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Effects of repeated bunch trampling by grazing cattle on the botanical composition of Argentinean grasslands

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Passiflora coerulea (Passifloraceae)

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List of Abbreviations

Days after Impact	DAI
DM	Dry matter of plant biomass
P1, P2, P3	Paddock, 1, 2 and 3
SGB	Standing green plant biomass
SDB	Standing dead plant biomass
SGM	Standing green plant material
SDM	Standing dead plant material

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Abstract

The grassland areas of Northern Argentina are mainly used for livestock production. Natural pasture in Corrientes has moderate to low quality, depending on the season. The need for high-yielding grassland with year-round fodder availability to feed an increasing number of cattle demand a change in the current farming management. A high accumulation of standing dead biomass and low stocking rates of herbivores hamper plant production and forage growth. It is therefore necessary to find ways to reduce standing dead material. For that reason an experiment with 150 cattle ha^{-1} day^{-1} was established on the experimental station Estación Experimental Agropecuaria Corrientes on a 24 ha large grassland area, split into three paddocks with 12 plots and a control. An intensive, monthly repeated bunch trampling by grazing cattle, was conducted in spatially confined paddocks. To investigate the changes in botanical composition, the assessment of biodiversity took place in 8 m^2 sampling areas. Total soil coverage of plant biomass, bare ground, litter and biodiversity parameters were estimated using a plant sampling assessment scale related to the dominant abundance of plants of Braun-Blanquet. Pasture vegetation turned out to be high, but mostly dominated by *Poaceae-, Cyperaceae-* and *Compositae* (*Asteraceae*). The repeated presence of livestock proved to enhance the growth of more favourable green standing plants biomass and reduced standing dead biomass in the experimental site ($p < 0.001$). The investigation on biodiversity parameters revealed no variation of species richness in the paddocks in comparison to the control. The Shannon-Wiener diversity index (H) and Shannon's equitability (E_H) showed that repeated trampling by grazing cattle does affect neither grassland diversity, nor equitability. The results of this thesis support the assumption that biodiversity and green biomass production of Argentinean grasslands are positively influenced by repeated bunch trampling by grazing cattle and could be an option to improve management practices in local pastures.

1 Introduction

1.1 Grassland – use as pasture

Grassland ecosystems are distributed all over the world. They comprise natural and semi-natural grassland areas (Alkemade *et al*., 2013), which contribute to important ecosystem functions such as water storage and carbon sequestration, and serve as multifunctional biotope for floral and faunal biodiversity (Frame and Laidlaw, 2011). Grasslands are often used for livestock production as their high biodiversity offers an energy efficient feeding source for ruminants. The outputs in form of milk, wool, and meat provide a source of income for pastoral farmers. About half of the world's bovine meat production comes from grassland areas in tropical and subtropical countries (Jank *et al*., cited in McGilloway, 2005, page 69) with low external inputs (Humphreys, 1991). Growing populations, cities and demand for food supply and energy resources have triggered changes in the management of grasslands around the world (Alkemade *et al*., 2013). To preserve these grasslands and their biodiversity, sustainable use and management of these valuable areas is preferred and requires a reconsideration of existing farming methods (Savory, 1989). The approach of holistic farming combines the process of planning with the improvement of specific land use characterisations and qualities (Ikerd, 1993; Butterfield *et al*., 2006). According to Alkemade *et al*. (2013), an estimated number of 200 million pastoralists contribute to meat production from grassland used as pasture. The use of these grasslands as pasture with grazing cattle causes aboveground biomass relocation and biomass incorporation into deeper soil layers (Alkemade *et al*., 2013). Nomadic and semi-nomadic pastoralists therefore use grazing cattle as natural effectors to manage their grassland (Dickhoefer *et al*., 2010). This farming system imitates the behavior of large herds of wild grazing animals. Animals are held in temporary paddocks for a certain time, before being moved to a new paddock. In so doing, the potential of plant biomass re-growth increases, defoliation at certain times is prevented, and the issue of under- or overgrazing of pasture can be resolved (Voisin, 1959, cited in Humphreys, 1991, page 2). The idea of using a similar approach in commercial farming for livestock production in subtropical parts of South American grassland may open financially attractive opportunities for a more sustainable livestock production.

1.2 Grassland management in Argentina with focus on the province of Corrientes

Argentina, the second largest country of South America, extends over about 3.700 km from north to south and includes a large number of agro-ecological zones (FAOSTAT, 2005). Agricultural production is highly diverse with strong regional variations. Argentina covers approximately 70 % of the grassland areas of South America, including the regions of Patagonia, the Central Pampas and the Gran Chaco. Continuous rises in the export of beef, promoted by globally increasing meat consumption, resulted in the expansion of cattle production in these grasslands (INDEC, 2007). Hence in the northeast of Argentina, particularly in the grasslands of the Gran Chaco, which includes the northwest of the province of Corrientes, cattle are produced on natural pasture. Livestock farming, beside forestry and the cultivation of paddy rice is a main source of income for the local population (FAOSTAT, 2005).

The province of Corrientes is mainly flat, except for some hilly areas in its northern parts (Schinini *et al*., 2004). The different vegetation of the province of Corrientes is an example of high biodiversity. Three phyto-geographical regions have been described in Corrientes, i) *Espinal*, ii) *Paranaense* and, iii) *Oriental-Chaqueña* (Cabrera, 1976). One third of the area of the Province of Corrientes is covered by grassland on soils of low permeability and with periodic flooding due to heavy rains and dry summers (Canevari *et al*., 1999, Ligier, 2002). *Poaceae* species are the most dominant vegetation group, among which some bunch grasses and lawn grasses have a moderate to high nutrional value for ruminants (Schinini *et al*., 2004). Several species of the plant family of *Leguminosae* are also found there which have a higher protein content but lower aboveground biomass yields than the *Poaceae* species. Moreover, species of the family of *Cyperaceae* are widespread in these grasslands (Schinini *et al*., 2004). The composition of aboveground plant biomass and the botanical presence or absence of certain plant communities in grasslands depend not only on environmental factors such as soil moisture content, ambient temperature, soil organic matter content, but also on the intensity of grazing and herbage consumption by livestock (Milchunas and Lauenroth, 1993). In the traditional farming systems in Corrientes, cattle are kept in large paddocks at low stocking rates all year round with 0.5 animal unit (AU) per year per hectare (Carnevali, 1994; Calvi, 2010). Even though cattle continuously graze on a plot, after some time the herds are moved from one paddock to the other by “gauchos” (Whigham, 1988). This system is quite inefficient due to low stocking rates, medium to low grass productivity in winter, but high productivity in summer. As a result, overgrown dead plant material and woody, non-edible weeds accumulate every growing season in the grasslands of Corrientes. To eliminate unproductive plant biomass in these grasslands, fire is regularly used by ranch owners. However, this common practice to prevent re-growth of unwanted plants is only partly effective as fire resistent, unwanted grass species or forbs persist (Goldfarb *et al*., 2003).

1.3 Purpose of this thesis

The grasslands in the province of Corrientes are exemplary for natural pasture with variations in biodiversity. The botanical composition by species varies here from poor to high values of fodder quality. Generally speaking, variation in the composition of plant species contributes to the fodder selection for cattle and therefore also influences the value of the area as pasture for livestock (Schinini *et al*., 2004). The production of forage in the province of Corrientes is seasonal dependent, with maximum growth rates in late spring, summer, and autumn. The lowest grassland biomass production of the province occurs in wintertime (Sampedro, 2004). During dry summer vegetation periods, Corrientes grasslands accumulate standing dead biomass. This reduces re-growth and thus grassland productivity and leads to lower fodder availability and nutritional quality for livestock during wintertime. There is a need for high yielding grasslands with year-round grass productivity in order to feed the increasing number of cattle without decreasing feed stock (Kurtz *et al*., 2010; Ligier *et al*., 2002). Individual plant species respond differently to external influences (Hooper *et al*., 1997), but vegetation dynamics and nutrient redistribution in grasslands can be influenced by the intensity of cattle activity (Kurtz *et al*., 2010). Repeated bunch trampling by grazing cattle facilitates the absorption of favourable nutrients into the soil through defecation and urination, increases the return of organic carbon and nutrient-enriched compounds as well as plant seeds to the field, and promotes natural plant growth (McIntyre *et al*., 1992). Therefore, cattle activity can contribute to the growth of new plant biomass and to changes in the pasture’s plant composition to more digestible plant species (Shakhan *et al*., 2013; Rogers and Whalley, 1989). Intensive grazing strategies of densely held cattle in Argentina’s grassland in combination with bunch trampling have been proposed as an alternative grassland management option (Kurtz *et al*., 2013). So far, repeated bunch trampling by

grazing cattle has not yet been investigated in the grasslands of Northern Argentina, but could be an option to improve management practices in local pastures.
The objectives of this thesis, which was embedded in a two-year PhD - project, were to (1) identify botanical composition and diversity indices in the grasslands of Corrientes, (2) specify plant families and their species occurrence, (3) measure biomass of plant families and their species occurrence according to the proportion of standing green plant material, (4) investigate changes in species composition in terms of the number of grazing impacts (either 1 or 2 grazing impacts) and seasonal effects, and (5) evaluate ground coverage after one and two grazing impacts.

Argentinean grasslands and local livestock production play an important role as a source of income for pastoral farmers. The effect of repeated bunch trampling by grazing cattle may provide an alternative management practice for favourable changes on botanical composition of pastures in comparison to common management practice in Argentinean grasslands.
In relation to this assumption, the following four hypotheses were assessed.

- Species richness and diversity indices vary under the effect of repeated bunch trampling by grazing by cattle in terms of the grazing tretament *per se*, the number of grazing impacts, and the season.
- Repeated bunch trampling by grazing cattle in Corrientes grasslands leads to changes of functional plant groups, such as C_3- and C_4-species, annual and perennial species, and monocotyledon and dicocotyledon plants.
- Repeated bunch trampling by grazing cattle induces favourable changes in plant families and species compositions by increasing the growth of those plants considered as good to very good fodder plants.
- An increase of the proportion of standing green plant material and litter and a reduction of standing dead plant material and bare ground are a result of repeated bunch trampling by grazing cattle.

2 Materials and methods

2.1 Study site

The study was conducted on the research station Estación Experimental Agropecuaria Corrientes which belongs to the national institution INTA (Instituto Nacional de Tecnologia Agropecuaria). The experimental station is situated 30 km away from Corrientes, the capital city of the province, in the north-eastern part of Argentina and in the subtropical part of South America (Figure 1). Approximately 931.000 inhabitants live in the province with a population density of 10.6 /km^2.

Figure 1 Maps of Argentina and the location of the study site in the province of Corrientes. http://www.lateinamerika.de, modified.

Data collection took place during the summer months, from December 2013 until March 2014. Ambient air temperatures and monthly precipitations for the study period, which were measured at the meteorological station in the city of Resistencia, are shown in Figure 2. The mean ambient air temperature was 27 °C (Minimum temperature 17.9 °C / maximum temperature 33.8 °C) and the total precipitation was 556.2 mm during the data collection of these four months. The experiment was carried out on an area of 24 ha within the 1175 ha of the experimental station of INTA (27°40’23.27° S, 58°44’12.94° W, 63 m a.s.l.).

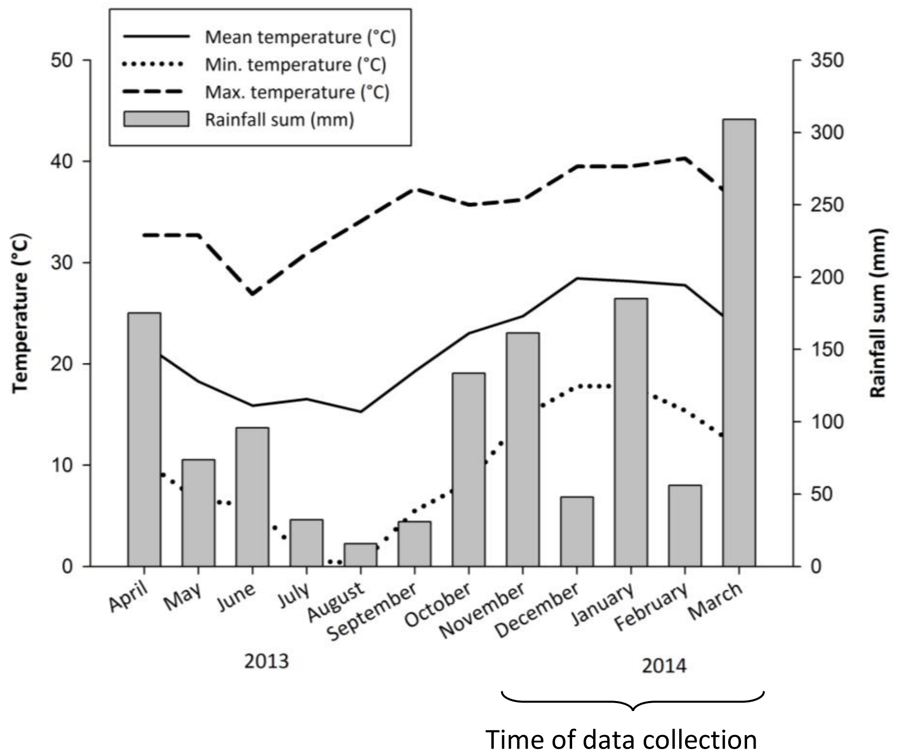


Figure 2 Temperature (°C) and rainfall sum (mm) from April 2013 until March 2014 on the experimental area.

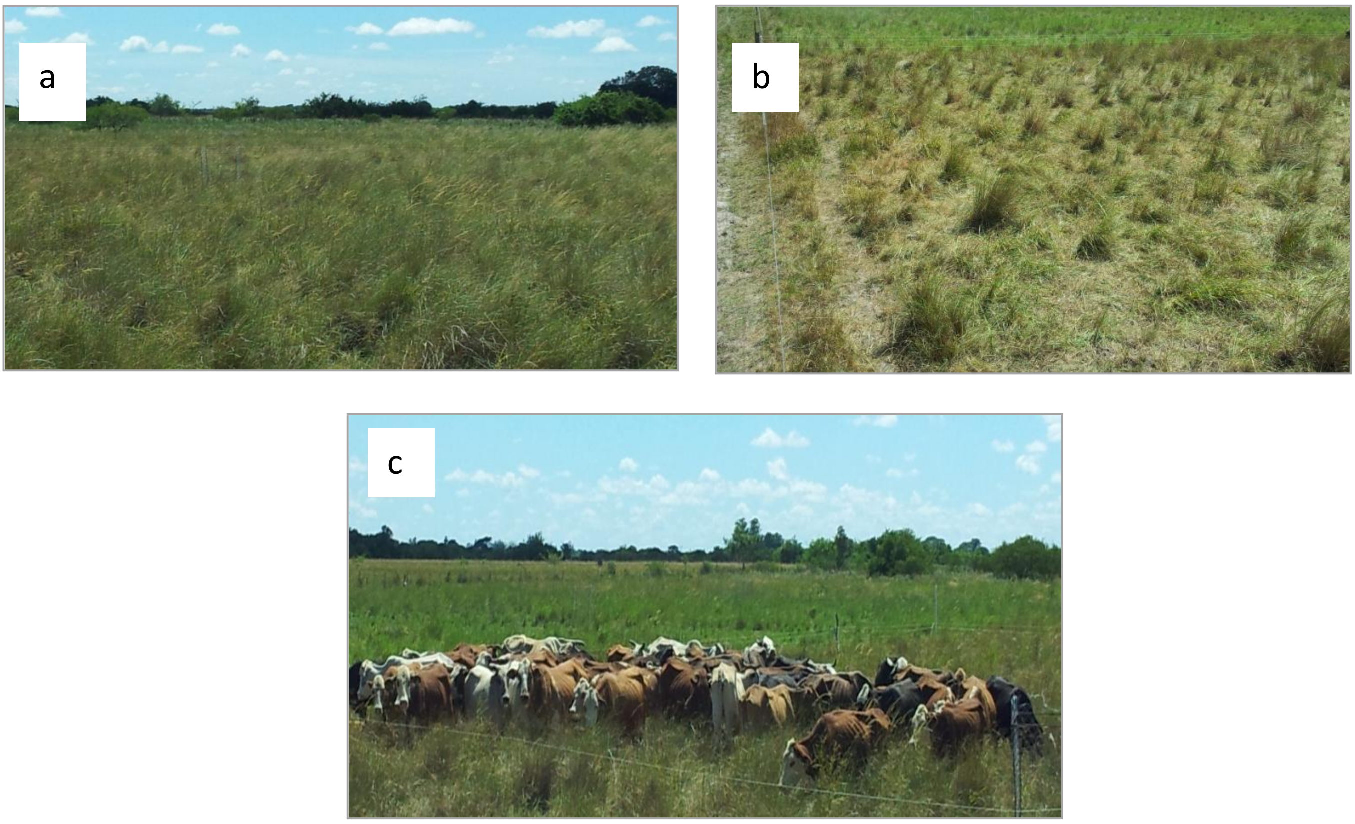
Soil characteristics of the experimental area are given in Table 1. They refer to the 30 cm of soil depth, which represents the main plant rooting depth on the experimental area (Escobar *et al.,* 1996).

Table 1 Characteristics of the soil type Treviño (based on the US. Land capability classification, Escobar *et al*., 1996).

Series	**Irrigation class**	**Effective deepness (cm)**	**Hill slope (%)**	**Capability class (Land suited to cultivation and other use)**	**Main limitation factors**	
Treviño	Moderate	65 cm	1-1.5 %	IIIe (III stands for limitation which reduce choice of plants, small e stands for risk of erosion)	Water erosion and water logging	
Particle analysis						
Horizon	**Depth (cm)**	**Organic Material (%)**	**Clay (%)**	**Loam (%)**	**Sand (%)**	**Silt (%)**
A1	0-17	1.72	11.6	21.5	64.7	2.2
A2	17-30	1.09	13.7	21.4	63.1	1.8
Nutrients						
Horizon	**Depth (cm)**	**Ca (meq/100g)**	**Mg (meq/100g)**	**K (meq/100g)**	**Na (meq/100g)**	**P (ppm)**
A1	0-17	3.5	2.9	0.1	0.3	1.3
A2	17-30	5.7	2.4	0.1	0.4	2.00

2.2 Experimental setting

The experimental area of the two-year PhD - project comprised four paddocks of 6 ha each that were surrounded with permanent fences (Figure 3). One of these paddocks was used as control and was subjected to the common management practice in the grasslands of Corrientes which involves low stocking rate of livestock farming. The remaining three paddocks were divided into 12 plots of 0.5 ha each and each representing an impact month. Three cattle were continuously grazing in the four paddocks. Around the 15th of every month one plot per paddock was subjected to repeated bunch trampling by grazing of 150 cattle ha $^{-1}$ day $^{-1}$. Bradford, Hereford and Braham cattle (the average weight of the cows was 232.8 kg) were introduced on one plot per paddock, temporarily fenced with mobile electronic wire fences for 3 days (Picture 1). Due to the herding effect of cattle, grassland biomass was either consumed by the cattle or incorporated into the soil through trampling. During the following month, another plot of each of the three paddocks was trampled down and grazed in the same manner, so that each 0.5 ha plot underwent a grazing impact once a year (Figure 3).



Picture 1 January plot, before (a) and after (b) the grazing impact in January 2014. Cattle introduced in impact month January in paddock P1, temporarily fenced with mobile electronic wire fences (c).

As the experiment started in July 2012, plot July was the first plot which underwent a grazing impact. In July 2013, plot July had a second grazing impact. By the time of the biodiversity assessments in February 2014, eight plots (those treated in July, August, September, October, November, December, January and February) had undergone two grazing impacts, whereas four plots (those treated in March, April, May and June) had undergone only one grazing impact.

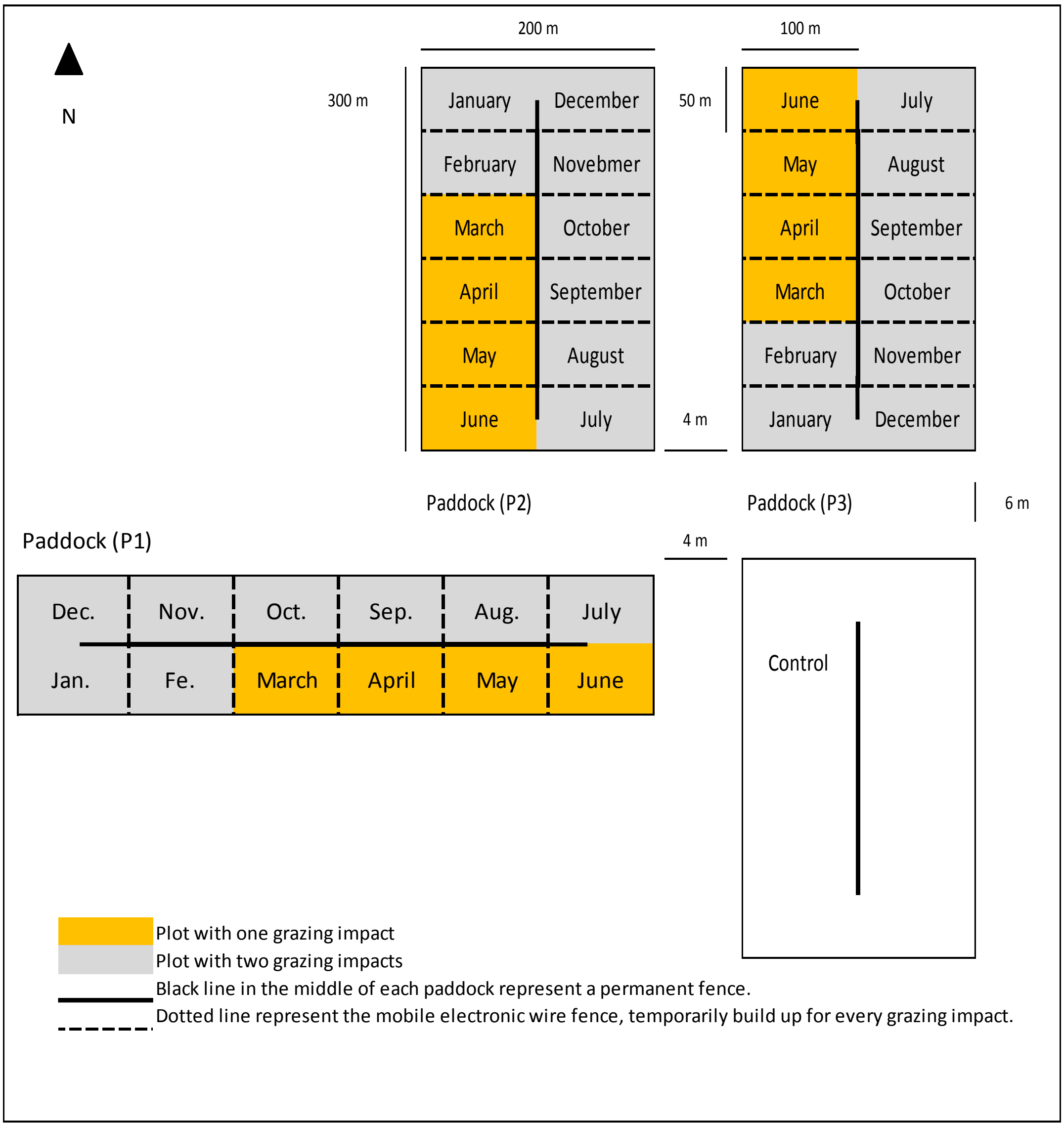


Figure 3 Experimental area with three paddocks that were subjected to grazing impacts by cattle (Paddock P1, P2 and P3) and one control paddock (Control) without grazing impacts. The month names represent the grazing cycle in the 12 plots (impact month) of each paddock, starting in impact month July, followed by August, September, October, November, December, January, February, March, April, May, and June.

2.3 Data collection

2.3.1 Transect assessment on plant composition

A first assessment of botanical composition of the grassland sward was conducted along transect lines, on both sides (approx. 1 m), on two diagonals of each 0.5 ha plot (n = 12) of every paddock for P1, P2 and P3, and on four randomly chosen fictive 0.5 ha plots within the control paddock. The two diagonals of 111.8 m each were directed from one edge of a plot to the opposite edge of the same plot (Figure 4). All present plant species were noted down in order to get a general overview of the botanical composition in the experimental area. The transect assessment was carried out during the period between 16.01.2014 and 31.01.2014 (for exact dates of transect recordings and plant species recording see Appendix Table A1 and Table A5).

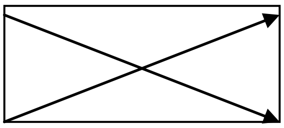


Figure 4 Method of transect recording: The two arrows illustrate the transect lines on two diagonals in a plot from one edge to the opposite edge of the plot.

2.3.2 Determination of the minimum area

The minimal sampling area (Picture 2) describes the smallest area size, which still covers enough plant species to represent the overall biodiversity in an area (Braun-Blanquet, 1951). With a view to determine the minimum sampling area for biodiversity assessments in the studied grassland, the number of sward plant species was counted in sampling areas of increasing area size, starting from 0.25 m^2 to 14 m^2 (Figure 5) and tested for significant differences between sampling areas and their species number ($p \leq 0.05$). The area size, from which no further

Picture 2 Minimum sampling area of 1 x 1 m^2.

increase of the total number of species (i.e. saturation point of species richness) occurs, represents the minimum area size needed for biodiversity monitoring, the so-called minimum area (Braun-Blanquet, 1951). The starting sampling area of 0.5 x 0.5 m^2 was increasingly extended and the largest sampling area tested for this study was 2 x 7 m^2 (Figure 2). For each sampling area size, three replicate measurements were conducted in impact month May and impact month October in the three paddocks subjected to animal grazing. Impact months May and October were chosen to compare plots, which underwent one grazing impact (impact month May) and two grazing impacts (impact month October) by the time of the biodiversity assessment. In the control paddock, which had no grazing impact, three replicate measurements were conducted in three randomly chosen fictive 0.5 ha plots. The determination of the minimal area was carried out between the 09.01.2014 and 15.01.2014 (for the exact dates of the minimum area recording and the number of sward plant species counted by increasing sampling area see Appendix Table A2 and Table A3).

Length	**Width**	**Area**
0.5 m	0.5 m	0.25 m^2
1 m	0.5 m	0.5 m^2
1 m	1 m	1 m^2
2 m	2 m	4 m^2
2 m	3 m	6 m^2
2 m	4 m	8 m^2
2 m	5 m	10 m^2
2 m	6 m	12 m^2
2 m	7 m	14 m^2

Table 2 Scale with increasing sampling area size to determine the minimum area (Ariza, 2013 modified).

2.3.3 Assessment of biodiversity and ground coverage

A rectangular frame of 8 m^2 was used for the ground coverage assessment of standing green plant material, standing dead plant material (%), litter (%), and bare ground (%) on the experimental area. Five samplings were carried out at randomly chosen places each within a 0.5 ha plot (n = 12) of the three paddocks subjected to grazing impacts of animals. In the control paddock without grazing impact, twenty samplings were carried out at randomly chosen places in fictive 0.5 ha plots. Standing green plant material (a), -standing dead plant material (b), -litter (d) and bare ground (c), were notated as seen in Picture 3:

Standing green plant material (%) + Standing dead plant material (%) + Bare ground (%) + Litter (%) = 100 % of ground coverage

Picture 3 Examples for standing green plant material (a), standing dead plant material (b), bare ground (c) and litter (d).

The assessment of plant species was carried out only for the present standing green plant material (%) on the experimental area (Picture 3 (a)). The plant species were recorded and their proportion of ground coverage with standing green plant material determined according to an assessment scale by Braun-Blanquet cited in Ariza (2013) in Table 3. Additionally, plant species sociability characteristics were recorded as described in Table 4.

Table 3 Assessment scale for the recording of present plant species in the experimental area.

Index	Proportion of ground coverage with standing green plant material of each plant species (%)
0.01	≤ 0.01 %
0.5	> 0.01 % and ≤ 1 %
1	> 1 % and ≤ 5 %
2	> 5 and ≤ 15 %
3	> 15 and ≤ 25 %
4	> 25 and ≤ 50 %
5	> 50 and ≤ 75 %
6	> 75 % and ≤ 100 %

Table 4 Assessment scale for sociability characteristics of individual plant species.

Index	Sociability
1	Individual plants grow solitary/by oneself
2	Individual plants grow intra-group, carpet like
3	Individual plants grow in plaits covering the soil surface
4	Individual plants grow in little colonies/bunches
5	Individual plants grow in big bunches, flocks

The assessment of biodiversity was carried out between the 16.01.2014 and 11.03.2014 (Table 5). The days after the last impact (DAI) were calculated considering the current date for the assessment of biodiversity in the impact month and the date of the grazing impact, the year before in 2013 and beginning of 2014 in the given impact month.

Table 5 Table with exact dates of the assessment of biodiversity in the three paddocks, subjected to grazing impacts by cattle (Paddock P1, P2 and P3) and in the control paddock without grazing impacts by cattle.

Dates of biodiversity recordings in paddocks (P1, P2 and P3 and control)			Impact month	Number of grazing impacts	Mean of days after last Impact	Season
16.01.2014 and 11./12.02.2014			Control	-	-	-
P1	P2	P3				
05.02.2014	03.02.2014	12.02.2014	July	2	206	Winter
06.02.2014	03.02.2014	13.02.2014	August	2	176	Winter
06.02.2014	04.02.2014	13.02.2014	September	2	146	Spring
06.02.2014	07.02.2014	13.02.2014	October	2	116	Spring
07.02.2014	10.02.2014	14.02.2014	November	2	87	Spring
07.02.2014	11.02.2014	14.02.2014	December	2	54	Summer
18.02.2014	24.02.2014	27.02.2014	June	1	253	Winter
19.02.2014	26.02.2014	27.02.2014	May	1	285	Autumn
24.02.2014	26.02.2014	27.02.2014	April	1	317	Autumn
04.03.2014	06.03.2014	11.03.2014	March	1	357	Autumn
07.03.2014	06.03.2014	06.03.2014	February	2	19	Summer
07.03.2014	11.03.2014	07.03.2014	January	2	52	Summer

Picture 4 Assessment of biodiversity and ground coverage in a sampling area.

2.3.4 Investigation of plant species

The plant species in the experimental area were recorded and grouped according to their plant type, origin, physiology, and life cycle. Species were thus categorized by cotyledon formation (monocotyledons and dicocotyledons), by their photosynthesis pathway (C_3- and C_4- species), or by their Crassulaceaen acid metabolism (CAM photosynthesis), and grouped into two types of life cycles (perennial and annual). Additionally, plant biomass of each grouped plant type was determined according to the proportion of ground coverage with standing green plant material.

2.3.5 Estimation of aboveground plant biomass

The aboveground plant biomass was cut at 1 cm height at two randomly chosen areas (each 1 m^2) in each plot of the impact months (n = 12) and the control paddock (n = 4).
Plant biomass was harvested, weighed, dried at 60 °C in a ventilated drying oven, and weighed again. Subsequently, dried biomass was sorted according to its green and dead plant material components to determine aboveground green and dead plant biomass within plots with grazing impacts at different times of the year as well as in the control. For this thesis, only the harvested aboveground plant biomass cut in February 2014 from the experimental area were included.

2.4 Calculations and statistical analyses

2.4.1 Shannon-Wiener index and Shannon's equitability

The Shannon-Wiener diversity index considers richness and evenness of individual (plant) species in an area (Holz, 2009). The Shannon-Wiener diversity index (*H*) is calculated as

$$H = \sum_{i=1}^{n} p_i \ln p_i$$

where n is the total number of species (i.e. species richness), p_i is the proportion of species *i* relative to the total number of species and ln is the natural logarithm.

To indicate how evenly different species are distributed within an area, the Shannon's equitability (E_H) also was calculated. Shannon's equitability (E_H) is defined as

$$E_H = H / \ln n$$

where n is the total number of species (i.e. species richness) in the community, *H* is the relative abundance of species, and ln is the natural logarithm.

2.4.2 Statistical analyses

A model was developed to test the effects of repeated bunch trampling by grazing cattle on the botanical composition. The experiment consisted of 24 ha of grassland paddocks split into 4 paddocks, of which three were subjected to repeated grazing impacts by cattle (P1, P2 and P3) and one control paddock remained without repeated grazing impacts by cattle (Figure 3). Each of the treated paddocks was divided into 12 plots that underwent a grazing impact at different times of the year. Due to the fact that these plots were not randomly arranged within each paddock but adjacent to each other and due to the fact that the control paddock was located at some distance away, a mixed model was required to fit serial and spatial variance covariance structure to compensate for autocorrelation (see for details Piepho *et al.*, 2004). Two additional random effects were taken into account: one was acknowledged through a serial autocorrelation (plots with a grazing cycle at different times of the year) with an auto-regressive covariance structure, and a second one was corrected for spatial auto-correlation by using a spherical covariance structure.

$$y_{ijkl} = \mu + Trt01_i + B_j + A_{jl} + S_{jl} + T_{ik} + IM_{ikl} + \epsilon_{ijkl},$$

where

y_{ijkl} = Average value of an individual plot for a given parameter,

μ = Overall mean,

$Trt01_i$ = Effect of the grazing treatment *per se* (control versus plots with grazing impacts)

B_j = Effect of paddock *j*,

A_{jl} = Effect of serial autocorrelation between plots,

S_{jl} = Effect of spatial autocorrelation between adjacent plots,

T_{ik} = Effect of the number of gazing impacts *k* nested in the treatment *per se*,

IM_{ikl} = Effect of the (grazing time) impact month, nested within the number of grazing impact *k* and grazing treatment *per se*,

ε_{ijkl} = Error term.

The effects B_j, A_{jl}, S_{jl} and the error term were considered random and all other effects were considered fixed.

Normality of residuals and homogeneity of error variances were checked visually. The level of significance used for testing fixed effects was α = 5 %.

Dependent variables such as standing green plant material (%) and standing dead plant material (%), as well as litter (%), and bare ground (%) were tested in the model. In addition, the harvested aboveground biomass of standing green plant biomass (t ha^{-1}) and of standing dead plant biomass (t ha^{-1}) were tested. The Shannon-Wiener diversity index (*H*), the Shannon's equitability index (E_H) and species richness (number of species) in the experimental area were also tested in the model.

Species abundance, categorised by cotyledon formation (monocotyledons and dicocotyledons), photosynthesis pathway (C_3- and C_4-species), and Crassulaceaen acid metabolism (CAM photosynthesis), were grouped into two types of life cycles (perennial and annual) and statistically tested as dependent variables under the effects of repeated bunch trampling by grazing cattle. Additionally, the plant biomass of each grouped plant type, determined by the proportion of ground coverage with standing green plant material, was tested as dependent variables under the effects of repeated bunch trampling by grazing cattle. Statistical analyses were performed with the software SAS (version 9.3).

3 Results

3.1 Minimum area

A sampling area of 8 m^2 was sufficient to determine the species richness in the experimental plots (i.e. the saturation point of species richness was reached). The species richness was significantly different ($p \leq 0.01$) in the areas of 0.25 m^2, 0.5 m^2, 1 m^2, 4 m^2 and 6 m^2, but not between 8 m^2, 10 m^2, 12 m^2 and 14 m^2 (Figure 5). In the plot that was subjected to grazing in impact month May and in the control, the species richness continuously increased with increasing sampling area from 0.25 m^2 to 8 m^2 and had a maximum of 50 species in 8 m^2. No further increase could be detected beyond an area of 8 m^2. Similarly, in the plot subjected to grazing in impact month October, no further increase in the species richness beyond 41 species could be detected, when the sampling area was greater than 8 m^2. Plant material, ground coverage, and biodiversity in this study were therefore investigated in an area of 8 m^2.

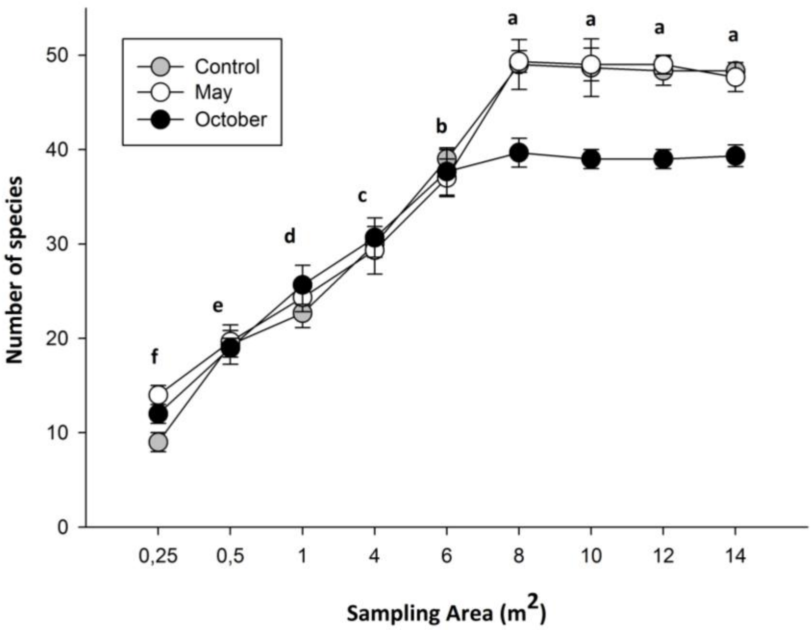


Figure 5 The number of species depending on the sampling area to determine the saturation point of species richness. Means ± standard deviations (n = 3) of species richness in the impact months May and October, subjected to grazing impacts by cattle and in the control without grazing impacts. Means with different letters are significantly different at $p \leq 0.05$. The data was determined between 09.01.2014 and 15.01.2014.

3.2 Ground coverage

The proportion of standing green plant material (%), as shown in Table 6, is significantly different for the grazing treatment *per se* ($p < 0.001$). The mean of standing green plant material (SGM) in the control was 25.0 ± 8.3 % compared to the mean of all impact months of 67.3 ± 16.6 %. Additionally, the number of grazing impacts had a significant effect on the proportion of SGM ($p < 0.001$). Impact months March, April, May, and June, which underwent one grazing impact resulted in the high SGM (SGM > 77.6 %) in comparison to all impact months, which underwent two grazing impacts. The only exception can be seen for impact month August with 78.2 ± 9.6 % of SGM in Table 7.
The proportion of SGM for the grazing time (impact month) also had a significant effect ($p < 0.001$). Impact month February and the control had much lower SGM (February 18.8 ± 5.9 %, control 25 ± 8.3 %) compared to all other impact months at different times of the year (Table 7).

The proportion of standing dead plant material (%) was significantly different for the grazing treatment *per se* ($p < 0.001$). The mean of standing dead material (SDM) in the control was 66.7 ± 13 % compared to the mean of all impacts months of 13.8 ± 10.7 %. The number of grazing effects also revealed significant differences between impact months with one or two grazing impacts ($p < 0.01$). The mean of SGM for the four impact months (impact month March, April, May, and June) with only one grazing impact was 6.7 ± 1.1 % in comparison to the impact months with two grazing impacts, which had a mean of 16 ± 12.5 %. The proportion of SDM for the grazing time (impact month) revealed additonally sigificant differenes ($p < 0.001$). As shown in Table 7, the control with 66.7 ± 13 % of SDM and the SDM in impact month February (45.1 ± 4.6 %) differed significantly from all other impact months. Impact month October had the lowest proportion of SDM (4.4 ± 0.8 %) and differed significantly from the impact months with SDM higher than 16.2 %, such as impact months January, Feburary, July, and December, and from the control (66.7 ± 13.0 %).

The proportion of ground coverage by litter had no significant effect for the grazing treatment *per se* ($p = 0.301$). The number of grazing impacts had a small but significant effect on the proportion of the ground coverage of litter ($p = 0.046$). The mean of ground coverage by litter in the impact months March, April, May, and June, which underwent one grazing impact, was with 11.8 ± 1.9 % smaller compared to the mean of ground coverage by litter in the impact months with two grazing impacts (17.4 ± 8.3 %). In terms of the grazing time (impact month) (Table 7), only impact month February differed significantly with 35.3 ± 9.0 % of ground coverage by litter from all other impact months.

The proportion of bare ground was very low (< 3.5 %) in all impact months at different times of the year (Table 7), except for the impact months of October and November. The control had the lowest proportion of bare ground (0.1 ± 0.2 %). Neither the grazing treatment *per se* (p = 0.400), nor the number of grazing impacts (p = 0.335) were significantly different. Significant differences were only revealed between impact months (p < 0.001)**.** The proportion of bare ground in impact month October (15.6 ± 5.6 %), followed by the impact month November (12.9 ± 8.9 %), differed significantly from all other impact months and the control (p < 0.001).

Table 6 P-values of the effect of the grazing treatment *per se*, the number of grazing impacts and the impact month on the proportion of standing green plant material, standing dead plant material, litter, and bare ground (%), as determined during the time between January and March 2014 (see Table 5).

Effect	**Standing green plant material (%)**	**Standing dead plant material (%)**	**Litter (%)**	**Bare ground (%)**
Grazing treatment *per se*	< 0.001 ***	< 0.001 ***	0.301 ns	0.400 ns
Number of grazing impacts	< 0.001 ***	< 0.01 **	0.046 *	0.335 ns
Impact month	< 0.001 ***	< 0.001 ***	< 0.022 *	< 0.001 ***

Significance level: * p ≤ 0.05; ** p ≤ 0.01; *** p ≤ 0.001; ns > 0.05.

Table 7 Means ± standard deviations of standing green plant material, standing dead plant material, litter, and bare ground (%) at varying days after impact.

Days after impact	Impact month	Number of grazing impacts	Standing green plant material (%)	Standing dead plant material (%)	Litter (%)	Bare ground (%)
-	Control	-	25.0 ^{d} ± 8.3	66.7 ^{a} ± 13.0	8.3 ^{b} ± 5.0	0.1 ^{b} ± 0.2
19	February	2	18.8 ^{d} ± 5.9	45.1 ^{b} ± 4.6	35.4 ^{a} ± 9.0	0.7 ^{b} ± 0.2
52	January	2	67.4 ^{ac} ± 7.8	16.2 ^{ce} ± 6.1	15.7 ^{b} ± 2.2	0.7 ^{b} ± 0.4
54	December	2	62.8 ^{bc} ± 9.7	18.5 ^{cd} ± 8.0	17.6 ^{b} ± 2.9	1.1 ^{b} ± 0.5
87	November	2	67.8 ^{ac} ± 6.5	10.3 ^{cf} ± 5.2	9.0 ^{b} ± 5.7	12.9 ^{a} ± 8.9
116	October	2	59.8 ^{c} ± 4.0	4.4 ^{f} ± 0.8	20.2 ^{b} ± 4.2	15.6 ^{a} ± 5.6
146	September	2	71.6 ^{ac} ± 16.1	8.4 ^{def} ± 3.4	19.4 ^{b} ± 12.8	0.6 ^{b} ± 0.4
176	August	2	78.2 ^{a} ± 9.6	11.2 ^{def} ± 5.9	9.7 ^{b} ± 4.7	0.9 ^{b} ± 0.8
206	July	2	67.8 ^{ac} ± 4.0	20.1 ^{c} ± 7.3	12.2 ^{b} ± 5.4	0.2 ^{b} ± 0.3
253	June	1	78.3 ^{a} ± 1.5	5.1 ^{ef} ± 1.5	13.2 ^{b} ± 3.2	3.4 ^{b} ± 1.2
285	May	1	77.6 ^{ab} ± 2.9	7.0 ^{def} ± 1.2	12.2 ^{b} ± 3.7	3.2 ^{b} ± 2.5
317	April	1	77.9 ^{a} ± 4.1	7.8 ^{def} ± 3.3	12.9 ^{b} ± 0.8	1.4 ^{b} ± 0.5
357	March	1	80.4 ^{a} ± 3.2	7.2 ^{def} ± 0.4	9.0 ^{b} ± 4.0	3.4 ^{b} ± 1.2

Means with different letters are significantly different at $p \leq 0.05$.

3.3 Harvested aboveground plant biomass

Standing green plant biomass (t ha^{-1}, dry biomass) did not differ for the grazing treatment *per se*, as harvested in February 2014 (Table 8). The standing green plant biomass ranged between 1.2 ± 0.5 t ha^{-1} and 2.6 ± 0.06 t ha^{-1} for the grazing time (impact month). The control revealed 5.4 ± 4.3 t ha^{-1}. There was neither a significant effect for the number of grazing impacts, nor for the grazing time (impact month).

In contrast, standing dead plant biomass (t ha^{-1}, dry biomass) differed for the grazing treatment *per se* ($p < 0.001$). The mean of the control (11.6 ± 2.3 t ha^{-1}) was distinctly higher compared to the mean of the impact months (2.4 ± 1.0 t ha^{-1}). Neither the number of grazing impacts nor the grazing time (impact months) had a significant effect on the proportion of standing dead plant biomass (Table 8, Figure 6).

Table 8 P-values of the effect of the grazing treatment *per se*, the number of grazing impacts and the impact month on the proportion of standing green plant biomass and standing dead plant biomass (t ha^{-1}, dry biomass), as determined during the time between January and March 2014 (see Table 5).

Effect	**Standing green plant biomass (t ha^{-1})**	**Standing dead plant biomass (t ha^{-1})**
Grazing treatment *per se*	0.296 ns	< 0.001 ***
Number of grazing impacts	0.571 ns	0.417 ns
Impact month	0.252 ns	0.241 ns

Significance level: * p ≤ 0.05; ** p ≤ 0.01; *** p ≤ 0.001; ns > 0.05.

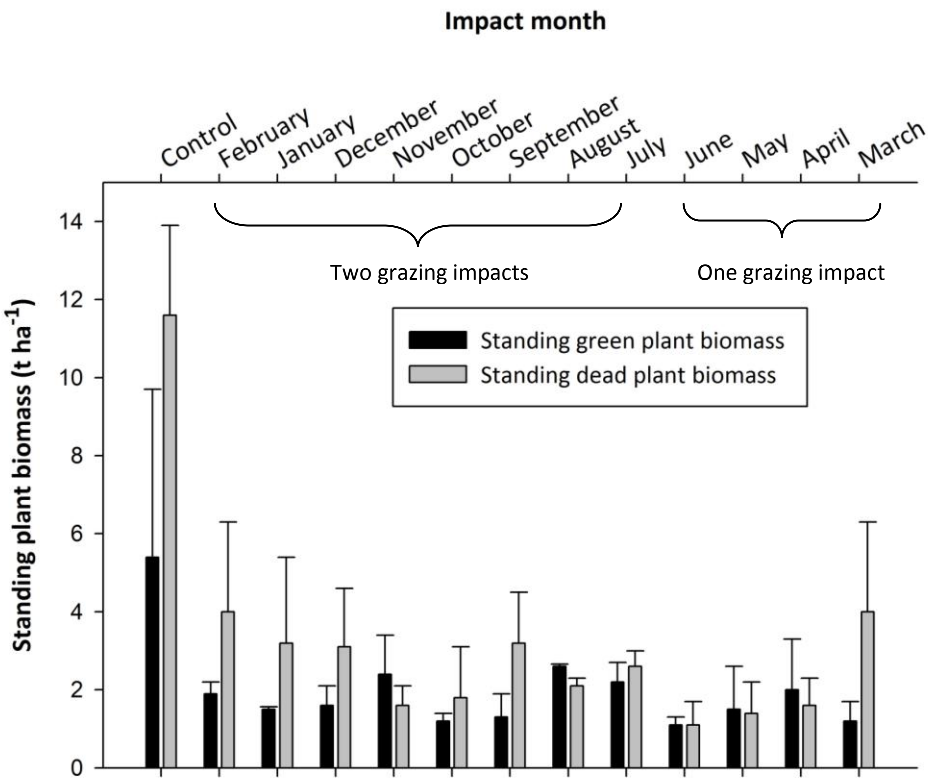


Figure 6 Standing green plant biomass and standing dead plant biomass (t ha^{-1}, dry biomass) in control and impact months subjected to grazing impacts by cattle as harvested in February 2014. Whiskers indicate the standard deviation. Means for standing green plant biomass and standing dead plant biomass were not significantly different at $p \leq 0.05$.

3.4 Biodiversity

3.4.1 Biodiversity parameter

3.4.1.1 Species richness

As shown in Table 10, the highest species richness was recorded for impact month June (n = 51.7 ± 7.7), followed by impact month March (n = 50.0 ± 6.5), and the control (n = 48.0 ± 6.9). The lowest species richness was found in impact month February (n = 22.3 ± 5.4). However, the number of species was neither significantly different for the grazing treatment *per se,* nor for the number of grazing impacts, nor for the grazing time (impact month).

3.4.1.2 Shannon-Wiener index and Shannon's equitability

The Shannon-Wiener diversity index (H) did not reveal any difference for the grazing treatment *per se* ($p = 0.946$). The number of grazing impacts differed significantly between impact months which were subjected to either one or two grazing impacts ($p < 0.018$). Mean of H of impact months March, April, May, and June ($H = 2.7 \pm 0.1$), which underwent one grazing impact was higher, in comparison to mean of $H = 2.3 \pm 0.2$ of all impact months with two grazing impacts (Table 10). H was the lowest in impact month February ($H = 1.8 \pm 0.3$) but not significantly different from all other impact months ($p = 0.221$).
The Shannon's equitability (E_H) did not reveal any difference for the grazing treatment *per se* ($p = 0.587$). The number of grazing impacts differed significantly between impact months which were subjected to either one or two grazing impacts ($p = 0.029$). The mean of E_H was higher for the impact months of one grazing impact ($E_H = 0.7 \pm 0.01$) compared to the mean of the months with two grazing impacts ($E_H = 0.5 \pm 0.03$). The E_H was the lowest in impact month February ($E_H = 0.5 \pm 0.07$) but not significantly different from all other impact months ($p = 0.631$).

Table 9 P-values of the effect of the grazing treatment *per se*, the number of grazing impacts and the impact month on the Shannon-Wiener index (richness, diversity (*H*), and equitability (E_H), as determined during the time between January and March 2014 (see Table 5).

Effect	Richness	*H*	E_H
Grazing treatment *per se*	0.420 ns	0.946 ns	0.587 ns
Number of grazing impacts	0.066 ns	0.018 *	0.029 *
Impact month	0.231 ns	0.221 ns	0.631 ns

Significance level: * p ≤ 0.05; ** p ≤ 0.01; *** p ≤ 0.001; ns > 0.05.

Table 10 Means ± standard deviations of the Shannon-Wiener index (richness, diversity (*H*) and equitability (E_H) at varying days after impact.

Days after impact	Impact month	Number of grazing impacts	Richness	*H*	E_H
-	Control	-	48.0 ± 6.9	2.6 ± 0.3	0.6 ± 0.06
19	February	2	22.3 ± 5.4	1.8 ± 0.3	0.5 ± 0.07
52	January	2	42.0 ± 5.4	2.5 ± 0.1	0.6 ± 0.001
54	December	2	43.0 ± 6.0	2.4 ± 0.1	0.6 ± 0.04
87	November	2	43 ± 6.1	2.6 ± 0.2	0.6 ± 0.04
116	October	2	36.3 ± 5.3	2.5 ± 0.2	0.6 ± 0.03
146	September	2	36.3 ± 5.3	2.4 ± 0.1	0.6 ± 0.07
176	August	2	40.7 ± 7.2	2.4 ± 0.2	0.6 ± 0.06
206	July	2	44.3 ± 7.2	2.5 ± 0.3	0.6 ± 0.05
253	June	1	51.7 ± 7.7	2.9 ± 0.1	0.7 ± 0.01
285	May	1	45.7 ± 7.8	2.8 ± 0.2	0.7 ± 0.03
317	April	1	44.0 ± 7.7	2.6 ± 0.3	0.7 ± 0.03
357	March	1	50.0 ± 6.5	2.7 ± 0.1	0.7 ± 0.05

Means for richness, *H* and E_H were not significantly different at p ≤ 0.05**.**

3.4.1.3 Plant species characteristics and biomass composition

There was a high abundance of species with a perennial life cycle and a low abundance of species with an annual life cycle (Figure 7). For the abundance of perennial plants, neither a significant difference was found for the grazing treatment *per se*, nor between the number of grazing, nor for the grazing time (impact month).

For the abundance of species with an annual life cycle, there was a significant difference among impact months (p = 0.047). Impact month February (n = 0.3 ± 0.6) differed significantly from the impact months March, June, August, September, November, and December, and the control (Figure 7).

Table 11 P-values of the effect of the grazing treatment *per se*, the number of grazing impacts and the impact month on the abundance of annual and of perennial species (Number of species), as determined during the time between January and March 2014 (see Table 5).

Effect	**Annual species (Number of species)**	**Perennial species (Number of species)**
Grazing treatment *per se*	0.369 ns	0.648 ns
Number of grazing impacts	0.944 ns	0.081 ns
Impact month	0.047 *	0.266 ns

Significance level: * p ≤ 0.05; ** p ≤ 0.01; *** p ≤ 0.001; ns > 0.05.

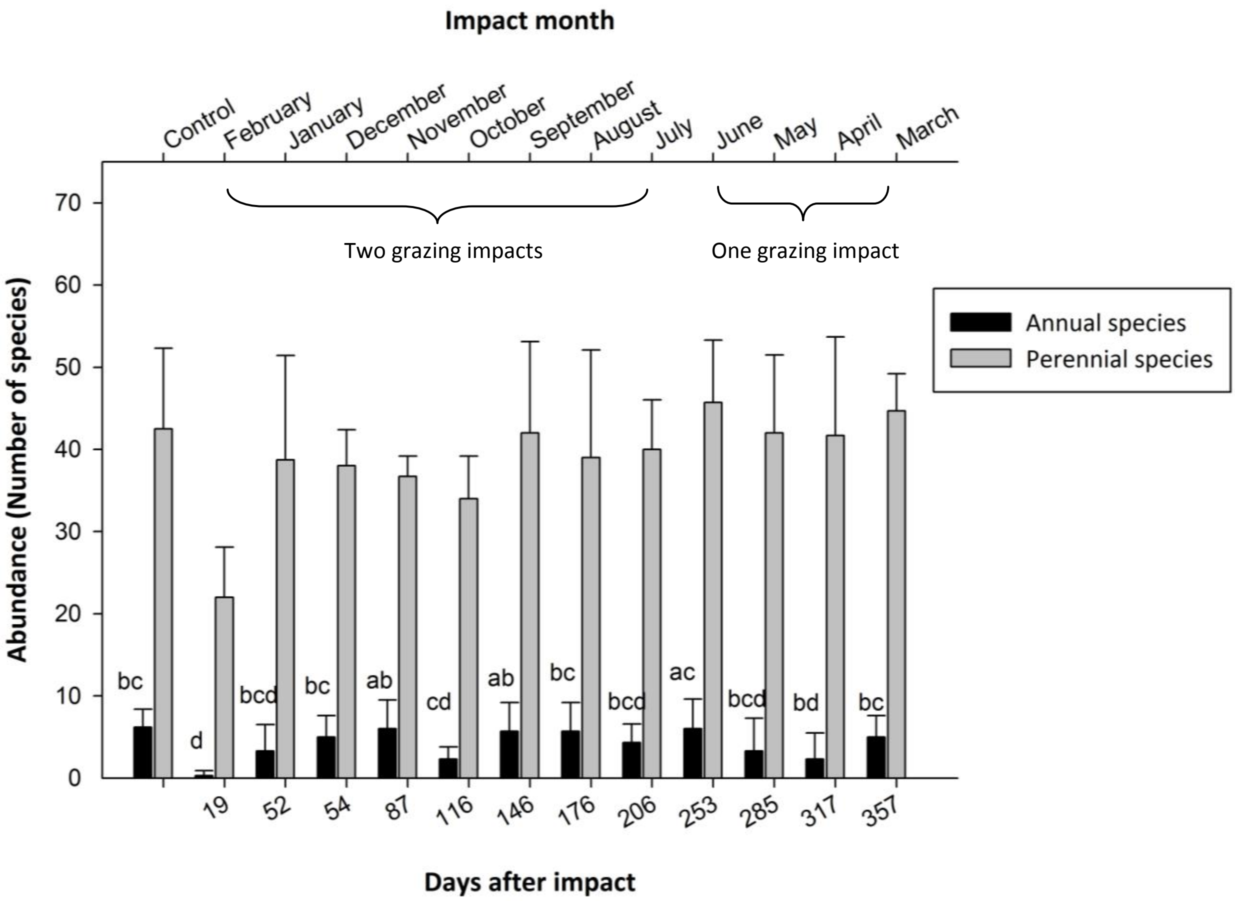


Figure 7 Species composition of annual and perennial species, based on their abundance (number of species) in control and in impact months subjected to grazing impacts by cattle at varying days after impact. Whiskers indicate the standard deviation. Means for annual species with different letters are significantly different at p ≤ 0.05**.** Means for perennial species were not significantly different at p ≤ 0.05**.**

In terms of the abundance of monocotyledon plants, there was neither a significant difference found for the grazing treatment *per se*, nor in the number of grazing impacts (Table 12). In terms of the grazing time (impact month), there was a significant difference (p = 0.023). Impact month February (n = 13.0 ± 3.6) differed significantly from impact months January, March, and June (n = 21.0 ± 4.3, n = 25.0 ± 1.7 and n = 24.3 ± 4.1).

In terms of the abundance of dicocotyledon plants, there was neither a significant difference found for the grazing treatment *per se*, nor in the number of grazing impacts, nor for the grazing time (impact month).

Table 12 P-values of the effect of the grazing treatment *per se*, the number of grazing impacts and the impact month on the abundance of Monocotyledons and Dicocotyledons (number of species), as determined during the time between January and March 2014 (see Table 5).

Effect	**Monocotyledons (Number of species)**	**Dicocotyledons (Number of species)**
Grazing treatment *per se*	0.289 ns	0.866 ns
Number of grazing impacts	0.578 ns	0.212 ns
Impact month	0.023 *	0.806 ns

Significance level: * p ≤ 0.05; ** p ≤ 0.01; *** p ≤ 0.001; ns > 0.05.

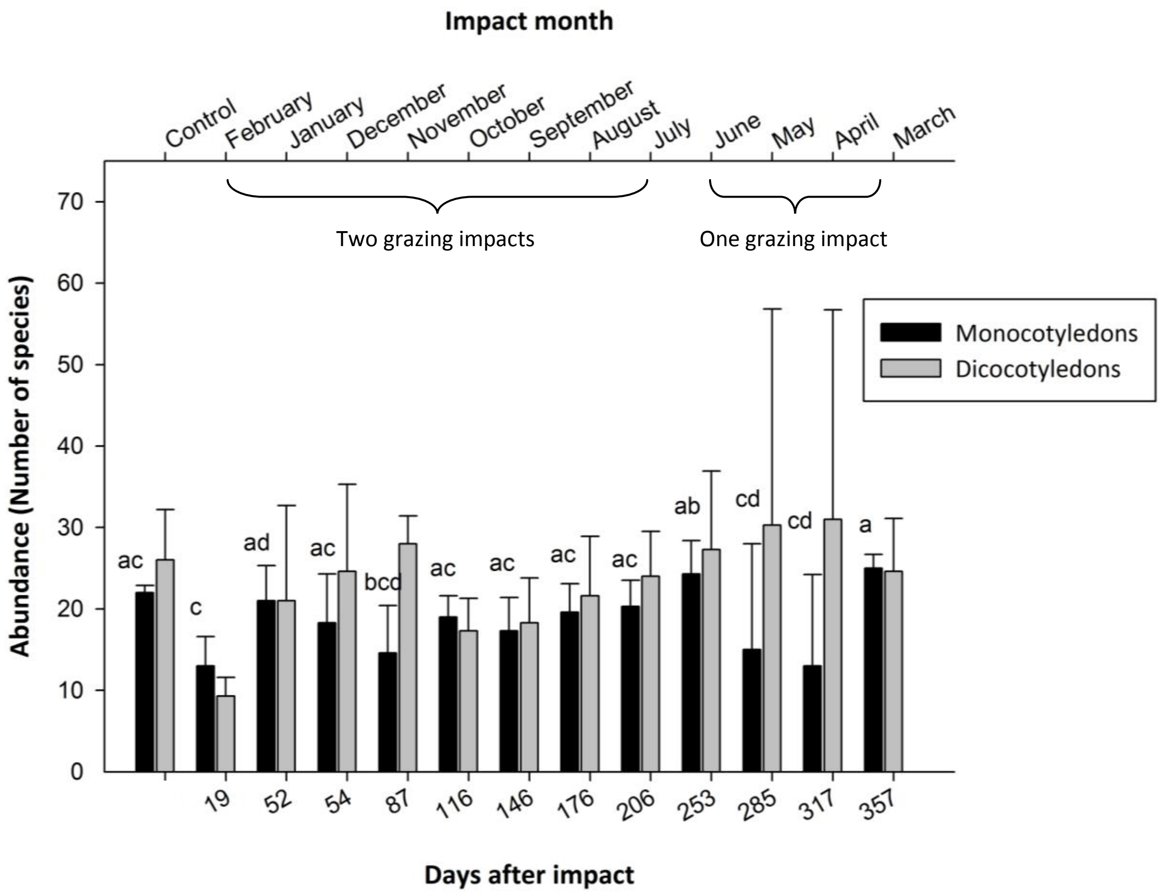


Figure 8 Species composition of Monocotyledons and Dicocotyledons, based on their abundance (number of species) in control and in impact months subjected to grazing impacts by cattle at varying days after impact. Whiskers indicate the standard deviation. Means for Monocotyledons with different letters are significantly different at p ≤ 0.05**.** Means for Dicocotyledons were not significantly different at p ≤ 0.05**.**

The abundance of C_3-, C_4- and CAM-species was neither significantly different for the grazing treatment *per se*, nor in the number of grazing impacts, nor for the grazing time (impact month).

Table 13 P-values of the effect of the grazing treatment *per se*, the number of grazing impacts and the impact month on the abundance of C_3-, C_4- and CAM-species (number of species), as determined during the time between January and March 2014 (see Table 5).

Effect	**C_3- species (Number of species)**	**C_4-species (Number of species)**	**CAM- species (Number of species)**
Grazing treatment *per se*	0.716 ns	0.279 ns	0.768 ns
Number of grazing impacts	0.139 ns	0.062 ns	1.000 ns
Impact month	0.337 ns	0.363 ns	0.277 ns

Significance level: * p ≤ 0.05; ** p ≤ 0.01; *** p ≤ 0.001; ns > 0.05.

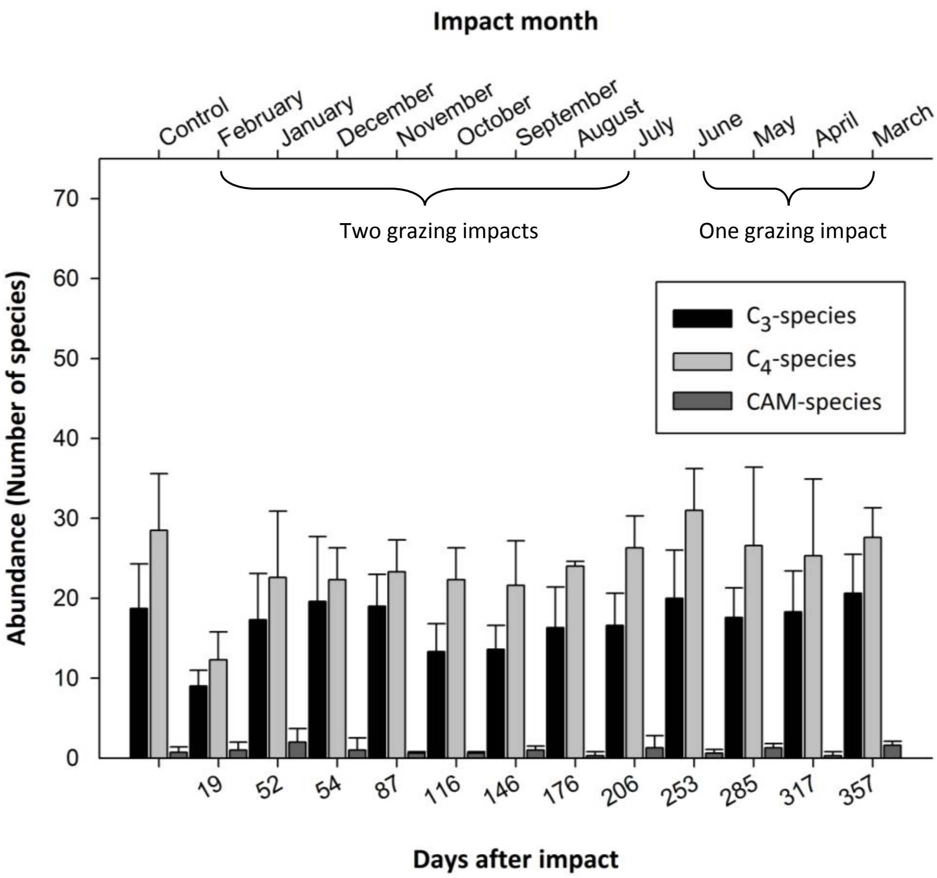


Figure 9 Species composition of C_3-, C_4- and CAM-species, based on their abundance (number of species) in control and in impact months subjected to grazing impacts by cattle at varying days after impact. Whiskers indicate the standard deviation. Means for C_3-, C_4- and CAM-species were not significantly different at $p \leq 0.05$.

Plant groups were analysed in order to determine variations in their proportion of ground coverage with standing green plant material (SGM, in %) with respect to the days which had passed since the last grazing impact in 2013 and at the beginning of 2014 (DAI).

For annual species, there was no significant difference found, neither for the grazing treatment *per se*, nor for the number of grazing impacts, nor for the grazing time (impact month, Table 14).

The proportion of SGM of perennial species was found to be higher than 60 % (Figure 10) for all impact months, except for impact month February (DAI 19) and the control, which differed significantly ($p < 0.001$) from all other impact months. Impact month March (DAI 357) revealed the highest proportion in perennial species in SGM with 78.9 ± 1.6 %, and differed significantly from all impact months, except for impact months April (DAI 317), May (DAI 285), and August (DAI 176). In terms of the number of grazing impacts, the mean of SGM in impact months with one grazing impact was with 75.1 ± 2.7 % higher than in impact months with two grazing impacts (56.3 ± 17.6 %), and they differed significantly ($p < 0.01$).

Table 14 P-values of the effect of the grazing treatment *per se*, the number of grazing impacts and the impact month on the proportion of standing green plant material (%) of annual and perennial species, as determined during the time between January and March 2014 (see Table 5).

Effect	**Standing green plant material of Annual species (%)**	**Standing green plant material of Perennial species (%)**
Grazing treatment *per se*	0.279 ns	< 0.001 ***
Number of grazing impacts	0.062 ns	< 0.01 **
Impact month	0.746 ns	< 0.001 ***

Significance level: * $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.001$; ns > 0.05.

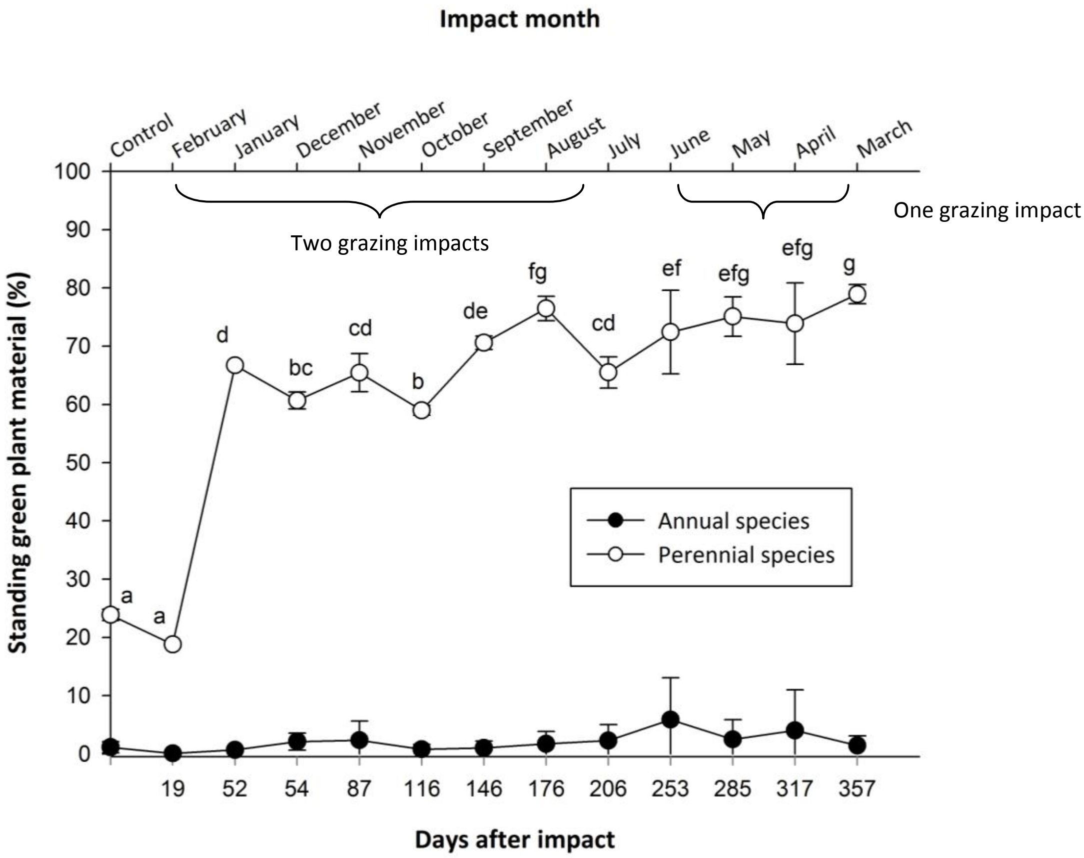


Figure 10 Species composition of annual and perennial species, based on their standing green plant material (%) in control and in impact months subjected to grazing impacts by cattle at varying days after impact. Whiskers indicate the standard deviation. Means with different letters for perennial species are significantly different at p ≤ 0.05. Means for annual species were not significantly different at p ≤ 0.05.

The proportion of SGM of monocotyledon plants (> 45 %) was higher than that of the SGM of dicocotyledon plants. Lower proportions of SGM of monocotyledon plant are indicated in Figure 11 in impact month February (DAI 19, 17.8 ± 0.6 %) and control (17.4 ± 1.6 %), which differed significantly from all other impact months ($p < 0.001$). The mean of SGM in impact months with one grazing impact was with 65.1 ± 5.2 % higher and differed significantly ($p < 0.022$) from the SGM of the impact months with two grazing impacts (51.8 ± 14.75 %).
For the proportion of SGM of dicocotyledon plants, no significant difference was revealed for the grazing treatment *per se*, neither for the number of grazing impacts, nor for the grazing time (impact month).

Table 15 P-values of the effect of the grazing treatment *per se*, the number of grazing impacts and the impact month on the proportion of standing green plant material (%) of Monocotyledons and Dicocotyledons, as determined during the time between January and March 2014 (see Table 5).

Effect	**Standing green plant material of Monocotyledons (%)**	**Standing green plant material of Dicocotyledons (%)**
Grazing treatment *per se*	0.013 *	0.545 ns
Number of grazing impacts	0.022 *	0.463 ns
Impact month	< 0.001 ***	0.587 ns

Significance level: * p ≤ 0.05; ** p ≤ 0.01; *** p ≤ 0.001; ns > 0.05.

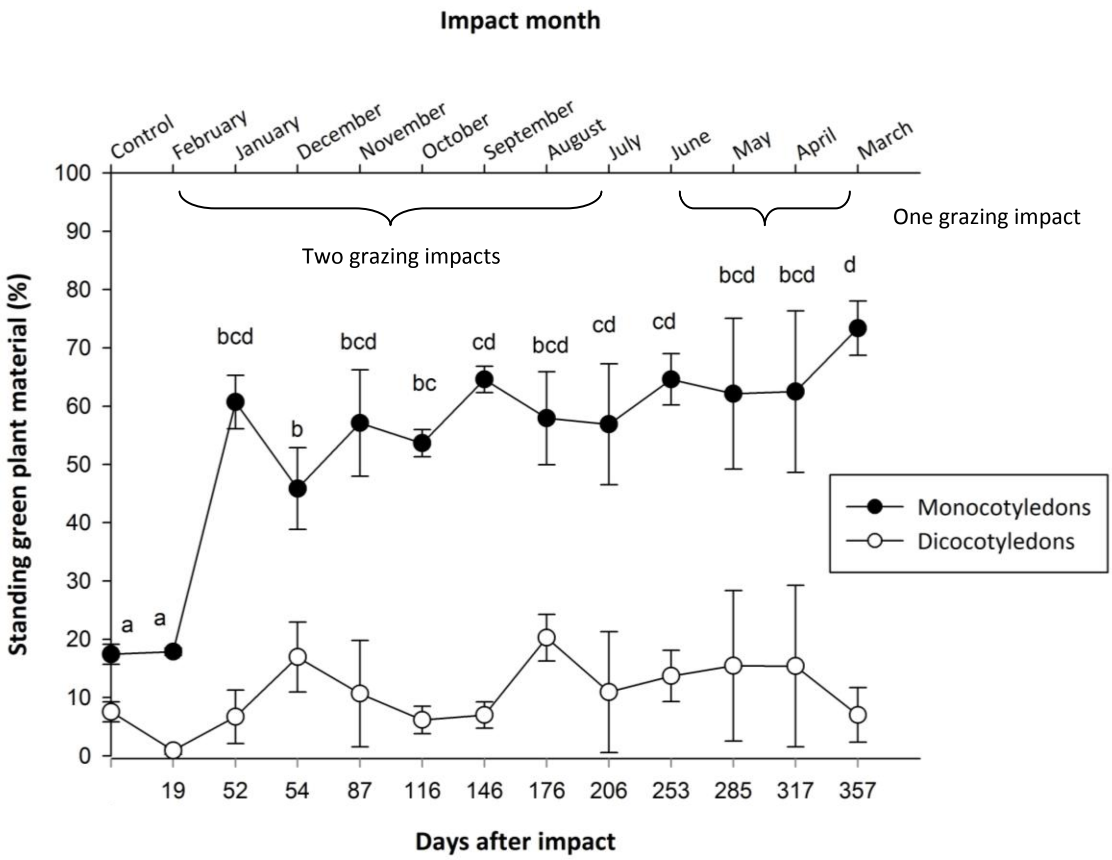


Figure 11 Species composition of Monocotyledons and Dicocotyledons, based on their standing green plant material (%) in control and in impact months subjected to grazing impacts by cattle at varying days after impact. Whiskers indicate the standard deviation. Means with different letters for Monocotyledons are significantly different at p ≤ 0.05. Means for Dicocotyledons were not significantly different at p ≤ 0.05.

The proportion of SGM of C_4-species differed significantly for the grazing treatment *per se* and their DAI ($p = 0.011$). The mean of SGM of the impact months of 44.8 ± 13.1 % was higher than the SGM in the control (12.6 ± 4.6 %). The mean of SGM of C_4-species in impact months with one grazing impact was with 54.4 ± 2.0 % higher than in impact months with two grazing impacts (40.03 ± 5.35 %) and differed significantly ($p < 0.012$). Grazing time (imapct month) differed for the proportion of SGM of C_4-species in impact month February (10.7 ± 5.4 % , DAI 19) and for the proportion of SGM in the control (12.6 ± 4.6 %) from all other impact months.

The proportion of SGM of C_3-species varied for the grazing time (impact months). Impact month February (DAI 19) differed significantly from all other impact months ($p = 0.046$) with 7.9 ± 5.3 % of SGM. SGM in impact months March, April, July, August and December differed significantly from impact month February and the control. Moreover, SGM in impact month December (32.1 ± 8.0 %) also differed significantly from impact month October, November, February, and control. The number of grazing impacts ($p = 0.624$) and the grazing treatment *per se* did not have an significant effect of the SGM of C_3-species ($p = 0.643$).

The SGM (%) of CAM-species was neither significantly different for the grazing treatment *per se* ($p = 0.576$), nor for the number of grazing impacts ($p > 0.677$), nor for the grazing time (impact month, $p = 0.587$), and never reached higher proportions of SGM than 0.5 ± 0.6 % in impact month January (DAI 52).

Table 16 P-values of the effect of the grazing treatment *per se*, the number of grazing impacts and the impact month on the proportion of standing green plant material (%) of C_3-, C_4,- and CAM-species, as determined during the time between January and March 2014 (see Table 5).

Effect	Standing green plant material of C_3-species (%)	Standing green plant material of C_4-species (%)	Standing green plant material of CAM-species
Grazing treatment *per se*	0.643 ns	0.011 *	0.576 ns
Number of grazing impacts	0.624 ns	0.012 *	0.677 ns
Impact month	0.046 *	< 0.001 ***	0.587 ns

Significance level: * p ≤ 0.05; ** p ≤ 0.01; *** p ≤ 0.001; ns > 0.05.

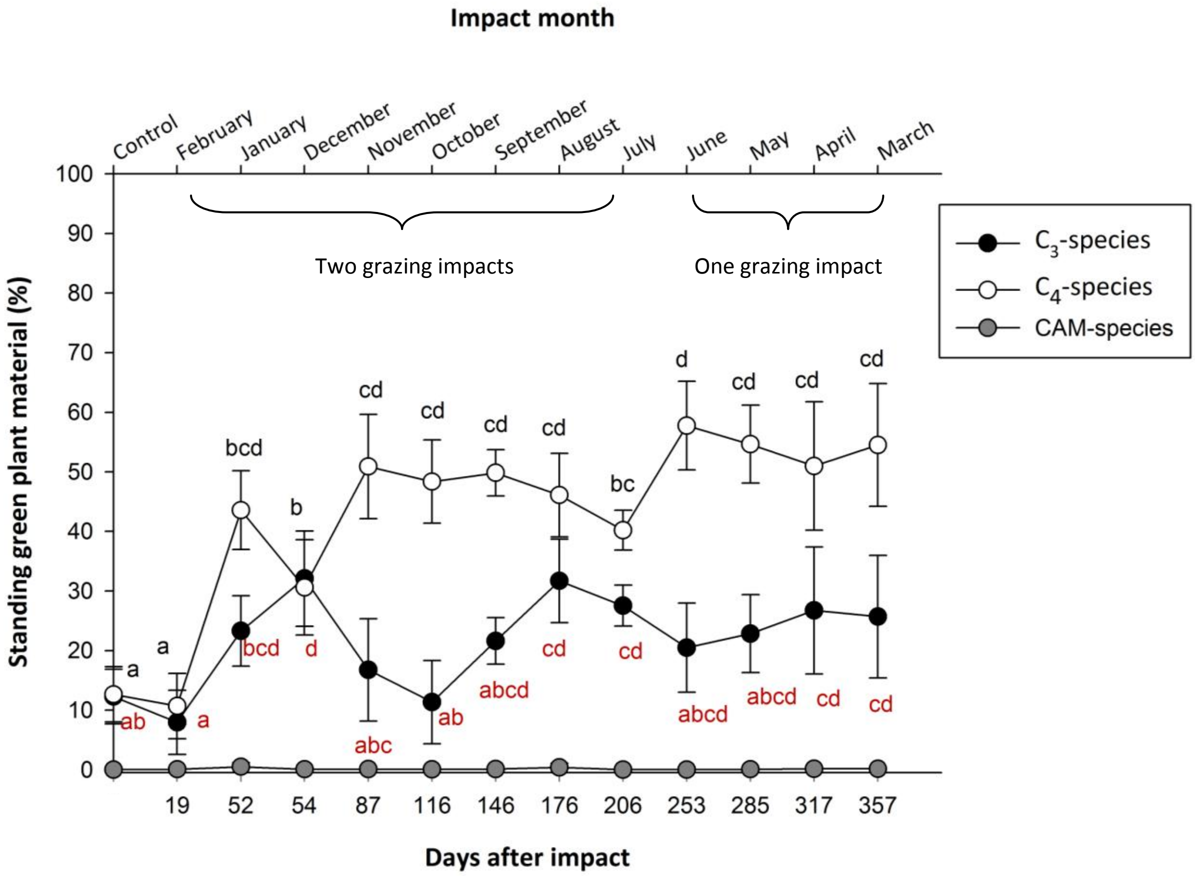


Figure 12 Species composition of C_3-, C_4- and CAM-species, based on their standing green plant material (%) in control and in impact months subjected to grazing impacts by cattle at varying days after impact. Whiskers indicate the standard deviation. Means with different letters for C_3-species (red colour) and C_4-species (black colour) are significantly different at $p \leq 0.05$. Means for CAM-species were not significantly different at $p \leq 0.05$.

3.4.1.4 Plant species composition

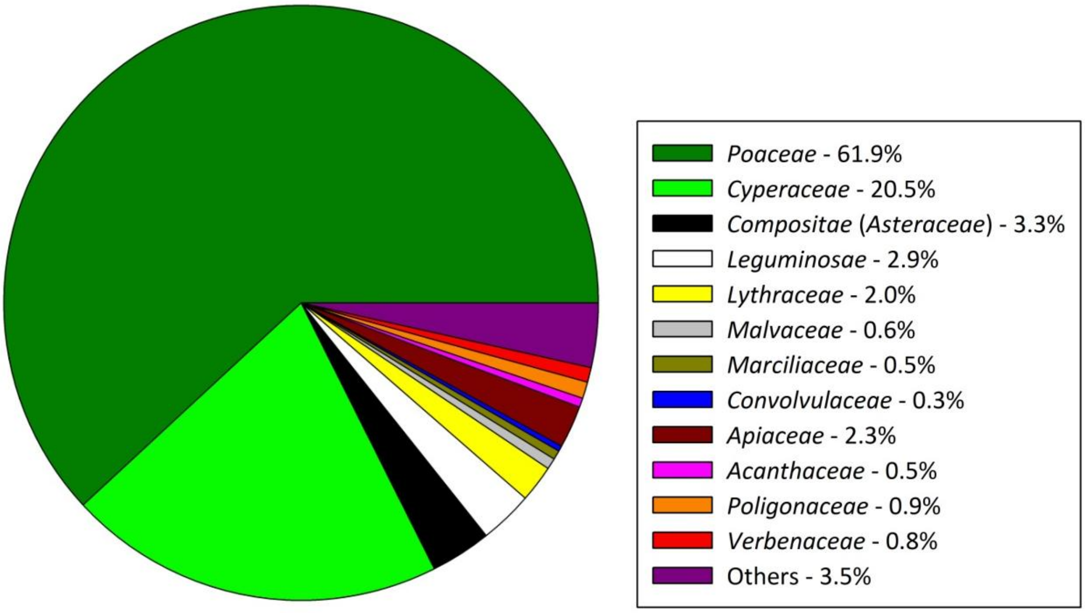


Figure 13 The twelve most common plant families and their proportion of standing green plant material (%) in the experimental area, as determined during the time between January and March 2014 (see Table 5).

A total of 39 plant families was identified in the experimental area. The family of *Poaceae* was the most dominating plant family (61.9 % of SGM), followed by the family of *Cyperaceae* (20.5 % of SGM). The family of *Compositae* (*Asteraceae*), the family of *Leguminosae* and the familiy of *Apicaceae* had proportions of SGM of 3.3 %, 2.9 %, and 2.3 % respectively (Figure 13). The remaining 26 identified plant families had proportions of SGM smaller than 0.3 %. A detailed list of all plant families and their proportion of SGM is shown in Appendix Table A6).

As shown in Figure 13, there were twelve plant families which had SGM higher than 0.3 %. Plant familes were statictically tested for significant differences (Table 17 and 19). SGM of the family of *Compositate* (*Asteraceae*) differed significantly for the grazing treatment *per se* ($p = 0.041$). The mean of SGM of the family *Compositae* (*Asteraceae*) in the control (10.3 ± 2.4 %) was higher than the mean of SGM of the impact months (2.5 ± 2.9 %). SGM of the family of *Convolvulaceae* also differed significantly for the grazing treatment *per se* ($p < 0.001$). The mean of SGM in the control (1.2 ± 0.8 %) was higher than the mean of SGM of the impact months (0.1 ± 0.07 %). SGM of the family of *Cyperaceae* was significantly different for the treatment *per se* ($p = 0.032$). The mean of SGM of *Cyperaceae* in the control

(4.0 ± 1.1 %) was lower than the mean of SGM in impact months (24.8 ± 7.5 %). For the family of *Lythraceae,* the mean of SGM in the months with one grazing impact (1.0 ± 0.4 %) was significantly lower ($p < 0.001$) than the mean of SGM for two grazing impacts (2.3 ± 0.9 %).

Table 17 P-values of the effect of the grazing treatment *per se*, the number of grazing impacts and the impact month on the proportion of standing green plant material (%) of the most common plant families, as determined during the time between January and March 2014 (see Table 5).

Effect	***Acanthaceae***	***Apiaceae***	***Compositae* (*Asteraceae*)**	***Convolvulaceae***	***Cyperaceae***	***Leguminosae***
Grazing treatment *per se*	0.689 ns	0.789 ns	0.041 *	< 0.001 ***	0.032 *	0.316 ns
Number of grazing impacts	0.432 ns	0.532 ns	0.841 ns	0.222 ns	0.912 ns	0.998 ns
Impact month	0.649 ns	0.548 ns	0.551 ns	0.752 ns	0.191 ns	0.812 ns

Significance level: * p ≤ 0.05; ** p ≤ 0.01; *** p ≤ 0.001; ns > 0.05.

Table 18 Means ± standard deviations of standing green plant material (%) of the most common plant families at varying days after impact.

Days after Impact	**Impact month**	**Number of grazing impacts**	***Acanthaceae***	***Apiaceae***	***Compositae* (*Asteraceae*)**	***Convolvulaceae***	***Cyperaceae***	***Leguminosae***
-	Control	-	0.9 ± 0.8	3.5 ± 2.3	10.3 ± 2.4	1.2 ± 0.8	4.0 ± 1.1	4.4 ± 1.9
19	February	2	0 ± 0	1.0 ± 1.2	1.0 ± 0.4	0 ± 0	29.8 ± 0.2	1.1 ± 1.3
52	January	2	0.3 ± 0.3	0.8 ± 0.6	0.4 ± 0.26	0.09 ± 0.1	26.0 ± 5.4	1.1 ± 1.2
54	December	2	0.8 ± 0.3	11.4 ± 0.7	1.7 ± 2.2	0.4 ± 0.1	8.4 ± 4.6	3.7 ± 2.8
87	November	2	0.7 ± 0.3	0.7 ± 0.1	2.0 ± 1.8	0.7 ± 0.9	16.9 ± 9.6	3.1 ± 1.9
116	October	2	1.2 ± 0.6	1.2 ± 0.9	0.6 ± 0.6	0.1 ± 0.1	32.2 ± 14.1	1.8 ± 1.9
146	September	2	0.4 ± 0.1	0.9 ± 0.2	0.5 ± 0.8	0.2 ± 0.2	30.4 ± 15.1	2.4 ± 3.1
176	August	2	0.2 ± 0.2	3.1 ± 5.1	10.4 ± 3.5	0.2 ± 0.1	21.7 ± 16.7	2.9 ± 3.0
206	July	2	0.4 ± 0.3	1.2 ± 1.3	5.5 ± 9.1	0.2 ± 0.3	14.6 ± 7.1	2.5 ± 1.6
253	June	1	0.3 ± 0.4	0.5 ± 0.7	1.7 ± 0.8	0.1 ± 0.2	17.2 ± 13.2	2.2 ± 1.3
285	May	1	0.05 ± 0.08	2.5 ± 3.0	4.7 ± 7.2	0 ± 0	22.4 ± 16.6	3.2 ± 3.0
317	April	1	0.9 ± 0.1	1.8 ± 2.9	1.6 ± 1.7	0.04 ± 0.07	25.1 ± 10.5	3.2 ± 3.3
357	March	1	0.09 ± 0.1	0.2 ± 0.2	0.9 ± 1.1	0 ± 0	22.9 ± 4.9	0.7 ± 0.5

Table 19 P-values of the effect of the grazing treatment *per se*, the number of grazing impacts and the impact month on the proportion of standing green plant material (%) of the most common plant families, as determined during the time between January and March 2014 (see Table 5).

Effect	***Lythraceae***	***Malvaceae***	***Marciliaceae***	***Poaceae***	***Poligonaceae***	***Verbenaceae***
Grazing treatment *per se*	0.677 ns	0.950 ns	0.750 ns	0.685 ns	0.786 ns	0.930 ns
Number of grazing impacts	< 0.001 ***	0.560 ns	0.640 ns	0.790 ns	0.694 ns	0.516 ns
Impact month	0.838 ns	0.641 ns	0.751 ns	0.060 ns	0.349 ns	0.728 ns

Significance level: * p ≤ 0.05; ** p ≤ 0.01; *** p ≤ 0.001; ns > 0.05.

Table 20 Means ± standard deviations of standing green plant material (%) of the most common plant families at varying days after impact.

Days after Impact	**Impact month**	**Number of grazing impacts**	***Lythraceae***	***Malvaceae***	***Marciliaceae***	***Poaceae***	***Poligonaceae***	***Verbenaceae***
-	Control	-	2.4 ± 2.2	0.7 ± 0.4	0.2 ± 0.1	65.2 ± 7.3	0.5 ± 0.2	0.8 ± 0.6
19	February	2	1.2 ± 1.1	0 ± 0.06	0.8 ± 1.5	63.5 ± 4.5	0.01 ± 0.01	0.3 ± 0.5
52	January	2	3.7 ± 3.0	0.1 ± 0.1	2.5 ± 0.6	61.1 ± 5.0	0.2 ± 0.3	0.8 ± 0.6
54	December	2	2.1 ± 1.0	0.6 ± 0.6	0.1 ± 0.3	64.2 ± 26.3	0	1.9 ± 2.4
87	November	2	3.2 ± 4.6	1.0 ± 1.7	0.2 ± 0.2	66.9 ± 5.6	0.5 ± 0.09	1.5 ± 1.4
116	October	2	2.0 ± 1.7	0.7 ± 0.7	0.06 ± 0.1	57.2 ± 10.2	0.4 ± 0.8	0.06 ± 0.1
146	September	2	2.2 ± 1.2	0.2 ± 0.4	0.06 ± 0.1	59.2 ± 12.9	0.2 ± 0.1	0.05 ± 0.09
176	August	2	3.1 ± 2.6	1.0 ± 1.4	0.04 ± 0.07	51.7 ± 13.6	0	0.7 ± 0.9
206	July	2	1.2 ± 1.6	0.6 ± 0.3	0	69.1 ± 8.9	0.2 ± 0.3	0.6 ± 0.5
253	June	1	1.7 ± 0.1	0.9 ± 1.2	0.2 ± 0.3	64.2 ± 11.9	4.1 ± 5.0	1.2 ± 1.3
285	May	1	1.0 ± 0.7	0.3 ± 0.3	0.6 ± 1.0	56.1 ± 2.9	2.5 ± 0.4	1.2 ± 1.3
317	April	1	0.9 ± 0.9	1.3 ± 1.2	0.4 ± 0.7	54.4 ± 12.8	2.9 ± 3.4	1.1 ± 1.4
357	March	1	0.7 ± 0.7	0.4 ± 0.4	1.3 ± 2.1	66.0 ± 7.6	1.1 ± 1.2	0.7 ± 0.6

A total of 167 different plant species was identified during the transect assessment and the biodiversity assessment. Most species belonged to the family of *Cyperaceae*, *Compositae* (*Asteraceae*), *Poaceae,* and *Leguminosae*. In Table 21, the most common species are characterised according to their family, physiology, life cycle, distribution, and sociability characteristics of individual plant species in the experimental area and according to their fodder value. Dominant bunch grass species, such as *Andropogon lateralis* and *Sorghastrum nutans* moderate to poor in fodder value, occurred with proportions of SGM higher than 10 %, whereas the species of the family of *Leguminosae*, good to very good in fodder value, had proportions of SGM smaller than 1 %. Some species, such as *Baccharis coridifolia*, *Senecio grisebachii, and Lantana sp*., are considered toxic in high amounts as forage (Bendersky *et al*., 2008).

Table 21 The most common plant species in the experimental area, as determined during the time between January and March 2014 (see Table 5). (Table according to Shakhane *et al.,* (2013), Breuer, (2012), modified).

Botanical name	**Family**	**Physiology**[1]	**Life Cycle**[2]	**Cotyledon formation**[3]	**Distribution**[4]	**Sociability**[5]	**Fodder value**[6]
Justicicia laevilingies (Nees) Lindau	*Acanthaceae*	C_4	p	d	S	1	Poor
Eryngium coronatum Hook. & Arn.	*Apiaceae*	C_3	p	d	S	1	Poor
Eryngium ebracteatum Lam.	*Apiaceae*	C_3	p	d	S	1	Poor
Eryngium horridum (*E. schwackeanum*) Urb. Ex H. Wolff, Malme	*Apiaceae*	C_3	p	d	P	1	Poor
Evolvulus sericeus Sw.	*Convolvulaceae*	C_4	p	d	S	1	Poor
Compuesta flora Amarillo (Unknow name) Baker	*Compositae* (*Asteraceae*)	C_4	p	d	S	1	Poor
Conyza bonariensis (L.) Cronquist	*Compositae* (*Asteraceae*)	C_4	a	d	S	1	Poor
Baccharis coridifolia D.C.	*Compositae* (*Asteraceae*)	C_4	p	d	S	1	Toxic
Pterocaulom sp. DC.	*Compositae* (*Asteraceae*)	C_4	p	d	S	1	Poor
Senecio grisebachii Baker	*Compositae* (*Asteraceae*)	C_4	p	d	S	1	Toxic
Vernonia chamaedrys Lees.	*Compositae* (*Asteraceae*)	C_4	p	d	P	2	Poor
Carex sororia Kunth	*Cyperaceae*	C_4	p	m	S	2	Moderate
Cyperus aggregatus (Willd.) Endl.	*Cyperaceae*	C_3	p	m	S	1	Poor
Cyperus entrerrianus Boeckeler	*Cyperaceae*	C_4	p	m	P	1	Poor
Cyperus obtusatus (J. Presl & C. Presl) Mattf. & Kük.	*Cyperaceae*	C_4	p	m	S	1	Moderate
Cyperus virens Michx.	*Cyperaceae*	C_4	p	m	P	1	Poor

Eleocharis nodulosa (Roth) Schult.	*Cyperaceae*	C_4	p	m	C	2	Moderate
Eleocharis viridans Kük ex. Osten	*Cyperaceae*	C_4	p	m	C	2	Moderate
Fimbristylis dichotoma (L.) Vahl	*Cyperaceae*	C_4	p	m	S	1	Moderate
Rhynchospora scutellata Griseb.	*Cyperaceae*	C_4	p	m	P	1	Poor
Rhynchospora tenuis Link	*Cyperaceae*	C_4	p	m	S	1	Moderate
Scleria sellowiana Kunth	*Cyperaceae*	C_3	p	m	S	1	Poor
Aeschynomene americana L.	*Leguminosae*	C_3	p	d	S	1	Very good
Chamaecrista rotundifolia (Pers.) Greene	*Leguminosae*	C_3	p	d	S	1	Good
Desmodium incanum DC.	*Leguminosae*	C_3	p	d	S	2	Good
Desmanthus virgatus (L.) Wild.	*Leguminosae*	C_3	p	d	S	1	Good
Indigofera asperifolia Benth.	*Leguminosae*	C_3	p	d	S	1	Good
Macroptilium lathyroides (L.) Urb.	*Leguminosae*	C_3	a or p	d	S	1	Moderate
Rhynchosia edulis Griseb.	*Leguminosae*	C_3	p	d	S	2	Good
Cuphea lysimachioides Cham. & Schltdl.	*Lythraceae*	C_3	p	d	S	1	Poor
Heymia salicifolia (Kunth) Link Otto	*Lythraceae*	C_3	p	d	P	1	Poor
Sida rhombifolia L.	*Malvaceae*	C_3	p	d	S	1	Poor
Marsilia consilia Mirb.	*Marciliaceae*	C_3	p	spore	S	3	Poor
Poligonum punctatum(Persicaria Punctata) Elliot	*Poligonaceae*	C_3	p	d	S	2	Poor
Andropogon lateralis (Paja colorada) Ness	*Poaceae*	C_4	p	m	D	4 or 5	Moderate
Axonopus fissifolius (Raddi) Kuhlm.	*Poaceae*	C_4	p	m	C	2	Good
Briza uniolae (Nees) Steud.	*Poaceae*	C_4	p	m	S	1	Good
Bothriochloa laguroides DC.	*Poaceae*	C_4	P	m	S	1	Moderate
Cynedon dactylon (L.) Pers.	*Poaceae*	C_4	p	m	S	1	Moderate

Digitaria phaeotrix (Trin.) Parodi	*Poaceae*	C_4	p	m	S	1	Moderate
Elyonurus muticus (Spreng.) Kuntze	*Poaceae*	C_4	p	m	S	1	Moderate
Eragrostis airoides Nees	*Poaceae*	C_4	p	m	S	4	Poor
Eragrostis bahiensis Roem. & Schult.	*Poaceae*	C_4	p	m	P	4	Moderate
Leersia hexandra Sw.	*Poaceae*	C_3	p	m	P	2	Very good
Paspalum notatum Flügé	*Poaceae*	C_4	p	m	C	2	Good
Paspalum plicatulum Michx.	*Poaceae*	C_4	p	m	P	4	Moderate
Piptochaetium montevidense (Spreng.)Parodi	*Poaceae*	C_4	p	m	S	1	Very good
Schizachyrium microstachyum (Desv.) Roseng.	*Poaceae*	C_4	p	m	S	2	Moderate
Setaria geniculata P.Beauv.	*Poaceae*	C_4	p	m	P	1	Moderate
Sorghastrum nutans (L.) Nash	*Poaceae*	C_4	p	m	D	4 or 5	Poor
Steinchisma laxa Ex Panicum laxum Sw.	*Poaceae*	C_4	p	m	S	1	Very good
Sporobolus indicus (L.) R. Br.	*Poaceae*	C_4	a	m	S	1	Poor
Tridens brasiliensis (Steud.) Parodi	*Poaceae*	C_4	p	m	S	1	Moderate
Glandularia peruviana (L.) Small	*Verbenaceae*	C_3	p	d	S	1	Poor
Lantana sp. (Flora amarilla) Moldenke	*Verbenaceae*	C_3	p	d	S	1	Toxic
Verbena litoralis Kunth	*Verbenaceae*	C_3	p	d	S	1	Poor

[1]**Physiology**: C_3- or C_4-Species, [2]**Life Cycle**: a = annual, p = perennial, [3]**Cotyledon formation**: m = Monocotyledons, d = Dicocotyledons,
[4]**Distribution structured according to the standing green plant material (%) of each species**: D = dominant (< 10 %), C = common (> 5-10 %), P = present (1 - 5 %), S = seldom (≤ 1%).
[5]**Sociability characteristics of individual plant species:** 1 = Individual plants grow solitary, 2 = Individual plants grow intra-group, 3 = Individual plants grow in plaits, 4 = Individual plants grow in little colonies, 5 = Individual plants grow in big bunches
[6]**Fodder values according to references: Fernández *et al*., (1983), Rosengurtt, (1979), Classification of the fodder value in Corrientes grassland:** Toxic, Poor = Crude protein content < 6g/100g DM, Moderate = Crude protein content > 6g/100g DM, Good = Crude protein content > 8g/100g DM, and Very Good = Crude protein content > 10g/100g DM.

Species with good to very good fodder value and the occurrence in impact months and the control are shown in Table 23 and 25 and tested for significant differences in their proportion of SGM. Additionally, SGM of the two most dominant bunch grass species *Andropogon lateralis* and *Sorghastrum nutans* with poor to moderate fodder values are shown. Pasture species which belong to the family of *Leguminosae* such as *Aeschynomene americana*, *Desmodium incarnum* and *Desmanthus virgatus*, *Indigofera asperifolia* and *Rhynchosia edulis*, were not significantly different in their proportion of SGM to the other pasture species. *Axonopus fissifolius*, which belongs to the family of *Poaceae*, was significantly different in its proportion of SGM between impact months ($p = 0.050$). SGM of impact month October (13.4 %) differed significantly to the SGM of all other impact months and control. *Leersia hexandra and Paspalum notatum,* both species of the family of Poaceae, differed significantly in its proportion of SGM for the grazing treatment *per se* ($p = 0.040$, $p = 0.044$). The proportion of SGM for the dominant species *Sorghastrum nutans* and *Andropogon lateralis* were not significantly different, neither for the grazing treatment *per se*, nor for the number of grazing impacts, nor for the grazing time (impact month).

Table 22 P-values of the effect of the grazing treatment *per se*, the number of grazing impacts and the impact month on the proportion of standing green plant material (%) of plant species, as determined during the time between January and March 2014 (see Table 5).

Effect	*Aeschynomene americana*	*Andropogon lateralis*	*Axonopus fissifolius*	*Briza uniolae*	*Desmodium incarnum*	*Desmanthus virgatus*
Grazing treatment *per se*	0.784 ns	0.876 ns	0.346 ns	0.876 ns	0.546 ns	0.124 ns
Number of grazing impacts	0.450 ns	0.124 ns	0.219 ns	0.734 ns	0.204 ns	0.145 ns
Impact month	0.304 ns	0.985 ns	0.050 *	0.974 ns	0.532 ns	0.205 ns

Significance level: * p ≤ 0.05; ** p ≤ 0.01; *** p ≤ 0.001; ns > 0.05.

Table 23 Means ± standard deviations of standing green plant material (%) of plant species with good to very good fodder value in comparison to the dominant species *Andropogon lateralis* at varying days after impact.

Days after Impact	Impact month	Number of grazing impacts	*Aeschynomene americana*	*Andropogon lateralis*	*Axonopus fissifolius*	*Briza uniolae*	*Desmodium incarnum*	*Desmanthus virgatus*
-	Control	-	0	8.8 ± 13.7	2.1 [a] ± 2.9	0.1 ± 0.01	0.3 ± 0.1	2.0 ± 0.4
19	February	2	0.2 ± 0.3	15.6 ± 27.1	0.1 [a] ± 0.2	0	0.4 ± 0.3	0
52	January	2	0.5 ± 0.7	17.4 ± 18.2	1.6 [a] ± 2.8	0	0.3 ± 0.3	0.05 ± 0.09
54	December	2	0.6 ± 0.9	10.0 ± 8.9	5.8 [a] ± 5.2	0	1.2 ± 0.9	0.9 ± 1.0
87	November	2	0.2 ± 0.1	18.6 ± 10.8	1.3 [a] ±2.2	0	1.05 ± 0.8	0.4 ± 0.3
116	October	2	0.1 ± 0.2	16.2 ± 8.2	13.4 [b] ± 7.7	0	1.3 ± 1.2	0
146	September	2	0	21.4 ± 14.4	4.4 [a] ± 5.7	0	0.4 ± 0.5	2.0 ± 3.4
176	August	2	0.1 ± 0.0	10.7 ± 10.0	0.6 [a] ± 1.0	0.1 ± 0.2	0.8 ± 1.5	0.7 ± 1.0
206	July	2	0.2 ± 0.1	6.8 ± 10.5	5.2 [a] ± 8.4	0	1.2 ± 0.9	0.7 ± 0.8
253	June	1	0.8 ± 0.6	13.2 ± 5.5	2.3 [a] ± 3.0	0.2 ± 0.3	0.5 ± 0.4	0.04 ±0.03
285	May	1	0.4 ± 0.6	11.9 ± 16.3	2.5 [a] ± 4.2	0.7 ± 1.2	1.0 ± 1.8	0.09 ± 0.1
317	April	1	0	11.8 ± 11.0	1.3 [a] ± 1.2	0.4 ± 0.7	1.6 ± 1.2	0.3 ± 0.4
357	March	1	0.1 ± 0.0	10.8 ± 8.1	2.11 [a] ± 2.0	0	0.08 ± 0.07	0.04 ±0.07

Table 24 P-values of the effect of the grazing treatment *per se*, the number of grazing impacts and the impact month on the proportion of standing green plant material (%) of plant species, as determined during the time between January and March 2014 (see Table 5).

Effect	***Indigofera asperifolia***	***Leersia hexandra***	***Paspalum notatum***	***Rynchosia edulis***	***Sorghastrum nutans***	***Steinchisma laxa Ex panicum laxum***
Grazing treatment *per se*	0.563 ns	0.040 *	0.044 *	0.912 ns	0.564 ns	0.345 ns
Number of grazing impacts	0.234 ns	0.312 ns	0.345 ns	0.234 ns	0.976 ns	0.129 ns
Impact month	0.730 ns	0.304 ns	0.311 ns	0.425 ns	0.253 ns	0.901 ns

Significance level: * p ≤ 0.05; ** p ≤ 0.01; *** p ≤ 0.001; ns > 0.05.

Table 25 Means ± standard deviations of standing green plant material (%) of plant species with good to very good fodder value in comparison to the dominant species *Sorghastrum nutans* at varying days after impact.

Days after Impact	**Impact month**	**Number of grazing impacts**	***Indigofera asperifolia***	***Leersia hexandra***	***Paspalum notatum***	***Rynchosia edulis***	***Sorghastrum nutans***	***Steinchisma laxa Ex panicum laxum***
-	Control	-	1.0 ± 0.8	0	1.0 ± 1.1	0	34.6 ± 21.2	0.4 ± 0.5
19	February	2	0	2.2 ± 1.9	8.8 ± 6.5	0	35.2 ± 27.4	0.01 ± 0.0
52	January	2	0.2 ± 0.3	5.4 ± 3.7	4.5 ± 3.4	0.04 ± 0.07	18.6 ± 6.1	0.2 ± 0.3
54	December	2	0.6 ± 0.1	0.05 ± 0.09	10.5 ± 9.2	0.1 ± 0.2	28.3 ± 4.4	1.9 ± 2.8
87	November	2	0.9 ± 1.0	0.04 ± 0.08	12.2 ± 9.9	0.2 ± 0.4	13.9 ± 4.7	2.2 ± 2.1
116	October	2	0.4 ± 0.7	1.5 ± 1.3	8.1 ± 5.5	0	9.7 ± 9.3	0.3 ± 0.1
146	September	2	0	1.9 ± 1.8	2.0 ± 2.9	0	19.8 ± 5.8	1.8 ± 3.1
176	August	2	0.9 ± 1.3	2.3 ± 4.1	0.7 ± 1.1	0.04 ± 0.07	24.4 ± 18.7	1.1 ± 2.0
206	July	2	0.3 ± 0.4	1.6 ± 2.8	5.0 ± 1.2	0.1 ± 0.2	12.2 ± 11.2	0.2 ± 0.1
253	June	1	0.4 ± 0.8	0.6 ± 0.6	12.4 ± 9.2	0.09 ± 0.1	31.2 ± 8.6	0.4 ± 0.7
285	May	1	0.5 ± 0.8	2.8 ± 2.7	7.7 ± 6.1	0.1 ± 0.2	12.1 ± 4.9	0.7 ± 1.1
317	April	1	1.1 ± 1.4	3.7 ± 4.3	7.7 ± 9.9	0.1 ± 0.3	16.9 ± 7.7	1.1 ± 1.4
357	March	1	0.3 ± 0.2	2.9 ± 3.1	8.1 ± 5.9	0.04 ± 0.07	20.3 ± 13.2	1.3 ± 2.1

4 Discussion

4.1 Species richness and diversity indices vary under the effect of repeated bunch trampling by grazing cattle

The first hypothesis of this thesis was that species richness and diversity indices vary under the effect of repeated bunch trampling by grazing cattle in terms of the grazing treatment *per se*, the number of grazing impacts, and the season. Grazing impacts can vary due to changes in animal behaviour relevant to the intensity of grazing and trampling, number of repetitions and seasonal abundance of plant species (Altesor *et al*., 2005; Watkinson and Ormerod, 2001). An assessment of biodiversity is an essential tool to understand shifts on floristic composition of pasture (Cabido, 1993). Therefore, first observations of sward communities were conducted on transect lines across each of the four paddocks in the experimental area and second, more detailed assessments of biodiversity in sampling areas were undertaken. Species recordings in a study of Altesor *et al*. (2005) on the effect of grazing on community structure and productivity of an Uruguayan grassland revealed higher species richness in intensively grazed regimes than in ungrazed regimes. Species richness was measured in the summer months similar to the biodiversity assessment of this thesis. Unlike the observations of Altesor *et al*. (2005), in this thesis, the assessment of species richness did neither reveal a significant effect of the grazing treatment *per se*, nor for the number of grazing impacts, nor for the grazing time (impact month). High biodiversity in the experiment's homogeneous local conditions in all paddocks may have contributed to this outcome, which is in accordance with results of Jacobo *et al*. (2006) and Rosengurtt (1979). The assessment of Shannon's diversity index (H) and equitability (E_{H}) in this thesis did not reveal a significant effect of the grazing treatment *per se*, neither for H nor for E_H. This differs from the study by Altesor *et al*. (2005), who found that H and E_{H} were higher in grazed areas than in the ungrazed regime. However, in the present thesis, the effect of the number of grazing impacts was significant both for H and for E_{H}. The slightly higher values for H and E_H in impact months with one grazing impact in comparison to those with two grazing impacts can be explained by the larger number of days which had passed since the last grazing impact in 2013 (DAI > 253), and the longer time period for re-growth of plant material in impact months that had been grazed only once (Table 10).

4.2 Changes in functional plant groups

Ecosystems such as pastures in the tropics and subtropics are open systems in which livestock farming contributes to continuous changes in the grassland vegetation (Glatzle, 1990). Therefore, it was hypothesized that repeated bunch trampling by grazing cattle in the grasslands of Corrientes leads to changes of functional plant groups, such as C_3- and C_4-species, annual and perennial species, and monocotyledon and dicocotyledon plants.

According to Bayer and Waters-Bayer (2013), C_4-grasses are considered to have lower digestibility than C_3- species**.** Therefore, an increase of C_3-species is generally appreciated in pasture (Lattanzi, 2010, cited in Schnyder *et al*., 2010, page 3; Bayer and Waters-Bayer, 2013). Grasslands in Corrientes are predominately covered by *Poaceae* and *Cyperaceae* species with C_4- photosynthesis pathway (Hack *et al*., 2009; Schinini *et al*., 2004). Groupings of detected plant species according to their photosynthesis pathways revealed mainly C_4-species in comparison to C_3-species and CAM-species in this thesis (Figure 9). However, neither the grazing treatment *per se,* nor the number of grazing impacts, nor the grazing time (impact month) had a significant effect on the abundance of C_3-, C_4- or CAM-species (Table 13).

According to Scholes and Archer (1997), C_4-species with high biomass occur mainly in open grasslands, without tree shading, an observation confirmed by this thesis. Warm season grasses and their proportion of standing green plant material (SGM) of the families of *Poaceae* and *Cyperaceae*, which are C_4-species, dominated the experiment (Figure 13), while most C_3-species belonging to families such as *Apiaceae*, *Leguminosae*, *Lythraceae*, *Malvaceae*, *Marciliaceae* and *Verbenaceae* occurred in smaller proportions of SGM. While the grasslands of Corrientes are dominated by the growth of C_4-species in the summer months (December, January and February), during the winter months, C_3-species such as *Leguminosae* are more present (Pallarés *et al*., 2005). SGM of C_4-species was the major component of the total SGM in all impact months and the control. The proportion of SGM of C_4-species in impact month February differed significantly from all other impact months (Figure 12). Although impact month February belongs to the summer months, the very low proportion of SGM of C_4-species in this plot can be explained by the short time period of re-growth of biomass since the last grazing impact (DAI 19). Jacobo *et al*. (2006) conducted an experiment of rotational grazing (3 to 15 days of intensive grazing) on rangeland vegetation in paddocks at different times of the year. The total basal cover of C_3-annual and C_3-perennial grasses increased, while C_4-species such as prostrate grasses decreased under rotational grazing. According to Deregibus *et al*. (1994, cited in Jacobo *et al*. (2006), page 255) winter grasses benefited from the effect of rotational grazing especially in autumn and winter months and an increased seed germination and establishment of C_3-species as a result of emerging gaps and direct light influence were promoted. In contrast to the results of Deregibus *et al*. (1994), cited in Jacobo *et al*. (2006), page 255), the SGM of C_3-species was neither significantly affected in the impact months, which underwent a grazing impact in autumn (impact month March, April, and May, DAI > 285), nor in winter (impact month June, July, and August, DAI > 176). No direct trend is noticeable for an increasing proportion of SGM of C_3-species related to seasonal influences. Therefore, the DAI do not seem to play a decisive role for choosing the right moment to perform a grazing impact.

The occurrence of plant species with an annual or perennial life cycle is of interest in terms of the classification of grassland phenological patterns (Taube and Kornher, 2000). Most plant species in the grasslands of Corrientes have perennial life cycles (Sampedro *et al*., 2004). The grazing time (impact month) had a significant effect on the abundance of annual species but not on that of perennial species (Table 11). Impact month February had a very low abundance of annual species (n = 0.3 ± 0.6) and differed significantly from impact months March, June, August, September, November, and December. The low abundance of annual plant species in impact month February can be explained by the grazing impact, which happened only 19 days before the assessment of biodiversity. According to Belsky (1992), while disturbance such as grazing by herbivores affects both annual and perennial species cover in pasture; annual species are frequently eaten first.

Grasslands are often dominated by monocotyledons (grass species) but also by dicocotyledons such as *Leguminosae* and forbs (Barker and Sulc, 2011, cited in McMahon *et al*., 2011, page 399). Neither the grazing treatment *per se,* nor the number of grazing impacts, nor the grazing time (impact month) had significant effects on the abundance of dicocotyledon plants (Table 12). However, the abundance of monocotyledon plants in impact month February was significantly lower than in impact months January, March, and June, in which more time for re-growth of plant species had passed since the last grazing impact. A grazing impact is considered a severe disturbance for pasture and its plant communities (McNaughton, 1985; Díaz *et al.*, 2001). Therefore changes in the plant species composition can be expected under grazing treatments. To increase growth rates, species have diverse adaption capabilities for photosynthesis production and nutrient absorption (Herms and Mattson, 1992). The temporal developments of the proportions of SGM of monocotyledon and dicocotyledon plants (Figure 11) are respectively similar to those of the proportions of SGM of C_4- and C_3-species (Figure 12). This can be explained by the fact that the experiment dealt mainly with C_4-species such as *Poaceae*- and *Cyperaceae* species which are monocotyledon plants and less so with C_3-species such as *Compositae* (*Asteraceae*) and *Leguminosae* species which are dicocotyledon plants (Figure 13).

4.3 Repeated bunch trampling by grazing cattle induces changes in plant families and species composition

One main objective of this thesis was to find out whether repeated bunch trampling by grazing cattle induces favourable changes in plant families and species compositions by increasing the growth of those plants considered as good to very good fodder plants. In the present thesis, 167 different plant species belonging to 39 families were identified. The families of Poaceae (61.9 %), Cyperaceae (20.5 %), and *Compositae* (*Asteraceae,* 3.3 %) had particularly high proportions of SGM as shown in Figure 13. In between, plant species with higher fodder quality were present, but in lower quantity, which corresponds to earlier findings of Luisoni (2010). The botanical presence of fodder plants with high nutritive value is a criterion for setting up natural pastures of high quality (Sampedro *et al.*, 2004).

Pasture communities change depending on grazing activity. Altesor *et al.*, 2006 observed that new plant families colonised and expanded on emerging gaps of grazed pastures, whereas ungrazed sites were covered with higher proportions of species resistant to the grasslands with low fodder quality which correspond to this thesis. Especially the shrub *Vernonia chamaedrys* belonging to the family of *Compositae* (*Asteraceae*) was common in the control and had a significantly higher proportion of SGM in the control than the mean proportions of SGM in the impact months (Table 17). This result corresponds to observations by other authors who reported an increasing risk of overgrowing pasture plants with lower fodder quality in low grazed areas (Cingolani *et al.*, 2005, Tobler *et al.*, 2003 cited in

Cingolani *et al*., 2005, page 51; Glatzle, 1990). Furthermore, it is assumed that repetitive grazing by cattle promotes growth of pasture plants with good fodder quality. Sward patches with species that are resistant to intensive grazing develop and the amount of species that are less favourable as forage and not tolerant to grazing disturbance decreases (Cingolani *et al*., 2005; Glatzle, 1990). Already slight vegetation changes towards beneficial pasture plants can be good for forage production (Jacobo *et al*., 2006). Fodder quality is seasonal, green material dependent, and subjected to a gradual decline. Most valuable is the green plant material at the beginning of the growing period. The crude protein content varies with plant maturation over time (Bayer and Waters-Bayer, 2013). Especially in wintertime, the crude protein content of forage in natural pasture in Corrientes can decrease to values lower than 4 g/100 g dry matter of plant biomass (DM), which greatly reduces nutrient-rich alimentation of livestock (Sampedro *et al*., 2004). Plants compete with other species in the grasslands for living space, nutrients, and water (Hodgson, 1990). This was noticeable for the two dominant bunch grass species *Andropogon lateralis* and *Sorghastrum nutans*, which had high proportions of SGM (Tables 23 and 25) and are considered as very resistant perennial plant species, which covered most of the grasslands of Corrientes grassland with extremely dense and high bunches (Luisoni, 2010). Although high proportions of plant biomass of these species were produced and consumed by cattle in the experimental area, they are considered poor to moderate fodder plants with low nutritive value (Fernández *et al*., 1983; Rosengurtt, 1979; verbal communication with Goldfarb, in February 2014, Table 21). According to Fernández *et al*. (1983), a possibility to overcome the dominant occurrence of these species and their SGM would be an intensive grazing by livestock in their most intensive growing phase during summer. However, neither a significant difference of the proportion of SGM of the grazing treatment *per se*, nor of the number of grazing impacts, nor of the grazing time (impact month) of these two species (Tables 22 and 24) were found. Nevertheless, these findings correspond to the findings of Belsky (1992), who observed that grazing by cattle on tall grass-communities of resistant *Poaceae* species had small effects. Intensive grazing nearby these two species enables other species to grow in emerging gaps on the ground surface. Hack *et al*. (2009) pointed out that favourable changes of floristic composition can be achieved by intensive grazing treatments in bunch grass-dominated grasslands. This thesis revealed that *Poaceae* species, such as *Leersia hexandra* and *Paspalum notatum*, were significantly promoted by enhanced growth in the grazing treatment *per se* (Table 24). According to Benítez *et al*. (2004), perennial *Paspalum* species such as *Paspalum notatum* are resistant to trampling by cattle and emerge repetitively from the ground surface. In this thesis, *Paspalum notatum*, a pasture plant with good fodder value (Rosengurtt, 1979) had the highest proportions of SGM of *Paspalum notatum (*12.4 ± 9.2 %) in impact month June. According to Fernández *et al*. (1983), this pasture plant can contribute between 10% and 35 % of the total fodder harvest in the grasslands of Corrientes. *Leersia hexandra,* a *Poaceae* species with a C_3-photosynthesis pathway, is a very good forage plant for cattle (Rosengurtt, 1979; verbal communication with Goldfarb, in February 2014). The complete absence of this species in the control but occurrence in the impact months indicates that the effect of repeated bunch trampling by grazing cattle promoted the plant growth of this species. The *Leguminosae* species *Desmodium incarnum*, a good to very good forage plant (Rosengurtt, 1979; verbal communication with Goldfarb, in February 2014; Fernández *et al*., 1988) was found in all impact months (Table 23) but it only contributed less than 1.6 % to the total SGM. This finding is in line with Fernández *et al*. (1983), who reported low fodder harvest (< than 2 %) for the proportion of *Desmodium incarnum* in the grasslands of Corrientes. Neither *Desmodium incarnum*, nor the other *Leguminosae* species and their SGM differed significantly for the grazing treatment *per se*, the number of grazing impacts, and grazing time (impact month). The effect of repeated bunch trampling and grazing by cattle could not enhance higher occurrence of favoured *Leguminosae* species in the experimental area in comparison to the control. No trend is noticeable for an increasing proportion of SGM for *Leguminosae* species related to seasonal influences. Therefore, the DAI do not seem to play a decisive role for choosing the right moment to perform a grazing impact.

4.4 Changes in aboveground biomass and ground coverage

The last hypothesis of this master thesis was that repeated bunch trampling by grazing cattle increases the proportion of standing green plant material and litter and leads to a reduction of standing dead plant material and bare ground in the grasslands of Corrientes. According to Noy-Meir (1978), the dynamics of pasture with available plant biomass should be in a steady balance between consumption and plant growth. Grasslands can either be over- or underused by livestock farming. His mathematical calculations revealed that a stable use of pasture and fodder availability for animals can only be safely ensured by a use of livestock and their grazing intensity that is in accordance with the re-growth potential of green plant biomass. If this balance is not ensured, an unbalance of aboveground SGM and SDM occurs. The results of the proportion of SDM in this thesis are in accordance with Noy-Meir (1978, Table 7). The control was continuously grazed by a low density of only three cattle. The proportion of SDM in the control (66.7 ± 13 %) was significantly higher than the mean of SDM in the impact months (13.8 ± 10.7 %), corresponding to the results of Altesor *et al*. (2005). He detected larger amounts of SDM than SGM in an untreated regime, comparable to the control in this thesis. On the other hand, the maximum productivity of SGM observed by Altesor *et al*. (2005) was in plots with grazing activities, an observation which corresponds to the result in this thesis. The mean proportion of SGM in impact months subjected to animal grazing was clearly higher (67.3 ± 16.6 %) compared to the low proportion of SGM in the control (25 ± 8.3 %). Forage productivity in pasture always depends on the growing season in the course of the year (Bayer and Water-Bayer, 2013). The production of forage in the province of Corrientes is seasonal, with maximum efficiency in late spring, especially in the months of October and November, in the summer months of December, January and February, and in the autumn months of March and April. The lowest biomass production in pasture occurs in wintertime, especially in the months of July and August (Sampedro *et al*., 2004). Depending on the number of days (DAI) since the last grazing impact in 2013 and in the beginning of 2014, the proportion of SGM had a high variability. Impact month February had a very low proportion of SGM because of a short time period since the last grazing impact (DAI 19) and therefore only a short time for re-growth of standing green plant material. Altesor *et al*. (2005) measured no significant difference in the amount of standing green biomass in treated plots in autumn and spring. His results correspond to the results of this thesis in which the SGM in impact months March, April and May (autumn) and the SGM of the two impact months September and November (spring) were not significantly different from each other. No direct trend is noticeable for an increasing proportion of SGM related to seasonal influences. Therefore, the DAI do not seem to play a decisive role for choosing the right moment to perform a grazing impact. Compared to the control, higher proportions of SGM are observed for all grazing times (impact months), except for impact month February (DAI < 19). These findings regarding SGM lead to the assumption that repeated bunch trampling by grazing cattle could contribute to a higher harvest of SGM in the Corrientes grasslands all year round. The findings on harvested aboveground plant biomass in February

2014 (Table 8) showed no significant effect for the grazing time (impact month) for SGB and confirm this assumption.

An increase of species growth in plant communities depends on the competitive strength of these species for a colonisation of empty gaps in swards between layers of litter and on bare ground (Braun-Blanquet, 1951). Jacobo *et al*. (2006) revealed an increase in litter cover after rotational grazing on rangeland vegetation in Flooding Pampa regions of Eastern Argentina. The proportion of bare ground was reduced under rotational grazing. The findings of Jacobo *et al*. (2006) concur with the results of this thesis. The proportions of ground coverage by litter (Table 7) were relatively homogeneous among control (8.3 ± 5.0 %) and impact months (> 9.0 %) except for impact month February (35.4 ± 9.0 %). The distinctly higher proportion of litter on the ground in impact month February was due both to the shorter time period since the last grazing impact (DAI 19) and the plant biomass having been heavily trampled down by cattle. In general, the relative even amount of ground coverage of litter, which was observed in all impact months, can be seen as an advantage as it reduces soil temperature and protects against water loss, especially in the dry season (Hall *et al*., 1992, cited in Jacobo *et al*., 2006).

The proportion of bare ground was relatively low, except for impact months October and November (> 12.9 %), which differed significantly from all other impact months. An explanation for this observation might be that the weather in October and November 2013 was wet and rainy, which prevented new species colonisation. Furthermore, impact months with one grazing impact (impact months March, April, May, and June) had slightly higher proportions of bare ground than the control and impact months with a second grazing impact (Table 7). The use of grasslands as pasture for grazing cattle causes aboveground relocation of biomass and biomass incorporation into deeper soil layers (Alkemade *et al*., 2013). A further reduction of bare ground through a second grazing impact and therefore an enhanced new colonisation of species on the bare ground can be assumed and would be in line with the findings by Jacobo *et al*. (2006) and Altesor *et al*. (2006).

5 Conclusion and outlook

The objective of this thesis was to determine whether repeated bunch trampling by grazing cattle has an effect on the botanical composition of Argentinean grasslands. The research area was dominated by *Poaceae* species, followed by *Cyperaceae* and *Compositae* (*Asteraceae*) species with high SGM. The biodiversity of species composition in the analysed area was high. It was hypothesised that species richness and diversity indices vary under the effect of repeated bunch trampling by grazing cattle. Yet, the analysis of biodiversity parameters revealed neither significant variation of species richness in the treatment *per se*, nor in grazing time (impact month). The Shannon-Wiener diversity index (H) and Shannon's equitability (E_H) were high, thus implying that intensive trampling and grazing does not damage existing flora of the grassland of Corrientes.

It was also hypothesised that repeated bunch trampling by grazing cattle in the grasslands of Corrientes leads to changes in functional plant groups, such as favoured C_3-species. The results showed high variation in terms of the DAI. However, no clear trend could be shown for an increasing proportion of favoured SGM of C_3-species depending on seasonal influences. Most of the plant species detected during the assessment of biodiversity are considered fodder plants of moderate quality, according to literature and verbal communication. Contrary to expectations, the proportion of SGM of *Andropogon lateralis* and *Sorghastrum nutans,* the two most dominating bunch grasses of the Poaceae species, was hardly reduced through intensive bunch trampling by grazing cattle and did not reveal any significant differences in the proportion of SGM for the grazing treatment *per se*, the number of grazing impacts, or the grazing time (impact month). However, repeated bunch trampling by grazing cattle enhanced the growth of new patterns with more good fodder plants, such as Poaceae species *Leersia hexandra* and *Paspalum notatum*. The proportion of SGM in impact months was significantly higher than in the control ($p < 0.001$), thus confirming the hypothesis that continuously repeated bunch trampling by grazing cattle induces an increase of the aboveground SGM and a decrease of the amount of SDM. In conclusion, these results support the assumption that the biodiversity and green biomass production of Argentinean grasslands are positively influenced by repeated bunch trampling by grazing cattle but has to be further investigated for other growing seasons in the grasslands of Corrientes.

6 Methods criticism

The assessment of biodiversity in the experiment was conducted in a timeframe of nine weeks (January to March 2014) in the summer growing season of plant vegetation in Argentina. For further investigations on changes in botanical composition of Argentinean grassland under the effect of repeated bunch trampling by grazing cattle, variations in the growing season of plant species in the course of the year should be taken into consideration. Some changes or additional species of the *Leguminosae* family might be more widespread in wintertime of the Argentinean growing season, but could not be assessed in this work. Additional influences, such as monthly precipitation, mean temperature, radiation, or nutrient availability from the soil during the growing period, and the developing stadiums of plant families and their species occurrence, were not included in the statistical analysis. The period of the biodiversity asssessment of nine weeks was too short to include all these external influences. Furthermore, the recording of plant species presented only a snapshot of the great local biodiversity. Differences between cattle intake of pasture plants and selectivity by grazing behavior, are not included. Therefore, some plant species might have been missed in the recordings. The quality of forage and their crude proteins, referred to in this thesis, rely on literature and verbal communication with employees of INTA. Further measurements in the laboratory should be included to make exact statements about fodder quality of the different plant species of Argentina's grasslands.

7 Declaration

With these words, I, Saskia Helen Windisch, Matriculation Number 454614, declare that this Master Thesis entitled “Effects of repeated bunch trampling by grazing cattle on the botanical composition of Argentinean grasslands“, has been independently prepared, solely with the support of the listed literature references, and that no information has been presented that has not been officially acknowledged.

Furthermore, I declare hereby that I have transferred the final digital text document (in the format doc.) to my mentoring supervisor and that the content and wording is entirely my own work. I am aware that the digital version of my document can and/ or will be checked for plagiarism with the help of an analyses software program.

Supervisor Prof. Dr. Folkard Asch,
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Thesis topic: Effects of repeated bunch trampling by grazing cattle on the botanical composition of Argentinean grasslands

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