Original Research Article

Organic carbon stored in the aerial phytomass of fire-threatened Andean grassland species

ABSTRACT

The practice of burning Andean grasslands in uncontrolled conditions and dry seasonal periods affects the sustainability of the ecosystem with the loss of native grasslands species with superficial roots, the volatilization of organic matter and superficial soil nitrogen, greater susceptibility to wind and rain erosion, which affect the forage supply of grazing areas that affect the economy of the cattle rancher, In addition to emitting abundant CO_2 into the atmosphere, the objective was to quantify the loss of organic carbon contained in the aerial phytomass of burned grasslands and the dynamics of recovery of their shoots, for which seven grasslands with different dominant species and the exclusion of grazing were chosen from five plots of 900 m² with five subplots of 64 m², whose aerial phytomass was harvested and the shoots were measured in their leaf height for nine months. As a result, variable amounts of carbon were obtained according to dominant grassland species for p: 0.001 from 5.02±1.05 to 20.02±0.95 t/ha, equivalent from 22.09 to 73.47 t.CO_2/ha. The recovery of shoot phytomass barely reached 37.32% to 55.94% concerning the initial amount obtained in the mother plants. It was concluded that each grassland has its performance of storage and recovery of stored carbon and the findings should be cause for reflection and be the basis for public policies to promote the protection of grasslands.

Keywords: Tussock grasslands, post-fire, phytomass-carbon

INTRODUCTION

The Andes Mountains of Peru and Latin America, are covered by natural grasslands that mostly consist of tussock grasslands, a type of vegetation dominated by tall matted species with higher lignin and cellulose content, which are scarcely or not at all consumed by livestock; however, these ecosystems are major providers of ecosystem services such as water regulation, CO_2 sequestration, and organic carbon storage, soil protection against erosion, filtration of surface runoff (Oliver et al., 2017; Bengtsson et al., 2019; Zhao et al., 2020), protection of vulnerable grassland species from where they provide seed for dissemination, shelter, and feeding of wildlife, among others (Yaranga et al., 2021). These ecosystems are being threatened by anthropogenic action (Sun et al., 2017), through frequent fires caused by local ranchers, with the idea of causing the temporary growth of tender shoots useful for animal feed.

The passage of fire through the pasture (Figure 1), causes the death of small animals, birds, insects, arthropods, and surface soil microflora, and also causes the death of low species of the same pasture that, precisely, is very important in animal feed such as the genera: *Poa, Muhlenbergia, Alchemilla, Stipa, Trisetum, Lupinus, Disanthelium*, etc. apart from many other families such as the Asteraceae, Rosaceae, and others (Tacuna et al., 2015; Gonnet et al., 2016). The negative effect on the soil constitutes the loss of surface organic matter, which becomes the cause of the reduction in soil fertility and productive potential due to the volatilization of this component. Under these conditions, the stability of biological diversity and the ecosystem services of the grassland become unsustainable to the detriment of the local downstream populations and the ecosystem itself (Bengtsson et al., 2019).

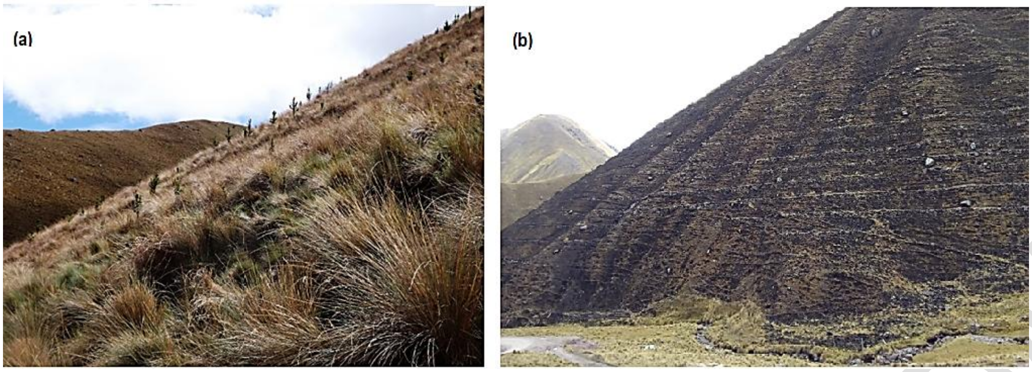

Figure 1. View of an Andean grassland 3 km from the study site. a) Recovering grassland with 3 years of temporary closure, b) the same area burned after 4 years of recovery. The grassland area corresponded to a grassland recovery project for four years and was burned at the end of the project.

On the other hand, the Andean scenario is losing its vegetation cover, which is evidenced by the presence of increasingly rarefied plants until it becomes a bald zone; this is aggravated by the rugged topography that also directly influences the spatial change of hydrological conditions through soil moisture, which in turn is responsible for the predominant edaphic and biotic characteristics (Wang et al., 2017; Dindaroglu et al., 2021). It is the microbial and biochemical properties of soil that undergo greater changes than chemical properties; thus we have the report on Iranian uplands where the change meant 36%, followed by the change in particulate organic carbon at 22%, microbial carbon at 15%, available phosphorus in 15%, etc., which concluded that microbial properties, labile carbon and phosphorus availability should be taken into account to detect the effects of fire on grasslands (Raiesi & Pejman, 2021), especially in highly degraded grasslands such as the Andean mountain range, except when the grasslands were cut, which in that case would condition a greater exposure of the soil to sunlight that would allow the appearance and temporary development of invasive species (Krieger et al., 2022).
Likewise, the effect of fire goes beyond the aforementioned to affect the socioeconomic conditions of the local population and microclimate (Makhaya et al., 2022). In the immediate environment, the consequences of these events affect the same rancher who caused the fire, through the loss of an important source of grazing. The opposite criterion is conceived for temperate grasslands where burning is a tool to control the functional pattern and increase biodiversity, thus avoiding the invasion of shrubs as a consequence of global warming (Overbeck et al., 2018)

On the other hand, grasslands play a very crucial role in CO_2 sequestration and organic carbon storage in plants and soil (Yan et al., 2021) which contribute to the reduction of greenhouse gas emissions. This goodness of grasslands is reduced when the soil is eroded and aggravated in each burning action, due to the effect of the drag caused by rainwater (Lal et al., 2018) and the presence of strong and frequent winds that also control the severity of soil erosion (Yuan et al., 2021), interacting with rainfall precipitation and vegetation cover characteristics, which according to Li et al. (2018) would explain up to 69% of the variation in the intensity of erosion. Therefore, grassland burning, directly affects soil-stored organic carbon and surface organic matter, more strongly in mountain ranges than in temperate sites (Yan et al., 2021).

Loss of diversity in grasslands affects not only aboveground biomass carbon, but also belowground biomass, soil organic carbon, and soil respiration (Wang et al., 2020).

This scenario has put us in concern and the need to quantify the volume of carbon that is lost or returned to the atmosphere when grassland is burned, therefore, it has been proposed as a research objective to quantify the organic carbon contained in the aerial phytomass of grasslands according to the dominant extensive species in the landscape and to track the rate of shoot growth in five species; to demonstrate the effect of grassland fire on the amount of organic carbon released, which will allow establishing the basis for social awareness processes for the rural population and public and private organizations involved in grassland management.

1. MATERIAL Y METHODS

1.1 *Study area*

The research was carried out in the rural communities of Acopalca, Chicche, and Vista Alegre, located in the central mountain range of Peru, whose location, name of the site, and intervened species are shown in Table 1. The spatial location of the plots was grouped into two areas on either side of the Mantaro River valley (Figure 2), where the main urban cities are located. The rural communities are populated by families dedicated to livestock raising with mixed herds of cattle, sheep, and alpacas. The pastures are located between 3800 and 4900 meters above sea level, but the control plots were located between 3860 and 4333 meters above sea level. The areas have a certain similarity in the climatic aspects that vary according to two well-differentiated seasonal periods. The average temperature varies from -8 °C at dawn to 16.2 °C during the day in the dry period (May to September) and from 4 °C to 12 °C in the rainy period (October to April) and the average annual rainfall is 1170 mm per year.

Tabla 1. Location of the grasslands that were intervened in the process of the research

Plots	Location	UTM coordinates (L18, S)	Altitude meters	Tussock grasslands species	Community 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. ssp*	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

1.1 Data collection

The intervention plots were selected taking into account the presence of tall species with extended coverage in the landscape. At the beginning of the research, seven areas were located: five on the east side of the Mantaro River and two on the west side, on which measurements of the amount of aerial phytomass produced in the area were taken. The species *Calamagrostis intermedia*, *C. antoniana*, *Festuca rigidifolia*, and *F. ssp* were located in a conserved condition in an optimal growth state; while the species *Festuca dolichophylla* was located in an area recently grazed by cattle, and the species Jarava ichu was located in an overgrazed area, both located on the west side. In a second moment, the five plots on the East side were fenced with spaces of 900 m² each, considering the method suggested by Otzen & Manterola, (2017). The fencing was carried out with wooden posts and barbed wire, to ensure the exclusion of grazing. The distance between plots was between 0.8 to 3 km.

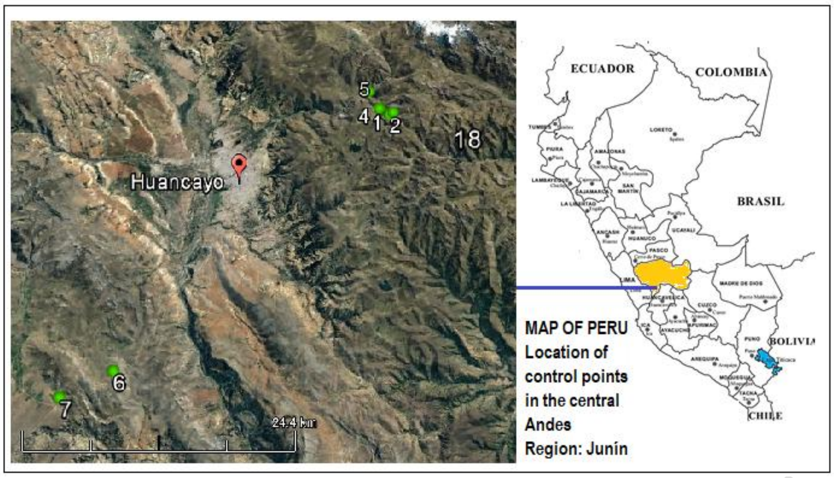

Figure 2. Location of the control plots on the Map of Peru. 5 plots on the east side and 2 on the west side of the Mantaro River.

1.2 Measurement of organic carbon stored in the aerial phytomass and canopy height of plants

A total of 100 plants were selected at random at each site and their average foliage height was previously measured with the help of a metallic flexometer graduated in millimeters, then the aerial phytomass was cut between 3 and 5 cm above the crown of the plant, with the help of a sawed metallic sickle. The phytomass obtained per plant was weighed with a digital balance and from each cut a sample of approximately 50 grams was extracted and packed in polyethylene bags previously coded for shipment to the Microbiology Laboratory of the Universidad Nacional del Centro del Perú, where they were dried at 75 °C for 48 hours, followed by the respective weighing with a digital analytical balance. Measurements were made on 700 plants included in 7 sites.

With the initial fresh weight and dry weight of the sample, the percentage of dry matter was calculated, with which the total dry matter content of each plant was calculated; with this data, the organic carbon content was calculated (Rügnitz et al. (2009); Yerena et al. (2012) and Orozco et al. (2013), who reported that the carbon content in grasslands corresponds to 50% of the weight of the dry matter or 1 g of biomass is equal to 0.5 g of carbon. Additionally, the density of plants per m² was estimated by counting the number of plants contained in each subplot and dividing by 64 m², to infer the total carbon stored per hectare for each species, by multiplying the total number of plants estimated per hectare by the average amount of organic carbon stored per plant.

1.3 Measurement of shoot development of cut plants and carbon content in the canopy

Five 900-m² plots in the same intervention sites were fenced with wooden posts and barbed wire to exclude them from grazing. Each plot was subdivided into five subplots, within which 20 plants were randomly identified and cut to generate shoots. The measurement of shoot development began 30 days after cutting, taking into account the height of foliage in cm, which was measured with the help of a metal flexometer graduated in cm, accumulating 100 measurements per plot and 500 plants per month for the experiment. At the ninth month of measurement, all the shoots were cut weighed and dried and the percentage of dry matter, dry phytomass per plant, and the content of organic carbon stored in the aerial phytomass were obtained according to species, following the same procedure detailed for the plants of origin.

The amount of CO per hectare contained in the aerial phytomass for each species was calculated considering the weight of carbon contained in each plant multiplied by the density of plants per square meter (F. ssp 11.37±0.43, Fedo 11.22±0.36, Cain 10.48±0.33, Caan 9.94±0.31, Cata 9.06±0.38 and Jaic 8.60±0.36) and by 10 000 to infer the reference per hectare.

1.4 Data analysis

The collected data were arranged in double-entry matrices, the variables: leaf height and weight of organic carbon stored in the aerial phytomass in rows and the monthly data in columns. All these data were digitized in an Excel spreadsheet. the contrastation of the study hypotheses was analyzed by the "Generalized linear mixed model" method recommended by Dicovskiy & Pedroza (2018), using the free software Rstudio vs. 4.1.2, using the following equation:

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

where:

Yijkl: Plant characteristic evaluated.

Ωi: The effect of the plot on the organic carbon content of the evaluated plant.

βj: The effect of the species.

λk: The random effect of the evaluated plant.

εijkl: The random effect of variation.

2. RESULTS

2.1 Organic carbon contained in the aerial phytomass of plants of

The organic carbon storage capacity in the aerial phytomass varied among species. The differences were grouped in three blocks for p-value = 0.01 (Figure 3) with the highest storage capacity were the species *Calamagrostis intermedia* (*Cain*) with 20.02±0.95 tons per hectare (t/ha), followed by the second block conformed by *Calamagrostis antoniana* (*Caan*) with 14. 92±0.89 t/ha, *Festuca rigidifolia* (*Feri*) with 12.3±1.18 t/ha and *Festuca ssp* (F. ssp) with 11.71±1.24 t/ha, and the third group conformed by *F. dolichophylla* (*Fedo*) with 7.64±1.05 t/ha, *Jarava ichu* (*Jaic*) with 6.55±1.05 t/ha and *C. tarmensis* (*Cata*) with 5.02±1.05 t/ha. Recalling that *Fedo* and Jaic were in degraded areas, as detailed in the data collection item.

On the other hand, the organic carbon contained in the aerial phytomass of the burned grassland species released 3.67 times of CO_2 to the atmosphere (Table 2), with the species Calamagrostis intermedia releasing the highest amount of CO_2 in the order of 73.47 tons per hectare and the lowest amount released by the species *Cata* with 22.09 tons per hectare.

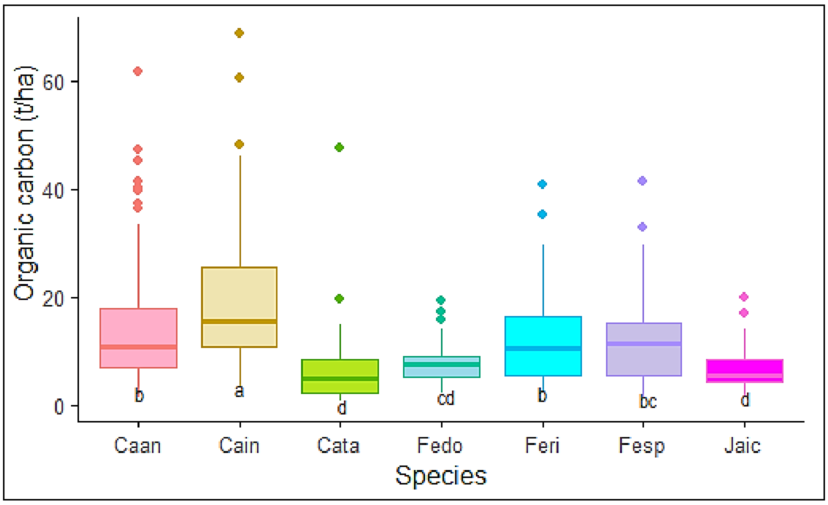

Figure 3. Organic carbon is stored in the dry phytomass (dry matter) of seven Andean grassland species.

Table 2. Equivalence between stored organic carbon and CO_2 released into the atmosphere due to grassland fire

Tussock species	Tons of organic carbon	Tons of CO_2
Calamagrostis intermedia	20.02	73.47
Calamagrostis antoniana	14.92	54.76
Festuca rigidifolia	12.30	45.14
Festuca ssp	11.71	42.98
Festuca dolichophylla	7.64	28.04
Jarava ichu	6.55	24.04
Calamagrostis tarmensis	6.02	22.09

2.2 Association between canopy height (CH) and plant density per m² (DM²) with the organic carbon (OC) stored in the aerial phytomass of each species

The linear regression analyzed between CH and DM² considered as independent variables with the OC stored in the aerial phytomass of each species considered as a dependent variable, yielded R^2 indicators that are shown in Table 4 of the appendix. The OC of Caan and Cain species was explained by only 6% and 17% in the relationship with both independent variables. However, in the species *Cata*. *F. ssp* and Feri the relationship of OC and CH the model explained from 30.74% to 38.55%, while in the relationship of OC and DM² only the *Feri* species was explained by 35.06%. The adjusted models in OC-CH considering those regressions with R2 greater than 0.03 resulted Y = -594.99 + 26.246X for *Cata*, Y = -745.67 + 36.791X for *F. ssp* and Y = 540.938 + 10.923X for *Feri*, in case of the OC-DM2 relationship for *Feri* resulted Y = -161.78 + 131.18X.

Table 3. R^2 of linear regression analysis between canopy height and plant density per m2 with organic carbon stored in aerial phytomass

Specie	Canopy height R^2	Plant density per m^2 R^2
Calamagrostis antoniana	0.0678	0.0154
Calamagrostis intermedia	0.0165	0.1768
Calamagrostis tarmensis	0.3406	0.2322

Festuca ssp	0.3855	0.1539
Festuca rigidifolia	0.3074	0.3506

2.3 Dynamics of shoot development of cut plants according to each species

The shoots of the plants in the five species had variable behaviors, even though the measurements were taken at 30 days after cutting were similar (Figure 4), they only remained similar in the following four species: *Cain*, *Caan*, *Feri*, *F.ssp*, until 60 days of growth, after which they showed visible differences except for the *Cata* species. After this period, they maintained differentiated growth, with the *Cain* species maintaining the highest development, while the *Cata* species maintained a low level of development throughout the control period.

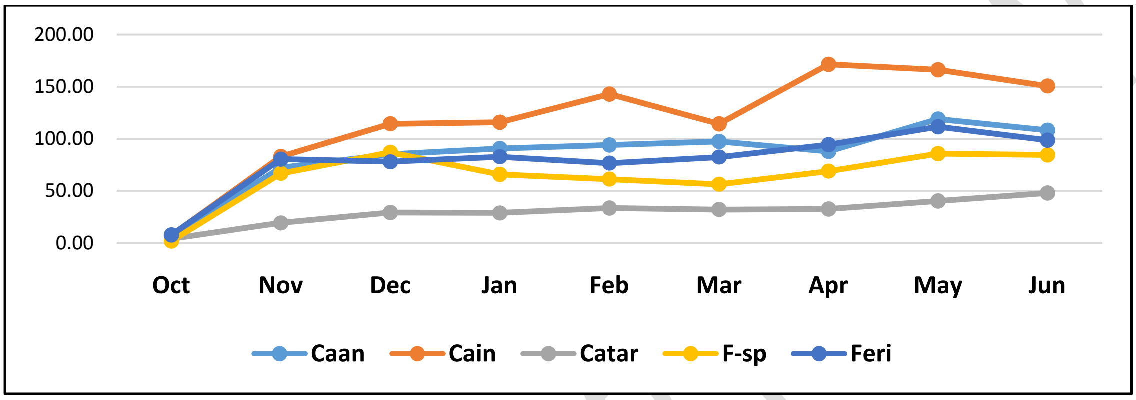

Figure 4. Monthly shoot development behavior after cutting, measured in cm of canopy height between 30 and 270 days.

2.4 Organic carbon stored in shoots

The organic carbon stored in the phytomass area of the shoots of grassland resulted different according to species for p = 0.05 (Figure 5) resulting in superior in *Cain* with 11.2±057 tons per hectare (t/ha), followed by *Caan* with 7. 11±0.51 t/ha and *Feri* with 5.89±0.57 that form a second group, finally in the third block the species *F.ssp* with 4.37±0.61 t/ha and *Cata* with 3.16±0.77 t/ha

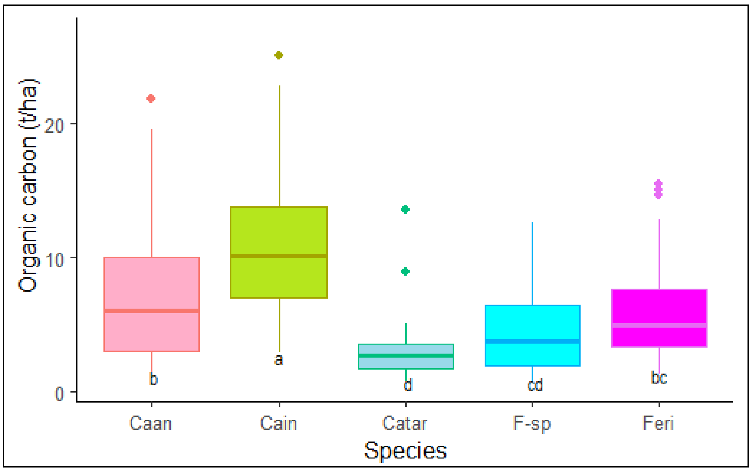

Figure 5. Organic carbon is stored in shoots (aerial phytomass) of Andean grassland species, 270 days after cutting, in tons per hectare.

3. DISCUSSION

3.1 *Understanding the change in the structure and function of the Andean grassland after the fire*

In the history of interaction between mankind and natural resources, cyclical patterns of wildfires have been created, both of natural and anthropogenic origin, developing vulnerable situations on both sides (Berangere et al., 2018), so understanding and predicting it is of vital importance to develop public management policies aimed at mitigating the risks and minimizing the associated consequences (Leonard et al., 2010; Farkhondehmaal & Ghaffarzadegan 2022). Approximately 80% of global fires occur in grasslands each year, accounting for about 40% of the global gross carbon dioxide emission (Leys et al., 2018; Wang et al., 2020). This situation should be considered as an emergency alert, to pay greater attention to the consequences of fire in rangelands and its sequelae on biodiversity, soil characteristics, and eco-systemic services.

From an environmental point of view, grassland burning generates the release of greenhouse gases, mainly carbon dioxide, which contributes to the increase in global warming of the earth (Farkhondehmaal & Ghaffarzadegan 2022). In addition, the action of fire on grasslands reduces their carbon sequestration and storage capacity in leaves, stems, and roots in the first year (Snyman, 2005) and during the time it takes to recover (Yan et al., 2021), especially when the fire is not controlled, with the aggravating factor that it occurs in dry seasonal period and the intensity of the fire (Gordijn and O'Connor, 2021). On the other hand, it causes the extinction of low-growing or shallow-rooted native species (Li et al. 2018). These are very important aspects that should be brought to the attention of rural dwellers to raise awareness and promote the care and protection of grassland ecosystems, mainly grasslands, which face the greatest threat of fire.

The effect of fire on plant diversity has been frequently studied in temperate zones where fires increase floristic, temporal, and invasive diversity, especially in places where the risk of rain and wind erosion are not as strong (Overbeck et al., 2018; Huang et al., 2018; Gordijn and O'Connor, 2021).

On the social side, the effect of grassland fires affects local economies, because the development of outbreaks does not occur immediately, but depends on the period and season in which it occurs; meanwhile, animals do not have the necessary forage for their feeding which compromises animal health and productivity (Overbeck et al., 2018).

The practice of burning Andean grasslands in uncontrolled conditions and dry seasonal periods, would affect the sustainability of the ecosystem due to the loss of native grassland species with shallow roots, volatilization of organic matter, and surface soil nitrogen (Bengtsson et al., 2019; Zhao et al., 2020), leaving the soil at the mercy of wind erosion and pluvial precipitation aggravated by abrupt geomorphology with a steep slope (Oliver et al., 2017), where the Andean tussock vegetation type is preferentially located, finally the loss of eco-systemic services (Bengtsson et al., 2019; Zhao et al., 2020). These would be the bases that configure the dynamics of the advancing desertification of the Andean tussock grasslands that determine the expansion of bare areas and rock outcrops in the high and steep areas, which are objectively observed in the last decades because of the practice of burning tussock grasslands.

3.2 Loss of organic carbon as a consequence of the fire

Currently, many researchers are engaged in measuring the impact of biomass carbon content in the face of climate change, considering that CO_2 sequestration by plants and greenhouse gas emissions vary as a function of land-use change (Yan, 2018) in which the loss of phytomass due to fire is also included. However, most studies conducted on carbon sequestration and storage have focused on soil organic carbon (SOC) content, placing plant biomass as only the contributor of litter and dead debris that is incorporated into the soil (Ma et al., 2019). This approach follows the criterion that more carbon is present in the soil than in the aboveground part of plants (Schipper et al., 2016), which may vary according to the location and species; on the contrary, Fernández et al. (2011) report that in tall grassland species above 4000 m.a.s.l., the live aerial biomass reaches up to 56% and when the necrotic part and dead leaves are included, it reaches up to 75%, depending on the morphology, the architecture of the species and its zonal location (temperate, arid or semi-arid).

Grasslands renew a large number of leaves and stems, according to the frequency of grazing, biomass harvest, or the sprouting of new leaves and stem after a burn, on which there is scarce information (Yan, 2018). The volume of CO stored in the phytomass of Andean grassland species depends on the morphological and growth characteristics of each particular species, therefore, the result of the researchers grouped the studied species into two different groups with high significance, which the species *C. antoniana, C.intermedia, F.ssp,* and *F. rigidifolia*, resulted with a higher value, because these are tall species with many bushes (Tovar, 1995) and that the two Calamagrostis have thicker stems, therefore, with higher lignin and hemicellulose content compared to the others (Quispe et al., 2021).

It is important to clarify that the species *F. dolichophylla* and *J. ichu* also have a good development of leaves and stems (Tovar, 1993), although not as thick as the previous ones; however, the results obtained did not show the real carbon storage potential of these species, because the intervened areas were grazed in the first species and very degraded in the second; which suggests that further research should be done with grasslands excluded from grazing or in a recovered condition. As for the *C. tarmensis*, this is a medium-sized species, with thin leaves and stems (Reynel, 2012), so it showed a low level of organic carbon in the aerial phytomass. These responses showed that the importance of the aerial phytomass of the grasslands is available according to the dominant species in the area and the conditions of use, apart from other abiotic factors.

3.3 Carbon sequestration and storage in grasslands recovering after mowing

Herbaceous plants, mainly perennials such as the species studied, recover immediately after cutting, whose speed depends on several factors such as the prevailing climate, soil moisture, and fertility, among others (Henn et al., 2022); however, Andean grassland ecosystems are very sensitive to climate change and play a fundamental role in the terrestrial carbon cycle, according to their different growth stages, which are still not well understood (You et al., 2020). The result of the evaluation showed that the growth responses in canopy height at 30 days after cutting were very fast, varying between 40% to 60% concerning the final height gained at 270 days. The difference between species concerning growth rate would have been favored by the difference in the amount of rainfall received in the area (Table 6 of the appendix). The species *C. intermedia* had the highest growth achieved during the entire research period, because it received more rainfall, while the species *C. tarmensis* maintained continuous growth, but with lower values than the others, aggravated by its location on very shallow, stony, and rocky soils (personal observation), which kept the soil in a drier condition, which agrees with what was stated by Henn et al. (2022).

The species studied showed higher growth speed until the third month after cutting to show some stability until the ninth month of control, except for the species *C. intermedia* that maintained the lowest development (Table 5); but this did not mean that the plant went into dormancy, but increased the total biomass through the birth and development of new tillers with leaves and stems that, is a characteristic of the Poaceae, responding to the stimulation of soil water available to the roots (Liu et al., 2018). At the observation made the most developed leaves were beginning to bend to the sides, which were no longer taken into account in the height measurement. This would mean that the shoots continue to accumulate organic carbon based on the expansion of their canopy cover and increased photosynthetic uptake rate (Fernandez et al., 2011).

The importance of organic carbon storage in the aerial phytomass of shoots did not change among the five species concerning the differences found in the results of the initial measurement, which would indicate that the species factor maintained its performance (Henn et al., 2022). However, the levels of organic carbon storage in the shoots showed a considerable reduction compared to the initial mother plant, in this sense, the reduction was observed between 48% and 56% in the *Calamagrostis* species with the highest stored volume. About this phenomenon, Morgan and Lunt (1999) and Fernandez et al. (2011) warned that the phytomass production is significantly reduced, after blind, frequent blind, and fire. On the other hand, the speed of recovery would depend on the cutting height, which according to Yan et al. (2020) should be between 6 and 12 cm in height, which allows an optimal growth response in tall grasses, in this sense, we cut between 5 to 7 cm.

To estimate the total recovery time of tall species cut, we have not found an adequate reference that would allow us to establish an appropriate period to recommend the second cut. However, we can affirm that the nine months of control carried out in the study was not enough because the plants continued to develop, which was not measured due to the entry of cattle returning from other grazing areas that destroyed the fences and consumed most of the shoots. This situation allows us to recommend that similar studies should be carried out over a longer period with the security of the permanent custodian.

4. CONCLUSIONS

It was evidenced that Andean tussock grasslands species store between 6 to 20 tons of organic carbon per hectare among their leaves and stems, which when burned release between 22 and 73 tons of CO_2 per hectare that contribute to the total of greenhouse gases that will favor the phenomenon of global warming of the earth, besides affecting the physicochemical characteristics of the soil, biodiversity and environmental services. This environmental quantification should serve as a point of reflection for the local population and as a basis for public policies in rangeland management. Each species, in particular, showed its performance in the capacity to capture and store carbon contained in its initial aerial phytomass, followed by a low recovery capacity in its shoots, which, in some of the species studied, barely recovered between 30% and 50% during the 9 months of evaluation. However, the continuity of shoot development in the following months observed by the researchers indicated that the evaluation period was insufficient to establish the time required for the plants to reach full maturity.

REFERENCE

Bengtsson, J., Bullock, J. M., Egoh, B., Everson, C., Everson, T., O'Connor, T., O'Farrell, P. J., Smith, H. G., and Lindborg, R. (2019). Grasslands—more important for ecosystem services than you might think. *Ecosphere* 10(2):e02582. https://doi.org/10.1002/ecs2.2582.

Chao Wang and Yujia Tang and Xiaona Li and Weiwei Zhang and Chunqiao Zhao and Cui Li. (2020). Negative impacts of plant diversity loss on carbon sequestration exacerbate over time in grasslands. 15(10): 104055. https://doi.org/10.1088/1748-9326/abaf88.

Dindaroglu, T., Tunguz, V., Babur, E., Menshov, O., & Battaglia, M. L. (2021). Determination of the relationship among compound Topographic Index (CTI), soil properties and land-use in karst ecosystems. Physical Geography, 1–23. https://doi.org/10.1080/02723646.2021.1961361.

Farkhondehmaal, F., Ghaffarzadegan, N. (2022). Un patrón cíclico de incendios forestales como resultado de un sistema natural humano acoplado. *Informe científico.* 12**,** 5280. https://doi.org/10.1038/s41598-022-08730-y.

Fernandez, J., Hiltbrunner, E., and Körner, C. (2011). Functional morphology and microclimate of Festuca orthophylla, the dominant tall tussock grass in the Andean Altiplano. *Flora - Morphology, Distribution, Functional Ecology of Plants*. 206(4): 387-396. https://doi.org/10.1016/j.flora.2011.01.001.

Gonnet, J., López, C., Aranibar, D., & Lictevout, E. (2016). *Manual de manejo de Vegas y bofedales*. Santiago de Chile: Norte Grande.

Gordijn, P. J., and O'Connor, T. G. (2021). Multidecadal effects of fire in a grassland biodiversity hotspot: Does pyrodiversity enhance plant diversity? *Ecological Applications*, 31(6):e02391, https://doi.org/10.1002/eap.2391.

Henn, J., Ladwig, L. and Damschen, E. (2022). Disturbance Type and Timing Affect Growth and Tolerance Strategies in Grassland Plant Leaves. *Rangeland Ecology & Management*. Vol 80:18-25. https://doi.org/10.1016/j.rama.2021.09.005.

Huang, Y, Wang, K, Deng, B, Sun, X, Zeng, D-H. (2018). Effects of fire and grazing on above-ground biomass and species diversity in recovering grasslands in northeast China. *J Veg Sci*. 29: 629–639. https://doi.org/10.1111/jvs.12641

Krieger, M.T., Ditton, J., Albrecht, H., Linderl, L., Kollmann, J., and Teixeira, L.H. (2022). Effects of shading and site conditions on vegetative and generative growth of a native grassland invader. *Ecological Engineering*. Vol 178, 106592. https://doi.org/10.1016/j.ecoleng.2022.106592.

Lal, R., Mokma, D., & Lowery, B. (2018). Relation between soil quality and erosion. In *Soil quality and soil erosion*, *CRC Press*, pp: 237-258).

Leonard, S., kirkpatrick, J., and Marsden-Smedley, J. Variation in the effects of vertebrate grazing on fire potential between grassland structural types. *Journal of Applied Ecology*, 47(4): 876-883, https://doi.org/10.1111/j.1365-2664.2010.01840.x

Leys, BA, Marlon, JR, Umbanhowar, C, Vannière, B. (2018). Global fire history of grassland biomes. *Ecol Evol*. 8: 8831– 8852. https://doi.org/10.1002/ece3.4394

Li, P., Liu, L., Wang, J., Wang, Z., Wang, X., Bai, Y. & Chen, S. (2018). Wind erosion enhanced by land use changes significantly reduces ecosystem carbon storage and carbon sequestration potentials in **se**miarid grasslands. *Land Degrad.* 29: 3469 – 3478. https://doi.org/10.1002/ldr.3118.

Li, P, Liu, L, Wang, J, et al. (2018). Wind erosion enhanced by land use changes significantly reduces ecosystem carbon storage and carbon sequestration potentials in semiarid grasslands. *Land Degrad Dev*. 29: 3469– 3478. https://doi.org/10.1002/ldr.3118

Ma, T., Dai, G., Zhu, S., Chen, D., Chen, L., Lü, X., et al. (2019). Distribution and preservation of root- and shoot-derived carbon components in soils across the Chinese-Mongolian grasslands. *Journal of Geophysical Research Biogeosciences.* 124, 420–431. https://doi.org/10.1029/2018JG004915

Makhaya, Z., Odindi J., & Mutanga O. (2022). The influence of bioclimatic and topographic variables on grassland fire occurrence within an urbanized landscape. *Scientific African*, Vol 15, 276 https://doi.org/10.1016/j.sciaf.2022.e01127.

Morgan, J.W., and Lunt, L.D. (1999). Effects of time-since-fire on the tussock dynamics of a dominant grass (*Themeda triandra*) in a temperate Australian grassland. *Biological Conservation*. 88(3): 379-386. https://doi.org/10.1016/S0006-3207(98)00112-8.

Oliver, V., Oliveras, I., Kala, J., Lever, R., & Teh, Y. A. (2017). No long-term effect of land-use activities on soil carbon dynamics in tropical montane grasslands. *Biogeosciences Discussions*, 1–25. https://doi.org/10.5194/bg-2017-113.

Orozco, M., Mireles, P., Valdez, M.E., y Valdez A.C. (2013). Cubiertas forestales y escenarios de carbono en el Estado de México 2002-2010. *Revista Geográfica de América Central*. 51(2): 169-188.

Overbeck, O., Furquim, J., Boldrini, I., & Weir,J. (2018). The South Brazilian grasslands – A South American tallgrass prairie? Parallels and implications of fire dependency. *Perspectives in Ecology and Conservation*, 16(1):24-30. https://doi.org/10.1016/j.pecon.2017.11.002.

Quispe, C., Ñaupari, J., Distel, R., and Flores. E. (2021). Feeding selection of sheep and alpaca on puna tussock rangelands grazed previously by cattle. *Small Ruminant Research*. 197: 106349. https://doi.org/10.1016j.smallrumes.2021.106349.

Raiesi F., & Pejman M. (2021). Assessment of post-wildfire soil quality and its recovery in semi-arid upland rangelands in Central Iran through selecting the minimum data set and quantitative soil quality index, *CATENA*, Vol 201, 105202. https://doi.org/10.1016/j.catena.2021.105202.

Reynel, Carlos. (2012). *Guía de identificación de las plantas comunes del derecho de vía del ducto de Perú LNG*. Melchorita Perú/LNG. 46 p.

Rügnitz, M. T.; Chacón, M. L.; Porro R. (2009). *Guía para la Determinación de Carbono en Pequeñas Propiedades Rurales*. Lima, Perú. Centro Mundial Agroflorestal (ICRAF) / Consórcio Iniciativa Amazônica (IA).79 p.

Sun, B., Li, Z., Gao, Z., Guo, Z., Wang, B., Hu, X., & Bai, L. (2017). Grassland degradation and restoration monitoring and driving forces analysis based on long time-series remote sensing data in Xilin Gol League. *Acta Ecologica Sinica*, *37*(4), 219–228. https://doi.org/10.1016/j.chnaes.2017.02.009

Snyman, H.A. (2005). Influence of fire on root distribution, seasonal root production and root/shoot ratios in grass species in a semi-arid grassland of South Africa. *South African Journal of Botany*. 71(2):133-144. https://doi.org/10.1016/S0254-6299(15)30125-3.

Tacuna, R., Aguirre, L., & Flores, E. (2015). Influencia de la revegetación con especies nativas y la incorporación de materia orgánica en la recuperación de pastizales degradados, *14*(2), 191–200.

Tovar, O (1993). *Las gramíneas (Poaceae) del Perú*. Monografías del Real Jardín Botánico RUIZIA, Madrid, p 481.

Wang, Z., Deng, X., Song, W., Li, Z., & Chen, J. (2017). What is the main cause of grassland degradation? A case study of grassland ecosystem service in the middle-south Inner Mongolia. *Catena*, *150*, 100–107. https://doi.org/10.1016/j.catena.2016.11.014.

Wang, S., Zhang, S., Lin X., Li, X., Li, R., Zhao, X., and Liu, M. (2022). Response of soil water and carbon storage to short-term grazing prohibition in arid and semi-arid grasslands of China. *Journal of Arid Environments*, Vol 202, 104754. https://doi.org/10.1016/j.jaridenv.2022.104754.

Wen-Shan Yang, Yu Liu, Jingxue Zhao, Xiaofeng Chang, Martin Wiesmeier, Jian Sun, Manuel López-Vicente, Roberto García-Ruiz, José Alfonso Gómez, Huakun Zhou, Jianjun Shi, Gao-Lin Wu. (2021). SOC changes were more sensitive in alpine grasslands than in temperate grasslands during grassland transformation in China. *Journal of Cleaner Production*, Vol 308, 127430. https://doi.org/10.1016/j.jclepro.2021.127430.

Yan Yan, (2018). Integrate carbon dynamic models in analyzing carbon sequestration impact of forest biomass harvest. *Science of The Total Environment*, Vol 615, 581-587. https://doi.org/10.1016/j.scitotenv.2017.09.326.

Yang, Z., Minggagud, H., Baoyin, T., and Li, F. (2020). Plant production decreases whereas nutrient concentration increases in response to the decrease of mowing stubble height. *Journal of Environmental Management*. Vol 253, 109745. https://doi.org/10.1016/j.jenvman.2019.109745.

Yaranga, R., Rojas, A. F., Vuure, A. Van, Llanos, R. F., Rojas, A. F., Vilchez, K. M., Herrera, D. C. (2021). Andean Grassland Species: Net Aerial Primary Productivity, Density, Eco

morphological Indices, and Soil Characteristics. *Journal of Ecological Engineering*, *22*(10), 163–175. https://doi.org/10.12911/22998993/138816.
Yerena, J., Jimenez, J., Aguirre, O., y Treviño, E. (2012). Contenido de carbono total en los componentes de especies arbóreas y arbustivas en áreas con diferente uso, en el matorral espinoso tamaulipeco, en México**.** *BOSQUE 33(2): 145-152. http://dx.doi.org/10.4067/S0717-92002012000200004*.
Yuan, I., Ouyang, Z., Zheng, H., and Su, Y. (2021). Ecosystem carbon storage following different approaches to grassland restoration in south-eastern Horqin Sandy Land, northern China. Global *Ecology and Conservation*. Vol 26, e01438. https://doi.org/10.1016/j.gecco.2020.e01438.
Zhao, Y., Chi, W., Kuang, W., Bao, Y., & Ding, G. (2020). Ecological and environmental consequences of ecological projects in the Beijing–Tianjin sand source region. *Ecological Indicators*, *112*, 9. https://doi.org/10.1016/j.ecolind.2020.106111.

Appendix:

Table 5. Shoot development in cm of canopy height in each species of grassland, measured every 30 days until 270 days of sprouting are completed.

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Caan	16.05	23.32	29.23	34.73	34.86	35.93	34.09	38.35	39.08
Cain	15.15	27.09	26.67	30.29	32.53	33.09	30.94	34.74	38.36
Catar	12.17	14.15	21.73	23.7	25.72	24.4	23.78	31.24	31.2
F-sp	14.64	18.61	23.44	28.23	27.8	28.48	27.21	33.39	32.06
Feri	19.14	29.21	24.39	30.09	27.84	29.87	28.49	30	33.97

Note: Caan = *Calamagrostis antoniana*, Cain = *Calamagrostis intermedia*, Catar = *Calamagrostis tarmensis*, F.ssp = *Festuca ssp*, Feri = *Festuca rigidifolia*

Table 6. Distribution of rainfall during the research period in liters per square meter

	Oct-20	Nov-20	Dec-20	Jan - 21	Feb-21	Mar-21	Apr-21	May-21	Jun-21
Aylli (P1)	47.75	0.00	109.42	158.76	67.84	79.58	64.66	3.98	1.99
Sillapata alta (P2)	35.81	0.00	89.13	157.96	39.39	71.62	59.68	1.99	1.99
Sillapata baja (P3)	3.98	0.00	99.47	171.89	48.94	79.58	67.64	15.92	3.98
Otush palla (P4)	35.81	0.00	92.51	167.11	25.86	79.58	85.55	5.97	0.00
Gerbacio (P5)	35.81	0.00	92.51	167.11	25.86	79.58	85.55	5.97	0.00
Monthly average	31.83	0.00	96.61	164.57	41.58	77.99	72.61	6.76	1.59