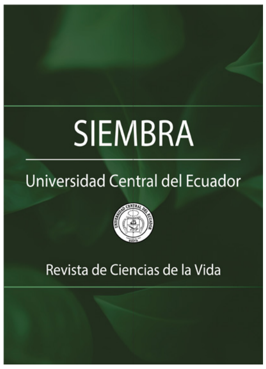
Assessment of scenarios for intensifying pasture management and grazing in fragile micro-watersheds of high Andean mountains



Evaluación de escenarios para la intensificación del manejo de pastos y pastoreo en microcuencas frágiles de alta montaña Andina

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Abstract

In the Andean hillsides of Ecuador, indigenous populations use land mainly for grazing sheep and cattle. Animal response depends exclusively on the quality of forage and the soil's physical and chemical conditions. The objective of this research was to evaluate two scenarios for intensifying pastures based on perennial ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*), used at rest periods of 45- and 60 days in sites between 3,000-3,400 m a.s.l. used for grazing sheep and cows. These scenarios were compared with a natural grassland based on a plant community composed of *Stipa ichu*, *Holcus lanatus*, *Rumex acetocella*, and *Paspalum sp*., used in a traditional system with rest periods of 60-75 days in sites between 3,500-3,700 m a.s.l. in the Chimborazo River micro-watershed. Soil sampling was conducted at both sites to determine the soil fertility profile. Regarding the forage component, chemical composition, animal carrying capacity, milk production, and estimated enteric CH_4 emissions were determined. In sheep serum, Ca, P, and Mg profiles, and the activity of AST, ALT, and FA enzymes were analyzed. The data were analyzed using ANOVA and Tukey 5% as a means comparison test. The results showed a better physicochemical property of the soil at the lower altitude. The intensification of pasture management and grazing through the utilization of rest periods of 45 days or less may represent a productive and low-emission option.

Keywords: rotational grazing, herbivores, emissions, ruminants.

Resumen

Las poblaciones indígenas en las laderas andinas de Ecuador utilizan sus tierras principalmente para el pastoreo de ovejas y ganado. La respuesta animal depende exclusivamente de la calidad del forraje y de las condiciones físicas y químicas del suelo. El objetivo de esta investigación fue evaluar dos escenarios para la intensificación de pastizales basados en ballica perenne (*Lolium perenne*) y trébol blanco (*Trifolium repens*), utilizados con intervalos de descanso de 45 y 60 días, en sitios situados entre 3.000-3.400 m s.n.m para el pastoreo de ovejas y vacas. Estos escenarios se compararon con un pastizal natural basado en una comunidad vegetal compuesta por *Stipa ichu*, *Holcus lanatus*, *Rumex acetocella* y

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Paspalum sp., utilizado en un sistema tradicional con periodos de descanso de 60-75 días en sitios situados entre 3.500-3.700 m s.n.m. en la microcuenca del río Chimborazo. Se realizaron muestreos de suelo en ambos sitios para determinar el perfil de fertilidad del suelo. En cuanto al componente forrajero, se determinó la composición química, la capacidad de carga animal, la producción de leche y las emisiones estimadas de CH_4 entérico. En el suero de oveja, se analizó el perfil de Ca, P, Mg y la actividad de las enzimas AST, ALT y FA. Los datos se analizaron utilizando ANOVA y Tukey al 5% como prueba de comparación de medias. Los resultados mostraron mejores propiedades químicas y físicas del suelo a menor altitud. La intensificación del manejo de pastizales y del pastoreo mediante la utilización de periodos de descanso de 45 días o menos aparentemente representa opciones productivas y de bajas emisiones.

Palabras clave: pastoreo rotacional, herbívoros, emisiones, rumiantes.

1. Introduction

The importance of animal ownership for indigenous communities throughout the inter-Andean region has been well- documented (Instituto Nacional de Estadísticas y Censos [INEC], 2022; Simbaña Pulupa y Tayupanta Escobar, 2014). Cattle and sheep farming is essential for the economy and family labor force, as well as for communities 'worldviews' (Mugnier et al., 2021). Animals have frequently been observed to demonstrate a greater degree of resilience in comparison to crops, thus serving as a sustainable solution to economic challenges, in addition to their role in providing manure, animal traction, and animal protein for the daily diet of peasant families (Palate Moreta, 2022; Pulido, 2018).

Nevertheless, the transition from traditional systems of land use known as "chacra" as a food provider for local families, to pastures for cattle and sheep grazing, has been identified as a recent socio-environmental phenomenon. The decline in agricultural productivity, caused by the erosion and degradation of hillsides, along with the limited availability of cultivable land due to a constant process of land division, have disrupted the balance of productive practices; consequently, families have been compelled to adopt livestock husbandry, cows and sheep specifically, as a means of subsistence (Grijalva et al., 2013; Yánez-Yánez et al., 2017).

Environmental problems have been observed in indigenous communities along the extensive Andean region which have been attributed to intensive agriculture on hillside terrains, the indiscriminate use of agrochemicals that contribute to soil and water contamination, and soil loss. In addition, traditional livestock management practices affect natural vegetation, contributing to soil erosion, factors that ultimately lead to low productivity and increased rural poverty (Bustamante, 2017; Espinosa et al., 2022). The "paramo" ecosystem's grasslands are frequently used for sheep grazing in a continuous grazing system of native or naturalized plant species with low productivity and nutritional value, which negatively impacts animal performance. Statistics show that sheep mortality can exceed 30%, primarily due to infectious diseases and fetal death resulting from metabolic disorders, as well as the consequences of inadequate grass and grazing management (Grijalva et al., 2016; León et al., 2018; Pulido, 2018).

It has been demonstrated by several authors that pastures can exhibit deficiencies and imbalances in one or more minerals (Palate Moreta, 2022; Suttle, 2016). The deficit and/or excess of minerals in soils of volcanic origin has been identified as a direct cause of low production and reproductive performance of ruminants under grazing (Grijalva et al., 2016). The solution to this problem appears to lie in a transition from traditional forages to the utilization of foreign pastures, a strategy that has been demonstrated to ensure high pasture persistence and generate greater economic returns for Indigenous families within the study area.

Considering the above, the purpose of this study is to evaluate two distinct scenarios for the intensification of grasslands based on perennial ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*). These scenarios will be implemented with rest intervals of 45 and 60 days in locations situated between 3.000-3.400 m a.s.l. used for grazing sheep and cows.

2. Materials and Methods

The research was conducted in the Chimborazo River micro-watershed, situated in the San Juan parish of the Riobamba canton, Chimborazo province, with geographical coordinates of 9825450 N and 746718 E. The mean temperature is 14.2 °C with a maximum of 21.3 °C and a minimum of 8.3 °C (Instituto Nacional de Meteorología e Hidrología [INAMHI], 2016).

For the soil component, soil samples were collected at altitudes of 3.500-3.700 and 3.000-3.400 m a.s.l in the micro-watershed, at depths of 0-10 and 11-20 cm, to evaluate bulk density (*Da*, g cm^{-3}) at the beginning of January 2016 and December 2023 using the known volume cylinder method with the equation [1].

$$Da = {Dry\ soil\ mass\ (g)} \Big/ {Total\ cylinder\ volume\ (cm^3)} \quad [1]$$

Soil samples were obtained to determine pH levels using a potentiometer in a 1:2.5 ratio of aqueous solution. Total nitrogen was determined by calculating the organic matter obtained through the wet combustion method. Assimilable phosphorus was determined by colorimetry using the modified OLSEN method, while potassium [K], calcium [Ca], and magnesium [Mg] were determined by the Atomic Absorption Spectrophotometry [AAS] technique.

For the pasture component, three plots for sheep and cow grazing were selected in six communities of the micro-watershed, which were identified as intensification scenarios: a) a natural grassland scenario composed of high Andean grasses such *as Stipa ichu*, *Holcus lanatus*, *Rumex acetocella,* and *Paspalum* sp.; here, grazing was conducted at intervals of 60-75 days; b) the mixed pasture scenario composed of perennial ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*) which was grazed at intervals of 45 days; and c) mixed pasture scenario similar to scenario b, but grazed at 60-day intervals.

In each intensification scenario, "semi-permanent exclusion cages" were installed, where grass samples were taken to evaluate the effect of each scenario on chemical composition and nutritional value. The proximate components were determined in the laboratory using the official methods proposed by (Latimer, 2019). The minerals present in pastures were analyzed using the Atomic absorption spectrometry [AAS] method, and the colorimetry method was used for phosphorus. The results obtained were expressed as a percentage or ppm (dry basis).

The equation [2], proposed by Cañas (1998), was used to estimate Total Digestible Nutrients [TDN] in percentages, based on the proximate values mentioned above:

$$Y = 92{,}46 - 3{,}33CF - 6{,}94EE - 0{,}76NFE + 1{,}11CP + 0{,}03CF^2 - 0{,}33EE^2 + 0{,}036CF * NFE + 0{,}207EE * NFE + 0{,}100EE * CP - 0{,}02EE^2 * CP \quad [2]$$

Where:

- *Y* = Total Digestible Nutrients.
- *CF* = Crude fiber.
- *EE* = Ether extract.
- *NFE* =Nitrogen free extract.
- *CP* = Crude protein.

To calculate energy partition, the equations [3], [4] and [5], described by the National Research Council (2001), were used:

$$DE = 0.04409\ x\ TDN \quad [3]$$

$$ME = 1.01\ x\ DE - 0.45 \quad [4]$$

$$NEL = 0.0245\ x\ TDN \quad [5]$$

Where:

- *DE* = Digestibility energy (Mcal kg^{-1}).
- *TDN* = Total digestibility of nutrients (%).
- *ME* = Metabolizable energy (Mcal kg^{-1}).
- *NEL* = Net energy lactation (Mcal kg^{-1}).

The stocking rate and carrying capacity were calculated based on the animal inventory, grazing area, and dry biomass yield (per ha^{-1} $year^{-1}$). These variables were expressed in Animal Units [AU], with a reference value of 1.0 AU for a "dry" cow weighing 400 kg (Bonilla Cárdenas & Lemus Flores, 2012). Daily measurements were taken of milk production for lactating crossbred cows in each grazing scenario, starting from the calving date and continuing for nine months of lactation.

To calculate emissions (equations [7] and [8]), the production of CH_4 per unit of animal product was considered as an appropriate index for comparing Greenhouse Gas [GHG] emissions from livestock under different feeding conditions (Bonilla Cárdenas & Lemus Flores, 2012). Consequently, the conversion of CH_4 to a percentage of gross energy intake [GEI] was done following recommendations provided by The Intergovernmental Panel on Climate Change [IPCC] (2006), which suggest the utilization of a gross energy value for feed equivalent to 18.45 MJ kg^{-1} of dry matter, and an energy value for CH_4 of 55.65 MJ kg^{-1} of dry matter.

$$CH_4 = 18 + 22.5DMI / DMI \quad 7]$$

$$CH_4 = CH_4 \times 100 / GEI \quad [8]$$

Where:

- CH_4 = Methane emissions (g kg^{-1} of dry matter).
- *DMI* = Dry Matter Intake (g day^{-1}).
- *GEI* = Gross Energy Intake (MJ day^{-1}).

Blood samples were obtained by puncturing the jugular vein of sheep in a "fasting catabolism" condition, for which 5.0 ml of blood per animal was collected. The enzymatic activity of aspartate aminotransferase [AST] and alanine aminotransferase [ALT], collectively known as GOT (glutamic-oxaloacetic transaminase), and alkaline phosphatase [AP] was measured using the method of the International Federation of Clinical Chemistry [IFCC]. For the ALT enzyme, the UV kinetic method was used, which is based on the kinetic determination of ALT activity, expressed in international units [IU] per liter.

The research data were analyzed using the analysis of variance [ANOVA] method, with Tukey's test at the 5% level used to compare the means of the various treatments. This analysis was conducted using Infostat software version 8 (Di Rienzo et al., 2020).

3. Results

Samples from grazing sites at lower altitudes (3.000 and 3.400 m a.s.l.) showed significantly higher values for most physicochemical properties of soil (Table 1), suggesting that soils in these regions might be more conducive to livestock farming. However, the analysis of soil bulk density [BD] did not reflect significant differences. Regarding soil minerals, statistical differences were reflected between the sites, with levels of Ca, P, and Mg being significantly higher at the lowest altitudinal level.

Table 1. Physicochemical properties of soils used for raising bovine and ovine livestock in high Andean micro-watersheds.**

Variable	Altitude limit (m)*		*P-value*
	Upper area Use in natural grassland	Lower area Use in pastures	
pH	6.10 ± 0.13	6.28 ± 0.45	*0.0504*
Organic Matter (%)	5.13^b ± 2.19	7.35^a ± 2.48	*0.0016*
N total (%)	0.25^b ± 0.11	0.37^a ± 0.12	*0.0009*
P (mg kg^{-1})	2.97^b ± 1.05	26.21^a ± 11.62	*<0.0001*
K (cmol kg^{-1})	0.27 ± 0.12	0.37 ± 0.28	*0.1249*
Ca (cmol kg^{-1})	8.62^b ± 1.68	13.26^a ± 1.74	*<0.0001*
Mg (cmol kg^{-1})	2.18^b ± 0.75	3.47^a ± 0.70	*<0.0001*
Bulk density (g cm^{-3})	0.97 ± 0.09	1.02 ± 0.10	*0.9260*

* Means on the same row for each parameter with different superscript letters reflect statiscally significant differences *($p < 0.05$)*
**This means that the data represents the average of 50 composite soil samples taken at yearly intervals over seven years of study.

The variables DM, CP, TDN, DE, ME, and NEL differ significantly within the pasture use scenarios and between these options and the natural grassland scenario (Table 2). The response in CP is inversely correlated with NDF and ADF ($p < 0.0001$). These results can be explained by the fact that the latter form of use is normally grazed at bi-monthly or even quarterly frequencies by the surrounding communities, which would result in a greater accumulation of dry matter. Statistical differences in Ca and P were observed between pastures and natural grassland, as well as between scenarios with pastures and different grazing intervals. The higher level of intensification or shorter grazing interval explains a higher mineral content in pastures.

Table 2. Chemical composition and nutritional value of pastures in various scenarios of pasture intensification in high Andean micro-watersheds.**

Variable	Pasture grazing frequency (days)*			*P-Value*
	Natural grassland	Pasture		
	75	60	45	
Dry Matter (%)	60.5^{c} **± 1.65**	26.5^{b} **± 1.13**	19.1^{a} **± 0.93**	*<0.0001*
Crude Protein (%)	$3.9^{a} \pm 0.99$	$9.9^{b} \pm 0.68$	$18.2^{c} \pm 0.56$	*<0.0001*
Ether extract (%)	$2.3^{a} \pm 0.21$	$2.1^{a} \pm 0.15$	$3.7^{b} \pm 0.12$	*<0.0001*
Crude Fiber (%)	$34.3^{b} \pm 0.81$	$20.9^{a} \pm 0.55$	$20.2^{a} \pm 0.46$	*<0.0001*
Ash (%)	$11.9^{b} \pm 0.49$	$9.6^{a} \pm 0.34$	$10.9^{b} \pm 0.28$	*0.0007*
NDF (%)	$58.5^{b} \pm 1.48$	$42.1^{a} \pm 1{,}02$	$44.2^{a} \pm 0.84$	*<0.0001*
ADF (%)	$42.0^{b} \pm 1.09$	$30.8^{a} \pm 0.74$	$29.3^{a} \pm 0.61$	*<0.0001*
ADL (%)	7.6 ± 0.56	6.5 ± 0.38	6.7 ± 0.32	*0.2812*
TDN (%)	$45.9^{a} \pm 1.42$	$56.5^{b} \pm 0.97$	$63.0^{c} \pm 0.80$	*<0.0001*
DE (Mcal kg^{-1})	$2.0^{a} \pm 0.06$	$2.5^{b} \pm 0.04$	$2.8^{c} \pm 0.03$	*<0.0001*
ME (Mcal kg^{-1})	$1.6^{a} \pm 0.06$	$2.1^{b} \pm 0.04$	$2.4^{c} \pm 0.04$	*<0.0001*
NE_L (Mcal kg^{-1})	$1.0^{a} \pm 0.04$	$1.3^{b} \pm 0.03$	$1.4^{c} \pm 0.02$	*<0.0001*
Ca (%)	$0.08^{a} \pm 0.05$	$0.25^{b} \pm 0.03$	$0.41^{c} \pm 0.03$	*<0.0001*
P (%)	$0.03^{a} \pm 0.02$	0.09b ± 0.01	$0.26^{c} \pm 0.01$	*<0.0001*
Mg (%)	$0.07^{a} \pm 0.03$	$0.34^{c} \pm 0.02$	$0.23^{b} \pm 0.02$	*<0.0001*
K (%)	$0.26^{a} \pm 0.16$	$1.00^{b} \pm 0.11$	$3.14^{c} \pm 0.19$	*<0.0001*

* Means on the same row for each parameter with different superscript letters reflect statistically significant differences ($p < 0.05$)
** The data represent the average of 75 samples and are expressed on a dry matter basis.

As demonstrated in Table 3, high Andean ecosystems can only support a maximum sustainable animal load of 0.1 AU ha^{-1} $year^{-1}$, which could range between 0.05-1.0 AU ha^{-1} $year^{-1}$due to their fragile environmental conditions associated with their biophysical characteristics, particularly low temperatures, periods of frost and seasonal rains, which hinders the intensification of natural pasture management. The analysis of CH_4 from carbohydrate fermentation suggests an increase in emissions as structural components, specifically FDN and FDA, increase.

Table 3. Animal stocking rate and carrying capacity, milk production, and estimated CH_4 emissions in three scenarios of grazing intensification in high Andean micro-watersheds.

Grazing intensification	Grazing frequency	Carrying Capacity*	Milk Production*	CH_4 emissions*	
	(days)	(AU ha^{-1})	(kg $ha^{-1}day^{-1}$)	(g kg^{-1} DM)	(% GEI)
Natural grassland	60-75	0.30^{c}	2.3^{c}	24.9^{b}	7.6^{b}
Pasture	45	2.1^{a}	11.0^{a}	23.7^{a}	7.2^{a}
	60	1.3^{b}	7.1^{b}	24.3^{a}	7.4^{a}
P-value		*0.0001*	*0.0001*	*0.045*	*0.046*

* Means on the same row with different superscript letters reflect statistically significant differences *($p < 0.05$)*

The results of the blood analysis in sheep grazing on high Andean micro-watersheds meadows and pastures are shown in Table 4. The mean mineral levels in their blood are within a normal range. However, a high degree of variation was observed in the ALT and AF enzymes, relative to established reference ranges. On the other hand, the AST enzyme demonstrated a profile that falls within the considered normal range.

Table 4. Mean levels of calcium, phosphorus, potassium, magnesium, and activity of various enzymes in the blood serum of sheep grazing on natural grasslands and mixed pastures in high Andean micro-watersheds.*

Variable	Mean ± SD	Minimum	Maximun	Reference value
Ca (mg dl^{-1})	9.2 ± 1.85	0.6	12.1	11-12 (Moyano et al., 2018)
P (mg dl^{-1})	7.2 ± 1.79	2.7	14.6	5.0-7.0 (Moyano et al., 2018)
K (mg dl^{-1})	5.4 ± 0.83	3.7	7.2	4.3-6.3 (Moyano et al., 2018)
Mg (mg dl^{-1})	2.4 ± 0.22	1.9	2.9	1.5-1.8 (Moyano et al., 2018)
ALT (U l^{-1})	130.6 ± 294.18	5.0	1192.1	14-38 (Núñez Ochoa & Bouda, 2007)
AST (U l^{-1})	59.2 ± 32.74	0.8	151.2	88.65 (Campos et al., 2007)
AF (U l^{-1})	259.6 ± 235.86	13.0	997.0	<237 (Núñez Ochoa & Bouda, 2007)

* The data represents the average of 75 samples of blood serum collected from grazing sheep.

4. Discussion

The findings of this research, under the high grazing scenario, demonstrate a prevailing tendency toward soil acidification, a phenomenon consistent with observations reported in the literature by several researchers. An acidic soil is characterized by high concentrations of Al^{+3} and H^{+} ions as the pH decreases, which impacts the chemical, physical, and biological characteristics of the soil, reducing plant growth and nutrient availability such as Ca, Mg, P, K, and other micro- elements (Espinosa et al., 2022).

Several authors have reported that soils of volcanic origin tend to retain large amounts of water and organic matter, (Espinosa et al., 2022; Yánez-Yánez et al., 2017), which coupled with the slow decomposition and mineralization of organic matter, could potentially limit the availability of nutrients to plants.

In lower areas that are actively used for livestock activity, the total nitrogen content of the soil is higher due, in part to, the contribution of nutrients from animal excreta. Soils with levels below 0.10-0.25% of N are classified as deficient. However, it is important to note that total N is not always a useful measure in soils of volcanic origin, since this component is very dynamic and is normally associated with the mineralization of organic matter, losses due to nitrification and denitrification, leaching, immobilization, and volatilization (Espinosa et al., 2022; Maresma Galindo, 2020).

On the other hand, the status of P indicates a more favorable situation in low-elevation sites, suggesting a significant contribution of animal excreta from grazing in these pastures. Levels lower than 10 ppm of P are often considered deficient, and this is precisely what occurs in the highest and most delicate sites associated with the "paramo" ecosystem. However, the absorption of this element by grass root systems may be limited by pH and allophane clay (Espinosa et al., 2022). Except for K, which demonstrates deficiency at the highest altitude, the other two elements (Ca and Mg) exhibit significantly higher values at the lower sites. Conversely, erosive processes contribute to the leaching of nutrients in the study areas located at higher altitudes above sea level.

The analysis of soil BD does not reveal significant differences. In this regard, Chinchilla et al. (2011) states that the density of andosol soils is generally less than 0.90 g cm^{-3}. These results are consistent with the findings of González Ponce (2009), who reported variations from 0.77 to 0.95 g cm^{-3} over a seven-year grazing period. It is important to note that all values reported by these authors are lower than the reference value of 1.3 g cm^{-3}, which is associated with soil compaction problems.

Several authors agree that the content and yield of DM in pastures generally increase with an increase in the frequency of rest or grazing. However, there is a simultaneous decrease in the nutritional value and animal consumption due to an increase in plant maturity (Merlo-Maydana et al., 2017; León et al., 2018; Pulido, 2018).

Our results demonstrate a negative correlation between crude protein [CP] and both NDF and ADF, indicating that an increase in NDF with advancing maturity increases is typically related to a decline in CP content, as suggested by several authors (Apráez et al., 2014; Posada Ochoa et al., 2013; León et al., 2018). In this regard, García-Bonilla et al. (2014) state that FDA is related to digestibility, with lower FDA values indicating higher Digestibility. Lignin did not show differences between alternatives. These results differ from other studies that reported lignin values of 18.2% in natural grasslands (Albarracín et al., 2015).

In relation to Ca and P, the higher level of intensification or shorter grazing interval caused a higher content of macro-mineral elements. In comparison to alternative intensification strategies, natural grassland exhibited significantly lower values, indicating a substantially restrictive environment concerning the provision of nutrients necessary for optimal animal productivity (Grijalva et al., 2016; Suttle, 2016; López-Vigoa et al., 2019; Palate Moreta, 2022).

The findings of this research indicate a correlation between elevated methane emissions and a high concentration of crude fiber, characterized by low protein content and digestibility, particularly in the high scenario. This observation aligns with the conclusions reported by several authors, suggesting consistency in the scientific community's findings indicating that GHG emissions or ruminal methane production constitute an energy loss that significantly contributes to GHG emissions into the environment. The magnitude of this phenomenon appears to be influenced by the consumption, chemical composition, and digestibility of pastures (Apráez et al., 2014; Bonilla Cárdenas & Lemus Flores, 2012; Garnsworthy, 2018; IPCC, 2006; Lovett et al., 2005; Ribeiro Pereira et al., 2015).

The mean concentrations of Ca, P, K, Mg and the activity of various enzymes in the blood serum of sheep grazing on natural grasslands and mixed pastures in high Andean micro-basins demonstrate trends similar to those reported by several authors, which may be indicative of a physiological response in grazing sheep according to Gioffredo (2011). However, considerable inter-individual variation was observed, with values ranging from below the minimum or normal range to well above the average.

Furthermore, the ALT and AF enzymes also show considerable variation in the established reference ranges (Avellanet et al., 2007). Conversely, the AST enzyme fell within a considered normal range, which agrees with the results reported by other authors (Djokovic et al., 2017). It has been established that the activity of the AF enzyme is associated with Ca content in the diet. An increase in AF levels has been observed during periods of dietary calcium deficiency, but not necessarily phosphorus deficiency (Braun et al., 2010; de Oliveira et al., 2014). This could potentially alter the calcium-to-phosphorus ratio and cause problems in animals exposed to changes in the quality of pastures or natural grasslands.

5. Conclusions

The natural grassland, which is based on a "pajonal" plant community, is frequently used for the grazing of sheep and cattle in Indigenous communities. This is done in a continuous grazing system of low productivity and quality, regardless of the stocking rate, which has a detrimental effect on the productive performance of the animals. The use of foreign pastures, such as ryegrass and clovers, at early utilization frequencies, appears to contribute to the intensification of livestock as a low-emission grazing proposal in the Andean ecoregion.

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Contributor roles

- Jorge Eduardo Grijalva-Olmedo: conceptualization, methodology, project administration, writing – original draft.
- Paola Mercedes Palate-Moreta: investigation, resources
- Roy Roger Vera-Vélez: methodology, writing – review & editing.
- Raúl Armando Ramos-Veintimilla: conceptualization, methodology.
- Jean-François Tourrand: validation, writing – review & editing.
- Arnulfo Portilla-Narváez: investigation, formal analisis.

Ethical implications

The utilization of animals in the research process was conducted in accordance with established veterinary and zootechnical protocols, ensuring that no harm or suffering to the animals. Consequently, formal approval from an ethics committee was not required.

Conflict of interest

The authors declare that they have no affiliation with any organization with a direct or indirect financial interest that could have appeared to influence the work reported.

References

Albarracín, K. G., Jaramillo, L. I., & Albuja, M. (2015). Obtención de bioetanol anhidro a partir de paja (*Stipa ichu*). Revista *Politécnica*, *36*(2), 109. https://revistapolitecnica.epn.edu.ec/ojs2/index.php/revista_politecnica2/article/view/526

Apráez G., E., Gálvez C., A., & Jojoa R., C. (2014). Valoración nutricional y emisión de gases de algunos recursos forrajeros del trópico de altura. *Revista de Ciencias Agrícolas*, *31*(2), 122-134. https://doi.org/10.22267/rcia.143102.36

Avellanet, R., Cuenca, R., Pastor, J., & Jordana, J. (2007). Parámetros hematológicos y bioquímico clínicosen la raza ovina xisqueta. *Archivos de Zootecnia*, *56*(Su1), 497-501. https://www.redalyc.org/articulo.oa?id=49509922

Bonilla Cárdenas, J. A., & Lemus Flores, C. (2012). Emisión de metano entérico por rumiantes y su contribución al calentamiento global y al cambio climático. Revisión. *Revista Mexicana de Ciencias Pecuarias*, *3*(2), 215-246. https://cienciaspecuarias.inifap.gob.mx/index.php/Pecuarias/article/view/1241

Braun, J. P., Trumel, C., & Bézille, P. (2010). Clinical biochemistry in sheep: A selected review. *Small Ruminant Research*, *92*(1–3), 10-18. https://doi.org/10.1016/j.smallrumres.2010.04.002

Bustamante, D. P. (2017). Escenario de cambio climático a nivel de subcuencas hidrográficas para el año 2050 de la provincia de Chimborazo-Ecuador. *La Granja*, *26*(2), 15-27. https://doi.org/10.17163/lgr.n26.2017.02

Campos, R., Cubillos, C., & Rodas, Ángela G. (2007). Indicadores metabólicos en razas lecheras especializadas en condiciones tropicales en Colombia. *Acta Agronómica*, *56*(2), 85-92. https://revistas.unal.edu.co/index.php/acta_agronomica/article/view/643

Cañas, R. (1998). *Alimentación y Nutrición Animal* (2ª ed.). Universidad Católica de Chile. https://hdl.handle.net/20.500.14001/53614

Chinchilla, M., Mata, R., & Alvarado, A. (2011). Andisoles, inceptisoles y entisoles de la subcuenca del río Pirrís, región de Los Santos, Talamanca, Costa Rica. *Agronomía Costarricense*, *35*(1), 83-107. https://doi.org/10.15517/rac.v35i1.6688

de Oliveira, R. P. M., Maduro, A. H. P., de Oliveira, F. F., & Lima, E. S. (2014). Perfil metabólico de ovelhas Santa Inês em diferentes fases de gestação criadas em sistema semi-intensivo no Estado do Amazonas. *Ciência Animal Brasileira*, *15*(1), 81-86. https://doi.org/10.5216/cab.v15i1.15720

Di Rienzo, J. A., Casanoves, F., Balzarini, M. G., Gonzalez, L., Tablada, M., & Robledo, C. W. (2020). *InfoS-*

tat versión 2020. Centro de Transferencia InfoStat, FCA, Universidad Nacional de Córdoba, Argentina. http://www.infostat.com.ar

Djokovic, R., Cincovic, M., Kurcubic, V., Ilic, Z., Lalovic, M., Jasovic, B., & Petrovic, M. (2017). Serum enzyme activities in blood and milk in the different stage of lactation in holstein dairy cows. *Biotechnology in Animal Husbandry*, *33*(2), 193-200. https://doi.org/10.2298/BAH1702193D

Espinosa, J., Moreno, J., & Bernal, G. (eds.), (2022). *Suelos del Ecuador, clasificación, uso y manejo*. Instituto Geográfico Militar [IGM]. https://www.geoportaligm.gob.ec/portal/index.php/estudios-geograficos/

García-Bonilla, D. V., Guerrero-Rodríguez, J. de D., García-de los Santos, G., & Lagunes-Rivera, S. A. (2014). Rendimiento y calidad de forraje de genotipos de *Lotus corniculatus* en el Estado de México. *Nova scientia*, *7*(13), 170-189. https://www.scielo.org.mx/scielo.php?script=sci_arttext&pid=S2007-07052015000100010

Garnsworthy, P. C. (2018). Reducing the environmental impact of animal production. *Archivos Latinoamericanos de Producción Animal*, *26*(1-2). https://ojs.alpa.uy/index.php/ojs_files/article/view/2625

Gioffredo, J. J. (2011). *Sanidad en ovinos y caprinos. Enfermedades metabólicas*. Sitio Argentino de Producción Animal. https://www.produccion-animal.com.ar/sanidad_intoxicaciones_metabolicos/enfermedades_caprinos/43-metabolicas.pdf

González Ponce, J. J. (2009). *Evaluación de tres sistemas sivopastoriles para la gestión sostenible de los recursos naturales de la microcuenca del río Chimborazo.* Escuela Superior Politécnica de Chimborazo. http://dspace.espoch.edu.ec/handle/123456789/351

Grijalva, J., Aguinda, H., Quisirumbay, J., & Salazar, R. (2016). Concentración de selenio sanguíneo y relación con el perfil mineral de suelos y praderas bajo pastoreo de ovejas en la región altoandina del Ecuador: implicaciones en la nutrición humana. *Revista de la Facultad De Ciencias Médicas (Quito)*, *41*(1), 159-168. https://revistadigital.uce.edu.ec/index.php/CIENCIAS_MEDICAS/article/view/1182

Grijalva, J., Ramos Veintimilla, R., Arévalo Vizcaino, V., Barrera, P., & Guerra, J. (2013). *Alternativas de intensificación, adaptación y mitigación a cambios climáticos. Los sistemas silvopastoriles en la subcuenca del río Quijos de la Amazonia ecuatoriana*. Publicación Miscelánea 414. INIAP. http://repositorio.iniap.gob.ec/handle/41000/2723

Instituto Nacional de Estadísticas y Censos [INEC]. (2022). *Encuesta de Superficie y Producción Agropecuaria Continua Abril, 2022*. INEC. https://www.ecuadorencifras.gob.ec/documentos/web-inec/Estadisticas_agropecuarias/espac/espac-2021/Bolet%C3%ADn%20t%C3%A9cnico.pdf

Instituto Nacional de Meteorología e Hidrología [INAMHI]. (2016). *Boletín climatológico del Instituto Nacional de Meteorología e Hidrología*. INAMHI. https://servicios.inamhi.gob.ec/boletines/

Latimer, G. W. (ed.). (2019). *Official methods of analysis of Association of Official Analytical Chemists International* (21st ed.). AOAC International. https://members.aoac.org/AOAC/AOAC/Item_Detail.aspx?iProductCode=1121&Category=OMA

León, R., Bonifaz, N., & Gutiérrez, F. (2018). *Pastos y forrajes del Ecuador. Siembra y producción de pasturas*. Editorial Universitaria Abya-Yala. https://dspace.ups.edu.ec/handle/123456789/19019

López-Vigoa, O., Lamela-López, L., Sánchez-Santana, T., Olivera-Castro, Y., García-López, R., Herrera-Villafranca, M., & González-Ronquillo, M. (2019). Evaluación del valor nutricional de los forrajes en un sistema silvopastoril. *Pastos y Forrajes*, *42*(1), 57-67. http://www.redalyc.org/articulo.oa?id=269159592007

Lovett, D. K., Stack, L. J., Lovell, S., Callan, J., Flynn, B., Hawkins, M., & O'Mara, F. P. (2005). Manipulating enteric methane emissions and animal performance of late-lactation dairy cows through concentrate supplementation at pasture. *Journal of Dairy Science*, *88*(8), 2836-2842. https://doi.org/10.3168/jds.S0022-0302(05)72964-7

Maresma Galindo, A. (2020). Maximizar la eficiencia en el uso del nitrógeno: clave para la sostenibilidad. En *Como gestionar la agricultura de forma eficiente y sostenible en las zonas vulnerables* [Video]. II Jornada de Zonas Vulnerables 2021. Youtube. https://www.youtube.com/watch?v=ycMutlO6iCM

Merlo-Maydana, F. E., Ramírez-Avilés, L., Ayala-Burgos, A. J., & Ku-Vera, J. C. (2017). Efecto de la edad de corte y la época del año sobre el rendimiento y calidad de *Brachiaria brizantha* (A. Rich.) Staff en Yucatán, México. *Journal of the Selva Andina Animal Science*, *4*(2), 116-127. https://doi.org/10.36610/j.jsaas.2017.040200116

Moyano, J. C., Caicedo, W., López, J. C., Vargas, J. C., Barbona, I., Marini, P. R., & Fischman, M. L. (2018). Characterization of macromineral content in the blood of Blackbelly sheep under free grazing conditions in Ecuadorian Amazon. *Cuban Journal of Agricultural Science*, *52*(3), 297-302. https://www.cjascience.

com/index.php/CJAS/article/view/810

Mugnier, S., Husson, C., & Cournut, S. (2021). Why and how farmers manage mixed cattle–sheep farming systems and cope with economic, climatic and workforce-related hazards. *Renewable Agriculture and Food Systems*, *36*(4), 344-352. https://doi.org/10.1017/S174217052000037X

National Research Council. (2001). *Nutrient Requirements of Dairy Cattle* (7th Rev. ed.). National Academies Press. https://doi.org/10.17226/9825

Núñez Ochoa, L., & Bouda, J. (eds.). (2007). *Patología clínica veterinaria* (2ª ed.). Universidad Nacional Autónoma de México.

Palate Moreta, P. M. (2022). *Evaluación del estatus de Ca, P y Mg en suelo, pasturas y suero sanguíneo de ovinos en pastoreo en la microcuenca del rio Chimborazo*. Universidad Central del Ecuador. http://www.dspace.uce.edu.ec/handle/25000/20762

Posada Ochoa, S., Cerón, J. M., Hamedt, J. F., Arenas, J., & Alvárez, A. (2013). Evaluación del establecimiento de ryegrass (*Lolium* sp.) en potreros de kikuyo (*Pennisetum clandestinum*) usando la metodología de cero labranza. *CES Medicina Veterinaria Y Zootecnia*, *8*(1), 26-35. https://revistas.ces.edu.co/index.php/mvz/article/view/2831

Pulido, R. (2018). Consumo de materia seca: limites e interaccion con suplementos nutricionales. En G. Albán, M. Caviedes, & C. Ponce, *Memorias del Simposio Internacional de Pastos y Forrajes de Clima Templado* (pp. 28-29). Archivos Académicos USFQ 16. https://doi.org/10.18272/archivosacademicos.vi16.1483

Ribeiro Pereira, L. G., Machado, F. S., Campos, M. M., Guimaraes Júnior, R., Tomich, T. R., Reis, L. G., & Coombs, C. (2015). Enteric methane mitigation strategies in ruminants: a review. *Revista Colombiana de Ciencias Pecuaria*, *28*(2), 124-143. https://doi.org/10.17533/udea.rccp.v28n2a02

Simbaña Pulupa, L. P., & Tayupanta Escobar, D. M. (2014). *Análisis de Resultados de Investigación en Sistemas Silvopastoriles en la Organización UCASAJ de la Microcuenca del Rio Chmborazo, Cantón Riobamba, Provincia de Chimborazo*. Universidad Central del Ecuador. http://www.dspace.uce.edu.ec/handle/25000/4447

Suttle, N. (2016). Ruminant Nutrition – Digestion and absorption of minerals and vitamins. En *Reference Module in Food Science*. Elsevier. https://doi.org/10.1016/B978-0-08-100596-5.00964-1

The Intergovernmental Panel on Climate Change [IPCC]. (2006). *IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme*. H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara, & K. Tanabe (eds). IGES. https://www.ipcc-nggip.iges.or.jp/public/2006gl/

Yánez-Yánez, W., Núñez-Torres, O. P., Yánez-Borja, D. B., Rivera-Guerra, V. E., López-Villacís, I. C., & Velástegui-Espín, G. P. (2017). Niveles de nitrógeno en suelos del cantón Chambo, provincia de Chimborazo. *Journal of the Selva Andina Animal Science*, *5*(2), 152-159. http://www.scielo.org.bo/scielo.php?script=sci_arttext&pid=S2308-38592017000200010