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Original Article

Characterization of the Environmental Condition of High Andean Grasslands

Caracterización de la condición medioambiental de praderas Altoandinas

HIGHLIGHTS:

- *The vegetation cover of the bofedal reaches 53.66%, with a dry forage production of 2340 kg/ha, positioning it as the most favorable option for alpaca grazing compared to other evaluated grasslands.*
- *The floristic analysis revealed that bofedales harbor 9 forage species and pajonales 18, although undesirable species are predominant, limiting the nutritional quality of grazing in these areas.*
- *Current grazing exceeds the optimal capacity by +3.31 AU/ha in bofedales and +3.48 AU/ha in pajonales, intensifying soil and native vegetation deterioration due to overgrazing.*

ABSTRACT: The study was carried out between August and December 2023 in the rural property Llartawuy Uju, with the objective of characterizing the environmental situation and proposing technologies to improve the high Andean grasslands. The "Transect by step" method was used together with evaluations of the Margalef Index and Shannon Index. The results indicated that the "Bofedal" type grasslands have deep soils while the "Pajonal de llama ichu" grasslands are shallow, with regular and poor environmental conditions respectively. Limitations were identified as the lack of water management for irrigation, excessive animal stocking and the absence of boundary delimitation. External factors include limited technical assistance and access to credit for alpaca farmers. Among the potentialities are water sources and the suitability of the bofedal for alpaca grazing. It is proposed to implement technologies such as rustic canals for minor irrigation, closure of degraded pasture areas, management of portable alpaca roosts, and construction of mini water reservoirs with pressurized irrigation systems. These measures are considered viable to improve alpaca breeding conditions in the region in the short, medium and long term.

Key words: wetland, vegetation cover, native prairie, habitat, grassland.

Caracterização da condição ambiental das pastagens altas andinas

RESUMO: O estudo realizado entre agosto e dezembro de 2023 na propriedade rural Llartawuy Uju teve como objetivo caracterizar a situação ambiental e propor tecnologias para melhorar os pastos altoandinos. Foi utilizado o método de "Transecto ao passo" junto com avaliações dos Índices de Margalef e Shannon. Os resultados indicaram que os pastos do tipo "Bofedal" possuem solos profundos, enquanto os pastos de "Pajonal de llama ichu" possuem solos superficiais, apresentando condições ambientais regulares e pobres, respectivamente. Foram identificadas limitações como a falta de gestão da água para irrigação, uma carga animal excessiva e a ausência de delimitação de fronteiras. Fatores externos incluem a limitada assistência técnica e o acesso restrito ao crédito para os criadores de alpacas. Entre as potencialidades, destacam-se as fontes de água e a aptidão do bofedal para o pastoreio de alpacas. Propõe-se a implementação de tecnologias como canais rústicos de irrigação menor, fechamento de áreas de pasto degradado, manejo de abrigos portáteis para alpacas e construção de mini reservatórios de água com sistemas de irrigação pressurizada. Essas medidas são consideradas viáveis para melhorar, a curto, médio e longo prazo, as condições para a criação de alpacas na Região de Puno.

Palavras-chave: zonas húmidas, cobertura vegetal, pradarias nativas, habitat, pastagens.

INTRODUCTION

Currently, the grasslands of the high Andean region in the southern and central parts of Peru are overexploited, resulting in a gradual state of overgrazing (Mosquera et al., 2022). The consequences are evident today, such as soil erosion, a reduction in vegetation cover, and consequently, a decrease in forage production. This, in turn, leads to low production and productivity of primary products (fiber, hides, meat, etc.) derived from the economic activity of domestic South American camelid farming (Medina et al., 2024).

Overgrazing is a practice that reveals the inadequate management of livestock grazing (alpacas, llamas, sheep, among other species) in native grasslands (Yaranga, Vuure, & Fuentes, 2021). It originates from the mistaken idea of giving more attention to the zootechnical factors of domestic livestock and less to environmental conditions, such as water, soil, vegetation, and climate (Choquehuanca, 2022). This information can be integrated based on a "Pasture Site" map, which reveals the "Condition of Native Grasslands" (Ochoa et al., 2020). This, complemented with the data obtained from the present research, will allow the development of proposals for "Management and Improvement Plans for High Andean Grasslands" (Barrantes et al., 2018).

According to Mamani et al. (2024), natural grasslands face challenges due to anthropogenic influences, which cause the loss of beneficial plant species and, therefore, a decrease in native forage available for animals such as alpacas, llamas, sheep, and cattle grazing in the high Andean grasslands. Moreover, the effects of climate change negatively impact vegetation cover, soil erosion, infiltration, and water retention due to the lack of organic matter and soil compaction caused by livestock trampling (Quiroga, 2004). Therefore, if this livestock activity continues in the ecosystems of the high Andean zone, it will result in harmful effects such as a reduction in grazing areas, loss of vegetation cover in native grasslands, and, ultimately, soil degradation by wind and rain, affecting large areas of pastureland in the high Andean region (Mayta & Maldonado, 2022).

9 The farming of domestic South American camelids (mainly alpacas) in the high Andean regions of southern and central Peru is being carried out without "Management and Improvement Plans for Native Grasslands" (Patiño et al., 2024). Such plans should include understanding the "Environmental Condition" of the native grasslands, which considers the availability of forage and vegetation cover in the native pastures (Onofre, 2020).

Recently in Peru, the restoration of biodiversity has been incorporated into the regulations for Environmental Impact Studies (EIA) for projects requiring environmental permits (Dolores & García, 2022). These regulations must include a management plan with actions for reduction, restoration, repair, or restitution. In response, the Ministry of the Environment (MINAM) has established a specific regulatory framework for implementing corrective environmental actions. These actions become an instrument to counteract damage caused by development projects and an opportunity to mobilize resources for conservation (Guidelines for Corrective Environmental Actions in R.M. N° 398-2014-MINAM, General Guide for Corrective Environmental Action Plans in R.M. N° 066-2016-MINAM, and Supplementary Guide for Corrective Environmental Actions in High Andean Ecosystems in R.M. N° 183-2016-MINAM).

Thus, the objective of the study was to characterize the current state of the environmental condition and formulate a proposal for management and improvement technologies for high

Andean grasslands to conserve the environmental condition of the Llartawuy Uju rural property, Cancha Cancha sector of the Orccontaqui farming community, Haquira district, Cotabambas – Apurímac.

MATERIAL AND METHODS

Soil Condition

To analyze the soil condition, the "Step Transect" method (Leyva et al., 1988) will be employed, which involves systematic measurements along a straight line across the terrain. This method will allow the recording of key parameters such as texture, structure, organic matter content, pH, and compaction. Soil texture will be evaluated based on the composition of sand, silt, and clay, classified into medium, heavy, light, very heavy, and very light categories. This analysis is essential to understand the soil's water absorption capacity and root development, providing valuable information for efficient soil management across various uses, such as agriculture, livestock farming, and conservation.

Forage Availability

Forage availability was estimated through an ex-ante reconnaissance of the rural property, enabling the identification of the general characteristics of the study area. Subsequently, the types of native grasslands present were identified and evaluated, classifying them according to their vegetation composition and ecological characteristics. Vegetation samples were collected using a representative sample size of 10% per type of grassland, employing a sampling frame of 0.50 m², and applying a uniformity criterion of cutting at ground level. Additionally, the grassland condition was evaluated in terms of its economic class by analyzing the biomass production of each type of high-Andean grassland. Furthermore, the vegetation association of each grassland type was considered, identifying its influence on biomass production. This approach enabled a precise estimation of forage availability in the evaluated grasslands (Flórez and Bryant, 1989).

Botanical Composition and Vegetation Cover

In parallel with forage harvesting, a vegetation survey was conducted in August using the "Step Transect" method (Leyva et al., 1988) to determine the botanical composition and vegetation cover of the grasslands in the study area. This method allowed for the identification and classification of forage species present in the native grasslands, following the cataloging established by the National Institute of Agricultural Research and Promotion (1984) in its study on grazing and pastures in the southern Peruvian Andes.

The process began with a reconnaissance of the rural property, which facilitated a clear understanding of the dominant vegetation in the area. Subsequently, the native grassland was divided according to the identified types, which in this case included two main types of high-Andean grasslands: bofedal (wetlands) and pajonal de llama ichu (llama grasslands). Within each grassland type, representative sites were selected for transect placement, with three transects established for each grassland type (Cochi, 2021).

The agrostological survey was conducted by recording 100 observations along 100 double steps using a sampling ring. The readings obtained from the transects were documented in a "Step Transect Record Sheet," providing detailed information on vegetation cover for each type of native grassland. The identified species were classified into three categories: desirable, moderately desirable, and undesirable, according to their forage value and presence in the study area.

Water Condition

The water resources available on the rural property were assessed by measuring the flow rate (l/s) of the permanent springs. Subsequently, the availability of surface water was identified, mapping the springs and determining their precise locations. The collected water samples were analyzed at the UPeU - Juliaca branch laboratories to measure pH, electrical conductivity, and calcium hardness. These analyses determined the feasibility of implementing irrigation systems, ensuring that the flow rates were adequate for use and met the national environmental quality standards.

Grassland Condition

The condition of the native grasslands was evaluated using the "Step Transect" method (Segura, 1963), complemented by assessing the richness of forage species through the Margalef Index. Additionally, the evenness of forage species was analyzed using the Shannon Index.

The Margalef Index measures the specific richness of an area and the relationship between individuals and the total sample size. It is calculated using the following formula:

$$I = (S - 1) / Ln.N \qquad (1)$$

Where: I: Biodiversity index, S: Number of species present, N: Total number of individuals found (belonging to all species), Ln: Natural logarithm..

The Shannon Index measures the probability of selecting all species in proportion to their population abundance. It is calculated using the following formula:

$$H = - \Sigma \, (pi. \, Ln.Pi) \qquad (2)$$

Where: H: Shannon Index, pi: Relative abundance (proportion of individuals of each species relative to the total), Ni: Number of individuals of each species y N: Total number of individuals..

Climate Situation

The meteorological data on rainfall and temperatures (maximum and minimum) for the study area were obtained from the records of SENAMHI, specifically from the Meteorological Station in the district of Tambobamba, province of Cotabambas, department of Apurímac. These data cover a 7-year period (2017–2023).

The data are presented and detailed in Tables 1 and 2. Additionally, they are illustrated in Figure 1 (rainfall) and Figure 2 (maximum and minimum temperatures).

Table 1. Rainfall in the Orccontaqui Rural Community (2017–2023) - Tambobamba Meteorological Station

Precipitation	Months												Total
	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	
Monthly (mm)	164	190	180	160	79.7	21.8	4.6	4.4	2	13	50	105	**975**
Accumulated (mm)	774.2					200.8							**975**
Percentage (%)	79.4					20.6							**100**

Table 2. Rainfall in the Orccontaqui Rural Community, 2023 (Tambobamba Meteorological Station).

Precipitation	Months												
	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Total
Monthly (mm)	110.5	150.4	185	173.5	89.7	18.4	9.2	0	0	30.1	56.7	156.9	**980.4**
Accumulated (mm)	709.1					271.3							**980.4**
Percentage (%)	72.33					27.67							**100**

Figure 1. Rainfall in the Orccontaqui Rural Community, 2023 (Tambobamba Meteorological Station).

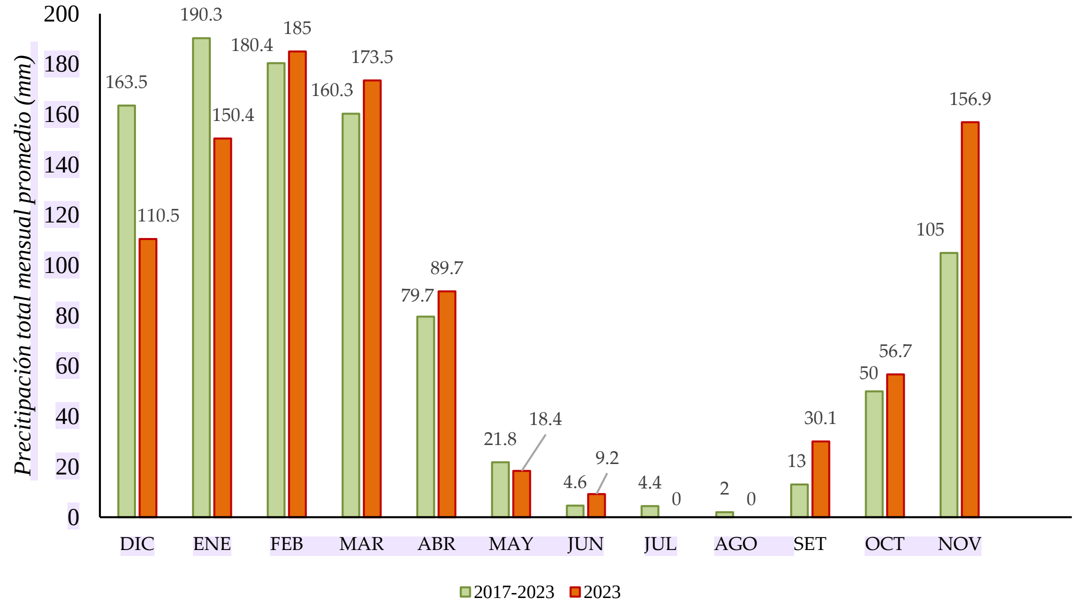
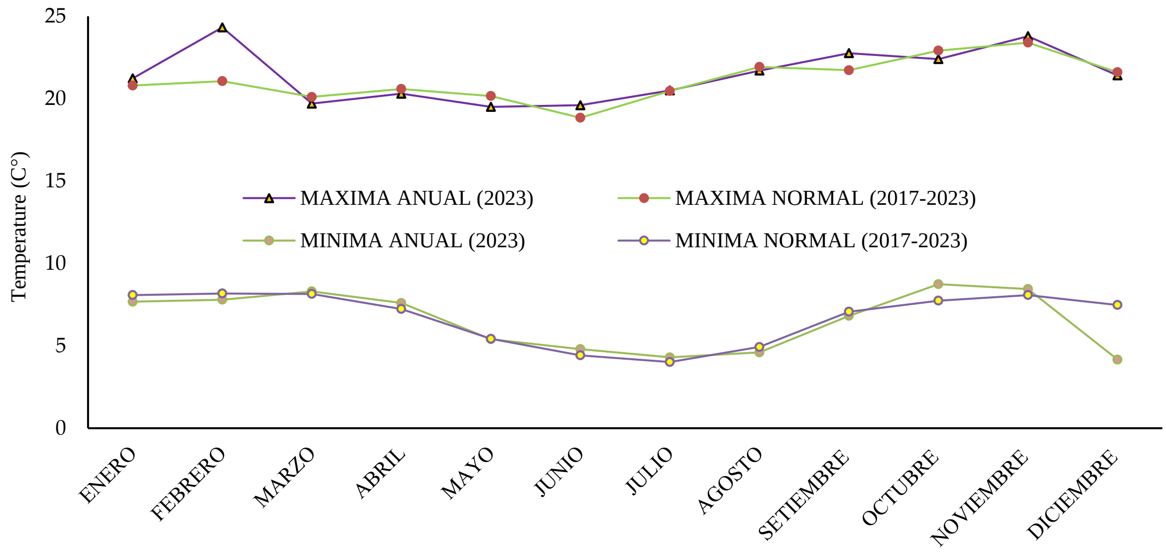


Figure 3. Source: Monthly Temperature in the Orccontaqui Rural Community (Normal: 2017/2022 and Annual 2023, Tambobamba Meteorological Station).



Limiting Factors and Physical-Biological Potentials of High Andean Grasslands

The "Production Systems for Domestic South American Camelids" approach (Figure 3) allows for the identification of factors that limit production in terms of biological and technological aspects, as well as those related to the socio-economic environment of the property (Leyva et al., 1988). Essentially, the proposed production systems research consists of five phases: a) Area selection; b) Characterization (static and dynamic); c) Design of alternatives; d) Validation; and e) Technology transfer (Zandstra, 1982, cited by Choquehuanca, 2015).

In this study, the identification of limiting factors and physical-biological potentials of high Andean grasslands was conducted using the production systems research methodology. For the present study, the "Characterization" phase was considered (Leyva et al., 1988).

Proposed technologies for management and improvement of high andean grasslands

The proposed technologies for the management and improvement of high Andean grasslands were developed based on the identification and prioritization of the physical-biological potentials offered by the property. This was carried out through an in situ agrostological evaluation, an assessment of water resources from available permanent springs, and other physical-biological aspects evaluated on the rural property.

For this research, the "Technology Design" phase was applied under the production systems research methodology approach for domestic South American camelids (Figure 3). The proposed technologies are intended for adoption and implementation in the short, medium, and long term at the level of the evaluated rural property (Leyva et al., 1988).

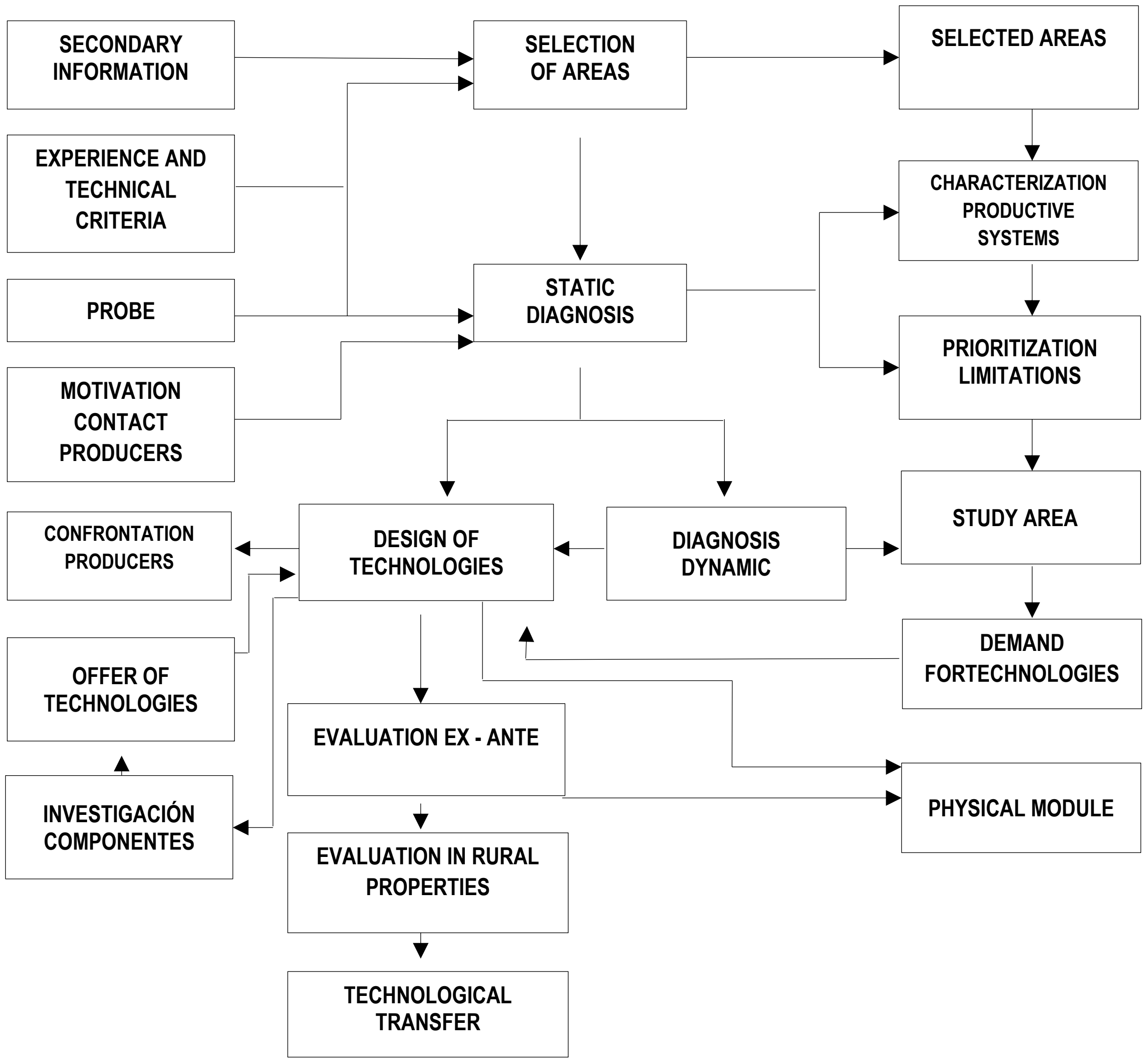
Statistical Analysis

The relationships among vegetational parameters (forage availability, botanical composition, and vegetation cover) of the grasslands were characterized using statistical analysis based on the "Step-Point Transect" method. Additionally, statistical tests (averages, standard deviations, coefficients of variation, significance levels, and others) were applied to the variables:

Environmental condition (dependent variable) and high Andean grasslands (independent variable).

Figure 2. Flowchart of the research methodology in production systems for domestic south American camelids.

SUPPORT **PHASES** **RESULTS**



Source: Zandstra (1982), cited by Leyva et al. (1988).

RESULTS AND DISCUSSION

Soils and Climate

The basic soil characteristics, based on the type of identified high Andean grassland, demonstrate that the "Bofedal" grassland type has an effective depth greater than 100 cm, with a heavy texture. Conversely, the "Pajonal de llama ichu" grassland type exhibits a depth of less than 30 cm (Table 3). In this regard, Flórez (1986) mentions that soils in areas with undulating to rugged topography predominate in the high Andean zone of the southern region of the country. These soils are characterized by a predominantly shallow arable layer (less than 30 cm), making them more susceptible to continuous water and wind erosion processes.

Table 3. Basic soil characteristics according to the type of high Andean grassland identified on the Llartawuy Uju rural property (August, 2024).

Grassland	Vegetation Association	Texture	Effective Depth (cm)	Dominant Slope (%)
Bofedal	*Distichia - Oxycloe*	Heavy	Greater than 100	10
Pajonal of llama ichu	*Festuca - Calamagrostis*	Light	Less than 30	25

The climatic pattern of rainfall in the high Andean zone of this part of the Apurímac department is defined by 5 rainy months and 7 dry and transitional months (Monhein, 1956). During this period, normal precipitation (2017/2023) accumulates 78.28% during the rainy season and 21.72% during the dry season. However, for the experimental period of 2023, precipitation accumulation was 82.56% during the rainy season and 17.44% during the dry season (Table 1, Table 2, and Figure 1). These results reveal that in 2023, precipitation was lower compared to the 7-year normal precipitation (2017/2023).

Meteorological data from recent years show significant climatic changes, such as the increase in recorded maximum and minimum temperatures at the Tambobamba Meteorological Station, as well as the occurrence of extreme events, among others. This highlights the rise in maximum temperatures during the 21st century (Figure 2).

Forage Production

The best availability of native forage was reported in the "Bofedal" grassland type, with 2340.40 kilograms (kg) per hectare (ha) of dry matter (DM), compared to the "Pajonal de llama ichu" grassland, which yielded 1254.70 kg/ha of DM (Table 4). The latter grassland is classified as a "Poor" pasture, corresponding to a fourth economic category. However, this fact should not be overemphasized, as the most significant cause of poor animal productivity in Peru is inadequate nutrition due to the low quantity and poor quality of native forages produced in high Andean grasslands (San Martin, 1991).

Table 4. Condition of the Grassland, Economic Class, and Biomass Production by Type of High Andean Grassland on the Llartawuy Uju Rural Property (August, 2024).

Grassland	Plant Association	Grassland Condition	Economic Class	Biomass Production (ms, kg/ha)
Bofedal	*Distichia - Oxycloe*	Regular	III	2340.4
Pajonal of llama ichu	*Festuca - Calamagrostis*	Poor	IV	1254.7

Nota: ms (materia seca) que es el contenido de forraje sin humedad; kg/ha (kilogramos por hectárea) que es la cantidad de forraje producido por hectárea.

Botanical Composition and Vegetative Cover

The plant species that make up the botanical composition and vegetation cover of the high Andean grassland types on the "Llartawuy Uju" property are detailed in Table 5. It is observed that the most frequent species belong to the genera Distichia, Calamagrostis, and Festuca. A total of 9 species were reported in the "Bofedal" grassland and 18 species in the "Pajonal de llama ichu" grassland. Additionally, these grasslands exhibit vegetation cover of 53.66% and 37.43% for the "Bofedal" and the "Pajonal de llama ichu," respectively. This indicates a moderate condition for the "Bofedal" and a poor condition for the "Pajonal de llama ichu."

Huisa (1996), in an agrostological study of a "Bofedal" at the La Raya Research Center-UNSAAC/Cusco, identified 24 plant species during the rainy season, with a vegetation cover of 96%. On the other hand, Flórez (1972), in a study on grazing intensity in the grasslands of Puno, reported negative changes in the botanical composition of native vegetation and lower production per animal unit under high stocking rates (3 sheep/ha) compared to light stocking rates (1.5 sheep/ha).

Table 5. Botanical Composition and Vegetation Cover by Type of High Andean Grassland on the Llartawuy Uju Rural Property

Species	Types of High Andean Grasslands	
	Bofedal	**Llama Ichu Grassland**
Desirable:		
Distichia muscoides	32	1
Alchemilla diplophylla	5.33	
Eleocharis retroflexa	3.33	
Calandrina sp	0.33	
Scirpus rigidus		0.43
Eleocharis retroflexa		0.57
Undesirable:		
Oxycloe andina	4.67	
Calamagrostis rigescens	3	
Plantago tubulosa	1.67	
Muhlembergia peruviana	0.33	
Festuca dichoclada		8.9
Calamagrostis crhysantha		15
Calamagrostis amoena		0.71
Stipa brachyphylla		0.43
Senecio sp		1.1
Azorella bilovata		1.1
Calamagrostis sp		0.29
Calamagrostis rigida		0.43
Muhlembergia peruviana		0.14

Calamagrostis sp		0.29
Undesirables:		
Aciachne pulvinata	3	
Polipodyum sp		0.14
Pycnophyllum molle		3.3
Aciachne pulvinata		2.29
Bacharis sp		0.6
Pycnophyllum molle		0.71
Vegetation Cover:	**53.66**	**37.43**

Animal Carrying Capacity and Current Grazing Stocking Rate

The carrying capacity for the “Bofedal” and “Pajonal de llama ichu” grasslands is considerably lower than the current stocking rate observed during the study (Table 6). This discrepancy suggests overstocking in both grasslands, with the number of animals significantly exceeding the recommended capacity. As a result, biological degradation and overutilization of forage resources are occurring on the evaluated rural property (Table 6).

Table 6. Condition of the Grassland, Carrying Capacity, and Current Grazing Stocking Rate in the Grasslands of the Llartawuy Uju Rural Property

Pradera	Asociación Vegetal	Área útil (Hectárea)	Condición Pradera	Capacidad de carga (UAA/ha/año)[1]	Carga animal actual pastoreo (UAA/ha/año) [1]
Bofedal	*Distichia - Oxycloe*	57.59	Regular	1	4.31 (250 cabezas)
Pajonal de llama ichu	*Festuca - Calamagrostis*	159.3	Pobre	0.33	3.81 (606 cabezas)
TOTAL:		216.89			

UAA: unidad animal anual,ha: hectárea, año: período de un año.

Water Resource

The availability of surface water from natural outflows, such as "manantes," in the high Andean zone of the evaluated property is adequate for management and use in irrigating rainfed native grassland areas. The possibility of implementing artisanal irrigation systems, through the construction of such systems at the Llartawuy Uju property, is viable due to the presence of three permanent springs located at the head of the local micro-watershed and on hillside areas. These springs have significant flow rates of 1.57, 0.37, and 0.38 liters per second (l/s). Furthermore, laboratory analysis of pH, electrical conductivity, and calcium hardness of these waters indicates their suitability according to the national environmental quality standard for water, making them appropriate for the use and management of irrigation in native grassland areas (Table 7).

Table 7. Basic Physicochemical Characteristics of the Water Condition from Permanent Springs on the Llartawuy Uju Rural Property (August, 2024)

Manante permanente	Ubicación georreferencial[1]	Altitud (msnm)	Caudal (l/s)	Potencial de hidrógeno	Conductividad Eléctrica (µS/cm)	Dureza cálcica (mg/l)
1	774,175E y 8’394181N	4,810	1.57	8.43	63.20	17.10
2	774,127E y 8’394301N	4.826	0.37	7.89	25.60	17.10
3	774,149E y 8’394322N	4.820	0.38	7.53	23.10	17.10

Current State of Environmental Conditions in the High Andean Grasslands of the Llartawuy Uju Property

The prevailing climate in the high Andean zone of the Apurímac department, as revealed by precipitation and temperature data recorded at the Tambobamba Meteorological Station, adjacent to the study area, shows significant climatic changes. These include erratic precipitation patterns and increases in both maximum and minimum temperatures (Tables 1, 2, Figures 1 and 2).

The soils of the "Bofedal" grassland type are very deep, while the "Pajonal de llama ichu" grasslands exhibit shallow soils (Table 3). In this regard, Flórez (1986) mentions that soils in areas with undulating to rugged topography predominate in the high Andean zone of southern Peru. These soils have a superficial arable layer, less than 30 cm deep, making them more prone to constant water and wind erosion processes. Additionally, these soils support a forage production of 2340.40 kg/ha of dry matter (DM) in the "Bofedal" and 1254.70 kg/ha of DM in the "Pajonal de llama ichu" (Table 4).

The "Bofedal" grasslands reported a total of 9 forage species, while the "Pajonal de llama ichu" contained 18 forage species. Furthermore, the vegetation cover was 53.66% for the "Bofedal" and 37.43% for the "Pajonal de llama ichu," respectively (Table 5). These results are directly related to grassland condition, as the "Bofedal" is classified as having a REGULAR condition, and the "Pajonal de llama ichu" is classified as POOR.

The carrying capacity for livestock in the "Bofedal" and "Pajonal de llama ichu" was found to be 1.00 and 0.33 Animal Unit Equivalent (AUE)/ha, respectively. However, during the grazing period in August, the actual livestock load was 4.31 and 3.81 AUE/ha in the "Bofedal" and "Pajonal de llama ichu," respectively (Table 6). This indicates an excess of animals by +3.31 and +3.48 AUE/ha.

Floristic diversity of native forage species in the high andean grasslands of the Llartawuy Uju rural property using diversity indices for richness and evenness analysis

The richness of forage species present in the high Andean grasslands, estimated using the Margalef Index, reports a diversity of 3.4730. This result indicates that the evaluated high

Andean grasslands exhibit a moderate diversity of species (Table 8). The evenness of forage species in the high Andean grasslands, estimated using the Shannon Index, reports a diversity of 2.2968. This result indicates that the evaluated high Andean grasslands exhibit low species diversity (Table 8).

Table 8. Floristic diversity of forage species in the high Andean Grasslands of the Llartawuy Uju Rural Property (August 2024)

N°	Species	Number of Individuals (n)	pi	pi * LnPi	Pi^2
1	Distichia muscoides (D) [1]	103	0.2434988	-0.3440	0.059292
2	Oxycloe andina (PD) [2]	14	0.0330969	-0.1130	0.001095
3	Alchemilla diplophylla (D)	16	0.0378251	-0.1240	0.001431
4	Calamagrostis rigescens (PD)	12	0.0283688	-0.1010	0.000805
5	Eleocharis retroflexa (D)	14	0.0330969	-0.1130	0.001095
6	Aciachne pulvinata (IND) [3]	9	0.0212766	-0.0820	0.000453
7	Plantago tubulosa (PD)	5	0.0118203	-0.0520	0.000140
8	Calandrinia sp (D)	1	0.0023641	-0.0140	0.000006
9	Muhlembergia peruviana (PD)	2	0.0047281	-0.0250	0.000022
10	Festuca dichoclada (PD)	62	0.1465721	-0.2810	0.021483
11	Polipodyum sp (IND)	1	0.0023641	-0.0140	0.000006
12	Pycnophyllum molle (IND)	28	0.0661939	-0.1800	0.004382
13	Calamagrostis chrysantha (PD)	103	0.2434988	-0.3440	0.059292
14	Calamagrostis amoena (PD)	5	0.0118203	-0.0520	0.000140
15	Aciachne pulvinata (IND)	16	0.0378251	-0.1240	0.001431
16	Stipa brachyphylla(PD)	3	0.0070922	-0.0350	0.000050
17	Senecio sp (PD)	8	0.0189125	-0.0750	0.000358
18	Baccharis sp (IND)	4	0.0094563	-0.0440	0.000089
19	Azorella bilovata (PD)	8	0.0189125	-0.0750	0.000358
20	Calamagrostis sp (PD)	4	0.0094563	-0.0440	0.000089
21	Eleocharis albibracteata(D)	2	0.0047281	-0.0250	0.000022
22	Scirpus rigidus (D)	3	0.0070922	-0.0350	0.000050
Summation:		**423**	**1**	**-2.2980**	**0.152088**

Results	Margalef Index	**3.473**
	Shannon Index	**2.2968**

Species: (D)[1] Desirable, (PD)[2] Less desirable, and (IND)[3] Undesirable.

Limiting factors and physio-biological potential affecting forage production in the high andean grasslands of the Llartawuy Uju Rural Property

Limiting Physical and Biological Factors Affecting Forage Production in the High Andean Grasslands of the Llartawuy Uju Property

Endogenous Limitations:

- Absence of practices and technologies for water management and use for irrigating areas of native grasslands under rain-fed and irrigated conditions.
- Lack of practices to improve soil fertility in native grasslands.
- Low livestock carrying capacity of native grasslands due to inadequate management of the current grazing load on the rural property.
- Absence of boundary demarcation on the North, East, South, and West sides of the rural property.
- Weak organization and management among alpaca breeders in the study area.

Exogenous Limitations:

- Limited technical assistance and training on management and improvement technologies for native grasslands provided by state and non-state rural development institutions.
- Lack of access to financial credit from state and private financial institutions for alpaca breeders in the study area.

Physical-Biological Potentials Influencing Forage Production in High Andean Grasslands of the Llartawuy Uju Rural Property:

Endogenous Potentials:

- Availability of water resources from three permanent springs located in the headwaters of the local micro-basin and hillside areas, with significant flows of 1.57, 0.37, and 0.38 liters per second (l/s).
- Existence of the "Bofedal" grassland type; native vegetation suitable for sustainable alpaca grazing.

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<u>Exogenous Potentials:</u>

- Accessible communication routes to the rural property and other areas via a gravel road from the town of Haquira.
- Strategic location of the rural property due to its access and proximity to the Haquira district, Cotabambas province, Apurímac department.
- A territorial habitat with natural resources and an environment suitable for sustainable alpaca farming.

Proposal for Management and Improvement Technologies for High Andean Grasslands to Enhance the Environmental Condition of the Llartawuy Uju Rural Property

The proposed management and improvement technologies for high Andean grasslands represent a viable approach for adoption and implementation in the short, medium, and long term by domestic South American camelid breeders (mainly alpacas). These technologies consider economic factors, labor availability, and the endogenous physical-biological resource potentials of the rural property. The technologies aimed at improving the environmental condition of the "Llartawuy Uju" rural property include the following: a) Construction of rustic irrigation channels for minor irrigation; b) Enclosure of degraded native grassland areas with livestock fencing; c) Management of portable alpaca sleeping areas using 9-strand livestock fencing; and d) Construction of a small artisanal water reservoir with geomembrane lining and a pressurized sprinkler irrigation system (Table 9).

In this regard, Alzerreca et al. (2002) state that in a technological proposal for the recovery of degraded grasslands in the high Andean zone of Bolivia, positive results were observed by combining good soil quality with rotational grazing practices and reseeding or interseeding native grasses. Similarly, Arenas (2003) reported experiences from farms in the municipality of Vigía (Mérida, Venezuela) with a technology proposal that included: a) Planting double rows of leguminous tree species (1 m apart) every 4 to 5 m, with a density of 5,000 shrubs/ha; b) Conditioning strips for legume planting to improve drainage, soil acidity, and fertility; c) Introducing fast-growing grasses such as Brachiaria (brizantha, decumbens, and radicans) and Cynodon plectostachyus; and d) Implementing grazing rest periods of 6 weeks and limiting grazing to less than 3 days per paddock.

Table 9. Proposed Management and Improvement Technologies for Native Grasslands in Habitats of Domestic South American Camelids in the High Andean Zone of Haquira District, Cotabambas Province – Apurímac.

Technology	Location	Grassland Zone	Objective	Unit	Basic Requirement	Execution Period	Observations
Construction of rustic minor irrigation channels.	Grassland sites with available surface water sources at the rural property level	Plains Foot of the slope Mid-slope	To utilize and manage water from natural sources (rivers, streams, and permanent springs) for irrigating native grassland areas under rain-fed and low-irrigation conditions.	Linear meter	Banco de herramientas. Non-qualified labor (NC)* Technical direction	Short, medium, and long term	Develop the technology in areas with permanent water sources, with a flow rate greater than 0.40 liters/second.
Closure of degraded native grassland areas with livestock fencing.	Grassland sites near rural grazing cabins located in the habitats of high Andean grasslands	Plains Foot of the slope Mid-slope	To recover and preserve native forage production in high Andean grasslands	Hectare	9-strand livestock fencing Eucalyptus posts Iron "T" posts Barbed wire Tar Tool bank Non-qualified labor (NC) Technical direction	Short, medium, and long term.	Based on livestock population, it is recommended to enclose degraded grassland areas in modules of 5 to 10 hectares.
Manage ment of portabl e alpaca	Areas of native grasslands	Plains	To distribute manure (solid waste and urine) as	Hectare	9-strand livestock fencing	Short, medium,	This activity should be conducted in

	adjacent to rural grazing cabins in the habitats of high Andean grasslands	Foot of the slope Mid-slope	a form of fertilization for high Andean grasslands		2½” angular iron Galvanized wire Tool bank Non-qualified labor (NC) Technical direction	and long term.	areas where overgrazing has degraded grasslands.
Construction of an artisanal mini-reservoir with geomembrane and pressurized sprinkler irrigation system.	To be constructed at grassland sites in the headwaters of micro-basins and mid-slopes, with the availability of permanent surface water springs	Mid-slope Foot of the slope	To store and use surface water for irrigating high Andean grassland areas under rain-fed and low-irrigation conditions	Unit	Specific project profile Specific technical construction file Technical direction	Medium and long term	Hydraulic technology gradually being adopted by domestic South American camelid breeders in the high Andean region of the country.

Note: Short term: 1 to 2 years; Medium term: 2 to 4 years; Long term: 4 or more years; y NC: Not qualified.

CONCLUSIONS

Based on the analysis and discussion of the results, the following conclusions are drawn:

1. The current environmental condition of the high-Andean grasslands of the Llartawuy Uju property, presents a prevailing climate with normal rainfall (2017/2023) of 975 mm; likewise, with the presentation of normal maximum temperatures of 25 °C and normal minimum temperatures of -5 °C, approximately.

2. The soils of the "Bofedal" type grassland are very deep; and the "Pajonal de llama ichu," has shallow soils. Providing these soils, a forage production of 2,340.40 kg/ha of dry matter (DM) in the "Bofedal" and, 1,254.70 kg/ha of DM in the "Pajonal de llama ichu"; likewise,

these grasslands reported a total of 9 forage species in the "Bofedal" and 18 forage species in the "Pajonal de llama ichu"; in addition, these grasslands show a vegetation cover of 53.66 and 37.43% for the "Bofedal" and "Pajonal de llama ichu," respectively. Results, which are directly related to the grassland condition, since the "Bofedal" and "Pajonal de llama ichu," have a condition of REGULAR and POOR, respectively. Where, the optimal animal load capacity of the "Bofedal" and "Pajonal de llama ichu" is 1.00 and 0.33 AU/ha, respectively. However, in the grasslands during the August period, a current animal load of 4.31 and 3.81 AU/ha was found in the "Bofedal" and "Pajonal de llama ichu," respectively. Which is equivalent to saying, that there are significantly more alpacas; overgrazing the grasslands by + 3.31 and + 3.48 AU/ha, in the "Bofedal" and "Pajonal de llama ichu," respectively.

3. Regarding the richness of forage species in the high-Andean grasslands, a diversity of 3.4730 is reported, which indicates that the evaluated grasslands, present a medium diversity of species; in contrast, regarding the evenness of forage species, a diversity of 2.2968 is reported, which indicates that the evaluated grasslands, present a low diversity of species.

4. Among the endogenous physical-biological limiting factors, affecting forage production in the high-Andean grasslands of the Llartawuy Uju property, are: a) Lack of practices and technologies for water management and use for irrigation of native grassland areas in dryland and under irrigation; b) No practice of improving the fertility of native grassland soils; c) Low animal load capacity of native grasslands due to inadequate management of the current animal load in grazing on the rural property; d) Lack of boundary delimitation on the North, East, South, and West sides of the property; and e) Weak organization and management of alpaca breeders in the study area. And, among the exogenous physical-biological limiting factors, are: a) Limited technical assistance and training on technologies and practices for the management and improvement of native grasslands by state sector institutions and non-state rural

development organizations; and b) No access to economic credit by state and private financial institutions for alpaca breeders in the study area.

5. Among the endogenous physical-biological potentialities, are: a) The availability of water resources from 3 permanent springs, located at the head of the local micro-watershed and on hillside areas, with significant flows of: 1.57, 0.37, and 0.38 liters per second (l/s); and b) The existence of the "Bofedal" type grassland; native vegetation with grazing suitability for the sustainable and sustained breeding of the alpaca species and class. And, among the exogenous physical-biological potentialities, are: a) Accessible communication routes to the rural property and other properties, from the locality of Haquira, via a gravel road; b) Strategic location of the rural property due to access and proximity to the Haquira district, Cotabambas province, Apurímac department; and c) Territorial habitat space with availability of natural resources and environment, suitable for the sustainable and sustained breeding of alpacas.

6. The management and improvement technologies for high-Andean grasslands, which are proposed; constitute a viable proposal for adoption and implementation in the short, medium, and long term by breeders of domestic South American camelids (alpacas, mainly); according to considerations (economic, labor, and endogenous physical-biological resource potentialities of the rural property). Technologies, which will improve the environmental condition of the rural property of "Llartawuy Uju," among other properties in the high-Andean zone of the Haquira district, Cotabambas province - Apurímac; technologies, which are textualized below: a) Construction of rustic minor irrigation canals; b) Closure of degraded native grassland areas with livestock mesh; c) Management of portable alpaca roosts with 9-strand livestock mesh; and d) Construction of artisanal mini water reservoirs with geomembrane and pressurized sprinkler irrigation system.

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