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Economic Valuation of Carbon Storage in Andean Puna Grass with Multivariate Application

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Abstract: ***High mountain ecosystems characterize a diversity of vegetation types and animal populations located from the upper line of forests and the lower base of glaciers, generally populated by herbaceous plants, mainly grasses. These ecosystems provide a wide range of environmental services for the well-being of humanity, with carbon sequestration being one of the most important services that contribute to mitigating the effects of CO^2 in the atmosphere. In this context, the following objectives were set: to determine the floristic structure of the plant formation of puna grass, to assess the level of carbon capture and storage in aerial, root and soil biomass, and to determine the canonical correspondence between the level of carbon capture and the characteristics of the soil, and to assess the economic usefulness of the carbon capture and storage service in Andean puna grass conditions. It was observed that vegetation cover was comprised of a variable floristic structure of 17 to 19 families, 24 to 35 genera and 33 to 40 species, with the participation of the families Poaceae and Asteraceae in 32.6% and 20.9% respectively; the level of carbon sequestration at phytomass level varied between 0.02±0.01 and 0.03±0.01Mg ha^{-1}; and, between 129.71±23.55 and 147.55±20.41 Mg ha^{-1} in the soil. A linear canonical correspondence explained at 76% was found between the level of carbon sequestration and the characteristics of the soil, besides the levels of phosphorus and nitrogen with the carbon of the soil, as well as the pH with the carbon in the phytomass that was explained at 11%. The economic value of organic carbon reached 1946.08 ± 253.94 and 2213.56 ± 224.06 Euros per ha. These results demonstrate the environmental importance of grassland ecosystems and plant formation in puna grass.***

Keywords: floristic composition, organic carbon, puna grass, economic value

1. Introduction

High mountain ecosystems characterize a diversity of vegetation types and animal populations located from the upper line of forests and the lower base of glaciers (Cuesta & Becerra, 2012; Armenteras et al., 2016), generally populated by herbaceous plants mainly composed of grasses (Lara & Gandini, 2014). These ecosystems provide a wide range of environmental services that help mitigate the effects of CO^2 on the atmosphere. Some of these services, such as carbon capture and storage, are not being considered in ecosystem management decision-making as a viable alternative for mitigating the harmful effects of greenhouse gases (GHGs) (Jiménez, A., Reyes, J., & Silveira, M., 2018). In this context, Andean grassland ecosystems are composed of herbaceous vegetation dominated by the Poaceae family: Stipa, Festuca, Calamagrostis, Poa, among others (Lara, 2016; Yaranga, 2019), which are present on soils highly vulnerable to erosion and climate (Scotton, 2019).

Studies on carbon capture and storage are very frequent in forests, but not in high mountain grassland ecosystems, so there is little information on the subject, despite the enormous importance of natural grasslands in mitigating environmental pollution (Jiménez et al, 2018), due to their high capacity for continuous increase and renewal of aerial and root biomass, as a consequence of the defoliation carried out by livestock during grazing (Oliver et al., 2017), reasons why natural grasslands are considered as a potential source of CO^2 storage.

Carbon storage is often estimated from four reservoirs such as: aerial biomass, root biomass, dead organic matter (OM) and soil organic carbon (OC), which are calculated using mathematical models, reference values or field methods and processing data of different levels of complexity (Bartholomée, Grigulis, Colace, Arnoldi, & Lavorel, 2018). According to Cespedes, FE; Fernandez, JA; Gobbi, JA and Bernardis (2012), soils constitute the largest carbon reservoir in terrestrial ecosystems, containing about 45% and 90% in scrub and grassland (Montaño et al., 2016).

The flow of CO^2 between the atmosphere and terrestrial ecosystems is controlled primarily by uptake, by photosynthesis of plants, and by release of gas through respiration, decomposition, and combustion of organic matter (Puastian et al. 2006; Montaño et al. 2016). Accurate estimation of carbon storage in vegetation and soil is not only essential for understanding current levels of carbon reservoirs, but also for mapping how these carbon reservoirs in terrestrial ecosystems change over time, which may be critical for assessing the global carbon budget as the primary predictor of climate change (Liu et al., 2016). For these reasons, monitoring the dynamics of biomass over time and OC stored in soil can be of paramount importance in understanding the ability to mitigate climate change by effect of OC capture and storage in Andean grassland ecosystems.

Regarding the storage levels of OC, Schossler et al. (2016) found an average stock of 54.37 $Mg.ha^{-1}$ in the current state and 23.61 $Mg.ha^{-1}$in the alternative state of OC in the soil, both for a weighted depth of 20 cm of soil. In Argentina, Céspedes et al. (2012) obtained 44.22 to 52.63 $Mg.ha^{-1}$in *Sorghastrum setosum* and *Cynodon lemfluensis* sward pastures; while Castañeda-martín & Montes-pulido (2017) indicated that, in moorland conditions, biomass contains between 13.21 and 18.3 tons per hectare, varying according to local environmental conditions, between 354 and 403 Gt/ha^{-1} in soil in the first 20 cm. In the Peruvian case, Oliver et al. (2017) when studying Andean grasslands, found between 122 and 146 Mg of OC/ha^{-1} at 20 cm from the soil and 150 to 189 Mg at 30 cm, and Oliva et al. (2017) estimated 10.1 tons of OC in aerial biomass per ha and reported 3.14 t/ha in grasslands of *Calamagostris vicunarum, Festuca dolichophylla* and *Muhlenbergia ligularis*.

Environmental economic valuation (EEV) is an instrument offered by economic science in its continuous purpose of contributing to sustainable development planning, for use in the formulation of policies for the protection and conservation of natural resources (Santoyo, Vilardell, León, Fernández, & Pérez, 2013). However, the lack of knowledge of the environmental benefits and economic costs involved facilitates the growing overexploitation and evident deterioration of grassland ecosystems (Miranda, Machado, Machado, & Duquesne, 2007). There is little information on the cost/benefit ratio of the ecosystem services provided by the Andean grasslands, since the valuation is still carried out only from the point of view of cattle ranching and some utilitarian aspects for the rural population (Varela, 2008), which prevents an integral view of the function of the plant community. The valuation of the economic and environmental usefulness of the Andean grassland ecosystems can be the fundamental basis for decision-making in the sustainable management of natural grassland, both at the level of local actors and by the institutions involved (Martin & Agüero, 2014).

2. Method

2.1 Study area

The investigation was carried out at 3 control points located in the Laive plain belonging to the community of Vista Alegre, province of Huancayo and Junin region, located at 3900 meters of altitude and at coordinates 12°18'89" LE and 75°20'33" LW (Figure 1), corresponding to the subhumid Sub alpine Tropical páramo (psh-SaT) life zone

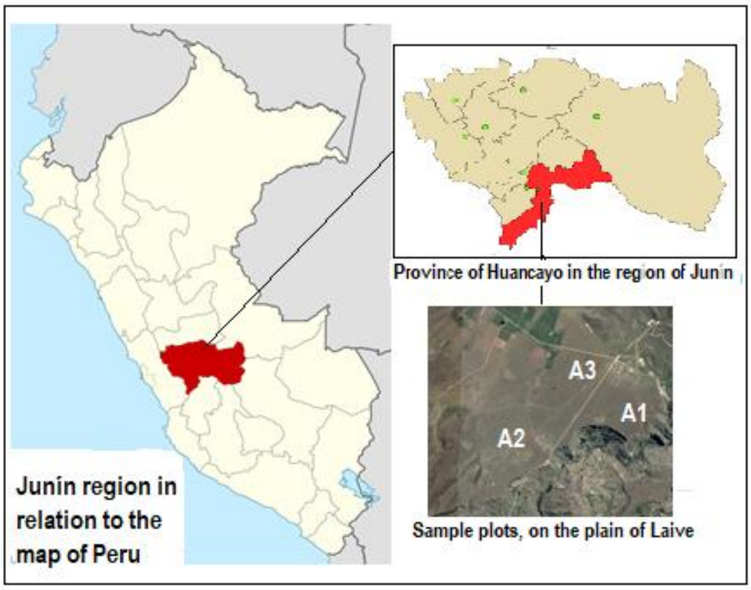


Figure 1: Localization map

The study area presents a physiography of a plain covered with natural grass vegetation, mostly Poaceae and Asteraceae, where the inter-family cattle activity of the peasant community of Chicche and Anexo de Vista Alegre is developed. The use of the natural pastures is made through sheep farming and a sector adjacent to the study area, with modules of dairy cattle of height. The soil of the study area is of colluvium-lacustrian origin with parental material formed mainly by rocks: sandstones, shales, slates and quartzite; they are shallow to medium deep with a clay layer between 10 and 30 cm deep, loamy clay-loam texture. Soil analysis found pH very variable between 4.5 and 7, organic matter between 3% and 10%, total nitrogen between 0.15% and 0.5%, the predominant soil color was brown. The classification of soils according to the "Soil Taxonomy" developed and coordinated internationally by the Ministry of Agriculture of the United States, corresponds to soils entisoles, containing less than 30% of rock fragments (United States Department of Agriculture - USDA, 2018).

From the point of view of the classification of major use of soils (MUS), they are lands P by their natural aptitude for the production of natural grasses, of average agrological quality to poor "P2", "P3", with limitations of soil "s" and climate "c" USDA, 2018). From the climatic point of view, the area received an accumulated rainfall of 793.76 mm between the years 2004 and 2014 whose data are published by SENAMHI in the Huayao Meteorological Station. The average maximum daytime temperature fluctuated between 12.87 and 14.63°C, the minimum nighttime and early morning temperature between 0.8 and 5.4°C. In some seasons it has been observed that the temperature drops to -10°C. The rainfall characterized two periods: one of rainfall between the months of October and April with a peak of higher rainfall between January and March with accumulated rainfall between 106 - 118 mm monthly, another dry period that occurred between the months of May and September with minimum rainfall of 8.9 - 28 mm monthly.

Field data collection

The field data were obtained in three sampling plots of 40000 m2, in which 12 sub-samples of 16 m2 were established, with a quadrant of 1 m2 for the reading of natural grass species and for the cutting of biomass. The survey of 12 soil samples for carbon analysis and 12 samples of aerial and root biomass (Figure 2).

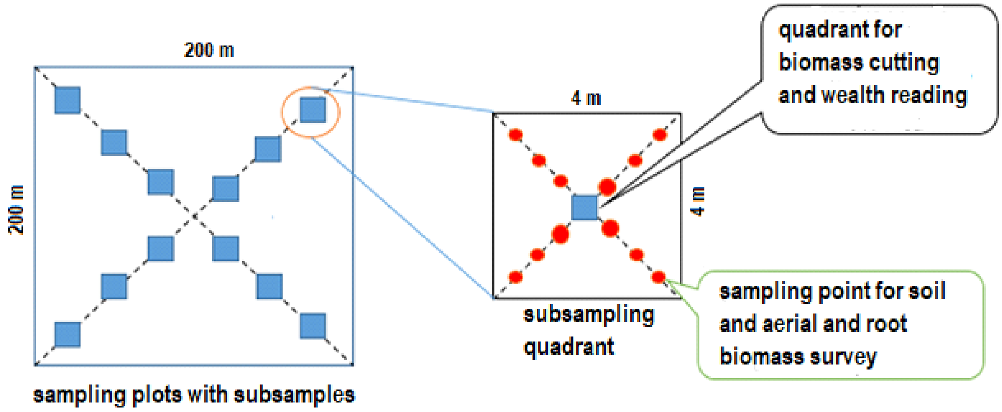


Figure 2: Two-hectare sampling plot, with 16 m^2 sampling sub-plots and a reading quadrant of 1 m^2 and 12 sampling points of material for organic carbon analysis

Before obtaining data in the field, the identification of species present in the sampling plots was carried out by an expert agronomist from the Faculty of Zootechnics of the National University of Central Peru, followed by the count of natural grass species within the quadrants marked for this purpose, recording in a field record identified for each of the 12 quadrants in each sampling plot, followed by the survey of biomass and soil samples for organic carbon analysis (Figure 2). This survey was carried out at 12 previously marked points, using an aluminum soil sampler drill, at the level of the 30 cm depth of the soil. From the collected soil and vegetation samples, the parts of aerial biomass, root biomass and soil were manually separated. Each part of the resulting sample in each quadrant was mixed manually on a cotton canvas, from which a final sample of 1 kg of sample was extracted, which were packaged and labeled with codes previously agreed to identify the quadrant of origin, then were transferred to the soil laboratory of the Agricultural Research Institute (INIA) Santa Ana de Huancayo, where they analyzed the organic carbon content, texture, pH, organic matter, nitrogen, phosphorus and potassium of the samples.

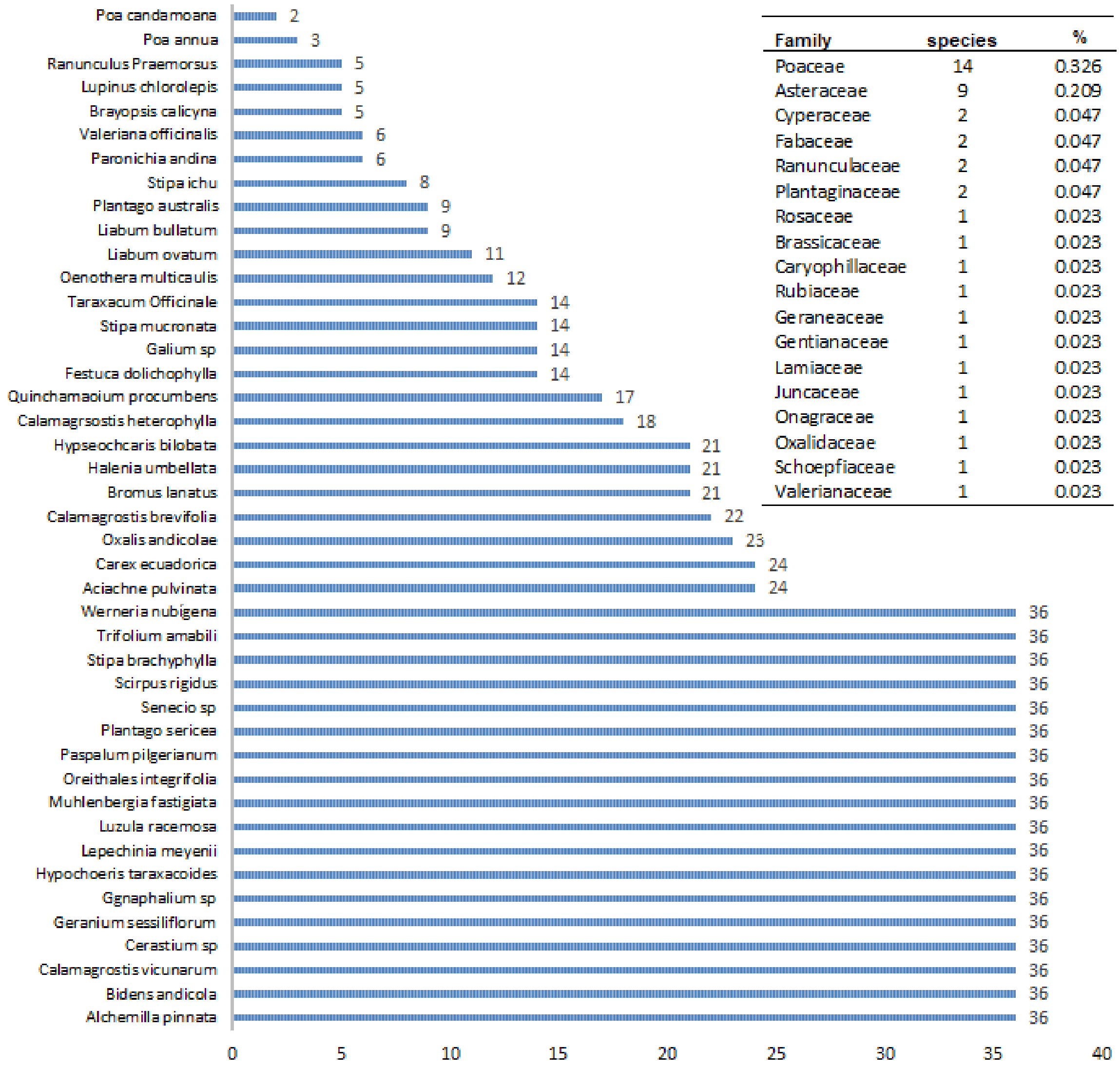
Data analysis

The data obtained were ordered in a double-entry matrix, using the Excel spreadsheet, from which appropriate tables were prepared for statistical analysis using the software RStudio v 5.4.2, using the generalized mixed linear model (GMLM), with a difference in $p \leq 0.05$ (Correa & Salazar, 2016; Bandera & Pérez, 2018). For multivariate correspondence, canonical correspondence analysis (CCA) was used (Cuadras, 2007; Cayuela, 2011; Arimoza et al., 2014; Montanero, 2018; Silva, P., 2018).

3. Results

Flower structure of the control area

The plant composition found in the Pampa of Laive, presented a floristic structure variable from 17 to 19 families, from 24 to 35 genera and from 33 to 40 species, of which 18 species were present in the 36 subquadrants (Figure 3). The species with minimum presence were *Poa candamoana* and *P. annua*. The Poaceae family participated with 32.6% of species, followed by the Asteraceae with 20.9% and the other families with percentages less than 4%.



Family	species	%
Poaceae	14	0.326
Asteraceae	9	0.209
Cyperaceae	2	0.047
Fabaceae	2	0.047
Ranunculaceae	2	0.047
Plantaginaceae	2	0.047
Rosaceae	1	0.023
Brassicaceae	1	0.023
Caryophillaceae	1	0.023
Rubiaceae	1	0.023
Geraneaceae	1	0.023
Gentianaceae	1	0.023
Lamiaceae	1	0.023
Juncaceae	1	0.023
Onagraceae	1	0.023
Oxalidaceae	1	0.023
Schoepfiaceae	1	0.023
Valerianaceae	1	0.023

Figure 3: Floristic structure found in the 36 subquadrants grouped in three sampleplots

Carbon capture and storage in phytomass and soil

The accumulation of organic carbon found in surface and root phytomass varied between 0.02±0.01 and 0.03±0.01 Mg per ha^{-1}, while soil carbon varied between 129.71±23.55 and 147.55±20.41 Mg ha^{-1} (Table 1). Two quadrants had very similar levels of carbon sequestration and the third was significantly higher for p = 0.001, as shown in Figure 4.

Table 1: Level of carbon sequestration at surface phytomass, root phytomass and soil level

Sampling plots	carbon in phytomass	Carbon in soil at 20 cm	Total carbon
1	0.02±0.01b	129.71±23.55b	129.82±26.38b
2	0.03±0.01ab	129.79±26.38ab	129.74±23.54a
3	0.03±0.01a	147.55±20.51a	147.57±20.51ab

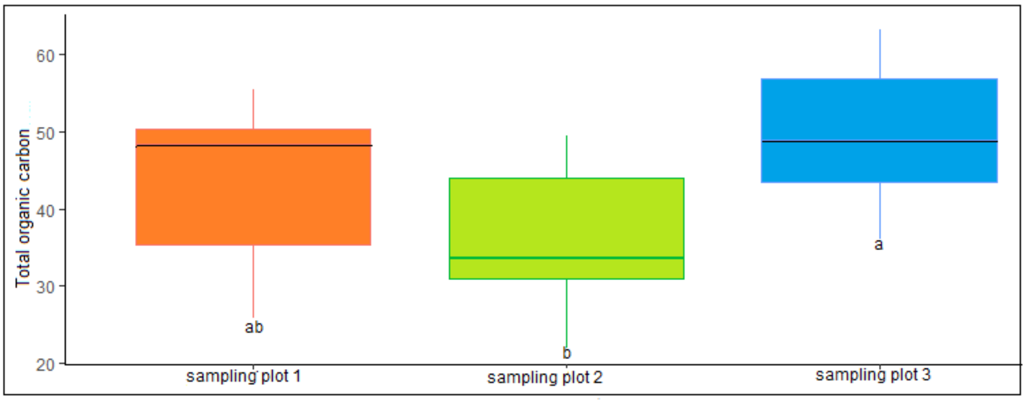
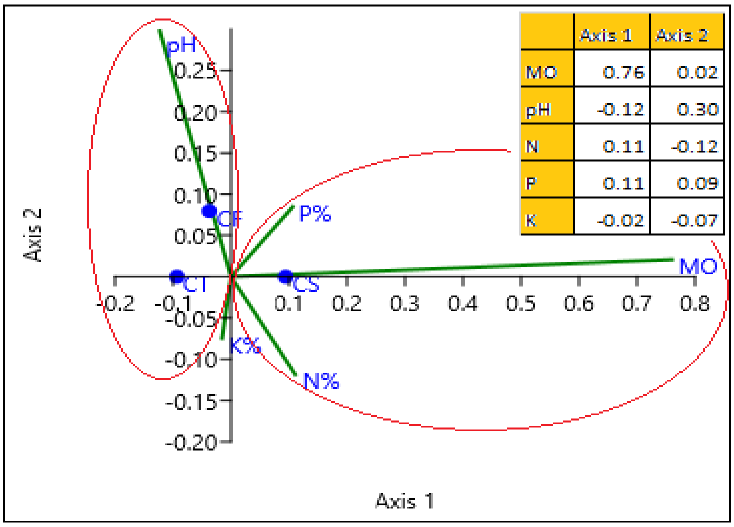


Figure 4: Total carbon upper limit difference whiskers box in three control quadrants, analyzed by GMLM

Canonical correspondence between carbon sequestration level and soil characteristics

The canonical correspondence analysis showed that, soil carbon was positively explained with organic matter at 76% level on axis 1, just as nitrogen and soil phosphorus explained the relationship of soil carbon at 11% level. On axis 2, pH showed a positive linear relationship with phytomass carbon at 30% level; while potassium only showed a negative relationship at 7% level with total carbon (Figure 5). Organic matter and carbon stored in soil play a very important role in carbon capture and storage in grasslands with puna grass, followed by phosphorus and nitrogen.



	Axis 1	Axis 2
MO	0.76	0.02
pH	-0.12	0.30
N	0.11	-0.12
P	0.11	0.09
K	-0.02	-0.07

Figure 5: Linear correspondence between soil characteristics and carbon capture and storage in phytomass and soil

Economic valuation of the carbon capture and storage service

The economic value of the carbon captured in the phytomass and stored in the soil, in puna grass conditions, varied between 1946.08 ± 253.94 and 2213.56 ± 224.06 Euros per ha^{-1} (Table 2), according to the prices of bonds paid in 2018 in European countries (TEC-review, 2018).

Table 2: Average economic value of carbon stored in phytomass and soil, in puna grass conditions (in Euros)

Sampling plot	1	2	3
Mean Value	1947.24±272.02	1946.08±253.94	2213.56±224.06

4. Discussion

Floral structure

The participation of the Poaceae family in the grassland ecosystem in the Pampa of Laive, indicated that the grassland ecosystem of the puna grass type presents the typical characteristic of the central Andes (Wiesmair, Otte, & Waldhardt, 2017; Yaranga, Custodio, Chanamé, & Pantoja, 2018; Van Rooyen et al.., 2019), with presence at a level greater than one third of the total plant cover, as well as in other areas of central Peru (Yaranga, 2018). With respect to richness, it was observed that 36% of the species were shared by all of the evaluated sub-plots, despite the fact that the dominant species in an area are represented by only two or three taxa (Uchida, Koyanagi, Matsumura, & Koyama, 2018); but it was also observed the rare presence of some species such as *Poa candamoana* and *Poa annua*, probably due to the chemical characteristic of the soil, which was found with acid pH less than five that puts it in the range of strongly acid, which is limiting to the growth and development of many species (Riesch, Stroh, Tonn, & Isselstein, 2018), also due to the low availability of nutrients in the soil in mountain conditions (Jimenez, Reyes, & Silveira, 2015).

Carbon capture and storage in phytomass and soil

The capture and storage of carbon in grassland ecosystems is considered very important, not so much because of the phytomass produced, but because of its great capacity to fix in the soil, in some cases more than in forests (Jimenez et al., 2015), so it was interesting to know the level of carbon sequestration in the plant formation with lower production of phytomass (Liu et al., 2016), as opposed to grasslands and mountain wetlands. The carbon captured by the phytomass of the puna grassland ecosystem in Pampa of Laive was 0.02 and 0.03 Mg ha^{-1}, which is far less than the level of capture observed in other plant formations, such as 10.1 t/ha in grasslands of the Amazon region (Oliva et al., 2017), from 13 to 18 t/ha in grasslands of the páramo of Ecuador (Castañeda-martín & Montes-pulido, 2017). This lower level of capture is due to the floristic composition that is constituted by species of low portage like *Stipa brachyphylla*, *Calamagrostis vicunarum*, *Paspalum pilgerianun*, *Aciachne pulvinada*, *Muhlenbergia fastigiata*, *Scirpus rigidus*, that hardly pass the 15 cm of height, and other species arrosetadas or almohadilladas like *Alchemilla pinnata*, *Plantago sp*, *P. Sericea*, *Hypochaeris taraxacoides*, *Paronychia andina*, *Trifolium amabili*, among others.

Carbon storage capacity in grasslands in High Andean of Puno in Peru ranged from 7.7 to 10.78 Mg OC/ha^{-1} in *Festuca dolichophylla* grasslands (Flores, M. 2017) in overgrazed grassland conditions and others in different degrees of use; in Mexico they found values ranging from 0.01 to 0.09 t/ha^{-1} (Jurado, Saucedo, Morales, & Martínez, 2013). These references indicate that the carbon fixation capacity in the phytomass depends on several factors such as plant formation, intensity of use, number of grazing per year

(Jimenez et al., 2015; Rojas, Santoyo, Gonzáles, Velásquez, & Pulido, 2017) that were not considered in this study.

Soil carbon storage is important because it constitutes one of the main sinks of atmospheric CO^2, as it reduces the burden of greenhouse gas (GHG) emissions. This storage action occurred during hundreds and thousands of years, so they are in different humification states (Orjuela, 2018), influenced by the retardant effect of the low temperature of the Andes in the decomposition of organic matter (Montaño et al., 2016; Castañeda-martín & Montes-pulido, 2017). The level of carbon stored in the soil was higher than several results reported from 108 to 110 Mg/ha at one-meter depth in Argentina (Cespedes, FE; Fernandez, JA; Gobbi, JA; Bernardis, 2012), from 23.6 to 54.37 Mg/ha in Paraguay (Schossler et al., 2016) and very close to the range of 119 to 397 t/ha at one-meter depth in Ecuador (Castañeda-martín & Montes-Pulido, 2017); while, in the present study the values corresponded to a depth of 20 cm, since there is the highest concentration of carbon

Canonical correspondence between carbon sequestration level and soil characteristics

There was an interest in simplifying multidimensional observations in the interaction between independent variables (Castillo et al., 2017), for which data on carbon concentration in phytomass and soil were integrated with soil characteristics, which were very important to understand the degree of relationship that these complex data have (Montanero Fernández, 2015). The observed linear relationship between organic matter and carbon concentration in soil benefits microbial activity in soil (Jaurixje et al, 2013). This benefit also shows a direct relationship with phosphorus and nitrogen (Grenacre & Primicerio, 2013; Cuadras, 2014), which provide favourable conditions for plant growth and therefore the capacity to capture carbon. On the other hand, the linear relationship observed between the pH of the soil and the concentration of carbon in the phytomass, reveals the influence of these characteristics in the phytomass production capacity, since this relationship determines the composition of plant species that cover the soil (Riesch et al., 2018), and in the case of Laive together with the physical characteristics of the soil determine the formation of puna grass. With the results obtained in the canonical correlation analysis, it can be said that the relationship between the concentration of carbon in the phytomass and in the soil with the chemical characteristics of the soil is predictable (Rougès, 2014), which can be used in wel monitoring and mapping of large areas of grassland (Orjuela, 2018).

Economic valuation of the carbon capture and storage service

The variation in the economic value reached between 1947 and 2213 Euros per ha^{-1}, in the puna grass in Laive at 2017 prices in Europe, is an indicator of the great importance of Andean grassland ecosystems in carbon sequestration; As such, it serves as a basis for establishing the value increases that could be converted into protection policies by the State and the Regional Government, through the implementation of investment programs in compliance with the Kyoto Protocol, which seeks to reduce greenhouse gas emissions and the implementation of clean development mechanisms; as they did in Mexico and other countries (TEC-review, 2018), in addition to explaining the interaction between ecology and the little-known economy (Mathur & Sharma, 2018).

Economic valuation was the basis for sustaining the conservation of the various species that play a role in carbon storage (Knops et al., 2017) and for generating payment for environmental services currently used by foundations and States (Mathur & Sharma, 2018) dedicated to this issue. This may be applicable in social programs to sensitize the population, which makes direct use of natural resources in grassland ecosystems. The economic value reached in the present study of 7 281.07 to 8 275.82 soles per hectare of puna grass (at the change in the date of 1 € = 3.74 soles), can be increased with actions of recovery and improvement of pasture, to access carbon credits (Bremer et al., 2019).

5. Conclusion

The puna grass formation in Laive is covered by plant species of Poaceae, followed by Asteraceae as in other grassland ecosystems in the world, in this case composed of low and padded plant species; but with great importance in the reduction of GEI emissions established by the Kyoto Protocol. The evidence of the positive linear relationship between organic matter, phosphorus and nitrogen with the carbon stored in the soil, suggests the continuation of work to accumulate enough data to establish prediction models, just by measuring some variable, in such a way that allows us to estimate the economic value in large spaces.

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