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Andean Grassland Species: Net Aerial Primary Productivity, Density, Ecomorphological Indices, and Soil Characteristics

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ABSTRACT
The tall grass vegetation in the Andean grassland ecosystems covers the largest area compared to other types of vegetation such as Puna grass, wetland and others. The grasslands are frequently set on fire by livestock farmer, seriously affecting the ecosystem. One way to mitigate this problem is to use these species as a source of plant fibre, which can be economically useful to the interests of the livestock family without affecting the ecosystem. To advance in this approach, it is necessary to know the functional characteristics of the plants; therefore, we evaluated the aerial primary productivity, plant density per m^2, basal cover, aerial cover and leaf height, whose data were analysed using the generalised linear mixed model and the correlation between these variables with the physical-chemical characteristics of the soil, by means of principal component analysis and canonical correlation, in seven species of grassland and seven control plots, located between 3860 and 4333 metres above sea level. The results showed significant differences for p=0.001 between species, and between plots, and a canonical correlation grouped in two clusters that showed the differentiated importance of soil elements with the phytomass produced

Keywords: Andean grassland, aerial phytomass productivity, Andean grassland species, plant density, plant-soil ratio

INTRODUCTION

Andean grassland ecosystems are located between 3500 and 5000 metres above sea level, in an area that extends from northern Colombia to southern Argentina, in which the plant communities are made up of herbaceous plants, shrubs and small stands of native trees (Cuesta & Becerra, 2012). This scenario is generally covered by grasses, among a mosaic of plant formations such as: the tall growing species of the Poaceae family; the puna grasslands populated by upright and stunted species of the Poaceae, Aseteraceae, Cyperaceae, Rosaceae families, among others; the wetlands with the presence of aquatic and semi-aquatic species of the Juncaceae, Plantaginaceae, Apiaceae, Isoetaceae families, among others (Tacuna et al., 2015; Gonnet et al., 2016; Yaranga et al., 2019). This Andean vegetation community is of great importance in the provision of fundamental ecosystem services for human life (Sun et al., 2017; Cabrera & Duivenvoorden, 2020); it also constitutes the natural base of the Andean livestock food resource, the main family economic activity, on which the survival and self-development of thousands of authentically rural families living in poverty depend (Fiallos, Herrera, & Velázquez, 2015; Yaranga, 2018).

These fragile ecosystems have been suffering from disturbances and threats that affect the sustainability of Andean natural resources, caused by various natural and anthropogenic factors (Cai et al., 2015; Albrecht et al., 2016; Sun et al., 2017); however, anthropogenic intervention has become the greatest threat, due to overgrazing of the natural grassland resource, as a consequence of grazing with high animal loads (Wang, Deng, Song, Li, & Chen, 2017), which is frequently applied by Andean cattle-raising families. Also the change of land use from pasture to agriculture (Andrade et al., 2015; Wehn, Anders Hovstad, & Johansen, 2018;) and grassland fires (Forkel et al., 2019), determine the loss of biodiversity and the decrease of primary production and environmental services (Wang et al., 2017; Hu & Nacun, 2018).

In the central Andes of Peru, the tall grassland vegetation in dry puna (Figure 1) is more exposed to the practices of pasture fires by ranching families, who try to obtain tender regrowth of burned species, which can be exploited by Andean camelids (Catorci et al., 2014; Yaranga, 2019). This criterion of the high-mountain rural rancher corroborates the lack of knowledge of the importance of grasslands as shelter for a diversity of vulnerable species of the grassland ecosystem (Hu & Nacun, 2018; Godde et al., 2020), which manage to complete their vegetative period and disseminate their seeds on other degraded areas such as Puna grasslands and wetlands, where normal reproduction of vulnerable species becomes impossible (Ernst & Morici, 2013).

On the other hand, fire on grasslands affects biodiversity, ecosystem services and soil cover (Loydi, Funk, & García, 2020). After fire, only species with deep roots resprout, leaving most of the soil bare, exposed to the erosive action of rain and strong winds, which are aggravated by the rugged, steep slope of the Andean mountain range (Ribeiro et al., 2020). Likewise, soils lose much of the surface organic matter and many of the microorganisms that maintain soil life (Crespo, 2011; Oliver et al., 2017), and their function of supporting the development of the plant community (Zhao et al., 2020). These events that occur in the grasslands after burning show more negative than beneficial effects for the ecosystem and the livestock activity of rural dwellers, which in the long term have an impact on the environmental and economic unsustainability of rural Andean peoples.

In order to respond to the negative consequences of the practices of burning Andean grasslands, it is necessary to articulate the use of the aerial biomass of the grasslands with other alternative activities, with which damage to the integrity of the grasslands can be avoided (Piqueray et al., 2015). A great opportunity for this case is the use of plant fibre in the manufacture of low-cost ecological construction material (Velásquez, Peláes, & Giraldo, 2016); however, there is very little knowledge about the productive potential of the net aerial biomass of the grassland species, which should be studied prior to the sustainable use action.

The biomass of Andean tall grass plants is made up of cellulose, lignin, pectin and hemicellulose elements that are the essential part of plant fibre, known as non-conventional fibre, due to its non-cultivated origin (Sfiligoj et al., 2019). The abundance of inflorescence stems and hard leathery leaves make these species a good alternative as an important source of plant fibre, of which a study conducted in the Altiplano of Bolivia found a concentration of 46.3% fibre in *Festuca orthophylla*, and in Peru 43% fibre in *Jarava Ichu* (Condori, 2019). This potential for plant fibre can be exploited by cutting biomass to generate green shoots, which is sought after by livestock farmers, without affecting the integrity of the ecosystem; and on the other hand, by leaving vulnerable species uncovered, temporary availability of forage for livestock would be added, thus avoiding: a) the negative effect of fire on the ecosystem (Crespo, 2011; Oliver et al, 2017; Zhao et al., 2020),

Fig. 1. An Andean grassland scenario (A), optimal growth of a grassland species (B), post-fire Andean grassland scenario (C)

b) ecological renewal of the accumulated aboveground biomass (Swanson et al., 2018) and c) additional income in the livestock farmer's economy from the sale of plant fibre source material (Sfiligoj et al., 2019).

With this new attitude, rural communities would be approaching the model of grassland management based on the interaction between human and natural resources (Briske, 2017).

In this context, the research aimed to quantify the productive potential of aerial plant biomass of the most widespread grassland species in the Andean area, the density of plants per square metre, the correlation with some eco-morphological characteristics of the plants and their relationship with the physical-chemical characteristics of the soil, in order to predict the availability of biomass as a source of plant fibre.

MATERIAL AND METHODS

Study area

The evaluation of grasslands was carried out in two sub-basins: a) five control plots in the grassland area corresponding to the territory of the Peasant Community of Acopalca, (Table 1, Figure 2). This communal territory is part of the sub-basin of the Shullcas river that flows into the Mantaro river basin. It has an urban area dedicated to agricultural activities in the lower part of the sub-basin, alternating with eucalyptus forests (*Eucalyptus globulus*), small natural forests of alizo (*Alnus jurulensis*) and shrublands on the banks of the Shullcas River. The grassland ecosystems show areas afforested with pine (*Pinus radiata*) since 2010 due to the intervention of a regional project financed by the World Bank, b) in two communal territories of the Cunas river sub-basin, in these grassland areas no reforested areas were observed.

In both sub-basins, the control plots are covered with various species of grassland (Table 1), which were chosen as having the optimum or good growth status for the plant species of interest, in order to establish a quantified baseline reference. The five areas in the Shullcas sub-basin are fenced and the other two plots in the Cunas sub-basin are free; in any case, these areas were being used for grazing by family livestock, consisting of sheep, cattle and Andean camelids (Yaranga, 2019). According to data from the Acopalca and Layve Meteorological Station of the "Servicio Nacional de Meteorología e Hidrología", the temperature is variable between day and night from 0°C to 16°C, the coldest period occurs between May and August in which the night temperature drops to -10°C, the annual rainfall reaches the average of 1170 mm in the sub-basin Shullcas and 830 mm in the sub-basin Cunas, always differentiating two seasonal periods: rainy (December to April) and dry (May to November), this difference influences the primary productivity of the ecosystem, related to the climatic seasonal period of the area (Padilla et al., 2019).

Data collection

A control plot with an area of 30×30 metres on a side (900 m^2) was established in each grassland, following the recommendation of Otzen & Manterola, (2017), who prefers to use the "intentional non-probabilistic" method, when areas are sparse or composed of rare or specific species; In addition, within each plot, five subplots of 8×8 metres (64 m^2) were systematically established, located in the four corners and one in the centre of the plot, in order to approach a real representativeness, as these areas have a very irregular surface (Kindt & Coe, 2005). In these subplots, 32 randomly selected plants were measured (160 plants per plot and 1190 in total), modifying the

Table 1. Location of control plots in Andean grassland ecosystems

Plots	Location	UTM coordinate (L18, S)	Altitude metres	Tall grassland species	Communal territory
P1	Aylli	492190 8771789	4333	*Calamagrostis intermedia*	Acopalca
P2	Sillapata alta	491837 8771586	4278	*Calamagrostis intermedia y Festuca rigidifolia*	Acopalca
P3	Sillapata baja	491122 8672126	4176	*Calamagrostis antoniana y F. sp*	Acopalca
P4	Utush palla	490701 8672404	4148	*Calamagrostis tarmensis*	Acopalca
P5	Gerbacio	489631 9674328	4012	*Calamagrostis antoniana*	Acopalca
P6	Mito pampa	469618 8645381	4039	*Jarava ichu*	Chicche
P7	Panteón pampa	465052 8642824	3860	*Festuca dolichophylla*	Vista Alegre

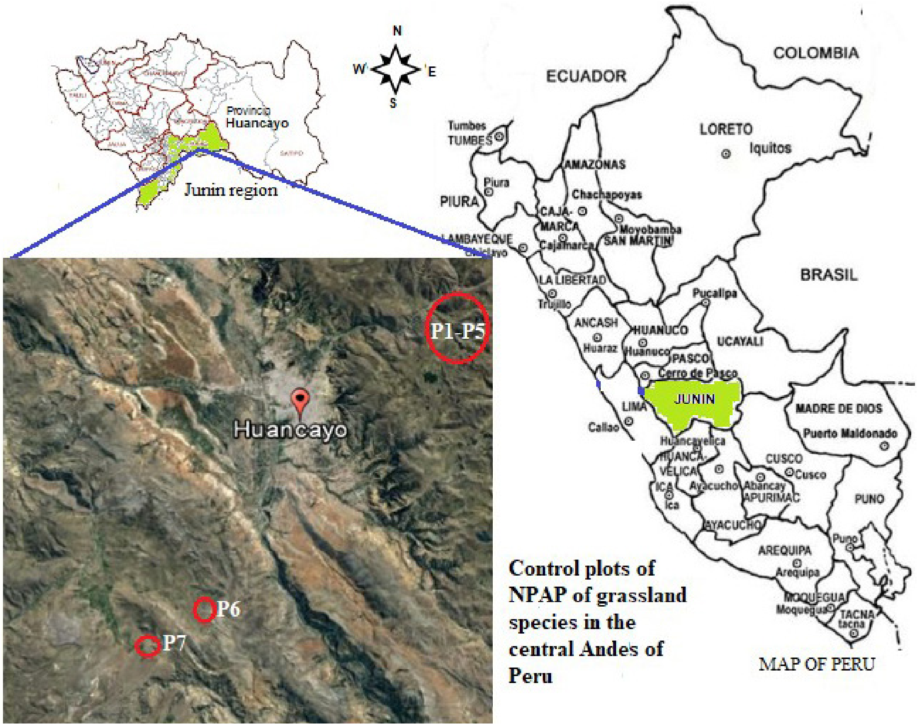

Fig. 2. Location of control plots in relation to the Junín region and the map of Peru (P1 ... P5: control plots)

recommendation of Hardy & Walker (1991) who stated that it was necessary to have 30 measurement units in natural pastures and on spaces of 400 m^2. Five observation plots were fenced with wooden posts and barbed wire in order to monitor the behaviour of other variables related to the study.

The number of plants in four random quadrats of 1 m^2 per subplot (20 quadrats per plot, 140 in total) was counted to obtain the average plant density, and then 16 plants per subplot (80 plants per plot, 560 in total) were randomly selected: (a) two diameters were measured crosswise at the level of the average height of the leaf flag, to obtain the aerial cover, (b) the aerial phytomass of the plant was cut between 5 to 7 cm above the crown, using garden shears, (c) two measurements were made crosswise of the diameter of the cut base of the plant, with the help of a 5-metre metal flexometer graduated in mm to obtain the basal cover. The phytomass obtained from each plant was weighed with a "portable electronic-scale" digital scale, then a sample of phytomass was extracted for packaging and shipment to the Microbiology Laboratory of the Universidad Nacional del Centro del Perú, where it was dried at 75°C for 36 hours and finally weighed to obtain the amount of dry phytomass produced by each plant.

Soil sampling was carried out using the "composite sample" method (Ali et al., 2017), for which 4 pre-samples were collected from each subplot (20 sub-samples per plot) with the help of a 25 cm deep cylindrical aluminium "Riverside-maser auger" sampler. These sub-samples were accumulated in a plastic bucket, then scrupulously mixed to obtain two 800 g samples, which were duly packed in polyethylene bags, with identification corresponding to each plot; the samples obtained were sent to the Soil Laboratory of the Universidad Nacional Agraria La Molina, for complete analysis: Degree of acidity (pH in dS/m), electrical conductivity (EC in mEq/100 g), calcium carbonate ($CaCO_3$ in %), organic matter (OM in %), phosphorus (P in ppm), potassium (K in ppm), mechanical analysis (sand, silt and clay in %), cation exchange capacity (CEC), exchangeable cations (Ca^{+2}, Mg^{+2}, k^{+}, Na^{+}, Al^{+3}, H^{+}).

Data analysis

The collected data were arranged in a double-entry matrix (subplots per plot in rows and in columns the data of cover, leaf height, density and dry matter weight) using the Excel spreadsheet, in which the average data reduction of 3 leaf height measurements and the calculation of the ellipsoidal area of the aerial and basal covers were performed, using the equation A= r1·r2·л, where: A is the area of cover, r1 is the radius of axis 1 in cm, r2 is the radius of axis 2, and л is the ratio between the length of a circumference and its diameter, as a constant element with a value of 3. 1416 (Martínez-Encino et al., 2013). On another sheet, the data resulting from the soil analysis were organised. From these matrices new tables were generated according to the requirement of the R-studio vs 4.0.2 software.

The contrasts of net aerial primary production, and plant density per m^2 according to species and plots, were analysed using the "Generalised linear mixed model" method (Dicovskiy & Pedroza, 2018), which uses the equation:

$$Yijkl = \mu + \Omega i + \beta j + \lambda k + \varepsilon ijkl$$

where: $Yijkl$ – Evaluated plant characteristic.
Ωi – The effect of the plot on the evaluated plant characteristic
βj – The effect of the species
λk – Random effect of the evaluated plant characteristic
$\varepsilon ijkl$ – Random effect of variation.

To calculate the correlation between the net aerial primary production of the grassland species studied with the morphological characteristics of the plants: basal cover, aerial cover, average leaf height, inflorescence height, plant dry phytomass and plant density, a double-entry matrix was organised: species in rows and variables in columns, from which a graphic analysis was carried out to visualise the correlation coefficients, using the R studio software. After identifying the variable with a significant regression coefficient, the most appropriate relationship was chosen to fit the linear regression model, using the equation (Tranmer et al., 2020):

$$y_i = \beta_0 + \beta_1 x_i + e_i$$

where: β_0 – the intercept also called the constant,
β_1 – the slope of the line,
e_i – the error term which is considered a value of 0.

Finally, in order to know the correlation between the grassland species and its net aerial primary production with the physical-chemical soil characteristic, another double-entry matrix was organised (in rows the grassland species and in columns the net aerial primary productivity, density and soil characteristic). First, the existence of a high correlation between the variables was verified as a requirement to continue with the principal component analysis (PCA), then the principal components including the variables with high correlation coefficients were chosen. With these chosen components, paired graphs were constructed to locate their location and relationship with the dry matter and species variables on the two axes (x, y) (Oksanen, 2015).

RESULTS AND DISCUSSION

Net aerial primary productivity

The grassland species studied, reached average weights in grams per plant (g/pl), in order of importance as follows: *Calamagrostis intermedia* 383±18.6, *C. antoniana* 313±17.6, *Festuca rigidifolia* 216±23.1, *Festuca sp* 182±24.3, *Jarava ichu* 132±20.5, *F. dolichophylla* 116±19.4 and *C. tarmensis* 104±21.6; of which, the first two obtained the highest productivity for p=0.001(Figure 3), leaving the remaining with lower productivity. Some plant weight averages did not fit the whisker box plot, as the presence of some very well-developed plants with abundant tufts provided much higher weights than the majority of plants. These data were not discarded from the data, so as not to lose the real explanation of the variability that exists in the natural condition of the plants.

Plot P-2 located in Sillapata alta was dominated by the species *Calamagrostis intermedia*, which reached the highest average weight with 358.1±20.9 g/pl for p= 0.01, followed by plots P-3 and P-1 located in the site Sillapata baja with the species *Calamagrostis antoniana* obtaining 309.8±20.9 and P-1 in the site Aylli with *C. intermedia* 279.9±19.8. 9 and plot P-1 of Aylli with *C. intermedia* 279.9±19.8; then with the lowest weights were the plots P-5 of Gerbacio with *C. antoniana* 248. 2±20, P-4 of Utushpalla with *C. tarmenis* 97.4±18.9, plot P-7 of Vista Alegre with *Festuca dolichophylla* 132±20.2 and plot P-6 of Mitopampa with *Jarava ichu* at 116.1±20.9. It is necessary to mention that the plots with *Festuca dolichophylla* and *Jarava ichu* were not at their optimum growth point because they were exposed to frequent grazing, which did not allow them to express their maximum productive capacity; meanwhile, the plot with *C. tarmensis* was not favoured because the plants are smaller, with thinner leaves and canes, on very superficial soil and in an eroded state.

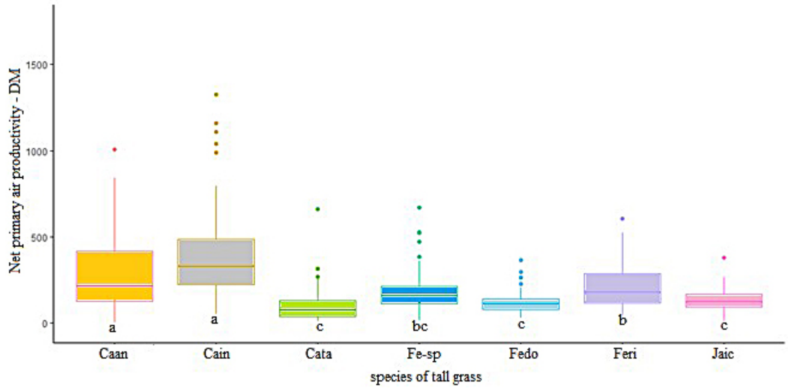

Fig. 3. Whisker box resulting from the comparison of net aerial primary productivity in g dry matter per species and per plant. The difference in letters indicates the limit of significance of means of primary productivity between grassland species for p=0.001

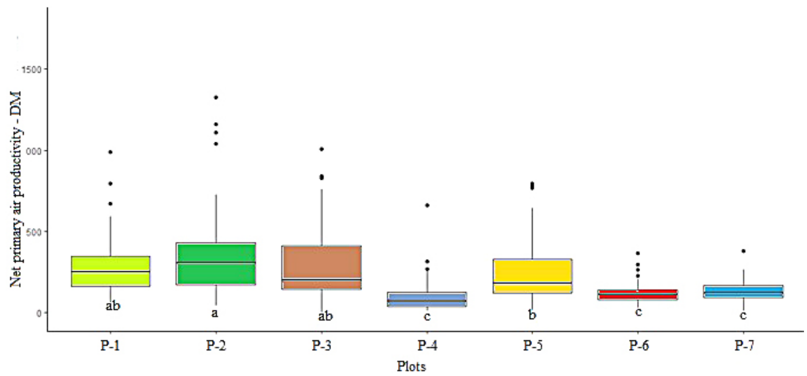

Fig. 4. whiskers box resulting from the comparison of net primary productivity in g of dry matter according to plots (P-1, ..., P-7). The difference in letters indicates the significance limit of means of primary productivity between plots for p=0.001

Tall Andean grasslands are formed on the basis of the dominance of grass species, which are characterised by their erect growth and larger size among the species of the grassland plant community (Catorci et al., 2014), with abundant macollage, cane and inflorescence (Tacuna et al., 2015). These conditions give it a fibrous phytomass-producing quality (Condori, 2019), which is little exploited by Andean livestock and thus prone to burning (Loydi et al., 2020). However, grasses include a diversity of species (Hu & Nacun, 2018), especially those of the genus *Calamagrostis* and *Festucas* that vary in size and primary production, from a few centimetres in height to 1.20 metres (Navarro, 2018; Yaranga, 2019; Cabrera & Duivenvoorden, 2020).

This variation supports the differences in the net aerial primary production of the grassland species studied, since the species *C. intermedia* and *C. antoniana* are some of the tallest species with abundant tillering, compared to the species *C. tarmensis*, which has medium growth, with thinner leaves and canes (Tovar, 1993). *C. tarmensis*, which has medium growth, with thinner leaves and canes (Tovar, 1993) and inhabits more arid areas than the previous ones; in the same way, the species *Festuca rigidifolia* vs. *F. sp*, differ in size, tillering and leaves, the former with preference in deep and humid soils as opposed to superficial and dry soils of the latter. However, it should be noted that the species *F. dolichophylla* and *Jarava ichu*, by not remaining excluded from grazing, were at a disadvantage compared to the other species evaluated (Fay et al., 2015), so the primary productivity obtained was not under optimal growth conditions, which should be observed under similar conditions.

Regarding the comparison between plots, some differences were observed, the first three are located at higher altitude, which normally receives more precipitation in its state of hail and snowfall, in areas with deeper soils > 25 cm deep and peaty, condition that favoured it to obtain the highest primary productivity (Oliver et al., 2017); whereas, the Utushpalla, Gerbacio and Mitopampa plots (P-4, P-5 and P-6) are located on shallow soils <20 cm, light brown in colour and with minimal surface peat thickness, which limited plant growth (Fay et al., 2015). Plot P-6 in Mitopampa where the *Jarava ichu* species lives with shallow, eroded and light reddish soil, and P-7 Panteon pampa in Vista Alegre with deep soil >45 cm and peaty soil preferred by *Festuca dolichophylla*, did not show their true productive potential (Crespo, 2011), due to their current grazing status. In this situation of comparison with the literature reviewed, it indicates that the productivity of the different grass species is clearly different, based on the soil and microclimatic characteristics of the specific area (Głąb et al., 2015; Cabrera & Duivenvoorden, 2020).

Plant density per square metre

The seven species evaluated showed heterogeneous plant density (Figure 5), as the species: *Festuca sp* presented 11.37±3.434 p/m^2, *F. dolichophylla* with 11.22±1.893 and *F. rigidifolia* 10.48±4. 253 and *Calamagrostis intermedia* presented 10.22±3.421, resulted with the highest number of plants significantly for p = 0.01, followed by the species *C. antoniana* with 9.94±2.256, *Jarava ichu* with 9.60±2.901 and *C. tarmensis* with 9.06±3.109 p/m^2. This difference is attributed to the height reached and the number of clumps of the plant, showing that the larger the size and the more clumps there are, the lower the density, which has led the *Festuca* genus to have a higher density than the *Calamagrostis* genus.

Plant density depends on the height and the aerial cover they project on the ground, seen from the morphological point of view (Maphisa et al., 2017), on the other hand, it depends on the negative feedbacks between the plant and the soil, which finally determine the morphological development of the dominant plant species (Xue et al., 2018). *Calamagrostis intermedia* and *C. antoniana*, are tall species apart from being highly tillers (Tovar, 1993); this condition becomes the competition factor between them (Maphisa et al., 2017), therefore, they coexist at distances dependent on the radius of leaf cover, their location on deep and peaty soils also allows them an appropriate plant development (Catorci et al., 2014; Tacuna et al., 2015; Condori, 2019), these aspects support the differentiation of plant density

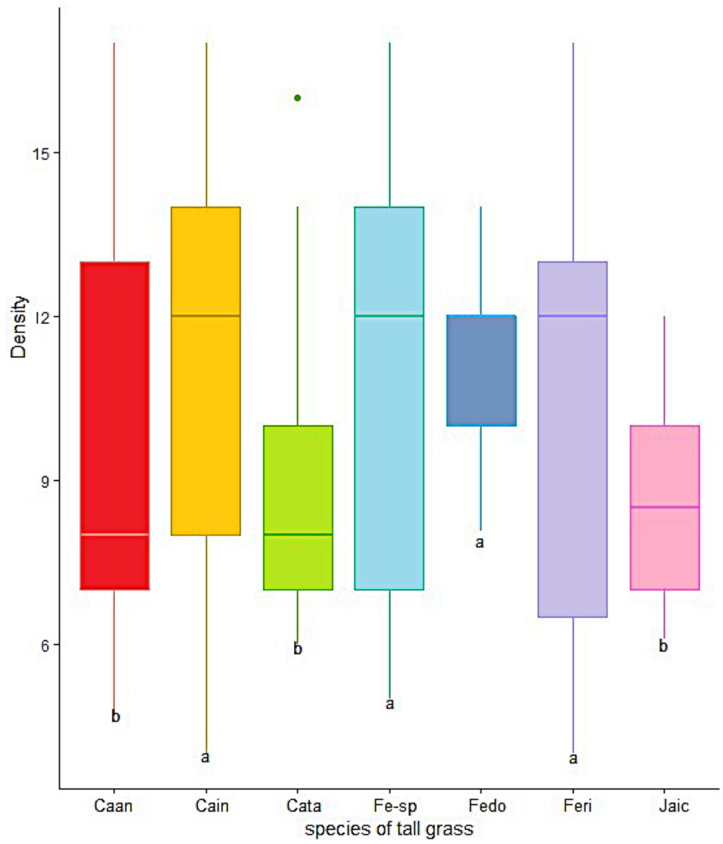

Fig. 5. Plant density per square metre of Andean grassland species. The difference in letters indicates the limit of significance of means of the density between species for p=0.01

between these two species; whereas, *C. tarmensis* has low height and smaller canopy area, she is more dependent on plant-soil feedback (Xue et al., 2018), so, the distance between plants is not related to the radius of leaf cover, but of the low nutritional response of the soil to the plant (Maphisa et al., 2017), due to its location in mostly eroded and poor soils (Crespo, 2011; Oliver et al., 2017; Ribeiro et al., 2020). These criteria demonstrate the basis for coexistence between plants with greater or lesser distances.

Festuca species of Andean tall grasslands, have erect and tall growth (1 meter) like *Calamagrostis*, but with thinner and folded or involutes leaves and thinner canes (Tovar, 1993), however, for their optimal development they require deep and peaty soils with medium humidity, which allows them optimal development and possibility of reproduction, which ultimately results in the presence of higher plant density (Gonnet et al., 2016; Catorci et al., 2014); however, it has been observed that *Festuca* has little tolerance to waterlogged soils or excessive water saturation. The scarce information regarding the primary productivity of grassland species did not allow us to make comparisons with data obtained in other areas.

Correlation between net aerial primary production, density and eco-morphological indices of the species studied

The correlation coefficients calculated between the different grassland species (Figure 6) and the other observed elements were minimal and not significant with coefficients ranging from -0.07 to -0.38, and also with the density whose coefficients ranged from -0.04 to -0.12; however, the correlation coefficient between the dry matter of the net aerial primary production and its basal cover was 0. 73 significant for p = 0.01, which can be used in the prediction

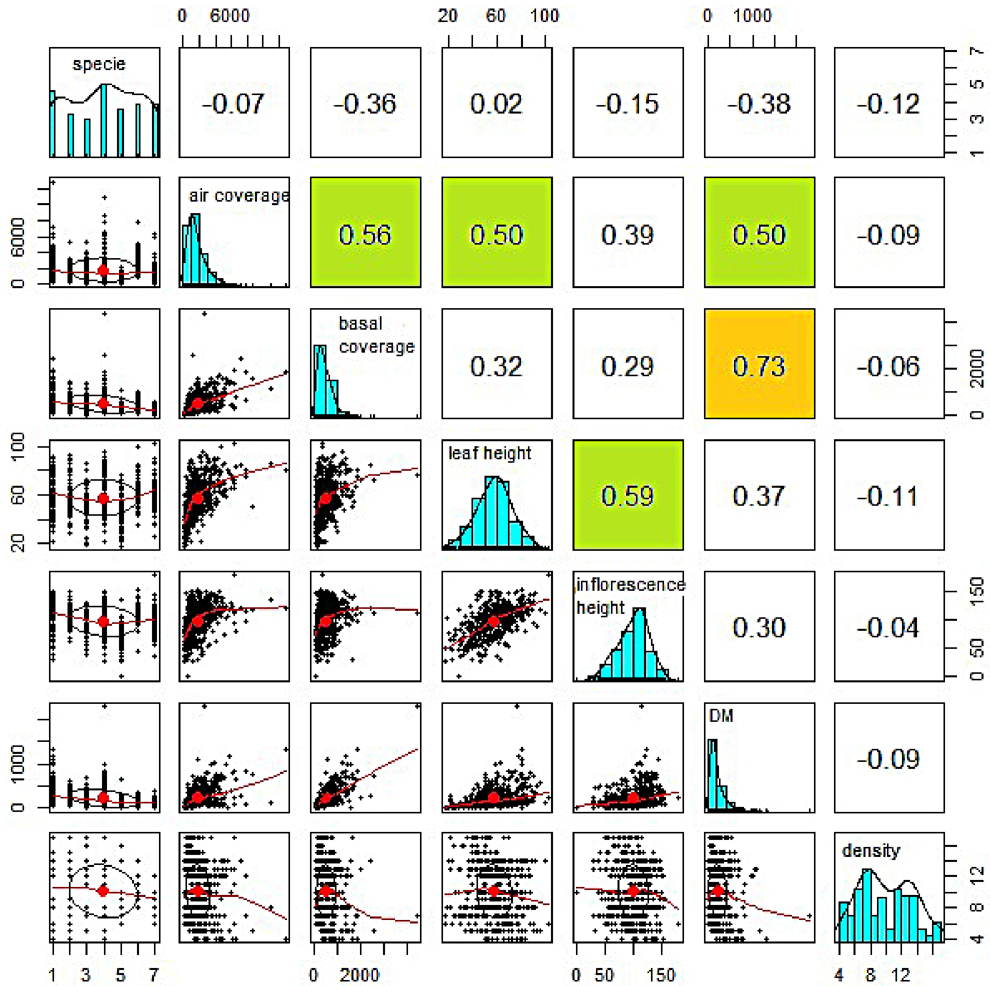

Fig. 6. Multiple correlation coefficients between plant species, aerial net primary production in dry matter per plant, plant density per m2, basal cover and aerial cover of the plant, average leaf height and average cane + inflorescence height

of the available phytomass from the measurement of basal cover, also with significant coefficients for p 0.05, were the basal cover and aerial cover of the plants (r = 0.56), between the average height of leaves of the plant and the aerial cover (r = 0.50) and between the dry matter produced by the plant and the aerial cover (r = 0.50) and between the dry matter produced by the plant and the aerial cover (r = 0.50) and between the dry matter produced by the plant and the aerial cover (r = 0.50).

From the higher coefficient (r = 0.73), the adjusted linear regression model was calculated, considering dry matter produced by a plant as the dependent variable and basal cover as the independent variable. An intercept of 28.61879 significant for p = 0.01 and the estimated line of 0.37606 also significant for p = 0.001 were obtained. The resulting model was y = 28.661879 + 0.37606(X), with $R^2 = 0.5327$.

Principal component analysis between species, net primary productivity of the grassland species and soil physico-chemical characteristics

The principal component analysis (PCA) of the net aerial primary production in grams of dry matter per plant and the plant species, with the physical-chemical characteristics of the soil, resulted in the grouping of seven principal components, of which the first three have greater importance according to the degree of correlation between the elements, so that comparative graphs were generated between CP1 and CP2, CP1 and CP3, CP2 and CP3 (Figure 7). The grouping of the items into two well-defined clusters was observed. In the first pair of CPs, the elements that are directly related show that: Plant species and dry matter produced are directly correlated with the elements: pH, K, Ca^{+2}, sand, silt, clay, $CaCo_3$, Na^+ and organic matter, in the second cluster were added: P, Mg^{+2}, cation exchange capacity, but disassociated from Na^+, K^+ and electrical conductivity; whereas, the third cluster maintained the correlation shown in the second cluster.

This explains that not all soil elements influence the net aerial primary production of Andean grassland species, the elements Na^+, K^+ and electrical conductivity do not directly influence the aerial primary productivity of grassland.

The correlation between primary production and its morphological characteristics of the plants are based on the functional traits of the plant, i.e. morphological, physiological and phenological properties of the plants that vary in response to the local environmental conditions (Da Silveira et al., 2015), it is also related to the quality and quantity of tillers which are determinant in phytomass production due to the higher amount of photosynthesising leaves (Głąb et al., 2015), this concept supports the high correlation found between dry matter produced per plant and basal cover and moderately with aerial leaf cover.

On the other hand, basal cover is determined by the number of tillers formed, on the number of which depends the production of phytomass and tolerance to water stress of the plant (Głąb et al., 2015), an aspect that confirms the high correlation referred to in the previous paragraph. This result provides the basis for further refinement of the regression model for each grassland species, in order to make future estimates of primary production of grasslands based on basal cover alone, with great applicability at the field level.

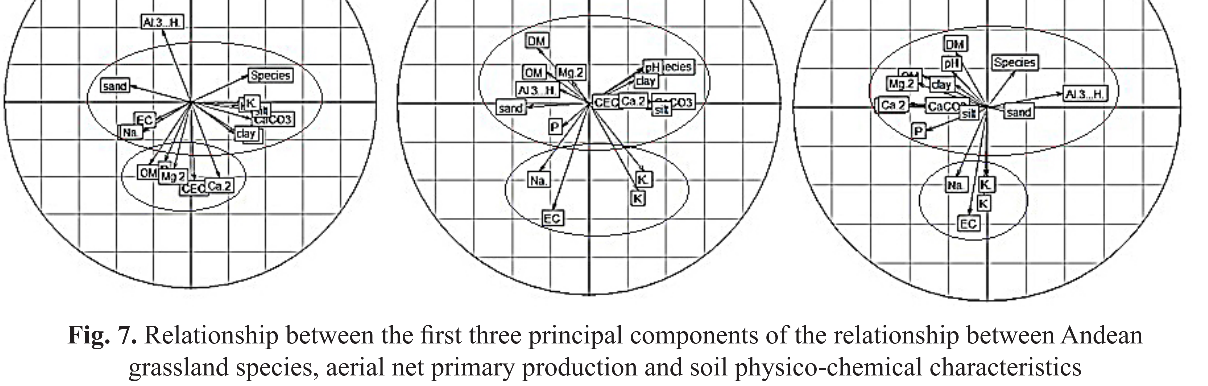

Fig. 7. Relationship between the first three principal components of the relationship between Andean grassland species, aerial net primary production and soil physico-chemical characteristics

Principal component analysis between net primary productivity of grassland species and soil physico-chemical characteristics

Statistical analysis of 16 correlated variables allowed us to graphically visualise the sharp clustering of these variables around aerial primary production and the grassland species, currently widely used in the analysis of biological issues (Oksanen, 2015). The main elements most closely related to the two biological variables were located on axis 1 (abscissa axis) and those with weak correlation were grouped on the ordinate axis (axis 2), arranging the patterns of similarity according to the function of the variables (Palacio et al, 2020).

The most important chemical element in the development of Andean grassland species was organic matter, which shows a high correlation with primary productivity because it is the element responsible for maintaining the physical characteristic: texture, structure, bulk density and water retention capacity (Beltran et al., 2017); the chemical characteristic: nutrient availability, cation exchange capacity, reduced aluminium toxicity and allelopathy (Getabalew & Alemneh, 2019) and the biological characteristic: nitrogen mineralising bacteria, nitrogen fixation, mycorrhizal fungi and microbial biomass (Fageria, 2012; Shang et al., 2016), even though the altitude in this case higher than 4000 meters, limits the decomposition of dead biological material and livestock depositions for transformation into organic matter, due to micro-climatic mountain effects (Ali et al., 2017; van Oijen et al., 2018).

The separation between the dry matter produced per plant and the plant species in the group of interest observed, shows that the plant cover, depending on the species of grassland, affects the organic matter and the elements that accompany it in the soil (Hoogsteen, 2020), which explains the difference in the soil characteristics where it lives and the level of development and productivity reached by the species studied, understanding this as the negative feedbacks between the plant and the soil, which explains Xue et al, (2018). Another very important element is pH, which depends on the type of rock from which it originates (Ujházyová et al., 2016), the altitude that influences through the action of low temperatures (Fay et al., 2015) and the type of vegetation cover. This element has a strong influence in controlling the effective utility of nutrients for the growth of plant species, in that, it can favour or restrict the processes of mineralisation and solubilisation (Riesch et al., 2018), to which the species are also adapted for their optimal development (Pham et al., 2018), whereby, the seven studied species have different acidity conditions that varied between 4.3 to 7.03, and distinguished the location of the species.

The obtained grouping of the physical-chemical elements of the soil around the species and primary production, induces us to obtain further specification according to the particularities of the most important grassland species for the extraction of plant fibre, oriented to determine in the future possible areas to restore or rehabilitate.

CONCLUSIONS

According to the results obtained and the argumentation referred to, it is concluded that the potential production of the grassland species should be obtained in plants that were not affected by grazing, in spite of the difficulty experienced at field level.

The net aerial phytomass production potential of the grassland species varied significantly between species and their location in the landscape. In addition, this variable depends on the functional traits of the particular species that determined the level of tillering, plant cover and height, plant

Table 2. Correlation between grassland species, dry matter production and plant density with plant morphological characteristics

Specification	Specie	Air coverage	Basal coverage	Leaf height	Inflorescence height	DM	Density
Specie	1.0000	-0.0733	-0.3605	0.0245	-0.1526	-0.3848	-0.1186
Air coverage	-0.0733	1.0000	**0.5635**	**0.5021**	0.3893	0.4973	-0.0936
Basal coverage	-0.3605	0.5635	1.0000	0.3218	0.2871	**0.7299**	-0.0622
Leaf height	0.0245	0.5021	0.3218	1.0000	0.5905	0.3735	-0.1137
Inflorescence height	-0.1526	0.3893	0.2871	0.5905	1.0000	0.2965	-0.0407
DM	-0.3848	0.4973	0.7299	0.3735	0.2965	1.0000	-0.0867
Density	-0.1186	-0.0936	-0.0622	-0.1137	-0.0407	-0.0867	1.0000

Table 3. Correlation coefficients of the variables grouped in the first three principal components

Specification	CP1	CP2	CP3
Species	0.30568693	0.144314159	0.1911446
DM	-0.27002418	-0.16301697	0.289742459
pH	0.28131019	-0.18295225	0.185592822
EC	-0.18862488	-0.0943512	-0.55655153
$CaCO_3$	0.32688029	-0.09081707	0.010056662
OM	-0.22438822	-0.33599345	0.163218899
P	-0.14052037	-0.31826642	-0.11977896
K	0.25571543	-0.016494	-0.45266158
Sand	-0.32769438	0.089222753	-0.01884098
Silt	0.32957411	-0.0424725	-0.02802699
Clay	0.23354528	-0.16908559	0.118286616
CEC	0.01727758	-0.42084789	0.008645265
Ca^{+2}	0.15521333	-0.40665849	0.01702277
Mg^{+2}	-0.09221464	-0.35909066	0.122102707
K^{+}	0.2871537	-0.0035858	-0.35549653
Na^{+2}	-0.25806545	-0.15878264	-0.35682075
$Al^{+3} + H^{+}$	-0.15522939	0.390526316	0.072270784

density per m^2. It was also shown that not all soil elements influence the net aerial primary production of Andean grassland species; however, organic matter and pH showed a high correlation, which, according to the literature, are the elements responsible for maintaining the physical characteristics: texture, structure, bulk density and water retention capacity, the availability of various chemical elements for the plants and the vitality of the biological component of the soil. On the other hand, the specific goodness observed in the different species suggests that the adjusted regression model should be specified in each species, mainly in those with the greatest productive potential and the greatest presence, such as *Calamagrostis intermedia*, *C. antoniana*, *Festuca Dolichophylla* and *Jarava ichu*, according to results after the first phytomass harvest.

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