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Above-ground phytomass and chemical composition dynamics of *Stipeta Zalesskii* phytocenosis in Ural-Ilek interfluves

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Abstract

We carried our investigationsin one of the typical phytocenosesof the Trans-Volga-Kazakhstan herb bunchgrass steppes underprotected regime conditions. Forb-fescue-feather grass steppe community (*Stipa zalesskii*, *S. lessingiana*, *Herbae stepposae*) with *Helictotrichon desertorum* (Less.) Nevski and petrophytous elementswere considered as a model. The dynamics of the above-ground phytomass stocks of this community was on the “Burtinskaya steppe” site in the Orenburg State Nature Reserve using thesquare sample cut method. The content of the main macroelements N, K, Na, Ca, P, and Mg is determined. The Federal State Budgetary Institution and the State Agrochemical Service Center “Orenburgsky” conducted the analysis of the plant samples.The resultsobtained were compared with the available literary data. Statistical analysis using the nonparametric Mann-Whitney U-test ($\alpha=0.05$) in Statistica 6.1 revealed significant differences in the content of some macroelements between the drought year 2015 and the wet year 2016. The share of cereals (dominant community *Stipa zalesskii* Wilensky, codominant *S. lessingiana* Trin. & Rupr.), both in living above-ground phytomass and in dead grass, have been prevailing. The following series of accumulation of elements: N>K>Na>Ca>P>Mg was common for both fractures in most reference periods. The above-ground phytomass stocks in the examined community ranged from 335 g/m² to 404 g/m² in 2015 and from 525 g/m² to 678 g/m² in 2016. The findings obtained complement the available data for grasslands and pastures, present the opportunity to assess them comparatively with reference to standard and steppe zones, and serve as the foundation for further monitoring.

Keywords
Steppes, plant communities, above-ground phytomass, macroelements, forb-fescue-feather grass stepp

Introduction

The above-ground phytomass of steppe communities is the basis of the forage reserve for animal phytophages, which, in turn, influences the intensity of food accumulation and the maintenance of the mineral matter balance. The purpose of our research is to elucidate the features of the functioning of steppe communities on the reference steppes. The aridity of the steppe zone determines the rapid change of all stages of plants, changes in their nutrient value. Thus, the necessity of understanding the above-mentioned processes increases. Numerous studies in this field confirm the dependence of the chemical composition on various environmental factors. (Abaturov 2005; Bulatov et al. 2016; Perelman 1975). Elements such as *N* and P, which are important for plant nutrition and growth, respond differently to lack of moisture in the soil (Lambers et al. 2008; Belnap 2011). The highest N concentration in plants was recorded at medium aridity levels and P concentration was at low aridity levels. Plants with a high nutrient content were also shown to increase their biomass during a drought, while others fell out of the grass stand (Luo et al. 2018). Processes in the biological cycle of substances vary depending on the type of anthropogenic load. Therefore, after steppe fires, nitrogenous compounds volatilize and completely disappear from the biological cycle of matter, while a part of the mineral matter is quickly released in the soil and becomes bioavailable for plants (Abaturov and Kulakova 2010). For example, after burning prairies, *N* was mobilized in underground phytomass, its loss was compensated, according to the author, by reducing its participation in leaching and denitrification processes (Dell et al. 2005).

Today, extensive material has been collected on the chemical composition of selected steppe plant species of the Streletskaya steppe, Askania-Nova, Altai Krai, Novosibirsk region (Bazilevich 1962), Western Kazakhstan (Bolyshev and Vorobyova 1958), and the southern steppes (Evseev 1954), forest pastures in Hungary (Kovács et al. 2000). Most of the examined communities demonstrated unbalanced ratios of macroelements. American researchers found an increased content of K compared to Na and Cl in plants of type C 4, which include most of the herbs of the Poaceae family and the genus *Stipa* (Mathews et al. 2016). In the studied area, (Evseev 1954; Miroshnikov et al. 2011; 2017) conducted similar investigations.

The relevance of similar research, conducted on the territory of the Orenburg region, is determined by the need to understand the characteristics of the seasonal dynamics of the above-ground phytomass and the chemical composition of typical phytocenoses during the evaluation of the forage reserve in the Ural-Ilek interfluve region, caused by the implementation of the Przewalski horse breeding project, as well as by the preservation of theneed to optimize the steppes and their sustainable use in the region.

The purpose of our research is to clarify theintensity of food accumulation and the maintenance of the mineral matter of vegetable cover. Our primary tasks included investigating the above-ground dynamics of the phytomass reserves and chemical substances in the phytocenoses of most of the typical zones.

Materials and methods

The dynamics of the above-ground phytomass stocks and their chemical composition have been analyzed on the territory of the "Burtinskaya steppe", the State Nature Reserve"Orenburgsky" in the Ural-Ilek interfluvial region. Botanically and geographically, this protected cluster is located in the Trans-Volga-Kazakhstan herb bunchgrass steppe (Ogureeva 1999; Safronova and Kalmykova 2012). The reservation conditions of the chosen site (introduced in 1989) present the opportunity to minimize the modern influence of the anthropogenic factor on the investigated object.

The Forb-fescue-feather grass steppe (*Stipa zalesskii*, *S. lessingiana*, *Herbae stepposae*) community with *Helictotrichon desertorum* (Less.) Nevski and petrophytous elements, belonging to the formation of *Stipeta zalesskii*, were considered as a model. Phytocenoses of this formation are the most widespread in the territory under study (Kalmykova 2010, 2012). The examined community is located in the upper-level part of the escarpment slope, periodically exposed to fire (1998, 2003, 2005, and 2009) (Pavleychik 2015; Dusaeva et al. 2019). The number of species in the community amounted to 48 in 2015 and 53 in 2016, while the total projective coverage was 97–98% and 95–97%, respectively. The *Stipa zalesskii*, the steppe xerophilous plant, was the predominant plant of the community. The codominant was *Stipa lessingiana* Trin. & Rupr. Among cereals, steppe xerophytes, such as *Festuca valesiaca* Gaudin, *Stipa capillata* L., *Koeleria cristata* (L.) Pers., and the mesoxerophyte *Helictotrichon desertorum*, reached a notable abundance. The meso xerophyte *Galium octonarium* (Klokov) Soó dominates in motley grass. Among dwarf semishrubs, the most numerous are steppe meso xerophytes: *Onosma simplicissima* L., *Eremogone koriniana* (Fisch. ex Fenzl.) Ikonn., *Artemisia marschalliana* Spreng. The steppe shrub *Spiraea crenata* L.was found singularly in the community.

Plant selection was carried out in the middle of each month from May to September during the 2015–2016 period. According to the Selyaninov hydrothermal index, 2015 was slightly dry (HI – 0.7), and 2016 was satisfactorily wet (HI – 1) (Dusaeva et al. 2019). A geobotanical area (10x10 m) was established on the territory of the phytocenosis examined. Standard geobotanical techniques present the opportunity to describe this area (Walter and Alyokhin 1936; Sukachev and Lavrenko 1952; Yaroshenko 1969). The efficiency of the above-ground phytomass was examined with the square sample cut method. The plants were cut flush with the soil after geobotanical descriptions in 0.25 m² sections of 0.25 m² in triplicate, and ground litter (L) was collected (Bakiev al. 2017; Bazilevich et al. 1978; Kin et al. 2015; Rodin et al. 1968). Each sample was divided into two fractures: green living phytomass (G), and dead grass (D). Plant samples were dried to an air-dry mass. The prepared medium samples were sent for chemical analysis (triple analysis of the cut plant samples was performed). The composition of dead grass was analyzed separately from the living phytomass. The following elements were found in the mineral part of the plant samples: Ca, P, K, Na, N, and Mg. The Federal State Budgetary Institution and the State Agrochemical Service Center 'Orenburgsky' conducted the plant samples. Data analysis was performed using Statistica 6.1 software. To assess statistical significance of differences in the chemical composition of burned phytomass in the stocks and control sites, we used Mann-Whitney U-test (α=0.05).

Result

The above-ground phytomass stocks (G+D+L) in the examined community ranged from 335 g/m² to 404 g/m² in 2015 and from 525 g/m² to 678 g/m² in 2016. The highest above-ground phytomass stocks in different years occurred in different periods: in the first year – in September, in the second year – in June. The highest stocks of green living phytomass (G) during the two years occurred at the time of blooming and fruiting of the main species of the community. During the dry period (2015), the least amount of living phytomass was recorded in September; during the wet period (2016), a significant G was observed and the minimum appeared in August. At the end of the above-ground 2015 vegetation period, the living phytomass stocks were 2.6 times lower than the above-ground dead phytomass (D) stocks. The highest concentration of D in the community (2015 – 185 g/m²; 2016 – 179 g/m²) was the reason for the decrease. The lowest amount of dead grass occurred in August 2015 (101 g/m²) and July 2016 (96 g/m²).

During the two-year observations, the share of cereals, both in the living above-ground phytomass and in the dead grass, was predominant in most of the observation periods. At the beginning of each season, the share of motley grasses and cereals was practically comparable. A similar consistent pattern was observed in living phytomass in 2015 not only in May, but also in August, and in June 2016, the share of motley grasses exceeded the share of cereals. Cereals prevailed in dead grass for two years of observation. Smooth accumulation of ground litter (L) was observed from May 2015 (79 g/m²) to September 2016 (313 g/m²).

In the above-ground living phytomass of the studied community, the content of N exceeded the content of all other elements examined. The average element concentration in G fractures in 2015 was 1.06%, in 2016 – 1.15%. Spring 2015 was characterized by a low N content, whereas the minimum was observed in early summer (0.86%) and the maximum element concentration was in mid and late summer (1.25%) (Fig. 1). The next year, the sharp variation in the concentration of this element during the growing season was not fixed: the maximum rates characterized the spring period (1.3%), the lowest for the end of summer (1%).

The dead phytomass, on average, was 0.88% in 2015, and 1.2% in 2016 Analysis of data received using the nonparametric Mann-Whitney U-test (α=0.05) revealed significant differences in the N content in the dead grass community between 2015 and 2016. At the beginning of the first year of summer, the lowest level of N content (0.77%) was observed in dead grass. Then in July, it reached the highest points (0.98%). In the wetter 2016, the N concentration increased and reached its maximum in May during the vegetative phase and the flowering of spring species (1.45%). In July, the N content of the dead above-ground phytomass decreased markedly while the dead grass stocks increased.

Figure 1. Mineral content in the above-ground phytomass of the forb-fescue-feather grass steppe community (*Stipa zalesskii*, *S. lessingiana*, *Herbae stepposae*) with *Helictotrichon desertorum* and petrophytous elements of the community (6B). G – living above-ground phytomass, D – dead above-ground phytomass.

In 2015, the average Ca concentration in the above groundliving community was lower (0.69%) than the following year (0.77%). The highest Ca concentration for this fraction was observed during the entire observation period in May 2015 (1.7%) (Fig. 1). Atthe beginning of the summer, it had decreased 3.8 times and by mid-summer it had decreased even twice more, reaching its lowest level for the summer (0.24%). The concentration of Ca in the living above-ground phytomass reached its maximum during the vegetation period (1.2%) at the beginning of summer 2016. During the remainder of a vegetation period, a decrease in the element concentration was observed with its minimum in September (0.34%).

In contrast, the dead above-ground phytomass in the first year of the investigation had a Ca concentration of 0.54%; in the following year, this figure decreased to 0.47%. In 2015, the lowest Ca concentration in the above-ground dead phytomass of the analyzed community contained the N concentration was observed at the beginning of the season (0.42 %), and did not change significantly during the vegetation period. However, the Ca concentration increased to the maximum level during the year and was 0.9% in the autumn. During the wetter of 2016, the maximum element concentration was typical for the beginning of the vegetation period (0.66%), and then its concentration decreased by 2.6 times before the autumn.

In 2015, the mean K concentration in living above-ground phytomass was higher (0.86%) compared to the following, wetter year (0.68%). The minimum figures of K concentration in this above-ground phytomass fraction were at the beginning of the season and equaled 0.6% in 2015 and 0.42% in 2016 (Fig. 1). Then, the element accumulation process occurred with the intense growth of the phytomass. July 2015 (1.1%) and September 2016 (0.84%) showed the maximum figures of its content.

The average K concentration in the above-ground dead phytomass in the community was higher (0.88%) in the first study year, compared to the following year (0.59%). Differences in K concentration in dead grass between the two seasons are statistically confirmed according to the Mann-Whitney U-test (α=0.05). In May 2015, the concentration of K element in this fraction was relatively high (0.96%) compared to 2016, when it was two times lower. At the end of summer, its concentration decreased to a minimum (0.78%) and reached a maximum (0.97%) in autumn. In 2016, the minimum concentration of elements was observed in the dead phytomass at the beginning of the season and midsummer (0.48%; 0.47%), and the maximum, similarly to the previous year, in the autumn (0.8%).

The average concentration of P was higher in the first year of the study (0.2%) than in the second year (0.13%), despite the more favorable weather conditions for its absorption during this vegetation period. In 2015, two peaks of P accumulation were observed in the living above-ground phytomass: at the beginning and end of summer (Fig. 1), when its concentration was 0.24% and 0.28% (the maximum concentration for the year), respectively. The lowest accumulation of P in living above-ground phytomass was recorded in September, 0.13%. Throughout the 2016 vegetation period, no significant changes in P concentration were observed, except for spring, when it reached the highest level for the year – 0.18%, then decreased to 0.12% and became the minimum in autumn (0.1%).

The concentration and dynamics of P accumulation in the dead phytomass differed insignificantly from those of the living phytomass during both years. However, statistically significant differences in P concentration between years were observed only for dead grass (according to the Mann-Whitney U-test with $\alpha=0.05$). In 2015, the average P concentration in dead grass was 0.192%, in 2016 – 0.122%. The minimum concentration of the element in dead grass in 2015 was in September (0.15%), and similar values were observed in mid-May, and the amount of P in the dead phytomasswas at its highest level – 0.25% in early summer. This value was slightly higher compared to data at the end of summer (0.23%). In the following year, the maximum concentration in the dead grass corresponded to the minimum values and was observed during the spring and midsummer period (0.15%). At the end of the year, the P concentration dropped to the lowest values of 0.08% in August and 0.09% in September.

However, statistically significant differences in Na concentration between two years for living above-ground phytomass, as well as for above-ground dead phytomass (according to the Mann-Whitney U-test with $\alpha=0.05$). In 2015, the average Na concentration was 0.72% and in 2016 – 0.41%. The maximum accumulation of Na was observed during the beginning of the vegetation period (0.98%). Then it gradually decreased at the end of the vegetation period (0.48%) (Fig. 1). In 2016, the reverse dynamics of the element was observed: for May, the minimum values – 0.3%, and the accumulation was observed from July to September (max – 0.53%). Additionally, an increase in the N share would intensify this process. The average Na concentration in dead grass was 0.57% in 2015, 1.7 times lower in 2016. From May to August, it varied within a small range: from 0.58% to 0.61%, and in September it decreased to its lowest level for the year – 0.47%. In 2016, the Na concentration in the dead phytomass increased from 0.21% to 0.4% until the end of summer, and in September it reached the annual maximum annual level of 0.5%.

In 2016, the average concentrations of Mg in living above-ground phytomass were 1.6 times higher compared to the figures in 2015. In 2015, the minimum accumulation level of Mg in this fraction was observed in June (0.05%) and the maximum in August (0.12%). The following year, the lowest figures were observed in September (0.07%) and the highest in June (0.17%). The average concentration of Mg in the dead phytomass during the 2-year period was 0.08%. This fraction of the above-ground phytomass demonstrated a similar trend of element accumulation in 2015 and 2016. In May we recorded the maximum concentration of Mg (2015 – 0.1%; 2016 – 0.15%), during the second half of summer, the concentration decreased to minimum (August 2015 – 0.05%; July 2016 – 0.05%).

The living above-ground phytomass (G) of the studied community in most periods of 2015 was characterized by the following series of element accumulation: N>K>Na>Ca>P>Mg (Fig. 2).

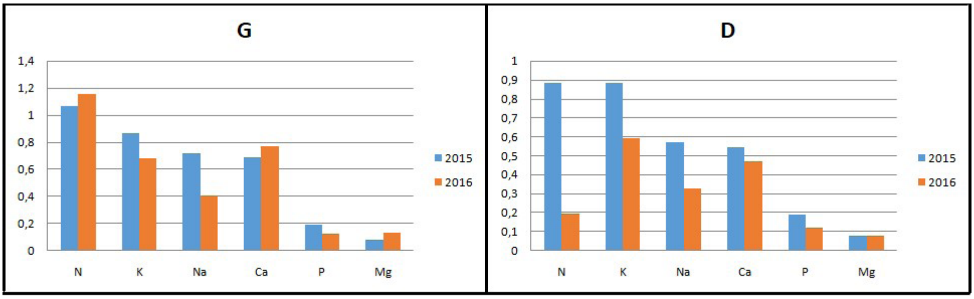

Figure 2. The average content of mineral elements in the above-ground phytomass of the forb-fescue-feather grass steppe (*Stipa zalesskii*, *S. lessingiana*, *Herbae stepposae*) with *Helictotrichon desertorum* and petrophytous elementsof the community. G – living above-ground phytomass, D – above-ground dead phytomass.

The beginning of the 2015 vegetation period demonstrated a high concentration of Ca and Na, which elevated the mentioned elements to first place in the accumulation chain. A repeated increase in Ca concentration was observed in September 2015, it continued up to June 2016, and the position of the element was shifted to a higher position during each accounting period. By August, its concentration decreased to the usual parameters. In 2016, the decrease in P concentration compared to last year influenced the redistribution of elements: N>K>Na>Ca>Mg>P.

In the above-ground dead phytomass of the studied community in most periods of 2015, the following distribution of elements was observed: N>K>Na>Ca>P>Mg (Fig. 2). However, during the season, K sometimes occupied the leading position in the accumulation chain. The highest values of N, compared to K, were recorded mainly during the fruiting and semination periods of the main plant species. The composition of the dead grass was more steady: N>Ca>K>Na>P>Mg. The concentration of N significantly exceeded the concentration of all other elements examined. September was an exception when an increase in the K concentration was observed, and the Ca concentration, unlike last year, at this period decreased N>K>Na>Ca>P>Mg.

Discussion

Numerous scientific research papers are devoted to the study of vegetation productivity. Nowadays, there are not only data on the study of phytomass stocks and its components, but also on the processes of production and destruction of plant matter. Furthermore, the influence of various factors on these processes (fires, grazing, and fertilizer distribution) has been considered. The values of the above-ground phytomass stocks obtained by us during the wetter 2016 correlate with the data obtained for the cereal and herb steppes of the Ural region in the meadow steppe zone

(636 g/m²) (Bazilevich1993). When comparing the above ground phytomass stock of the steppes of the Southern Urals (Morozova 1990), the index of the community that we studied was higher and more correlated with the hay plant bunchgrass used for haying (570 g/m²). In drier 2015, the above-ground phytomass stocks were significantly lower than in 2016, while higher than in the cereal herb steppes with *Stipa zalesskii* dominance in the zone of arid steppes (219 g/m²) (Bazilevich 1993). The maximum above-ground phytomass stocks for the given vegetation period did not differ from the data given for the current bunchgrass steppes of the southern Urals in hay fields and pastures with average grazing (419 g/m²). A similar decline in above-ground phytomass stocks in the studied community, was primarily due to the limited supply of moisture in the soil during spring, because of the last dry winter, and the fact confirmed by the literature data (Kurkin 1986; Morozova 1990).

Although the largest stocks of living phytomass (G) were observed during the blooming and fruiting of the main species of the community during the whole period of observations, the dominants of the studied community have a greater nutritive value before fruiting and during secondary vegetation (Larin et al. 1956). These stocks have high feeding qualities and produce good fertilizer after grazing. Before the fruiting period in 2015, the living above-ground phytomass was enriched with Ca and Na, in 2016 with Ca, P, Mg. Maximum concentrations of other macroelements fell in the middle of vegetation periods, coinciding with a decrease in the feeding qualities of the herbage.

Comparison of the results obtained with the existing data on natural pasture Ca concentration in the herbage (Sechin 2017) shows that in the studied plant samples and the living above-ground phytomass, as well as in the above-ground dead phytomass, the sufficient amount of this element was found during the entire vegetation period. Compared to available data on P concentration in hay from natural areas, the plant samples in the study showed low concentration, especially in 2016, which slightly exceeds the element concentration norms in the hay in natural areas (Kosolapov et al. 2019). At the same time, the optimal concentration of P in feeds, according to data from the literature, is 0.35 to 0.55 % in dry matter (Kosolapov et al. 2019). The increased Na concentration is more comparable to the data given for halophytic plant species (Grishina, Samoilova 1971). Both the above-ground phytomass fractions showed low K concentrations (Kosolapov et al. 2019) during the two vegetation seasons, except for the living phytomass in July 2015. There were no significant differences in element content in the two different fractions, indicating that this does not coincide with some data in the literature. According to Kidin (2016), young plant organs contain more K than old ones: it is more abundant in those organs and tissues where metabolic processes and cell division are intensive. By the time of flowering of the main dominant cereals in the community, the maximum potassium content was accumulated, which was in agreement with some literature data (Kuznetsov and Dmitrieva 2019). According to other data, during the flowering period of cereal crops, the consumption of the element was suspended, but further flow of the element into the soil was recorded after the ripening of the grains (Kidin

2016). The K concentration is higher in those organs and tissues, where metabolism and cell division processes are actively occurring. However, there are multiple uses for this element in plants: it is easily transferred from old plant tissues, where it was used, to young ones (Kosolapov et al. 2019).

The dependence of the chemical composition of plants on various factors was one of limitations of the current research, requiring additional soil analyzes. Identification of these dependencies was not part of the current research, but some tendencies and hypotheses have been noted concerning the mutual influence of macroelements on each other. Thus, according to Miroshnichenko (1976), during examination of the ash composition of plants, the need for Ca in sandy needle grass and Volga fescue increases during the fruiting period. In the investigated community, the opposite trend was observed during the two vegetation periods. A factor contributing to the decrease in Ca concentration during blooming and fruiting could have been an increase in nitrogen concentration (Ilyin 1985).

The minimum K concentration coincided with the crucial period of its consumption (the beginning of the vegetation period) (Kidin 2016); in 2016, high nitrogen concentrations could have also suppressed this. In the same year, despite more favorable conditions for P assimilation, they observed a decrease in P with a pH variation of 7.4–8.4, which may be caused by an increase in Ca content (Kosolapov et al. 2019). In September and earlier in July, the high K concentration also affected the decrease in element concentration (Ilyin 1985). The rain in the first ten-day period did not have an effect on the better uptake of the element.

Excess accumulation of the N element (Ilyin 1985) also provided a high Na concentration during spring. However, the increased concentration of K in this period did not show an effect on its content, which contradicts some data from the literature (Ilyin 1985; McDonnellet al. 2018). The concentration of Mg in cereals decreases from the beginning to the end of the vegetation season (Kosolapov et al. 2019). This was observed for the community studied only during the second wetter year of the investigation.

Additional limitations of similar studies were related to the processing of duration of the plant samples related to the separation of above-ground phytomass into dead grass and living phytomass. The narrow leaves of the cereals of the dominant community presented the greatest difficulty during cameral treatment.

Conclusion

According to research conducted on the territory of the State Nature Reserve "Orenburgsky" the investigated parameters of the forb-fescue-feather grass steppe community (*Stipa zalesskii*, *S. lessingiana*, *Herbae stepposae*) with *Helicotrigichon desertorum* (Less.) Nevski and petrophytous elements, our model parameterscan be compared with data of similar communities on other territories with anthropogenic impact. Comparative analysis with the available data revealed that the phytomass stocks are mainly determined by the weather of the vegetation period. Therefore, the lack of moisture in soils significantly reduces the stock of above-ground phytomass. In a wetter year, the results obtained were comparable to the cereal-herb steppes of the meadow steppe zone. The seasonal dynamics of the living phytomass stocks were also different in two years. It reached its maximum reserves during the blooming and fruiting periods of the dominant species of the community. However, the most favorable period for steppe phytophages to graze is the beginning of the vegetation period due to the higher nutritional value of the main dominant cereals. The dynamics of the dead grass stocks was more stable. At the end of summer, the predominant transformation processes of dead grass into litter result in a smaller amount of dead grass during this period compared to September. At the same time, secondary generation of cereals was recorded, increasing the nutritional qualities of the herb. The distribution of macroelements during vegetation periods was diverse, complicating the identification of the most appropriate grazing period according to this parameter.

A nitrogen-potassium type of biological cycle was revealed for the community in most accounting periods. There were no statistically significant differences (according to the Mann-Whitney U-test) in the mineral composition between living and dead above-ground phytomass, except for separate accounting periods, Ca and Mg. However, statistically significant differences, according to the selected criterion, have been confirmed in the mineral element content of Na (G, D), P (D), K (D), N (D) between the drought year 2015 and the wet year 2016.

The practical relevance of similar research consists in the evaluation of the nutritional properties of the vegetation cover. The results obtained will help to identify the degree of availability of animal feed during the entire growing season to determine the most appropriate time for grazing.

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