next winter and early spring (3-6 MAI). The HIG_{winter} also favours better grass quality, while HIG_{summer} showed no positive effects.

Concentrations of CP in the herbaceous GB on control sub-plots was much lower (5 g 100 g^{-1} DM) than the suggested threshold for proper rumen fermentation and functioning (Crowder 1985; Golding 1985; McDowell 1985) which in turn may reduce voluntary feed intake of cows. Hence, our previous findings suggested higher feed intake in HIG sub-plots compared to that of animals on the control sub-plots (Kurtz et al. 2016). After HIG, DOM reached almost 45 g kg^{-1} DM, and less than 37 g kg^{-1} DM in control and after $HIG_{summer.}$ Interesting is that the limited literature only provides DOM values for cultivated grass in the order of 50-75% (Avila et al. 2014). All together, lower forage intake, the inferior CP, EM and DOM in the GB of the control sub-plots explain the lower live-weight gains of cows in the control compared to the cows in the HIG sub-plots.

4.4.2 *Limited soil fertility*

In these soils, fertility may be quite an important limiting factor (Table 4.S9). For example, HIG increases up to 20% the N soil content, compared to the control (1.6 g kg^{-1} vs. 1.8-2.2 g kg^{-1}), which was enough to almost double the CP in GB (Fig. 4.3a-4.3b-4.3d). Here again HIG_{summer} was the exception, as biomass was at peak biomass, total aboveground biomass was trampled down and more active soil microbes in summer, could have therefore soil-immobilized the added N, by active nitrification bacteria (Blaya & García 2003), thereby reducing nitrogen availability for further plant uptake.

4.4.3 *Forage accessibility and species palatability*

After HIG, the proportion of GB was higher compared to control sub-plots, but most important was that HIG markedly reduced the deterrent SDB and consequently canopy height was also reduced, resulting in better accessibility of GB for grazing animals (Limb et al. 2010). Nevertheless, the proportion of species with different palatability remained mostly unchanged.

4.4.4 *Management implications*

Tall grass canopy is a barrier to herbivores, therefore protecting more palatable understory species (Limb et al. 2010). Compared to the control, HIG resulted in higher DOM, which may have in turn allowed for higher feed intake of cows (Coleman and Moore 2003). The amount of CP per unit area (hectare) available in GB was sufficient or even much higher than the CP requirements of 13 kg ha^{-1} month^{-1} for maintenance and growth of a 250 kg grazing cow (Hidalgo and Cauhépé 2009) in the local grassland at a stocking density of 0.5 animal units ha^{-1} year^{-1} (Calvi 2010; Fig. 4.7). Moreover, not only the amount of CP is of key interest, grass CP content should be at a minimum of 6-7 g kg^{-1} DM (Crowder 1985; Golding 1985; McDowell 1985) in order to meet N requirements of rumen microbes, this requirement bas barely met after HIG, but was not met on the control and after HIG_{summer}. Nevertheless, we are aware that this comparison of availability vs. requirements is somehow misleading, as the animals will not and cannot consume all available biomass. From a long term point of view, enough biomass should remain on the plots for sustainable grassland productivity.

Similarly, after HIG the total ME was always enough to cover the monthly average metabolisable energy requirement threshold of approximately 1500 MJ month^{-1}, maintenance and growth requirement of a 250 kg cow (Hidalgo and Cauhépé 2009), equivalent to the average stocking rate of 0.5 animal unit ha^{-1} year^{-1} in Corrientes, north-eastern Argentina. The lesser available ME was more evident after HIG_{autumn}, likely because compared to summer time, the growth of C_4 grasses is low in the following winter and spring due to low temperatures and solar radiation (Heckathorn et al.1999; Fig. 4.8d). Shortly after HIG_{winter} and HIG_{spring} the ME was barely enough to cover monthly average metabolic energy requirements, but already 2-3 months after HIG, the ME threshold was overcome at least 2-3 times after HIG_{spring} (Fig. 4.8b) and 4-5 times after HIG_{winter} (Fig. 4.8a). The amount of ME in GB after HIG_{summer} was similar to that in the control sub-plots (Fig. 4.8c). Finally, HIG_{summer} actually had a limited effect on forage quality (i.e. CP and DOM and ME) therefore it is not recommendable from that point of view. Nevertheless, forage quality is only one of other aspects, HIG_{summer} still could be favourable as it reduces SDB and decreases the dead to green ratio (Kurtz et al. 2016) and it favours forage accessibility.

Timely-well managed, HIG has the potential not only to reduce SDB pools, but also deliver benefits towards increased fodder quality. In Corrientes, grassland forage normally fails to support adequate production and supplemental forage for deficient quality may be provided (Coleman and Moore 2003). This situation is particularly often in Northeast Argentina, during winter time, which limits stocking density increase. We have shown that forage quality was enhanced during autumn, winter and spring after HIG. Nevertheless the positive effects lasted only for up to 4 months. Further studies should assess the effects of repetitive HIG that could maintain these positive effects and reduce the negative consequences that could arise.

4.5 *Conclusions*

Grassland sustainable management have raised concern worldwide. Specifically in Northern Argentina urgent management options are needed to increase grassland use efficiency. Our study showed that, in the grasslands of the subtropical Province of Corrientes, HIG can have positive effects on forage quality. The current results confirm that, besides enhancing the accessibility of GB due to less deterrent SDB, HIG improves the nutritive value of GB due to increased CP, DOM, and ME concentrations that last for several months after HIG, depending on the season and the time passed after HIG. Timing of HIG needs to be considered as HIG_{summer} did not exert any positive effects on the nutritional quality of GB in grasslands.

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Table 4. S9. Soil physical and chemical properties, the arithmetic means represent the average values of the treatments, n is the sample size and SE is the standard error. All variables analyzed in the top 0–5 cm soil layer. C and N analyzed with LECO Truspec ® Analyzer. Electrical conductivity measured in the saturation soil extract, pH measured in 1:2.5 soil:water solution. Bulk density based on core method.

		Treatments (months after HIG)				
		Control	1	3	6	9
Bulk density (Mg m^{-3})	Mean	1.17	1.09	0.99	1.06	1.13
	n	6.00	12.00	9.00	6.00	9.00
	SE	0.07	0.05	0.05	0.07	0.05
	p-value 0.266					
Soil C (g kg^{-1})	Mean	18.00	22.3	25.40	20.60	20.70
	n	6.00	12.00	9.00	6.00	9.00
	SE	0.1	0.07	0.08	0.10	0.08
	p-value <0.0001	c	b	a	bc	b
C Stock (Mg ha^{-1})	Mean	25.50	23.69	22.34	24.54	25.41
	n	6.00	12.00	9.00	6.00	9.00
	SE	1.85	1.31	1.51	1.85	1.51
	p-value 0.589					
Soil N (g kg^{-1})	Mean	1.60	1.9	2.20	1.80	1.80
	n	6.00	12.00	9.00	6.00	9.00
	SE	0.01	0.01	0.01	0.01	0.01
	p-value <0.0001	c	b	a	bc	b
N Stock (Mg ha^{-1})	Mean	2.20	2.04	1.92	2.12	2.19
	n	6.00	12.00	9.00	6.00	9.00
	SE	0.16	0.11	0.13	0.16	0.13
	p-value 0.5802					

pH	Mean	5.61	5.32	5.13	5.32	5.28
	n	6.00	12.00	9.00	6.00	9.00
	SE	0.08	0.05	0.06	0.08	0.06
	p-value 0.0008	a	b	b	b	b
Soil conductivity (dS m^{-1})	Mean	0.04	0.08	0.07	0.03	0.06
	n	6.00	12.00	9.00	6.00	9.00
	SE	0.01	0.01	0.01	0.01	0.01
	p-value 0.0011	c	a	ab	c	bc

5 General discussion

5.1 The effect of high impact grazing on grassland biomass

Up to now, not much evidence has been provided about the effects of HIG on biomass dynamics on C_4 dominated grasslands, where vegetation growth shows a seasonal pattern linked to the climate conditions (Knapp and Medina, 1999; Martín et al. 2011; Ötztürk et al. 1981; Royo Pallarés et al. 2005). We found that HIG did not produce over-compensatory growth as reported by McNaughton (1979; 1983) nor it reduced productivity following the impact. The monthly growth rate remained similar between HIG and control sub-plots indicating that it is a rather resilient rangeland in response to grazing disturbance. On the other hand, we found that HIG reduced both, the standing total (STB) and standing dead biomass (SDB) (Fig. 5.1). Besides, it also affected grassland biomass growth dynamics strongly depending on the season when HIG was applied (McNaughton 1983). HIG sub-plots showed a different growth pattern anti-cyclic compared to that of the control, with an active growth phase during autumn when the biomass accumulation in the control sub-plots decreased. The declining trend of STB in the control sub-plots was negative in autumn due to strong SDB biomass decay, whereas the response to HIG resulted in active tillering that built up new biomass as most of the biomass was previously removed or trampled down. In the untreated control sub-plots as a result of the seasonal growth, STB accumulated from spring to summer and decreased approaching the end of the growing season in late autumn until the end of the winter in August. The negative rate of STB accumulation was directly related to the climatic conditions, particularly to the low temperature (Long, 1999) and the less light interception due to the shade produced by the high amounts of biomass (Heckathorn et al. 1999; McMillan et al. 2011; Ötztürk et al. 1981) which in turn reduced photosynthesis (Heckathorn et al. 1999; Pearcy et al. 1981). As the decreasing temperatures affect both the HIG and the control sub-plots equally, the better light penetration in the HIG sub-plots induced the active growth observed in autumn in the HIG sub-plots and improved the ratio between SGB and SDB. Compared to HIG in winter, summer or spring (STB accumulation between ~400 to 800 g m^{-2}), HIG in autumn produced exceptionally low STB (~200 to 600 g m^{-2}). It is highly likely that the HIG towards the end of the growing season in autumn impeded the allocation of photosynthates to roots (Knapp and Medina, 1999). Therefore, the HIG in autumn, by destroying all present biomass, interfered with root resources allocation which translated into low growth on the following growing season. HIG in autumn could have been amplified by water logging resulting in soft water saturated soil horizons (Striker et al. 2011). High rainfall and low potential evapo-transpiration during autumn indeed resulted in water-logging during HIG on our experimental sites. Therefore HIG during that time has likely triggered enhanced stalks injury and serious root damage (Dunne et al. 2011; Striker et al. 2006), responsible for the reduced growth during the next spring and even summer.

In general, the control sub-plots offered a mixed bunch of green and huge amounts of deterrent SDB hardly accessible for the cows (Balph and Malecheck, 1985; Moisey et al. 2006) and only 22% green biomass through the year. In contrast, the proportion of green biomass was almost doubled after HIG. On average it was above 35% after HIG in spring and autumn, 38% and 42% after HIG in winter and summer through the year respectively.

5.2 The effect of high impact grazing on grassland diversity and plant functional groups (PFGs)

Rangelands of Corrientes have been subjected to continuous grazing for more than 500 years (Carnevali 1994). Nevertheless, these grasslands are well adapted to eventual but intensive defoliation (Fidelis et al. 2013) as induced for example by natural or anthropogenic fires (Kurtz et al. 2010). As a result, and even though the nutrient status of the Corrientes soils is low (Escobar et al. 1996), the disturbances by severe defoliation are compensated by the availability of resources under the favourable climate conditions. Due to both, the high primary productivity and the usually low stocking rates, HIG effects on vegetation should therefore be reversible, according to a general understanding of grassland response to disturbances (Cingolani et al. 2005; Milchunas et al. 1988, Milchunas and Lauenroth 1993). However, since HIG is entirely different to a continuous grazing pressure, the results derived from the analysis of permanent grazing might substantially deviate with regard to the effects on diversity. We found that HIG disturbance does neither enhance (Schnoor et al. 2015; West 1993) nor does reduce species diversity (Carter et al. 2014) (Fig. 5.1). Both parameters showed a rapid recovery to pre-HIG levels within one growing season. Up to now, results from Corrientes rangelands, showed that permanent high stocking rates decrease evenness and the Shannon-Wiener diversity index, however without affecting species richness (Pizzio et al. 2016). Nevertheless, Pizzio et al. (2016) warned that increasing grazing pressure will lead to reduced forage quality because of the loss of palatable grasses and the increase of forbs. The idea of HIG, which is the tightly-closely together use of cattle to trample down not only the excess dead material, but inevitably also the green biomass, generated an historical strong debate and concern, not only among the international scientific community (Briske et al. 2013; Teague et al. 2011) but also among local researchers and local rangers in Corrientes (*personal communication*). These partially controversial results suggest that we need to intensify our research efforts to improve our understanding of ecological processes as induced by HIG and include more parameters such as species palatability and fodder quality in order to get a more complete picture of this promising management option.

5.3 HIG against undesirable plants

After HIG, approximately 90% of the species increased their green cover, most probably due to resistant belowground structures like xylopodia (Fidelis et al. 2014). Dicotyledonous species profit from disturbance, 81% of it increased their cover and only 9.6% decreased it. Nevertheless the monocotyledonous species (mostly *Poaceae*) increased cover to up to 92%, due to a combination of both, the high tiller density (Fidelis et al. 2014; Striker et al. 2011) and the better light interception (Heckathorn et al. 1999; McMillan et al. 2011; Ötztürk et al. 1981) after the removal of the dead material. We also found that monocots and dicots, annuals and perennials, C_3 and C_4, and green and dead cover are inversely opposite and exclusive, suggesting that an increase of one variable will lead to a decrease of the other. These similarities across the year could indicate that natural ecosystem dynamics affecting diversity are superimposing possible management effects. HIG is therefore obviously not interfering with grasslands natural diversity and PFGs dynamics.

In the Chaco region, encroachment is a major threat to both grasslands productivity and diversity (Carnevali 1994; Grau et al. 2014). Grassland encroachment occurs when small trees, forbs or shrubs contribution to green ground cover increases. In this region most of these are dicotyledonous species like *Prosopis* sp. (Grau et al. 2014) or most frequently *Vernonia* species belonging to the *Asteraceae* family (Kurtz et al. 2010). Among the wide range of possible treatments to fight encroachment, most physical elimination methods are expensive and time consuming. HIG was suggested as a tool to fight undesirable weeds (Frost et al., 2012) and it was already reported that grass tolerates trampling more than forbs (Striker el al. 2011). Our research confirms that the after HIG biomass recovered rapidly and the green cover of *Poaceae* and *Fabaceae* species was not diminished. Besides that, HIG increased *Cyperacea* species cover and produced a great reduction on *Asteraceae* species cover; the latter includes several non palatable or even toxic species for cattle. Trampling of the grassland when undesirable forbs are abundant would be an option for its positive effects on grass and the decline of the weed species (Striker et al. 2011). Our results suggest that HIG would tend to a progressive de-encroachment of the natural grasslands, but more research on that topic would be needed.

Logically, by removing dead biomass and producing bare ground, HIG improved the conditions for enhanced species cover compared to the control. By opening the canopy, light transmission was favoured (Heckathorn et al. 1999; McMillan et al. 2011; Ötztürk et al. 1981) producing that more than 80% of all species from the different PFGs increase their cover compared to the control sub-plots. Remarkably is that after HIG, 88% of all C_3 species increased their cover, up to date there was no previous report of such an increase (Feldman et al. 2008). This finding opens an interesting option to introduce HIG in order to take advantage of the nutritious quality of C_3 green biomass species (Jacobo et al. 2006), like for example the trampling tolerant *Fabacea* species *Desmodium incanum* Vog.

Nevertheless, HIG could produce delayed long term responses affecting diversity; for example, due to more bare ground patches on HIG sub-plots, the altered competition resulting from to the removal of perennials biomass (Milchunas et al. 1988), the strongly reduced total biomass in turn affecting light transmission and so the energy budgets, and last but not least, the trampling impacts on the top-soil, changing nutrient dynamics and cycling as well as physical soil properties.

5.4 Forage nutritional value

The effects of HIG in GB quality are scarce in sub-tropical regions (Hempson et al. 2014) and are particularly missing for sub-tropical Argentina (Kurtz et al. 2016). In general, herbage quality was enhanced by HIG_{winter}, HIG_{autumn}, HIG_{winter}, but not HIG_{summer}, particularly resulting in more CP and ME contents and better DOM (Fig. 5.1). Results of this research confirmed that natural grasslands forage in Corrientes is characterized by low CP concentrations (Bernardis et al. 1997; 2005; Casco and Bernardis 1992; 1993; 1994) which limit rumen fermentation and nutrient digestibility by ruminants (Crowder 1985; Golding 1985; McDowell 1985). However, HIG increased CP concentrations in GB and the enhanced CP lasted up to 4 MAI HIG. Different to mechanical harvest, the urine and faeces depositions by HIG contribute to this extended and enhanced higher CP proportion (Cromsigt and Olff, 2008; Savory 2005). Concentrations of CP in the herbaceous GB on control sub-plots was much lower (5 g 100 g^{-1} DM) than the suggested threshold for proper rumen fermentation and functioning (Crowder 1985; Golding 1985; McDowell 1985) which in turn may reduce voluntary feed intake of cows.

After HIG, DOM reached almost 45 g kg^{-1} DM, and less than 37 g kg^{-1} DM in control and after HIG_{summer}. Interesting is that the limited literature for Argentina, only provides DOM values for cultivated grass in the order of 50-75% (Avila et al. 2014). All together, the inferior CP, EM and DOM in the GB of the control sub-plots explain the lower live-weight gains of cows in the control compared to the cows in the HIG sub-plots. Hence, after any HIG, but HIG_{summer} CP concentrations, EM and DOM increased compared to the control. The better forage quality and more available ME of the GB, constitutes additional evidence to confirm the reasons of 30% more cow liveweight gain on HIG sub-plots compared to the control. Compared to the control, HIG resulted in higher DOM, which may have in turn allowed for higher feed intake of cows (Coleman and Moore 2003).

Nevertheless, these positive effects of HIG may be even stronger and last longer depending on HIG timing. Logically, these quality parameters decreased as the grazing season advanced. We found that CP, DOM and ME declined after HIG, most probably as a result of plant ageing (Greenwood et al. 1990; Lemaire et al. 2007) with heading. On the opposite, grassland quality in the control remained stable but at lower values compared to HIG subplots, (excluding HIG_{summer}). When HIG_{summer} is applied most grasses where probably already mature and had already lost its quality (Royo Pallarés et al. 2005). Our results suggest that, HIG_{spring} by favouring CP and ME contents and better DOM, could directly improve the forage quality during the winter (3-6 MAI), with potential positive impacts on livestock performance. On the other hand low GB production and high quality grass after HIG_{autumn} may constitute an important constraint for the next winter and early spring (3-6 MAI). The HIG_{winter} also favours better grass quality, while HIG_{summer} showed no positive effects.

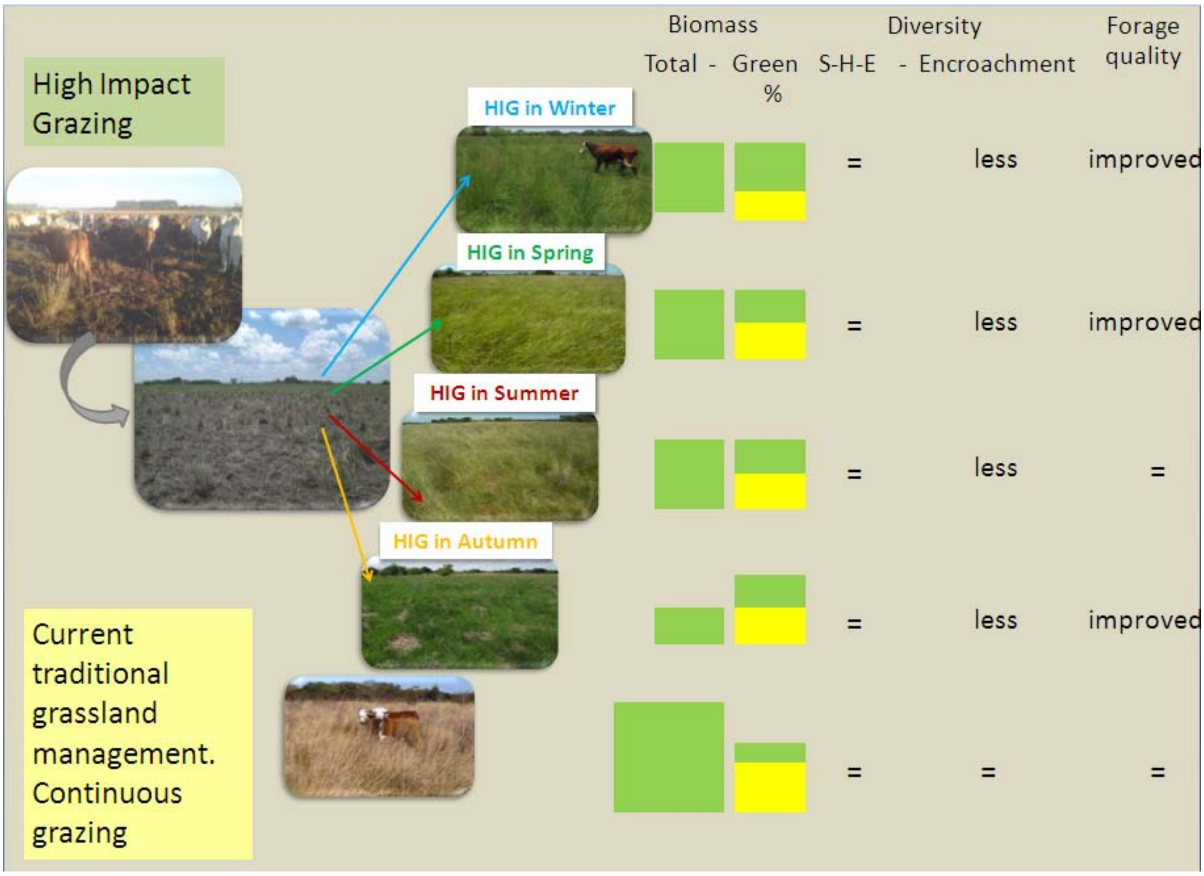

Fig. 5.1. Comprehensive diagram depicting the effects of high impact grazing (HIG) on biomass pools, species diversity and forage quality.

5.5 Implications for range management and meat production

Despite that overall biomass was reduced, the amount of palatable biomass (SGB) in the HIG sub-plots was still sufficient to feed cows throughout the year, without reducing species diversity. Moreover, during the first three months after HIG in winter (the less productive season), grassland had enough green biomass (~170 kg biomass ha^{-1}) to feed 0.5 A.U. which is the normal stocking rate in the Province (considering a theoretical daily feed intake of 12 kg dry matter or 3% of life weight of a 400 kg cow). After HIG in spring, summer or autumn, the available SGB was between 2 and 6 times more than needed at that stocking rate. On the other hand, control sub-plot had 4 to 10 times the amount of green biomass at that stocking rate, but was barely accessible due to the huge volume of deterrent SDB. Our results clearly show that cows' weight increased significantly more on the grasslands subjected to HIG than on the control sub-plots. Grazing was less efficient in the control since cows probably spent more time and energy searching for forage (Abdel-Magid et al 1987; Heckathorn et al. 1999). The HIG, with monthly time intervals on adjacent areas, produced a combination of areas of low, but high quality biomass and areas of high bulk but low quality biomass, which enhanced ruminant resources utilization (Hempson et al. 2014).

Our results suggest that impact grazing in (late) winter result in most beneficial rangeland properties with regard to biomass re-growth dynamics, green to dead proportions and extended growth periods. An impact during autumn, however, could i) significantly reduce the fodder availability during the winter and ii) jeopardize the next years productivity due to the threat of serious root destruction in waterlogged soils. The proportion of SGB (SGB/SDB ratio) should be further explored to function as indicator for the positive effects of HIG. Although the amount of SGB produced was less when HIG was applied in summer or autumn compared to the winter or spring impact, the positive effects for the winter and spring period (the most difficult period for animal nutrition) are of higher relevance for the overall productivity. HIG at any time of the year increased the SGB/SDB ratio which consequentially enhanced energy capturing during winter and early spring periods when grass growth is normally light limited by the SDB.

The amount of CP per unit area (hectare) available in GB was much higher than the CP requirements of 13 kg ha^{-1} $month^{-1}$ for maintenance and growth of a 250 kg grazing cow (Hidalgo and Cauhépé 2009) at a stocking density of 0.5 animal units ha^{-1} $year^{-1}$ (Calvi 2010). Moreover, not only the amount of CP is of key interest, in order to meet N requirements of rumen microbes, this requirement bas barely met after HIG, but was not met on the control and after HIG_{summer}. Nevertheless, we are aware that this comparison of availability vs. requirements is somehow misleading, as the animals will not and cannot consume all available biomass. From a long term point of view, enough biomass should remain on the plots for sustainable grassland productivity.

Similarly, after HIG the total ME was always enough to cover the monthly average ME requirement threshold of approximately 1500 MJ $month^{-1}$, maintenance and growth requirement of a 250 kg cow (Hidalgo and Cauhépé 2009), equivalent to the average stocking rate of 0.5 animal unit ha^{-1} $year^{-1}$ in Corrientes. Lesser available ME was more evident after HIG_{autumn} likely because, compared to summer time, the growth of C_4 grasses is low in winter and spring due to low temperatures and solar radiation (Heckathorn et al.1999). Shortly after HIG_{winter} and HIG_{spring} the ME was barely enough to cover monthly average metabolic energy requirements, but already 2-3 months after HIG, the ME threshold was overcome at least 2-3 times after HIG_{spring} and 4-5 times after HIG_{winter}. The amount of ME in GB after HIG_{summer} was similar to that in the control sub-plots. Finally, HIG_{summer} actually had a limited effect on forage quality (i.e. CP and DOM and ME) therefore it is not recommendable from that point of view. Nevertheless, forage quality is only one of other aspects, HIG_{summer} still could be favourable as it reduces SDB and decreases the dead to green ratio (Kurtz et al. 2016) and it favours forage accessibility.

Timely-well managed, HIG has the potential to deliver benefits towards increased fodder quality. We have shown that forage quality was enhanced during autumn, winter and spring after HIG. Nevertheless the positive effects lasted only for up to 4 months.

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General conclusion

Grassland sustainable management have raised concern worldwide. Specifically in Northern Argentina urgent management options are needed to increase grassland use efficiency. We provide first hand evidence of a HIG management alternative for Argentinean ranchers in order to reduce the unproductive and grazing deterrent standing dead biomass. HIG effect on the biomass pools lasted for several months thereby increasing the green to dead biomass ratio. Timing of the HIG is most important and should consider the natural seasonal dynamics of the grassland ecosystem. Best results in terms of standing dead biomass reduction and dead to green ratios were achieved with HIG_{winter}; HIG_{autumn}, however, could reduce fodder availability and reduce next year's grassland's productivity. Irrespectively of the season applied, HIG produced an extended growth phase which lasted until the next autumn. This growth response has not been observed or reported up to now for the region, and should be explored for the potential to improve the fodder availability for cattle right at the beginning of the winter. Dead to green biomass ratios as a result of HIG should be further analysed to function as an indicator for improved pasture management. High impact grazing (HIG) did not alter grassland diversity indicating that this ecosystem is very resilient against HIG disturbance. Shifts in plant functional groups towards less dicotyledonous and annual plants and more C_4 and C_3 grasses as a result of HIG may contribute to increase forage quality and counteract negative processes of "low value" species encroachment. Our study showed that, HIG can have positive effects on forage quality. The current results confirm that, besides enhancing the accessibility of GB due to less deterrent SDB, HIG improves the nutritive value of GB due to increased CP, DOM, and ME concentrations that last for several months after HIG, depending on the season and the time passed after HIG. Timing of HIG needs to be considered as HIG_{summer} did not exert any positive effects on the nutritional quality of GB in grasslands. In addition our results contribute to a better understanding of ecosystem disturbance mechanisms with potential to be used for enhanced rangeland management. HIG could be a valuable alternative for range managers seeking not only for a different method to reduce dead biomass pools, but also working towards a sustainable intensification providing nutritious green forage at levels equal or even higher than those achieved under continuous traditional grazing. HIG could be a management option towards sustainable intensification, however, further field studies are needed to analyse long-term or legacy effects and the interaction with climate variability or the dynamics of other natural processes.