Nativa, Sinop, v. 12, n. 4, p. 755-763, 2024.
Pesquisas Agrárias e Ambientais
DOI: https://doi.org/10.31413/nat.v12i4.17958
ISSN: 2318-7670

Productive impact of forage grasses and legumes in the Central Jungle of Peru

Keneth REÁTEGUI-DEL ÁGUILA [1], Vitelio ASENCIOS-TARAZONA *[1],
Ronald Marlon LOZANO-REÁTEGUI [1], Ayda Guisella AVALOS-DÍAZ [1],
Jorge SAAVEDRA-RAMÍREZ [2], Elías TORRES-FLORES [3], Guillermo VÁSQUEZ-RAMÍREZ [3]

[1] Faculty of Engineering and Environmental Sciences, National Intercultural University of the Amazon, Pucallpa, Peru.
[2] Faculty of Engineering, National Autonomous University of Alto Amazonas, Yurimaguas, Peru.
[3] Faculty of Agricultural Sciences, National University of San Martin, Tarapoto, Peru
*E-mail: vasenciost@unia.edu.pe

Submitted on: 06/28/2024; Accepted on: 11/07/2024; Published on: 12/06/2024.

ABSTRACT: The study's objective was to evaluate the establishment and production of forage grasses and legumes in acidic and degraded soils of Puerto Bermúdez, Peru. Two treatments were experimented with, consisting of 3 grasses *(Brachiaria decumbens, Andropogon gayanus and Brachiaria dictyoneura) and 12 legumes (Stylosanthes guianensis, Desmodium ovalifolium, Centrosema pubescens, Zornia latifolia, Stylosanthes capitata, Centrosema macrocarpum, Centrosema sp., Centrosema brasiliensis, Centrosema arenarium, Zornia glabra, Aeschynomene histrix, and, Pueraria phaseoloides),* in monoculture plots, using a Completely Randomized Design, showing statistically significant differences. The grass that had the highest plant height (73 ± 0.01 cm) was *Andropogon gayanus*, dry matter (4,325 ± 435.88 kg ha^{-1}), and the percentage of cover (100% m^{-2}) was *Brachiaria dictyoneura*. The legume that stood out in plant height was *Stylosanthes capitata* (34 ± 0.01 cm), in dry matter, *Stylosanthes guianens* (2265 ± 294.95 kg ha^{-1}), and, in percentage of cover (100%), *Stylosanthes guian*ens stood out, *Desmodium ovalifolium*, *Zornia latifolium*, *Pueraria phaseoloides*, respectively. The study's findings highlight the significant differences in the performance of certain grasses and legumes in acidic and degraded soils and the need for further research on associated crops, fertilization, and agronomic management to fully exploit their potential.
Keywords: pasture establishment; forage height; dry mass production; coverage percentage; tolerance to soil acidity.

Impacto produtivo das gramíneas e leguminosas forrageiras na Selva Central do Peru

RESUMO: O objetivo do estudo foi avaliar o estabelecimento e produção de gramíneas e leguminosas forrageiras em solos ácidos e degradados de Puerto Bermúdez, Peru. Foram experimentados dois tratamentos, compostos por 3 gramíneas *(Brachiaria decumbens, Andropogon gayanus e Brachiaria dictyoneura)* e 12 leguminosas *(Stylosanthes guianensis, Desmodium ovalifolium, Centrosema pubescens, Zornia latifolia, Stylosanthes capitata, Centrosema macrocarpum, Centrosema sp., Cent*rosema brasiliensis, Centrosema arenarium, *Zornia glabra, Aeschynomene histrix e Pueraria phaseoloides*), em parcelas de monocultivo, utilizando delineamento inteiramente casualizado, apresentando diferenças estatisticamente significativas. A gramínea que apresentou maior altura de planta (73±0,01 cm) foi *Andropogon gayanus*, massa seca (4.325±435,88 kg ha^{-1}) e porcentagem de cobertura (100% m^{-2}), foi *Brachiaria dictyoneura*. A leguminosa que se destacou em altura de planta foi *Stylosanthes capitata* (34±0,01cm), em massa seca *Stylosanthes guianens* (2265±294,95 kg ha^{-1}) e, em porcentagem de cobertura (100%), *Stylosanthes guianens* se destacou*, Desmodium ovalifolium, Zornia latifolium, Pueraria phaseoloides*, respectivamente. Concluindo que o melhor desempenho é atribuído a uma maior adaptação das gramíneas às condições edáficas limitantes e à sua eficiência fotossintética, enquanto as leguminosas apresentaram menor tolerância à acidez do solo devido ao efeito do alumínio (Al). Mais pesquisas são necessárias, como culturas associadas, fertilização e manejo agronômico.
Palavras-chave: estabelecimento de pastagem; altura de forragem; produção de massa seca; porcentagem de cobertura; tolerância à acidez do solo.

1. INTRODUCTION

Peru is part of the Amazon basin, about 730,000 km^2 (approximately 60%). It has a representative Amazon strip called the Peruvian Amazon (SÁNCHEZ et al., 2021). The second largest in South America and the tenth most densely forested country on Earth. In this space, feeding cattle is one of the main problems that affect livestock production in this region.

The scarcity and low quality of natural pastures and the lack of forage alternatives adapted to edaphoclimatic conditions limit the development of livestock activity and its profitability. The problem has been asserted by Balehegn et al. (2020), who indicate that all livestock production systems in many low- and middle-income countries, where there are limited food supplies and the high cost of good quality feed, severely limit the exploitation of livestock activity.

Therefore, it is necessary to evaluate and introduce forage species that improve the supply and nutritional value of food for livestock and that, in turn, contribute to the conservation and recovery of degraded soils. In this trend, Wang et al. (2023) state that the establishment of cultivated pastures, which has spread in developed countries, has proven to be effective in increasing forage yield, restoring degraded grasslands, and could also provide a great boost to livestock production.

The association of crops, used as forage material to promote livestock activity through mixtures of grasses and legumes, have greater nutritional value, digestibility, degradability and animal production potential than monoculture, becomes an option to improve yields and ensure the sustainability of livestock activity, as mentioned by Rusdy (2021) and Alemayehu et al. (2017), who applied technologies based on the use of improved forage plants, through the introduction of forage species with higher yield and quality, including legumes, with application in livestock with mixed crops of small farmers, in semi-intensive and intensive systems. and mixed crops in a grazing system to increase the availability of forage and its nutritional value and reduce seasonal fluctuation in availability.

In this context, the objective of this article is to describe and compare the results of research on the establishment and production of forage grasses and legumes in acidic and nutrient-poor soil planted in monoculture, in the district of Puerto Bermúdez, Oxapampa province, Pasco department, Peru. The results allow us to identify the best group of grasses or legumes to improve cattle feeding in the study area and their advantages and disadvantages. Likewise, practical implications and recommendations for the proper management of introduced forage species are discussed.

2. MATERIAL AND METHODS

2.1. Experimental

The study was carried out at the "La Esperanza" Agricultural Experimental Station, Valle del Pichis, town and district of Puerto Bermúdez, province of Oxapampa, department of Pasco, Peru, during May to August 2021, presenting an altitude of 300 m above sea level and had as coordinates 10°18' south latitude and 74°54' west longitude, where the average annual rainfall is 3,312 mm, and the average temperature is 26 °C (Fig. 1). Soil analyzes were carried out in two strata: 0-15 cm and 15-30 cm, to determine calcium (Ca), magnesium (Mg), potassium (K), zinc (Zn), iron (Fe), phosphorus (P), manganese (Mn), aluminum (Al) (Table 1). Two treatments were evaluated: The first consisted of three species of grasses: *Brachiaria decumbens, Andropogon gayanus and Brachiaria dictyoneura*; the second of twelve species of legumes: *Stylosanthes guianensis, Desmodium ovalifolium, Centrosema pubescens, Zornia latifolia, Stylosanthes capitata, Centrosema macrocarpum, Centrosema sp., Centrosema brasiliensis, Centrosema arenarium, Zornia glabra, Aeschynomene histrix, and, Pueraria phaseoloides.*

All species were established in monoculture experimental plots. The experimental design was completely randomized, with 100 repetitions per treatment.

The variables evaluated were:

- Plant height (cm): It was measured with a graduated ruler from the base of the plant to the apex. Ten measurements were taken per plot, and the average was calculated.
- Dry matter (kg ha^{-1}): It was determined by cutting all the aerial biomass contained in a quadrant of 0.25 m^2 per plot. The samples were dried in a forced air oven at 60 °C until constant weight.
- Coverage (% m^{-2}): It was determined visually using the quadrant method.

The data were analyzed using descriptive statistics, which calculated the mean, standard deviation, and coefficient of variation. The Tukey test was used to compare multiple means between treatments. All analyses were performed at a 5% significance level.

3. RESULTS

3.1. Climatological characteristics of the Pichis Valley-Puerto Bermúdez

The average temperature ranges around 25 °C, with approximately 120 mm of rainfall being the lowest and 500 mm the highest in August and December, respectively.

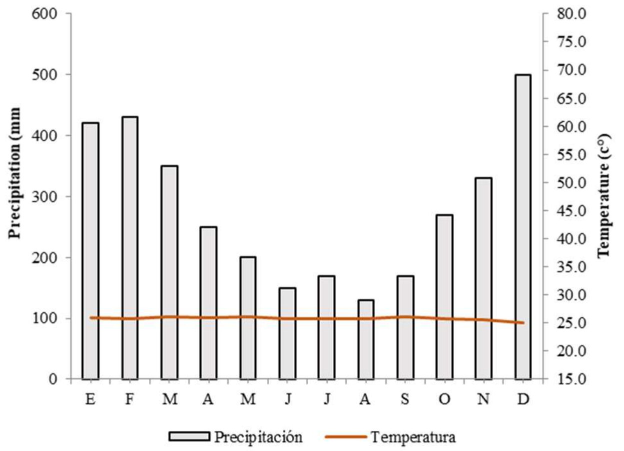


Figure 1. Climatological characteristics of the study area (Pichis Valley).

Figura 1. Características climatológicas da área de estudo (Vale do Pichis).

3.2. Soil characterization

The soil of the experimental plot showed the values indicated in Table 1, taken in two strata.

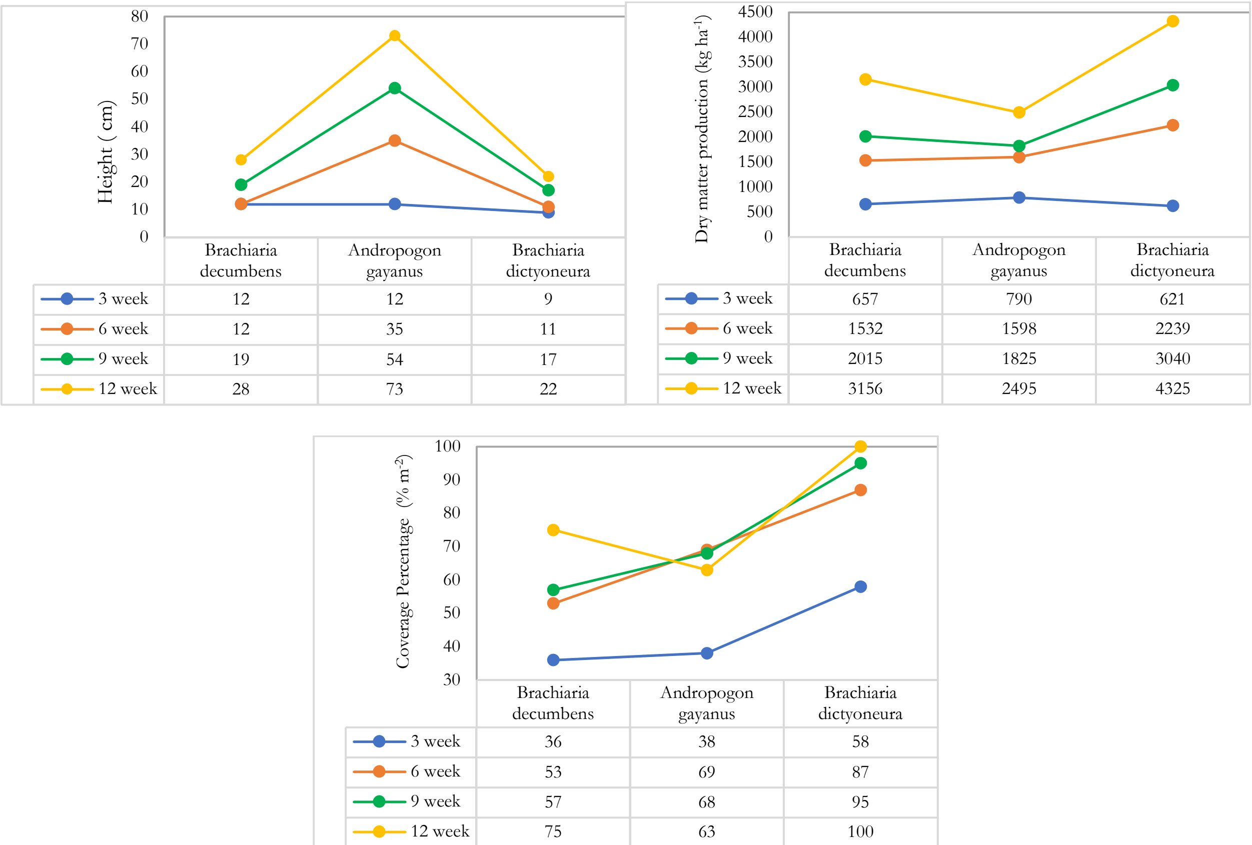
Table 1. Chemical characteristics of the station's soils.

Tabela 1. Características químicas dos solos da área de estudo.

Stratum (cm)	pH	Acidity							
		Meq 100 mL^{-1}			ppm				%
		Ca	Mg	K	Zn	Fe	P	Mn	Al
0 – 15	4.2	4.0	1.1	0.10	18.0	1,731.0	8.0	6.0	77.0
15 - 30	4.2	4.2	1.0	0.08	15.0	1,970.0	6.8	8.0	79.0

3.3. Establishment and production of grasses and legumes

In Figures 2, 3, 4 and 5, a better performance of the grasses is observed in terms of height *(Andropogon gayanus) and production of dry material (Brachiaria dictyoneura)*, but in percentage of coverage, the legumes *(Stylosanthes guianensis, Desmodium ovalifolium, Zornia latifolia,* and, *Pueraria phaseoloides),* surpassed the grasses.

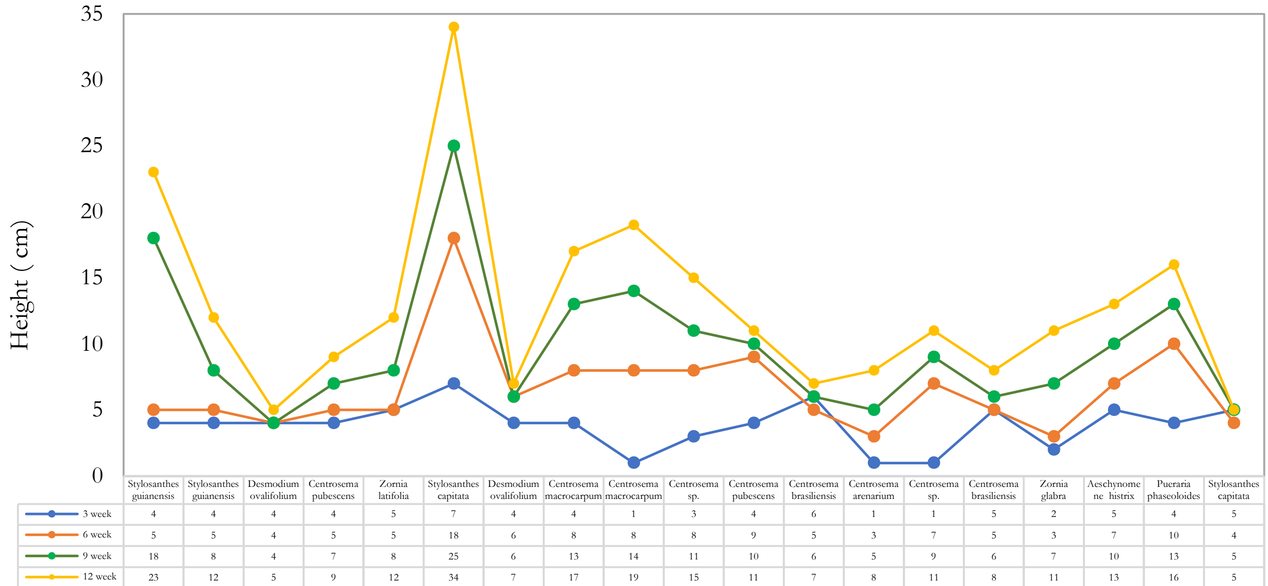


	Brachiaria decumbens	Andropogon gayanus	Brachiaria dictyoneura
3 week	12	12	9
6 week	12	35	11
9 week	19	54	17
12 week	28	73	22

	Brachiaria decumbens	Andropogon gayanus	Brachiaria dictyoneura
3 week	657	790	621
6 week	1532	1598	2239
9 week	2015	1825	3040
12 week	3156	2495	4325

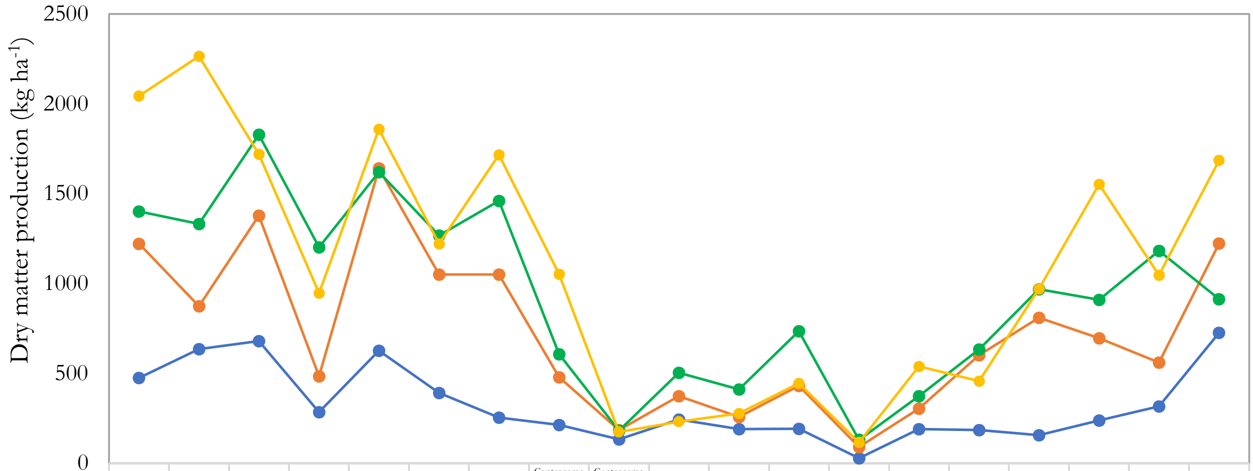
	Brachiaria decumbens	Andropogon gayanus	Brachiaria dictyoneura
3 week	36	38	58
6 week	53	69	87
9 week	57	68	95
12 week	75	63	100

Figure 2. Variation in height (A), dry matter production (B) and percentage of cover (C), according to the weeks of development of the grass species.
Figura 2. Variação da altura (A), produção de matéria seca (B) e porcentagem de cobertura (C), de acordo com as semanas de desenvolvimento das espécies de gramíneas.



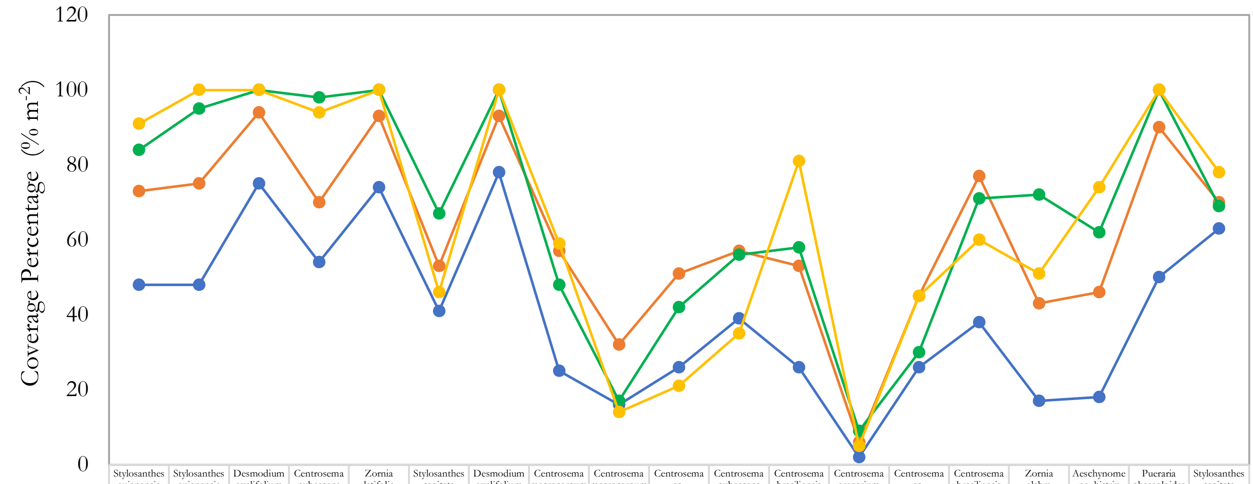
	Stylosanthes guianensis	Stylosanthes guianensis	Desmodium ovalifolium	Centrosema pubescens	Zornia latifolia	Stylosanthes capitata	Desmodium ovalifolium	Centrosema macrocarpum	Centrosema macrocarpum	Centrosema sp.	Centrosema pubescens	Centrosema brasiliensis	Centrosema arenarium	Centrosema sp.	Centrosema brasiliensis	Zornia glabra	Aeschynomene histrix	Pueraria phaseoloides	Stylosanthes capitata
3 week	4	4	4	4	5	7	4	4	1	3	4	6	1	1	5	2	5	4	5
6 week	5	5	4	5	5	18	6	8	8	8	9	5	3	7	5	3	7	10	4
9 week	18	8	4	7	8	25	6	13	14	11	10	6	5	9	6	7	10	13	5
12 week	23	12	5	9	12	34	7	17	19	15	11	7	8	11	8	11	13	16	5

Figure 3. Variation of height according to weeks of forage legume species.
Figura 3. Variação da altura em função das semanas de espécies de leguminosas forrageiras.



	Stylosanthes guianensis	Stylosanthes guianensis	Desmodium ovalifolium	Centrosema pubescens	Zornia latifolia	Stylosanthes capitata	Desmodium ovalifolium	Centrosema macrocarpum	Centrosema macrocarpum	Centrosema sp.	Centrosema pubescens	Centrosema brasiliensis	Centrosema arenarium	Centrosema sp.	Centrosema brasiliensis	Zornia glabra	Aeschynomene histrix	Pueraria phaseoloides	Stylosanthes capitata
3 week	475	635	679	283	626	390	253	213	133	243	190	191	27	190	184	156	237	316	726
6 week	1220	873	1377	483	1640	1050	1049	478	183	373	256	430	90	303	601	809	695	560	1222
9 week	1400	1330	1828	1200	1619	1266	1460	606	180	503	410	734	130	373	632	968	909	1181	913
12 week	2044	2265	1720	946	1858	1221	1715	1052	173	230	276	443	116	538	456	969	1552	1046	1685

Figure 4. Variation of dry matter production according to weeks of forage legume species.
Figura 4. Variação da produção de matéria seca em função das semanas de espécies de leguminosas forrageiras.



	Stylosanthes guianensis	Stylosanthes guianensis	Desmodium ovalifolium	Centrosema pubescens	Zornia latifolia	Stylosanthes capitata	Desmodium ovalifolium	Centrosema macrocarpum	Centrosema macrocarpum	Centrosema sp.	Centrosema pubescens	Centrosema brasiliensis	Centrosema arenarium	Centrosema sp.	Centrosema brasiliensis	Zornia glabra	Aeschynomene histrix	Pueraria phaseoloides	Stylosanthes capitata
3 week	48	48	75	54	74	41	78	25	16	26	39	26	2	26	38	17	18	50	63
6 week	73	75	94	70	93	53	93	57	32	51	57	53	6	45	77	43	46	90	70
9 week	84	95	100	98	100	67	100	48	17	42	56	58	9	30	71	72	62	100	69
12 week	91	100	100	94	100	46	100	59	14	21	35	81	5	45	60	51	74	100	78

Figure 5. Variation of the coverage percentage according to the weeks of the forage legume species.
Figura 5. Variação da porcentagem de cobertura em função das semanas da espécie leguminosa forrageira.

4. DISCUSSION

Figure 1 shows the climatological characteristics of the Pichis-Puerto Bermúdez Valley, with a high temperature, a marked seasonality, and high levels of rainfall, which usually lasts from October to April, with significant local variations (Zubieta et al., 2017), and are indicative of a typical hydro climatology of the Peruvian Amazon-Andean basin, where the Andean influence is reflected in the seasonal variability of precipitation, while high temperatures and high levels of rainfall are more characteristic of the Amazon region. Still, in both areas, there is diurnal variability, pointed out by Segura et al. (2019), as a daily thermal amplitude exceeding 15°C in the high Andean areas, while in the Lower Amazon, this variation is less than 10°C.

In Table 1, the pH is shown to be acidic, with high levels of aluminum, results that agree with what was stated by Quesada et al. (2020), indicating that the soils of the Amazon are acidic, characterized by a pH of 4.0 to 5.5 and a low CEC, due to the saturation of exchange sites for aluminum and hydrogen. The high acidity of the soil, according to Li et al. (2023), often coexists with P deficiency and Al toxicity, the combination of which drastically impedes crop growth and yield since Arévalo-Hernández et al. (2022) also state that root elongation and biomass production decrease.

Also, the low CEC limits the retention of essential nutrients such as Ca, Mg and K, affecting soil fertility and plant growth. In addition, the high saturation of Al in very acidic soils becomes toxic for many plant species (RITTER et al., 2018).

Zuquim et al. (2023), investigating soils from the Brazilian Amazon, determined that the Sum of Bases (SB) refers to the sum of the concentrations of calcium (Ca^{++}), magnesium (Mg^{++}) and potassium (K^{+}), expressed in mol (+) kg^{-1}, at the soil surface, in samples taken no more than 30 cm below the surface. Amazonian soils have a variable load since, according to Sadeghian (2016), the increase in acidity due to a reduction in pH leads to a decrease in the CICE (calculated by adding the cations Ca^{++}, Mg^{++}, K^{+} and Al^{+++}), which has effects in the fertility of the soil and the efficiency of fertilization, since the more acidic it is, it will lose its capacity to retain or store cations since there will be more Al^{+++} occupying the exchange sites, leading to the lower participation of the exchangeable bases Ca^{++}, Mg^{++} and K^{+}, and greater susceptibility to loss through leachate.

Table 2. The heights of three varieties of grasses and 12 varieties of legumes were evaluated and analyzed using the Tukey test (P > 0.05).
Tabela 2. Altitude para três variedades de gramíneas e 12 variedades de leguminosas foram avaliadas e analisadas pelo teste de Tukey (P > 0,05).

N°	Ecotypes	Code	Height (cm)			
			3 week	6 week	9 week	12 week
	Grass					
1	*Brachiaria decumbens*	606	12±0.01^{f}	12±0.03^{hi}	19±0.01^{k}	28±0.01^{k}
2	*Andropogon gayanus*	621	12±0.03^{f}	35±0.01^{k}	54±0.02^{m}	73±0.01^{m}
3	*Brachiaria dictyoneura*	6133	9±0.02^{e}	11±0.03^{i}	17±0.03^{j}	22±0.03^{ij}
	Legumes					
4	*Stylosanthes guianensis*	136	4±0.10^{bcd}	5±0.06^{abcde}	18±0.03^{bcd}	23±0.01^{j}
5	*Stylosanthes guianensis*	184	4±0.11^{abcd}	5±0.12^{bcde}	8±0.08^{bcd}	12±0.02^{fg}
6	*Desmodium ovalifolium*	350	4±0.13^{abcd}	4±0.09^{ab}	4±0.10^{ab}	5±0.06^{a}
7	*Centrosema pubescens*	438	4±0.06^{abcd}	5±0.07^{abcd}	7±0.05^{bcd}	9±0.02^{cdef}
8	*Zornia latifolia*	728	5±0.08^{cd}	5±0.07^{abcde}	8±0.06^{bcd}	12±0.01^{fg}
9	*Stylosanthes capitata*	2252	7±0.06^{d}	18±0.02^{j}	25±0.04^{l}	34±0.01^{l}
10	*Desmodium ovalifolium*	3784	4±0.08^{bcd}	6±0.05^{bcde}	6±0.05^{def}	7±0.05^{abc}
11	*Centrosema macrocarpum*	5062	4±0.03^{abcd}	8±0.06^{defgh}	13±0.03^{gh}	17±0.01^{h}
12	*Centrosema macrocarpum*	5065	1±0.01^{a}	8±0.03^{fghi}	14±0.02^{gh}	19±0.01^{hi}
13	*Centrosema sp.*	5112	3±0.25^{abc}	8±0.03^{efgh}	11±0,03^{h}	15±0.02^{h}
14	*Centrosema pubescens*	5189	4±0.08^{abcd}	9±0.03^{ghi}	10±0.03^{hi}	11±0.02^{fg}
15	*Centrosema brasiliensis*	5234	6±0.04^{cd}	5±0.05^{bcde}	6±0.04b^{cdi}	7±0.05abc
16	*Centrosema arenarium*	5236	1±0.01^{a}	3±0.08^{abc}	5±0.03^{ab}	8±0.05^{bcde}
17	*Centrosema sp.*	5568	1±0.01^{a}	7±0.05^{cdefg}	9±0.02^{abefg}	11±0.02^{efg}
18	*Centrosema brasiliensis*	5712	5±0.07^{bcd}	5±0.07^{ab}	6±0.04^{cde}	8±0.03^{bcd}
19	*Zornia glabra*	7847	2±0.29^{ab}	3±0.11^{a}	7±0.08^{a}	11±0.03^{defg}
20	*Aeschynomene histrix*	9690	5±0.07^{bcd}	7±0.06^{bcde}	10±0.05^{fgh}	13±0.02^{g}
21	*Pueraria phaseoloides*	9900	4±0.09^{bcd}	10±0.03^{ghi}	13±0.04^{i}	16±0.01^{hj}
22	*Stylosanthes capitata*	10280	5±0.07^{cd}	4±0.12^{abcd}	5±0.010^{abc}	5±0.07^{ab}

Note: Letters with the same value in the column indicate no statistically significant differences.

Table 3. Dry matter production for three varieties of grasses and 12 varieties of legumes was evaluated and analyzed using the Tukey test (P > 0.05).
Tabela 3. Produção de matéria seca para três variedades de gramíneas e 12 variedades de leguminosas foram avaliadas e analisadas pelo teste de Tukey (P > 0,05).

N°	Ecotypes	Code	Dry Matter Production (kg ha^{-1})			
			3 week	6 week	9 week	12 week
	Grass					
1	*Brachiaria decumbens*	606	657±32.71^{o}	1532±207.36^{p}	2015±238.74^{s}	3156±248.99^{t}
2	*Andropogon gayanus*	621	790±31.93^{r}	1598±264.57^{q}	1825±194.93^{r}	2495±277.48^{s}
3	*Brachiaria dictyoneura*	6133	621±28.80^{m}	2239±313.04^{s}	3040±432.43^{t}	4325±435.88^{u}
	Legumes					
4	*Stylosanthes guianensis*	136	475±28.63^{l}	1220±42.66^{n}	1400±356.37^{o}	2044±389.87^{q}
5	*Stylosanthes guianensis*	184	635±30.33^{n}	873±27.38^{l}	1330±408.65^{n}	2265±294.95^{r}
6	*Desmodium ovalifolium*	350	679±25.88^{p}	1377±216.79^{o}	1828±158.11^{r}	1720±304.95^{o}
7	*Centrosema pubescens*	438	283±17.88^{i}	483±30.49^{g}	1200±21.68^{l}	946±114.01^{h}
8	*Zornia latifolia*	728	626±29.49^{m}	1640±244.94^{r}	1619±349.28^{q}	1858±194.93^{p}
9	*Stylosanthes capitata*	2252	390±33.61^{k}	1050±207.36^{m}	1266±240.83^{m}	1221±277.48^{k}
10	*Desmodium ovalifolium*	3784	253±24.89^{h}	1049±370.13^{m}	1460±339.11^{p}	1715±350.71^{n}
11	*Centrosema macrocarpum*	5062	213±26.07^{f}	478±33.91^{g}	606±244.94^{f}	1052±148.32^{j}
12	*Centrosema macrocarpum*	5065	133±36.05^{b}	183±22.80^{b}	180±28.81^{b}	173±22.8^{b}
13	*Centrosema sp.*	5112	243±27.02^{g}	373±23.02^{e}	503±28.66^{e}	230±32.4^{c}
14	*Centrosema pubescens*	5189	190±24.49^{e}	256±29.49^{c}	410±22.360^{d}	276±20^{d}
15	*Centrosema brasiliensis*	5234	191±36.47^{e}	430±37.81^{f}	734±27.77^{h}	443±28.28^{e}
16	*Centrosema arenarium*	5236	27±4.55^{a}	90±23.02^{a}	130±17.32^{a}	116±18.16^{a}
17	*Centrosema sp.*	5568	190±33.61^{e}	303±19.49^{d}	373±23.02^{c}	538±16.73^{g}
18	*Centrosema brasiliensis*	5712	184±28.28^{d}	601±24.08^{i}	632±29.66^{g}	456±29.15^{f}
19	*Zornia glabra*	7847	156±28.28^{c}	809±36.05^{k}	968±31.14^{j}	969±46.36^{i}
20	*Aeschynomene histrix*	9690	237±38.98^{g}	695±27.02^{j}	909±250.99^{i}	1552±164.31^{l}
21	*Pueraria phaseoloides*	9900	316±32.09^{j}	560±17.89^{h}	1181±356.37^{k}	1046±219.08^{j}
22	*Stylosanthes capitata*	10280	726±38.34^{q}	1222±134.16^{n}	913±378.15^{i}	1685±89.44^{m}

Note: Letters with the same value in the column indicate no statistically significant differences.

Table 4. Percentage coverage for three varieties of grasses and 12 varieties of legumes were evaluated and analyzed using the Tukey test (P > 0.05).
Tabela 4. Porcentagem de cobertura para três variedades de gramíneas e 12 variedades de leguminosas foram avaliadas e analisadas pelo teste de Tukey (P > 0,05).

N°	Ecotypes	Code	Percentage coverage (% m^{-2})			
			3 week	6 week	9 week	12 week
	Grass					
1	*Brachiaria decumbens*	606	36 ± 2.38^{d}	53 ± 1.81^{f}	57 ± 1.34^{f}	75 ± 2.16^{hi}
2	*Andropogon gayanus*	621	38 ± 1.41^{de}	69 ± 2.44^{h}	68 ± 1.81^{h}	63 ± 1.67^{g}
3	*Brachiaria dictyoneura*	6133	58 ± 2.38^{g}	87 ± 2.48^{k}	95 ± 1.78^{k}	100 ± 0.83^{l}
	Legumes					
4	*Stylosanthes guianensis*	136	48 ± 2.38^{f}	73 ± 1.51^{j}	84 ± 0.54^{j}	91 ± 1.30^{k}
5	*Stylosanthes guianensis*	184	48 ± 1.67^{f}	75 ± 1.64^{kl}	95 ± 1.92^{k}	100 ± 1.81^{l}
6	*Desmodium ovalifolium*	350	75 ± 1.94^{i}	94 ± 1.34^{m}	100 ± 2.82^{l}	100 ± 2.34^{l}
7	*Centrosema pubescens*	438	54 ± 2.34^{g}	70 ± 2.48^{lm}	98 ± 1.09^{l}	94 ± 3.28^{k}
8	*Zornia latifolia*	728	74 ± 1.81^{ij}	93 ± 2.3^{lm}	100 ± 2.28^{l}	100 ± 1.811
9	*Stylosanthes capitata*	2252	41 ± 1.48^{e}	53 ± 2.28^{gh}	67 ± 2.04^{h}	46 ± 1.51^{e}
10	*Desmodium ovalifolium*	3784	78 ± 3.13^{j}	93 ± 2.5^{m}	100 ± 2.16^{l}	100 ± 2.60^{l}
11	*Centrosema macrocarpum*	5062	25 ± 1.30^{c}	57 ± 2.28^{e}	48 ± 2.12^{e}	59 ± 1.87^{g}
12	*Centrosema macrocarpum*	5065	16 ± 1.81^{b}	32 ± 2.48^{b}	17 ± 2.07^{b}	14 ± 2.16^{b}
13	*Centrosema sp.*	5112	26 ± 1.30^{c}	51 ± 2.77^{d}	42 ± 1.67^{d}	21 ± 1.78^{c}
14	*Centrosema pubescens*	5189	39 ± 1.51^{e}	57 ± 2.82^{f}	56 ± 2.07^{f}	35 ± 2.16^{d}
15	*Centrosema brasiliensis*	5234	26 ± 2.01^{c}	53 ± 1.87^{f}	58 ± 1.78^{f}	81 ± 1.64^{j}
16	*Centrosema arenarium*	5236	2 ± 0.83^{a}	6 ± 2.61^{a}	9 ± 2.16^{a}	5 ± 1.51^{a}
17	*Centrosema sp.*	5568	26 ± 1.92^{c}	45 ± 1.58^{c}	30 ± 1.87^{c}	45 ± 1.81^{e}
18	*Centrosema brasiliensis*	5712	38 ± 2.16^{de}	77 ± 1.81^{hi}	71 ± 2.38^{hi}	60 ± 1.94^{g}
19	*Zornia glabra*	7847	17 ± 1.14^{b}	43 ± 3.03^{i}	72 ± 1.51^{i}	51 ± 2.60^{f}
20	*Aeschynomene histrix*	9690	18 ± 1.92^{b}	46 ± 1.87^{g}	62 ± 1.87^{g}	74 ± 2.07^{h}
21	*Pueraria phaseoloides*	9900	50 ± 2.04^{f}	90 ± 2.31^{lm}	100 ± 2.3^{l}	100 ± 2.50^{l}
22	*Stylosanthes capitata*	10280	63 ± 1.09^{h}	70 ± 0.83^{hi}	69 ± 1.94^{hi}	78 ± 1.94^{ij}

Note: Letters with the same value in the column indicate no statistically significant differences.

According to Navas et al. (2020), the behavior of the study variables is attributed to the fact that the growth of forages is largely determined by edaphic and climatic conditions (MORENO-CARRILLO et al., 2015). These results coincide with what was reported by Blanco; Lal (2023) in terms of greater coverage of the legume Pueraria phaseoloides. They also relate to the type of soil in which the species developed.

The best performance of grasses, according to studies with other species not considered in the present study, such as *Axonopus affinis,* according to Schwalbert et al. (2022), is due to its interaction with greater availability of soil Zn, which improves the concentration of photosynthetic pigments, promoting their production (Crespo-Flores et al. 2024), and with it the photosynthetic rate, promoting an increase of biomass accumulation, which positively influences the characteristics studied.

In experiences of sowing grasses and legumes as monocultures, it has already been shown that legumes greatly improve the soil by behaving as promoters of the abundant growth of bacteria and fungi, compared to grasses, which indicates that legumes could be important for restoring ecological function in degraded soils (MEIMEI et al. 2008). In this regard, Li et al. (2023) show that the incorporation of legumes significantly increases the concentrations of microbial biomass carbon (MBC), dissolved organic carbon (DOC), particulate organic carbon, light fraction carbon (LFC), heavy fraction carbon, deposit of labile carbon and recalcitrant carbon deposit.

The greater height reached by the grasses could be due to a greater adaptability of their root system to the limiting edaphic conditions of the area, which would allow them to make better use of soil resources and, according to Rao et al. (2016), through mechanisms of adaptive responses of roots to low supply of mineral nutrients, such as low availability of nitrogen (N) and phosphorus (P), and toxic levels of Al, observed in varieties of *Brachiaria spp*., and hybrids of *brachiaria*, as very resistant to acidic soils and with high Al content.

The photosynthetic efficiency of tropical grasses with the C4 mechanism is a key factor in their adaptation and productivity; since this mechanism concentrates CO_2 around the Rubisco enzyme, reducing photorespiration and increasing efficiency (von Caemmerer; Furbank, 2016), they make use of efficient of water, due to the lower stomatal opening for the same CO_2 fixation (Stata et al., 2019), they have a higher growth rate, as a direct result of photosynthetic efficiency, allowing greater biomass production (BRÄUTIGAM; GOWIK, 2016). Compared to C3 plants (tropical legumes), they adapt to high temperatures, maintaining high photosynthetic efficiency in warm conditions, typical of tropical regions (Sonawane et al., 2017), and make better use of nitrogen, requiring less nitrogen to achieve photosynthetic rates similar to C3 (CUI, 2021).

According to Zhang et al. (2023), grasses produce the highest dry matter because they tolerate the acidic pH of the soil better and are capable of absorbing nutrients from both the rhizosphere and bulk soils, compared to legumes; this is the case of *Brachiaria dictyoneura.*

In the growth of tropical grasses, there is a greater competitive power of grasses over legumes and, according to López et al. (2024), present morphological and physiological responses to the quantity and quality of sunlight (phenotypic plasticity) and, according to Rao et al. (2016), all resistance is related to lower Al accumulation, particularly in root hairs, followed by an Al-induced increase in chlorogenic acid, indicating a possible role of chlorogenic acid as an initiator of changes in the pattern of root epidermal cells that may contribute to Al hyper resistance in grasses. Furthermore, according to Alotaibi et al. (2021), grasses show greater tolerance to soils with high Al content, depending on the mitigating action of *arbuscular mycorrhizal fungi* (AMF), inducing the positive regulation of proline biosynthesis through the pathways of the glutamate and ornithine.

According to Ma et al. (2014), another grasses' tolerance strategy to acidic soils is a common mechanism for secreting anions of organic acids (citrate and malate) from the roots through the activity of genes identified and belonging to the ALMT (Al-activated malate transporter) and MATE (extrusion of toxic compounds and multiple drugs), which are involved in defensive secretion.

On the contrary, the legumes evaluated showed, on average, lower height and biomass production. According to Alotaibi et al. (2021), soil acidity, due to the presence of Al, also increases sensitivity to the decrease in N mineralization rates (Zhang et al., 2023), affecting performance. They state that it reduces growth and photosynthesis rates.

Quiñones et al. (2022) state that legumes have a low tolerance to the acidity and Al toxicity of these soils since Jaiswal et al. (2018) indicate that Al3+ predominates at pH < 5 in soils and becomes a limitation for the productivity of legumes through its lethal effect on rhizobia, the host plant and their interaction, having lethal effects and in many aspects of the rhizobia/legume symbiosis, leading to a decrease in root elongation and hair formation, a decrease in the soil rhizobia population, and, the suppression of nitrogen metabolism, which leads to the reduction of nitrates, nitrite reduction, nitrogenase activity, and the functioning of hydrogenase absorption (Hup), which ultimately impairs the N_2 fixation process.

However, its usefulness in mixed systems with grasses should be considered due to its benefits as a nitrogen fixer. Production in a monoculture system of grasses and legumes leads to grasses, according to Zhang (2022), absorbing elements similar to lime, such as cations, for their nutrition, whose harvest leads to the loss of part of the basic material. Responsible for counteracting the acidity developed by other processes, which causes an increase in the acidity of the soil, and with the rise in the yields of grass crops, leading to the elimination of greater quantities of basic material.

Silva et al. (2022) state that intercropping grasses and legumes can increase productivity, improve the nutritional quality of the crop and promote soil microbiological activity, which leads to higher yields in successive crops.

Tables 2, 3 and 4 show that, between grass and legume crops, there were statistical differences at P<0.005, highlighting grasses in height and dry matter and legumes, showing significant differences in percentage of coverage due to their differences. Morphological, phenotypic plasticity, and the responses they showed to edaphoclimatic factors.

Under the specific conditions of this trial, the grasses *Brachiaria decumbens, Andropogon gayanus* and *Brachiaria dictyoneura* proved to be more promising than the legumes evaluated to improve the availability and quality of forage for cattle in degraded acid soils of Puerto Bermúdez. However, more research is required considering other planting arrangements, agronomic management and environmental conditions (DEL ÁGUILA et al., 2023).

5. CONCLUSIONS

The performance of three ecotypes of grasses and twelve tropical forage legumes, evaluated for twelve weeks in height, dry matter production and soil cover, demonstrated considerable diversity.

Regarding the highest plant height (73 ± 0.01 cm), the grass *Andropogon gayanus stood out* in dry matter (4,325 ± 435.88 kg ha^{-1}), and, percentage of coverage (100% m^{-2}), it was *Brachiaria dictyoneura*. The legume that stood out in plant height was *Stylosanthes capitata* (34 ± 0.01cm); in dry matter, *Stylosanthes guianens* (2265 ± 294.95 kg ha^{-1}), and, in the highest percentage of coverage (100%), *Stylosanthes prevailed. guianens, Desmodium ovalifolium, Zornia latifolium, and Pueraria phaseoloides*, respectively.

The superior performance in the three variables evaluated of grasses, compared to legumes, can be attributed to a greater adaptation of their root system to nutrient-poor soils, greater photosynthetic efficiency, high growth rates, and better tolerance to Al^{3+}, which is typical of acidic soils, observing diverse growth and production patterns, from rapid and constant increases to slower or fluctuating developments, demonstrating different adaptation strategies and potential for use in forage systems.

Under the conditions of this trial, the grasses evaluated demonstrated more promise than legumes in improving the availability and quality of forage in degraded soils of Puerto Bermúdez, suggesting their potential for high production systems.

The observed variability in growth and cover patterns offers options for various management strategies, from intensive grazing to soil conservation. Therefore, these results provide a solid basis for decision-making in designing more tropical pasture systems that are efficient and sustainable and adapted to the specific needs of different agroecosystems.

More research is required in the area to consider other planting arrangements, such as associated crops, fertilizer application and agronomic management.

6. REFERENCES

LEMAYEHU, M.; GEZAHAGN, K.; FEKEDE, F.; GETNET, A. Overview of improved forage and forage seed production in Ethiopia: lessons from fourth livestock development project. **International Journal of Agriculture and Biosciences**, v. 6, n. 4, p. 217-226, 2017.

ALOTAIBI, M. O.; SALEH, A. M.; SOBRINHO, R. L.; SHETEIWY, M. S.; EL-SAWAH, A. M.; MOHAMMED, A. E.; ELGAWAD, H. A. Arbuscular mycorrhizae mitigate aluminum toxicity and regulate proline metabolism in plants grown in acidic soil. **Journal of Fungi**, v. 7, n. 7, e531, 2021. https://doi.org/10.3390/jof7070531

ARÉVALO-HERNÁNDEZ, C. O.; ARÉVALO-GARDINI, E.; FARFAN, A.; AMARINGO-GOMEZ, M.; DAYMOND, A.; ZHANG, D.; BALIGAR, V. C. Growth and nutritional responses of juvenile wild and domesticated cacao genotypes to soil acidity. **Agronomy**, v. 12, n. 12, e3124, 2022. https://doi.org/10.3390/agronomy12123124

BALEHEGN, M.; DUNCAN, A.; TOLERA, A.; AYANTUNDE, A. A.; ISSA, S.; KARIMOU, M.; ZAMPALIGRÉ, N.; ANDRÉ, K.; GNANDA, I.; VARIJAKSHAPANICKER, P.; KEBREAB, E.; DUBEUX, J.; BOOTE, K.; MINTA, M.; FEYISSA, F.; ADESOGAN, A. T. Improving adoption of technologies and interventions for increasing supply of quality livestock feed in low-and middle-income countries.

Global Food Security, v. 26, e100372, 2020. https://doi.org/10.1016/j.gfs.2020.100372
BLANCO, H., LAL, R. **Soil Conservation and Management**. 2 ed. Springer eBooks, 2023. 611p. https://doi.org/10.1007/978-3-031-30340-8
BRÄUTIGAM, A.; GOWIK, U. Photorespiration connects C3 and C4 photosynthesis. **Journal of Experimental Botany**, v. 67, n. 10, p. 2953-2962, 2016. https://doi.org/10.1093/jxb/erw056
CUI, H. Challenges and approaches to crop improvement through C3-to-C4 engineering. **Frontiers in Plant Science**, v. 12, e715391, 2021. https://doi.org/10.3389/fpls.2021.715391
DEL AGUILA, K.; BAIQUE, N.; RAMÍREZ, J. S.; DELGADO, A. H. C.; RAMÍREZ, G. V. Estudio estadístico para la introducción de especies mejoradas de pastos en el valle de Pichis, Perú. **Investigación Operacional**, v. 44, n. 1, p. 62-67, 2023.
JAISWAL, S. K.; NAAMALA, J.; DAKORA, F. D. Nature and mechanisms of aluminum toxicity, tolerance and amelioration in symbiotic legumes and rhizobia. **Biology and Fertility of Soils,** v. 54, n. 3, p. 309-318, 2018. https://doi.org/10.1007/s00374-018-1262-0
LI, G.; TANG, X.; HOU, Q.; LI, T.; XIE, H.; LU, Z.; ZHANG, T.; LIAO, Y.; WEN, X. Response of soil organic carbon fractions to legume incorporation into cropping system and the factors affecting it: A global meta-analysis. **Agriculture, Ecosystems & Environment**, v. 342, e108231, 2023. https://doi.org/10.1016/j.agee.2022.108231
LI, X.; ZHANG, X.; ZHAO, Q.; LIAO, H. Genetic improvement of legume roots for adaption to acid soils. **The Crop Journal**, v. 11, n. 4, p. 1022-1033, 2023. https://doi.org/10.1016/j.cj.2023.04.002

LÓPEZ FONSECA, D.; VIVAS QUILA, N.; CUERVO MULET, R.; RODRIGUEZ MOLANO, C. E. Contribution of forage grasses to biological nitrogen fixation and their response to diazotroph inoculation **Revista Mexicana de Ciencias Pecuarias**, v. 15, n. 2, p. 446-461, 2024. https://doi.org/10.22319/rmcp.v15i2.6539
MA, J. F.; CHEN, Z. C.; SHEN, R. F. Molecular mechanisms of Al tolerance in gramineous plants. **Plant and Soil**, v. 381, n. 1-2, p. 1-12, 2014. https://doi.org/10.1007/s11104-014-2073-1
MORENO-CARRILLO, M. A.; HERNÁNDEZ-GARAY, A.; VAQUERA-HUERTA, H.; TREJO-LÓPEZ, C.; ESCALANTE-ESTRADA, J. A.; ZARAGOZA-RAMÍREZ, J. L.; JOAQUÍN-TORRES, B. M. Productividad de siete asociaciones y dos praderas puras de gramíneas y leguminosas en condiciones de pastoreo. **Revista Fitotecnia Mexicana**, v. 38, n. 1, e101, 2015. https://doi.org/10.35196/rfm.2015.1.101
QUESADA, C. A.; PAZ, C.; OBLITAS MENDOZA, E.; PHILLIPS, O. L.; SAIZ, G.; LLOYD, J. Variations in soil chemical and physical properties explain basin-wide Amazon forest soil carbon concentrations. **Soil**, v. 6, n. 1, p. 53-88, 2020. https://doi.org/10.5194/soil-6-53-2020
QUIÑONES, M. A.; LUCAS, M. M.; PUEYO, J. J. Adaptive mechanisms make Lupin a choice crop for acidic soils affected by aluminum toxicity. **Frontiers in Plant Science**, v. 12, e810692, 2022. https://doi.org/10.3389/fpls.2021.810692
RAO, I. M.; MILES, J. W.; BEEBE, S. E.; HORST, W. J. Root adaptations to soils with low fertility and aluminum toxicity. **Annals of Botany**, v. 118, n. 4, p. 593-605, 2016. https://doi.org/10.1093/aob/mcw073
ROSLING, A.; MIDGLEY, M. G.; CHEEKE, T.; URBINA, H.; FRANSSON, P.; PHILLIPS, R. P. Phosphorus cycling in deciduous forest soil differs between stands dominated by ecto- and arbuscular mycorrhizal trees. **The New Phytologist**, v. 209, n. 3, p. 1184-1195, 2016. https://doi.org/10.1111/nph.13720
RUSDY, M. Grass-legume intercropping for sustainability animal production in the tropics. In: Perspectives in Agriculture Veterinary Science Nutrition and Natural Resources, **CAB Reviews**, v. 2021, n. 21, 2021. https://doi.org/10.1079/PAVSNNR20211602
SADEGHIAN, S. La acidez del suelo, una limitante común para la producción de café. **Avances Técnicos Cenicafé**, v. 466, p. 1-12, 2016. https://doi.org/10.38141/10779/0466
SÁNCHEZ, A.; BANDOPADHYAY, S.; ROJAS BRICEÑO, N. B.; BANERJEE, P.; TORRES GUZMÁN, C.; OLIVA, M. Peruvian Amazon disappearing: transformation of protected areas during the last two decades (2001–2019) and potential future deforestation modeling using cloud computing and MaxEnt approach. **Journal for Nature Conservation**, v. 64, e126081, 2021. https://doi.org/10.1016/j.jnc.2021.126081
SEGURA, H.; ESPINOZA, J. C.; JUNQUAS, C.; TAKAHASHI, K. Evidencing decadal and interdecadal hydroclimatic variability over the Central Andes. **Environmental Research Letters**, v. 11, n. 9, e094016, 2016. https://doi.org/10.1088/1748-9326/11/9/094016
SILVA, L. S.; DOS SANTOS LAROCA, J. V.; COELHO, A. P.; GONÇALVES, E. C.; GOMES, R. P.; PACHECO, L. P.; CARVALHO, DE F. P.C.; PIRES, C. G.; OLIVEIRA, L. R.; DE SOUZA, A. J. M.; FREITAS, M. C.; CABRAL, A. C. E.; WRUCK, J. F.; DE SOUZA, D. E. Does grass-legume intercropping change soil quality and grain yield in integrated crop-livestock systems?. **Applied Soil Ecology**, v. 170, e104257, 2022. https://doi.org/10.1016/j.apsoil.2021.104257
SONAWANE, B. V.; SHARWOOD, R. E.; VON CAEMMERER, S.; WHITNEY, S. M.; GHANNOUM, O. Short-term thermal photosynthetic responses of C4 grasses are independent of the biochemical subtype. **Journal of Experimental Botany**, v. 68, n. 20, p. 5583-5597, 2017. https://doi.org/10.1093/jxb/erx350
STATA, M.; SAGE, T. L.; SAGE, R. F. Mind the gap: the evolutionary engagement of the C4 metabolic cycle in support of net carbon assimilation. **Current Opinion in Plant Biology**, v. 49, p. 27-34, 2019. https://doi.org/10.1016/j.pbi.2019.04.008
VON CAEMMERER, S.; FURBANK, R. T. Strategies for improving C4 photosynthesis. **Current Opinion in Plant Biology,** v. 31, p. 125-134, 2016. https://doi.org/10.1016/j.pbi.2016.04.003
WANG, B.; YAN, H.; LIU, H.; PAN, L.; FENG, Z. Keep sustainable livestock production without Grassland degradation: Future cultivated pasture development simulation based on agent-based model. **Journal of Cleaner Production**, v. 417, e138072, 2023. https://doi.org/10.1016/j.jclepro.2023.138072

ZHANG, H. **Causa y efectos de la acidez del suelo: Por qué los suelos se están volviendo más ácidos**. Oklahoma: Servicio de Extensión Cooperativa de Oklahoma, 2022. 3p. (PSS-2239) Available on: https://extension.okstate.edu/fact-sheets/print-publications/pss/pss-causa-y-efectos-de-la-acidez-del-suelo.pdf

ZHANG, Y.; WANG, R.; SARDANS, J.; WANG, B.; GU, B.; LI, Y.; LIU, H.; PEÑUELAS, J.; JIANG, Y. Resprouting ability differs among plant functional groups along a soil acidification gradient in a meadow: A rhizosphere perspective. **The Journal of Ecology**, v. 111, n. 3, p. 631-644, 2023. https://doi.org/10.1111/1365-2745.14051

ZUBIETA, R.; SAAVEDRA, M.; SILVA, Y.; GIRÁLDEZ, L. Spatial analysis and temporal trends of daily precipitation concentration in the Mantaro River basin: central Andes of Peru. **Stochastic Environmental Research and Risk Assessment: Research Journal**, v. 31, n. 6, p. 1305-1318, 2017. https://doi.org/10.1007/s00477-016-1235-5

ZUQUIM, G.; VAN DONINCK, J.; CHAVES, P. P.; QUESADA, C. A.; RUOKOLAINEN, K.; TUOMISTO, H. Introducing a map of soil base cation concentration, an ecologically relevant GIS-layer for Amazonian forests. **Geoderma Regional**, v. 33, e00645, 2023**.** https://doi.org/10.1016/j.geodrs.2023.e00645

Authors' contributions: K.R.D.: conceptualization, investigation or data collection, acquisition of financing, supervision, validation, writing (original draft); V.A.T.: methodology, statistical analysis, validation, writing (review and editing); R.M.L.R.: methodology, statistical analysis, validation, writing (review and editing); A.G.A.D.: conceptualization, investigation or data collection, validation, writing (original draft); J.S.R.: conceptualization, acquisition of financing, methodology, supervision, validation; E.T.F.: methodology, validation, writing (original draft); G.V.R: conceptualization, investigation or data collection, acquisition of financing (original draft).
All authors read and agreed to the published version of the manuscript.

Data availability: The corresponding author can obtain study data by e-mail.

Conflicts of Interest: The authors declare no conflict of interest. Supporting entities had no role in the study's design, data collection, analysis, or interpretation, manuscript writing, or decision to publish the results.