Agrociencia Uruguay 2021 | Volume 25 | Number 2 | Article 417
DOI: 10.31285/AGRO.25.417
ISSN 2730-5066

Floristic composition and above-ground net primary production in natural grasslands on basaltic deep soils

Editor

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Received *29 Sep 2020*
Accepted *22 Feb 2021*
Published 17 *May 2021*

Citation
Basile P, Formoso D, Blumetto O. Floristic composition and above-ground net primary production in natural grasslands on basaltic deep soils. Agrociencia Uruguay [Internet]. 2021 [cited dd mmm yyyy];25(2):e417. Available from: http://agrocienciauruguay.uy/ojs/index.php/agrociencia/article/view/417.

Composición florística y productividad primaria neta aérea de campos naturales sobre suelos profundos de basalto

Composição florística e produtividade primária aérea liquida de campos naturais sobre solos de Basalto profundo

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Abstract

In natural grasslands of the basaltic region, livestock management is applied traditionally associated with continuous high stocking density resulting in the degradation of natural grasslands. Traditionally, aboveground net primary production (ANPP) was estimated from biomass cuts made in the fields. Today, it is possible to estimate ANPP using remote sensing techniques by synthetic images of enhanced vegetation index (EVI). Considering these, we aimed this study to: a) determine the effect of contrasting grazing managements on floristic composition, b) estimate the radiation use efficiency coefficient (RUE) and its seasonal variation, and c) determine the ANPP for two contrasting grazing methods. The experiment was carried out in five farms in the basaltic region of Uruguay with mixed grazing under natural grasslands from spring 2013 to summer 2015. Paddocks with contrasting livestock management were chosen in each site. Vegetation growth was measured using the regrowth technique with three exclusion cages. Floristic composition was estimated using the Braun Blanquet scale. RUE coefficient was estimated following the equation: ANPP = APAR×RUE, where APAR is the absorbed photosynthetically active radiation. Changes in the floristic composition, ANPP, and RUE coefficient were recorded throughout the study in the two treatments. The RUE data obtained will be used to estimate ANPP in natural grasslands more accurately.

Keywords: RUE, degradation, grazing management

Resumen

En la actualidad, los campos naturales de la región basáltica de Uruguay se encuentran deteriorados dado que históricamente se ha utilizado un manejo de carga continua sin ajuste a la productividad primaria neta aérea (PPNA) de la comunidad vegetal. Actualmente es posible estimar la PPNA mediante sensores remotos utilizando imágenes sintéticas del índice de vegetación mejorado (EVI). Los objetivos del trabajo fueron determinar el efecto de la disminución de la intensidad de pastoreo en la composición florística, la PPNA y el coeficiente de eficiencia de uso de la radiación (EUR) de la comunidad vegetal de suelos profundos de basalto y determinar la variabilidad estacional del EUR. El trabajo se realizó entre la primavera de 2013 y el verano de 2015 en cinco establecimientos ganaderos de la región basáltica de Uruguay, en los cuales se eligieron dos potreros con manejo ganadero contrastante. Se midió el crecimiento de la vegetación mediante la técnica del rebrote utilizando jaulas de exclusión. La composición florística se estimó mediante la escala Braun-Blanquet. El EUR se estimó a partir de la radiación absoluta absorbida por la planta (RFAA) y la PPNA siguiendo la ecuación: EUR=PPNA/ (RFAA×10). Se registraron cambios en la composición florística, la PPNA y el EUR a lo largo del estudio en los dos tratamientos. Los datos de EUR obtenidos servirán para poder estimar con mayor precisión la PPNA en campos naturales.

Palabras clave: EUR, degradación, manejo ganadero

Resumo

Os campos naturais da região de basalto do Uruguai estão atualmente deteriorados, uma vez que o gerenciamento de carga historicamente contínuo tem sido usado sem ajuste à Produtividade Primária Líquida (PPNA) da comunidade de plantas. Atualmente, é possível estimar o PPNA por sensoriamento remoto utilizando imagens sintéticas do índice de vegetação aprimorado (EVI). Os objetivos do trabalho foram determinar o efeito da diminuição da intensidade de pastejo sobre a composição florística, o PPNA e o coeficiente de eficiência no uso de radiação (EUR) da comunidade vegetal presente em solos basálticos profundos e determinar a variabilidade sazonal do EUR. O trabalho foi realizado entre a primavera de 2013 e o verão de 2015 em cinco fazendas de gado na região basáltica do Uruguai, nas quais foram escolhidas duas áreas de pastagem com manejo pecuário contrastante. O crescimento da vegetação foi medido pela técnica de rebrota em gaiolas de exclusão. A composição florística foi estimada pela escala de Braun-Blanquet. EUR foi estimado a partir da radiação fotossinteticamente ativa absorvida pela planta (PGRFA) e o (PPNA) seguindo a equação: EUR = PPNA / (PGRFA x 10). Mudanças na composição florística, PPNA e EUR foram registradas ao longo do estudo em ambos tratamentos. Os dados EUR obtidos poderiam ser utilizados para estimar com uma maior precisão o PPNA em campos naturais.

Palavras-chave: EUR, degradação, gestão pecuária

1. Introduction

Continuous grazing management[1] with high animal density, high sheep:cattle ratio, and without resting periods[2][3][4] has been traditionally applied in the Uruguayan basaltic region, causing overgrazing that produced a deterioration of the natural grass cover[2].

The implementation of controlled grazing where grazing time and defoliation intensity can be adjusted allows mitigating the degradation process of the natural field, and could sometimes reverse it[5][6]. Traditionally, the aboveground net primary production of pastures (ANPP), that is, the amount of biomass accumulated per unit area, was estimated from biomass cuts carried out in the field[7]. Nowadays, it is possible to estimate ANPP by remote sensors using synthetic images of improved vegetation index that detect the fraction of photosynthetically active radiation that is absorbed by plants (fPAR). This methodology allows covering larger areas and easily achieve repeated measurements over time from the same place[8]. To convert fPAR into ANPP, it is necessary to consider the efficiency with which plants transform radiation into biomass, which is the coefficient of radiation use efficiency (RUE)[9]. This coefficient is affected by environmental factors such as temperature and precipitation and by the floristic composition, which in turn is affected by livestock management[8][10].

The study aimed to determine the effect of the decrease in grazing intensity on the floristic composition, the ANPP and the RUE coefficient of the Basalto deep soil plant community, and to determine the seasonal variability of the RUE.

2. Materials and methods

2.1 Study area

The study was carried out between spring 2013 and summer 2015, in five farms of livestock producers with mixed grazing (sheep/cattle) on natural field (Table 1). The farms were located in the municipalities of Tacuarembó and Salto, Uruguay, in the Cuesta Basáltica geomorphological region[11].

Table 1. Main characteristics of the farms under study

Farm	Geographical coordinates	Surface (ha)	Average animal load of the farm LU ha^{-1} *	Sheep/Cattle relationship
A	31°39'21.91"S/ 56°31'39.50" O	462	0.64	2
B	32°35'20.69"S/ 56°07'21.75" O	2200	0.79	1.97
C	31°20'39.34"S/ 56°34'22.94" O	174	1	11.45
D	31°15'08.80"S/ 56°28'21.00" O	441	0.55	2.9
E	31°37'34.52"S/ 56°27'04.15" O	1200	0.75	2.79

* LU: livestock unit

In each farm, the effect of the change in grazing management was evaluated on a paddock with a history of continuous grazing and high load (1.0-1.1 LU:ha), and on another paddock with the same grazing method but with load reduction over time. Loads are defined as the number of livestock units (LU) per hectare, which in Uruguay is equivalent to the maintenance requirements of a 380 kg live weight cow[12]. In each farm, considering the producers' opinion, two paddocks with a history of contrasting livestock management were selected, one with continuous grazing and animal load 1.0-1.1 LU:ha (hereinafter AC), and another with continuous grazing and animal load 0.69-0.8 LU:ha (hereinafter CC). During the study, paddock AC underwent a change in grazing management that implied a decrease in animal load to 0.8 LU:ha similar to CC, which maintained its management. As shown in Gomez Miller[13], the animal load had a variation of 12% in the period of study and in all farms.

The study unit was the deep-soil plant community[14] within each paddock.

2.2 Weather information

The region has an average annual temperature of 19.4 °C with an average of 25.2 °C in summer and 13.6 °C in winter[15]. During the study period (spring 2013-summer 2015) the evolution of the temperature was similar to the seasonal average for the period 1980-2009, with an annual average of 20.3 °C[15]. As for rainfall, the accumulation for the spring 2013-summer 2015 period was higher than the accumulated annual average for the region (1992 mm vs 1339 mm)[15]. At seasonal level, the highest rainfall records were in spring 2013 (388 mm) and summer 2015 (423 mm) (Table 2).

2.3 Measurements

The ANPP was determined by the regrowth technique using three mobile cages of 1 m^2 per paddock, installed with prior homogenization of the vegetation at a height of 1 cm. The regrowth harvest was carried out every 45-55 days in two squares of 0.5×0.2 cm with scissors and a remnant height of 1 cm[16]. The harvested material was dried in a forced-air oven at 60 °C for 48 hours. The floristic composition was estimated by the cover:abundance of the species using the Braun-Blanquet scale modified by Lezama and others[14]. In the case of the Cyperaceae, the species level was not reached, so the determinations were made at family level. Recordings were made in a 1 m^2 square inside the cage each time cuts were made to determine growth, and in five similarly sized squares outside the cage in fall and spring to consider possible seasonal changes. The RUE coefficient was estimated from the absorbed photosynthetically active radiation (APAR) and the aboveground net primary production (ANPP) following the Monteith equation[9]: RUE = ANPP / (APAR×10). APAR was calculated from fPAR obtained from synthetic images of improved vegetation index (spatial resolution 250×250m, US Geological Survey) and photosynthetically active radiation (PAR) calculated as 48% of incident solar radiation using radiation data from the agro-climatic stations of the Instituto Nacional de Investigación Agropecuaria (INIA)[17]. The following equation was used: APAR = fPAR×PAR.

Table 2. Precipitation and temperature, historic average vs 2013-2015 average

	Winter	Spring	Summer	Autumn
PP historical average (1961-1990)	74.6	118	122	125
PP average (2013-2015)	126.3	377	355.5	328.6
T°C historical average (1961-1991)	12.3	17.8	24.1	18.2
T°C average (2013-2015)	13.1	19.7	25.4	18.1

Source: Based on INIA[15]. PP: precipitation (mm); T°C: temperature (°C).

2.4 Statistical analysis

The average daily growth rates for each farm and treatment were calculated from the ANPP data. Growth rates were analyzed from ANOVA using LSD Fisher test to compare differences between treatment means at baseline. Seasonal growth rates for each treatment were then calculated and analyzed through ANOVA using LSD Fisher test to compare separately the effect of each treatment over time. The average daily growth rates at baseline (spring 2013-summer 2014) and at the end of the study (spring 2014-summer 2015) were also calculated separately, and ANOVA was performed using LSD Fisher test to compare the difference between the means of the two treatments at both times. To carry out these analyzes, the InfoStat software was used[18].

The floristic composition data at species level were standardized and grouped into functional groups[19] in C4 grasses, C3 grasses, forbs, bushes, legume and graminoids; and analyzed with multivariate ordering techniques, carrying out principal component analysis to estimate variability between measurements and identify associations between functional groups[20].

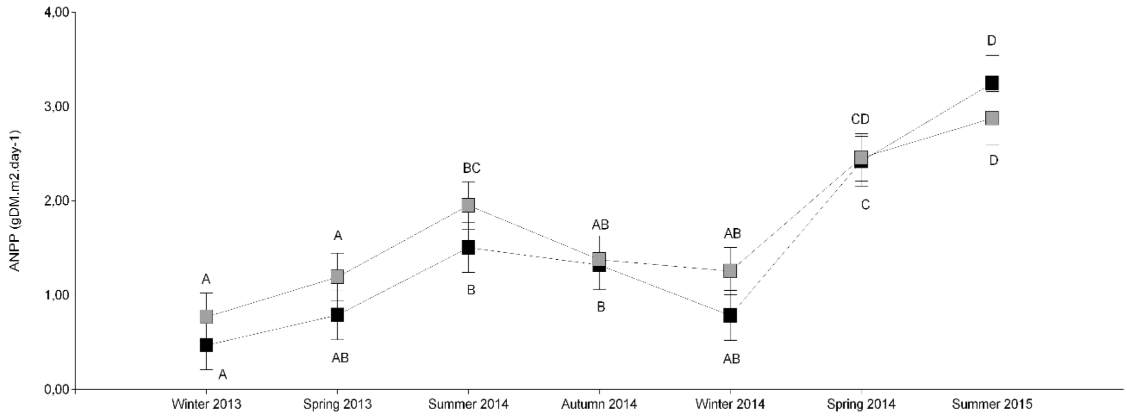
The data of the RUE coefficient obtained for the total period evaluated in all farms and treatments were grouped according to the season and the year in order to estimate the existing seasonal variability. Therefore, the data were analyzed from an ANOVA comparing the difference between the means for each season and year. Then, an ANOVA was performed for each treatment separately to compare the difference between the means at the beginning (spring 2013-summer 2014) and at the end of the study (spring 2014-summer 2015). Finally, from the data of the RUE coefficient obtained at the beginning of the study, an ANOVA was performed to compare the difference between the means of the two treatments. LSD Fisher test was used in the comparisons and the analyzes were performed with InfoStat software[18].

3. Results

3.1 Aboveground net primary production

In both treatments, the obtained ANPP values showed a seasonal variation with statistically significant differences (*P*<0.05) (Figure 1). In the CC treatment, the highest ANPP values were recorded during summer 2015 (2.88 gDM.m^2.day^{-1}) and spring 2014 (2.46 gDM.m^2.day^{-1}), while the minimum values were obtained in the winter months of 2013 (0.72 gDM.m^2.day^{-1}), spring 2013 (1.19 gDM.m^2.day^{-1}), autumn 2014 (1.38 gDM.m^2.day^{-1}) and winter 2014 (1.26 gDM.m^2.day^{-1}) (Figure 1). Regarding the AC treatment, the maximum ANPP values were obtained in the summer 2015 (3.25 gDM.m^2.day^{-1}), while the minimum values were recorded in the winter months of 2013 (0.47 gDM.m^2.day^{-1}), spring 2013 (0.79 gDM.m^2.day^{-1}) and winter 2014 (0.78 gDM.m^2.day^{-1}) (Figure 1).

Figure 1. Seasonal variation of ANPP for both treatments. Black squares: AC treatment; grey squares: CC treatment. Different letters mean significant differences, *P*<0.05 (LSD Fisher test)



Furthermore, the values obtained at the beginning of the study (spring 2013-summer 2014) were significantly different from those obtained at the end of the study (spring 2014-summer 2015), both in the CC treatment (1.57 gDM.m^2.day^{-1} vs 2.64 gDM.m^2.day^{-1}, *P*<0.05) (Table 3) as in the AC treatment (1.15 gDM.m^2.day^{-1} vs 2.79 gDM.m^2.day^{-1}, *P*<0.05) (Table 3).

Table 3. Comparison of the initial (spring 2013-summer 2014) and final (spring 2014-summer 2015) average of ANPP for both treatments

	Moment		
Treatment	P13-V14	P14-V15	p
AC	1.15 a	2.79b	<0.05
CC	1.57a	2.64b	<0.05

Different letters mean different means, *P*<0.05 (LSD Fisher test).

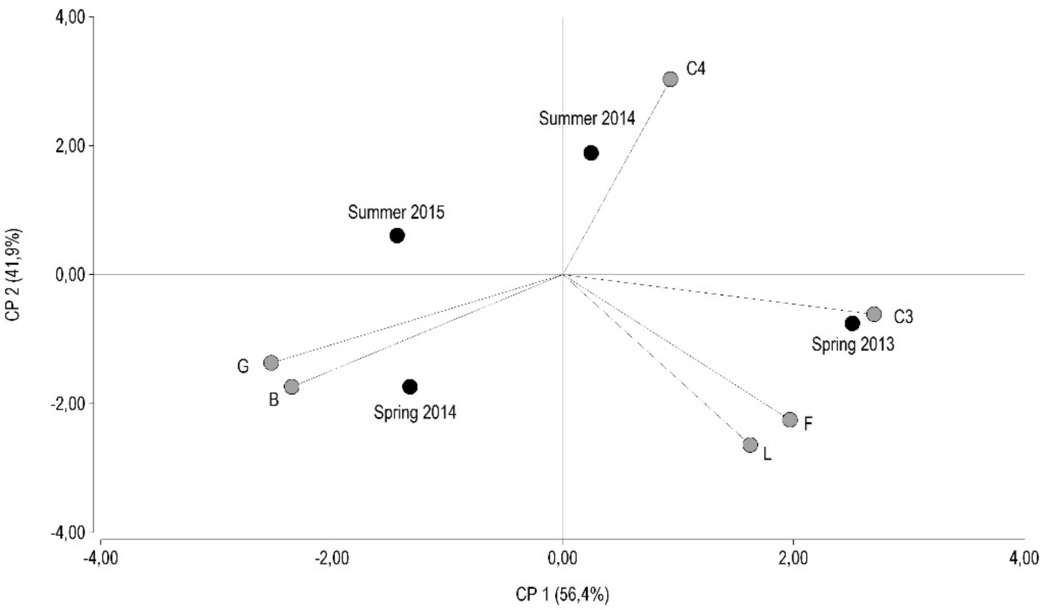
When comparing the average APPN values obtained at the beginning of the study period (spring 2013) no statistically significant differences are seen between the two evaluated treatments (1.15 $gDM.m^2.day^{-1}$ vs 1.57 $gDM.m^2.day^{-1}$, $P > 0.05$) (Table 3).

3.2 Floristic composition

In the main component analysis of the AC treatment, the first two components of the floristic composition explained 98.3% of the variation (Figure 2). The CP1 axis, which explains 56.4% of the variance, represents time evolution since it clearly separates the floristic composition at the beginning (spring 2013 and summer 2014) and at the end (spring 2014 and summer 2015) of the study. At the beginning of the study, the floristic composition of the paddocks with AC livestock management was composed of winter species with C3 metabolism with a high correlation with the CP1 axis (0.96), summer species with C4 metabolism, forbs and legumes, while at the end of the study, the floristic composition was characterized by the presence of graminoids such as the species of the Cyperaceae family (correlation with the CP1 -0.90 axis) and shrubs.

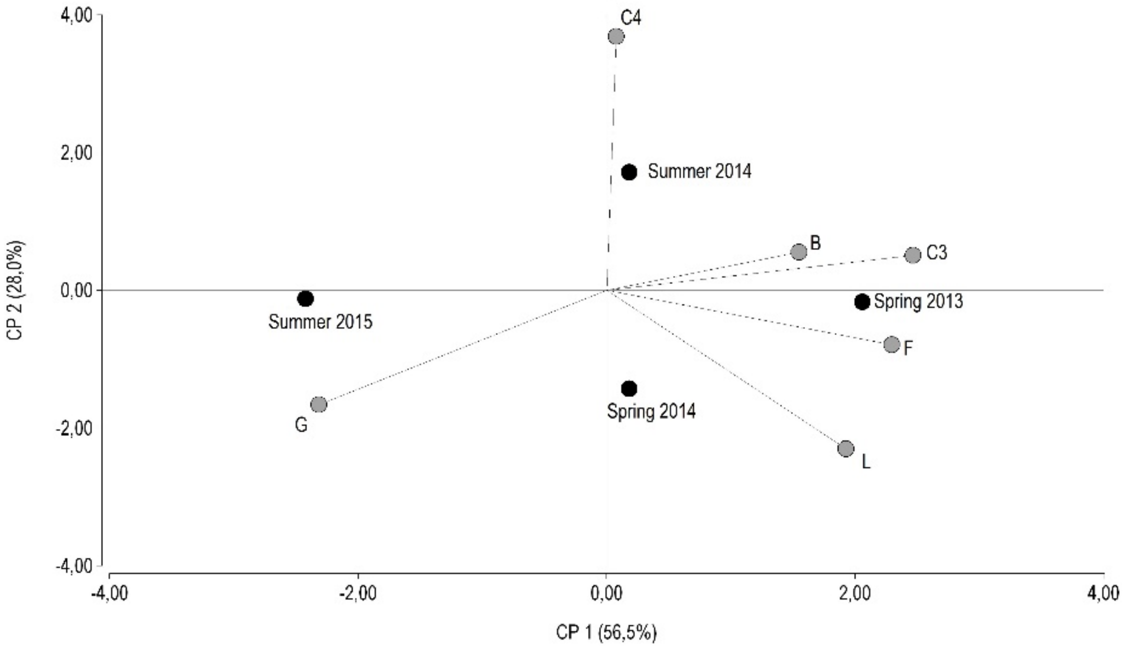
On the other hand, the CP2 axis, which explains 41.9% of the variance, represents the intra-annual variability of the floristic composition since it separates spring from summer (Figure 2). During the spring months, the floristic composition of these paddocks was characterized by the presence of C3 bush species, leguminous species, forbs, and graminoids, while during the summer months (2014 and 2015) grass species with C4 metabolism predominated, being this the variable that had the highest correlation with the CP2 axis (0.93) (Figure 2).

Figure 2. Principal components analysis of floristic composition × season. Treatment AC. G:graminoids; L:legumes; C4:grasses with C4 photosynthetic metabolism; C3: grasses with C3 photosynthetic metabolism; B:bushes; F:forbs



With respect to paddocks with CC treatment, the first two main components explained 84.5% of the occurred variation (Figure 3). The CP1 axis, which explains 56.5% of the variance, separates the summer 2015 season from the rest of the seasons, summer 2014, spring 2013 and spring 2014. According to this axis, the floristic composition of the paddocks with the CC treatment during the summer of 2015 was characterized by the presence of graminoids such as the species of the Cyperaceae family. In the rest of the evaluated seasons, the paddocks with CC treatment had a floristic composition made up of bushes, legume, forbs and C3 species, the latter functional group having the highest correlation with the CP1 axis (0.95). On the other hand, the CP2 axis explains 28% of the variance and separates summer 2014 with a floristic composition of mainly C4 species (correlation with the CP2: 1 axis) from summer 2015, spring 2014 and spring 2013 seasons with a floristic composition characterized by species of graminoids, forbs and bushes (Figure 3).

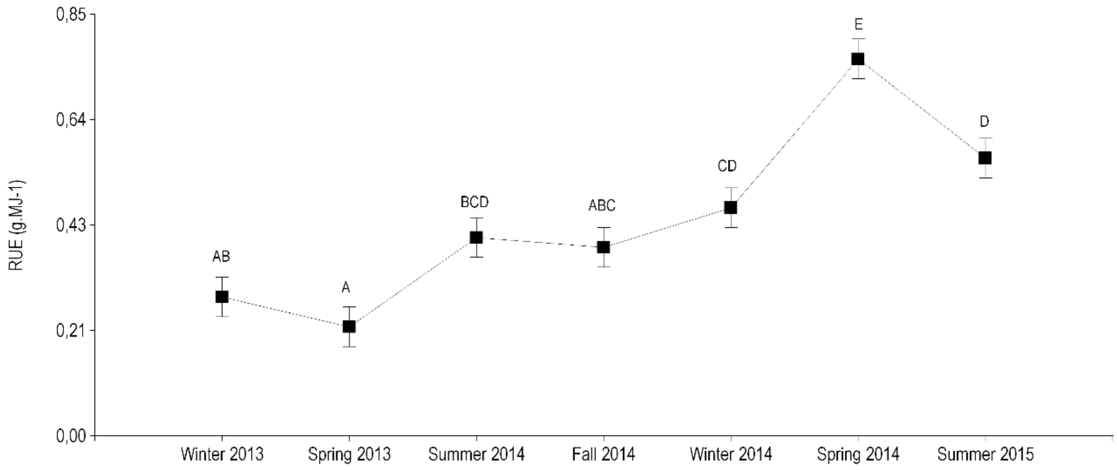
Figure 3. Principal components analysis of floristic composition × season. Treatment CC. G: graminoids; L: legumes; C4: grasses with C4 photosynthetic metabolism; C3: grasses with C3 photosynthetic metabolism; B: bushes; F: forbs



3.3 RUE coefficient

The values of the RUE coefficient obtained in the total period and for the two treatments showed a seasonal variation with an average of 0.41 $g.MJ^{-1}$ and a maximum value obtained during the months of spring 2014 (0.62 $g.MJ^{-1}$, *P*<0.05) (Figure 4). Furthermore, the RUE coefficient showed an annual variation given that the values obtained during the second year (spring 2014 and summer 2015) were higher than those obtained during the first year in the months of spring 2013 and summer 2014 (0.25 and 0.37 $g.MJ^{-1}$ vs. 0.62 and 0.51 $g.MJ^{-1}$, *P*<0.05) (Figure 4).

Figure 4. Seasonal variation of RUE coefficient average for all farms and treatments. Different letters mean different means, P<0.05 (LSD Fisher test)



The RUE coefficient values obtained at the beginning of the study (spring 2013-summer 2014) were statistically different (P<0.05) from those obtained at the end of the study (spring 2014-summer 2015) for the AC and CC treatments when comparing the results obtained within each treatment separately (Table 4). The RUE values obtained at the end of the study were higher than those obtained at the beginning both in the CC treatment (0.39 g.MJ^{-1} vs. 0.61 g.MJ^{-1}) and in the AC treatment (0.22 g.MJ^{-1} vs. 0.53 g.MJ^{-1}) (Table 4).

Table 4. Comparison of the initial (spring 2013-summer 2014) and final (spring 2014-summer 2015) average of RUE coefficient for both treatments

	Moment		
Treatment	P13-V14	P14-V15	*P*
AC	0.22	0.53	<0.05
CC	0.39	0.61	<0.05

Different letters mean different means, P <0.05 (LSD Fisher test).

On the other hand, when comparing the RUE values obtained in the two treatments at the beginning of the study (spring 2013-summer 2014), it is observed that the average value of the RUE coefficient of paddocks with AC treatment was different from the value obtained in the CC paddock (0.22 vs 0.39 g.MJ^{-1}, P <0.05) (Table 4).

4. Discussion

The ANPP values obtained are similar to those reported by Berreta and others[21] in natural fields on deep Basalt soils in years with good precipitations, with maximum peaks in the summer months and minimum peaks in winter. The APAR values had a seasonal variation similar to that of the ANPP with maximum peaks in the summer months and minimum during the winter months. The maximum peaks recorded during the summer months would be associated with the moments with the highest APAR, and could be due to the floristic composition of the paddocks that were mainly composed of grass species with C4 metabolism[22][23].

The highest ANPP values obtained during spring 2014 and summer 2015, within each treatment, would be associated with rainfall and temperatures above the annual average that were recorded during the years in which the study was carried out.

The analysis of the floristic composition grouped by functional groups showed changes in the vegetation of the two treatments over time. During spring 2014 and summer 2015, an increase in the presence of species of the Cyperaceae family was observed, which would be associated with the climatic conditions existing during the study with high temperatures and above-average annual rainfall, added to the effect of grazing on promoting the presence of graminoids species[24]. Furthermore, the increase of Cyperaceae species classified by Rosengurtt[25] as ordinary species with low palatability could adversely affect forage quality[26].

The values obtained from the RUE coefficient are similar to those obtained by Oyarzabal and others[10] in natural fields on deep basalt soils (0.3-1.0 $g.MJ^{-1}$), but higher than those published by Baeza and others[27] also in basalt fields (0.1-0.3 $g.MJ^{-1}$). At seasonal level, the values obtained showed a variation in the RUE coefficient with maximum values in the spring and summer months and minimum values in winter. This seasonal variation of the RUE coefficient has been reported by other authors, although with maximum values in winter and minimum in summer[8][10]. According to these authors, rainfall (positively) and temperature (negatively) are the main variables that affect the RUE coefficient. This implies that during the summer months in which high temperatures and periods of water deficits are recorded RUE has minimum values. The fact that the results obtained in this work regarding the seasonal variation of the RUE are contrary to those reported by these authors with maximum peaks in summer could be associated with the climatic conditions that were recorded during the evaluated period with rainfall above annual average. The favorable environmental conditions not only allowed maximum RUE values to be recorded in the summer months, but the values of this coefficient that were obtained at the end of the study were higher than those obtained at the beginning for all paddocks and treatments.

However, it is important to note that the RUE values presented here could have a prediction error associated with the work scale given by the size difference between the sites in which the ANPP was determined (exclusion cages of $1m^2$), and MODIS pixels (approximately 6 ha) from which the APAR data were obtained. Furthermore, since there were small changes in the animal loads during the study, the ANPP values obtained could be given by the residual effect of the animal loads before the study.

Therefore, the comparison of the AC and CC treatments at the beginning of the study showed differences regarding the RUE coefficient without ANPP differences. Thus, the RUE coefficient was higher in paddocks with CC treatment than in those with AC treatment. This RUE difference between treatments could be due to the differences in the diversity of the deep soil of basaltic communities of the two treatments, that would imply differences in the floristic composition, as reported by Nouvellon and others[28].

5. Conclusions

Changes in the floristic composition, ANPP and in the RUE coefficient were recorded throughout the study in the two treatments that were mainly associated with rainfall and temperatures above the annual average recorded during the evaluated period. The RUE data obtained will help to estimate more accurately the ANPP in natural grasslands on deep soils of the basaltic region.

Author contribution statement

All authors (PB, DF and OB) of the paper contributed in an equal manner to the development and finalization of the manuscript.

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