



Pastos y Forrajes

ISSN: 0864-0394

ISSN: 2078-8452

Estación Experimental de Pastos y Forrajes Indio Hatuey

Obando-Enríquez, Bayron Giovanni; Hernández-Oviedo,
Filadelfo; Portillo-López, Paola Andrea; Castro-Rincón, Edwin
Productividad y calidad del forraje de *Cenchrus clandestinus* (Hochst. ex
Chiov.) Morrone en dos sistemas pastoriles en la cordillera andina colombiana
Pastos y Forrajes, vol. 46, e09, 2023, January-December
Estación Experimental de Pastos y Forrajes Indio Hatuey

Available in: <https://www.redalyc.org/articulo.oa?id=269176991009>

- How to cite
- Complete issue
- More information about this article
- Journal's webpage in redalyc.org

UAEH
redalyc.org

Scientific Information System Redalyc

Network of Scientific Journals from Latin America and the Caribbean, Spain and
Portugal

Project academic non-profit, developed under the open access initiative

Forage productivity and quality of *Cenchrus clandestinus* (Hochst. ex Chiov.) Morrone in two pastoral systems in the Colombian Andes

Bayron Giovanni Obando-Enríquez <https://orcid.org/0000-0002-7669-442X>, Filadelfo Hernández-Oviedo <https://orcid.org/0000-0002-1549-4926>, Paola Andrea Portillo-López <https://orcid.org/0000-0003-1189-9173> and Edwin Castro-Rincón <https://orcid.org/0000-0001-9841-8242>

¹Corporación Colombiana de Investigación Agropecuaria-AGROSAVIA Centro de Investigación Obonuco, km. 5, vía Pasto-Obonuco, San Juan de Pasto, Nariño, Colombia. E-mail: bobando@agrosavia.co, fhernandez@agrosavia.co, pportillo@agrosavia.co, ecastro@agrosavia.co

Abstract

Objective: To determine the effect of *Alnus acuminata* Kunth on the yield and nutritional quality of *Cenchrus clandestinus* (Hochst. ex Chiov.) Morrone in two pastoral systems in the Colombian Andean mountain range.

Materials and Methods: For the evaluation of the yield and quality of the forage biomass of *C. clandestinus*, an experiment was conducted in a silvopastoral system and a pasture without tree cover. A complete randomized block design was established, defined by the presence or absence of *A. acuminata*, with pasture cutting frequency every 35 or 45 days. Four treatments and three replicas were defined to determine statistical differences. An analysis of variance and Tukey's test were performed. The variables green forage production, dry matter, crude protein, neutral detergent fiber, acid detergent fiber, dry matter digestibility and net lactation energy were evaluated.

Results: The experimental units of the silvopastoral system were statistically superior to the uncovered pasture treatments. They showed higher yields, in terms of green forage and dry matter, and stood out for their nutritional attributes of crude protein, digestibility and net lactation energy. The treatment with the incidence of the forest species *A. acuminata* and pasture utilization at 45 days recorded the highest averages in green forage and dry matter (19 360,3 and 123,5 kg) and the best nutritional quality, followed by the silvopastoral system with cutting frequency every 35 days.

Conclusions: The silvopastoral system obtained the best results in production and quality of *C. clandestinus* grass, which indicates the positive impact of the tree species on the evaluated indicators, due to the different interactions that the tree promoted in the agroecosystem.

Key words: agroforestry, *Alnus acuminata*, agricultural productivity, nutritional value

Introduction

Tropical grasses are considered the feeding basis in Latin American animal husbandry (Murgueitio-Restrepo *et al.*, 2016). However, they have moderate to low nutritional quality in protein, energy and minerals. Additionally, they are exposed to constantly changing climates and are subject to trampling and overgrazing, as well as inadequate agronomic practices (Arcos-Álvarez *et al.*, 2018).

In the Colombian high Andean region, in the dairy basins, permanent pastures of *Cenchrus clandestinus* (Hochst. ex Chiov.) Morrone, a grass that is adapted to the high tropics, predominate, although its productivity in cold areas is low (Portillo-López *et al.*, 2019). This trend is common in specialized dairy farming in Colombia (Vargas-Martínez *et al.*, 2018) and in conventional systems of livestock utilization in the Nariño Andean mountain range, where it is established as monoculture, associated with other grasses or trees (Muñoz-Guerrero *et al.*, 2018).

The inferior quality of *C. clandestinus*, which is due to insufficient net lactation energy (NLE), with averages of 1,15 Mcal kg⁻¹ DM and 10,5 % soluble carbohydrates, originates an inadequate relationship between nitrogen and ruminal energy. Similarly, the NDF content (56,2 % average) causes poor digestibility of pastures (Cardona-Iglesias *et al.*, 2020).

In addition to low yield, in the global environmental context, the establishment of grasses in monoculture in animal husbandry farms must be rethought (Soriano-Robles *et al.*, 2018). This is why silvopastoral systems (SPS) are currently promoted as a sustainable productive alternative. Through their different positive interactions, SPS exert a favorable action on the natural resources of agroecosystems and allow to improve pasture and forage productivity (Silva-Parra *et al.*, 2017; Buitrago-Guillen *et al.*, 2018).

In the Andean region of Nariño, *Alnus acuminata* Kunth is a native forest species with potential

Received: January 4, 2023

Accepted: February 23, 2023

How to cite a paper: Obando-Enríquez, Bayron-Giovanny; Hernández-Oviedo, Filadelfo; Portillo-López, Paola Andrea & Castro-Rincón, Edwin. Forage productivity and quality of *Cenchrus clandestinus* (Hochst. ex Chiov.) Morrone in two pastoral systems in the Colombian Andes. *Pastures and Forages*. 46:e09, 2023.

This is an open access article distributed in Attribution NonCommercial 4.0 International (CC BY-NC4.0) <https://creativecommons.org/licenses/by-nc/4.0/>. The use, distribution or reproduction is allowed citing the original source and authors.

in agricultural systems. Commonly known as alder (Muñoz *et al.*, 2013), it is generally established in live fences, boundaries, perimeter hedges and scattered trees in grasslands. It is frequently associated with *C. clandestinus* (Muñoz-Guerrero *et al.*, 2018). However, information regarding the agronomic and productive characteristics of *C. clandestinus* in SPS for Colombian high tropic conditions is limited.

In the mountains of Colombia, in the Nariño dairy basins, the project “Improvement of forage supply, optimization of feeding systems and assurance of milk quality and safety in the high tropics of the department of Nariño” was developed. Among other studies, AGROSAVIA’s Obonuco Research Center (RC) evaluated the production and quality of *C. clandestinus* in two environments: under shade (US) of *A. acuminata* and free solar exposure (FSE) and two pasture utilization times (35 and 45 days), to determine if these indicators influenced the productivity and nutritional content of one of the most used forages in the cold zone of Colombia. Hence, the objective of the work was to determine the impact of *A. acuminata* on the yield and nutritional quality of *C. clandestinus* pasture in two pastoral systems in the Colombian Andean Cordillera.

Materials and Methods

Location and description of the study site. The study was carried out at the Obonuco Research Center (RC) of AGROSAVIA, in the Pasto municipality, Colombia, between September, 2021, and March, 2022.

Edaphoclimatic characteristics. The work area is located in the life zone Low Mountain Dry Forest df-LM (Holdridge, 1978) at 2,760 m.a.s.l., at coordinates 1° 11' 52" N - 77° 18' 13" W. In terms of geology, according to IGAC (2004), the soils originated from volcanic ashes (Andisols) characterized by being moderately deep, well to imperfectly drained. Climate indicators and their variation were recorded from the Obonuco weather station 52045010 (IDEAM, 2022), located in the Pasto municipality. During the evaluation, the average temperature was 13,2 °C; the maximum was 17,6 °C and the minimum was 8,8 °C. The sun shone between 3,8 and 4,3 hours per day, the average insolation was four hours day⁻¹. There were 646,5 mm of rainfall, accumulated in six months. The month with the highest rainfall was December with 172 mm and the lowest was September, with 21,3 mm (IDEAM, 2022).

Plant species. The study was conducted in a 22-year-old scattered tree SPS. *C. clandestinus* was

associated with the forest species *A. acuminata*, established at a density of 200 units per ha⁻¹, with planting distances of 5 x 7m. The trees showed average values in total height of 11,74 m, trunk diameter at breast height of 19,17 cm; crown height of 2,30 m. The grasslands evaluated in the SPS and in free sun exposure were monophytes or composed of a single pasture (Pizzio *et al.*, 2021) and belong to the plant collections of AGROSAVIA. The lot used for the evaluation was not fertilized and was managed in rotational grazing.

Treatments and experimental design. A complete randomized block design (CRB) was used, with four treatments and three replicas for 12 experimental units of 4 x 3 m each, and a total experimental area of 144 m². The production and quality of forage biomass of *C. clandestinus* were compared in two environments (traditional pasture and SPS) and two cutting times (45 and 35 days). Treatments 1 and 2 were established under free sun exposure (FSE) and 3 and 4 under shade (US).

Variables. During the evaluation period, the methodology proposed by Toledo and Schultze-Kraft (1982) was used to determine green forage (GF) and dry matter (DM) yield. Four cuts were made every 35 and 45 days, according to treatment. A 50 x 50 cm (0,25 m²) frame was used. The herbaceous plant was cut 10 cm above the ground and the fresh sample was weighed. Subsequently, for 72 hours, they were dried in a forced ventilation oven at a temperature of 65 °C until a constant DM weight was obtained.

Regarding nutritional quality, subsamples were taken from the first and third cuts of the evaluation period, and were sent to the animal nutrition laboratory of RC Tibaitatá of Agrosavia (Bogotá, Colombia), where bromatological analyses were carried out to determine: crude protein (CP); neutral detergent fiber (NDF); acid detergent fiber (ADF); DM digestibility (IVDMD) and net lactation energy (NLE) using the near infrared reflectance spectroscopy technique NIRS (Ariza-Nieto *et al.*, 2018) with the NIRS DS 2500-FOSS Analytical A/S, Denmark.

Statistical analysis. The evaluation data were subject to variance analysis, with the statistical program R (R Core Team, 2020) using the agricultural package (Mendiburu, 2021). A significance level of $p \leq 0,05$ was considered, and Tukey’s test was used in order to establish differences between treatments. For this purpose, the cutting frequency and the pastoral system evaluated in the production and quality of the pastures were considered. The normality test

of mean distributions was performed, according to Shapiro-Wilks.

Results and Discussion

Biomass production. In green forage, the best yields were obtained in the SPS (table 1). Significant statistical differences were established between T3 and the other treatments. T3 showed yield higher than 50 % compared with the monoculture plots. Regarding T4, it had higher pasture production (36,6 %). T4 did not differ statistically from T1 ($p > 0,05$). T4, with regards to T2, showed significant differences, with a 35-% increase in yield. In pastoral systems with free sun exposure, pasture production was similar in both treatments.

In terms of DM, the SPS plots presented superior performance when compared to the DM results of the traditional pasture. T3 statistically outperformed T1. There were no differences between T2 and T4. T4 showed the second best DM yield, with an increase of 41,1 and 24,9 % with regards to T1 and T2. However, it was not significant. T1 and T2 were statistically similar. However, a higher DM yield was recorded with a percentage rate of 21,6 in favor of T2.

In this study, the accumulated rainfall (600 mm in six months) yielded average above 100 mm month⁻¹, data that exceed historical rainfall records for this region (IDEAM, 2018). According to Avellaneda-Avellaneda and Mancipe-Muñoz (2020), agronomic variables of *C. clandestinus* can change as a function of soil conditions, rainfall and grassland management. In several studies, altitude, water intensity and days of regrowth were found to affect the morphological response of *C. clandestinus*. Better DM yield performance was found in rainy seasons (Portillo-López *et al.*, 2019) with longer time between pasture cuts.

These results are lower than those reported by Insuasty-Santacruz *et al.* (2011), who evaluated the incidence of a SPS composed of *A. acuminata* and *C. clandestinus* in Holstein heifer rearing in the Nariño highlands and obtained in *C. clandestinus* in monoculture 13 910 and 3 900 kg of GF and DM ha⁻¹; and 19 640 and 4 700 kg of GF and DM ha⁻¹ in the SPS. The better performance of the pasture in association could suggest a positive effect of trees on the productive yields of pasture.

The DM production results of this research were higher than those mentioned by Portillo-López *et al.* (2019) in the Sapuyes and Pasto municipalities. For the cutting frequency every 35 days, T2 and T4 registered lower means compared with the report in Alto de Chicamocha, Bogotá and Ubaté Chiquinquirá by Avellaneda-Avellaneda and Mancipe-Muñoz (2020). In the same study, at 45 days, pastures had higher yields in Chicamocha and Chiquinquirá, compared with T3. Finally, T1 showed lower yields than those described in the three locations.

Regarding similar works in SPS, Giraldo and Bolívar (1999) found yields of 2,084 kg DM ha⁻¹, similar to those reported for T3 and T4. Silva-Parra *et al.* (2017) evaluated pasture yield with cuts every 30 and 45 days in SPS and obtained 3 200 and 4 470 kg DM ha⁻¹, higher than those found in this work.

Biomass quality. Regarding the average CP content, the best results were obtained in the SPS experimental units (table 2), which did not differ significantly from each other. T4 was significantly different from the monoculture plots. In addition, it achieved yields more than 30 % higher than these treatments. T3, like T4, when evaluated with T1 and T2, was statistically better, and its yield was higher.

Table 1. Green forage and dry matter of *C. clandestinus* in pasture systems with free sun exposure and under *A. acuminata* shade.

Treatment	Green forage, kg ha ⁻¹	Dry matter, kg ha ⁻¹
T1 FSE, 45 days	9 349,8 ^{bc}	1 156,4 ^b
T2 FSE, 35 days	8 012,9 ^c	1 475,3 ^{ab}
T3 US, 45 days	19 360,3 ^a	2 123,5 ^a
T4 US, 35 days	12 335,7 ^b	1 964,0 ^{ab}
SE ±	221,345	66,345
P - value	< 0,001	< 0,001

FSE: free sun exposure; US: shaded.

a, b and c: means with different letters in the same column differ from each other, according to Tukey ($p \leq 0,05$).

Table 2. Composition of macrocomponents of *C. clandestinus* in pastoral systems with free sun exposure and under the shade of *A. acuminata*.

Treatment	CP, %	EE, %	NDF, %	ADF, %	IVDMD, %	NLE, Mcal kg DM ⁻¹
T1 FSE, 45 days	14,8 ^b	1,8 ^b	60,2 ^a	36,2 ^a	59,9 ^b	1,2 ^b
T2 FSE, 35 days	15,3 ^b	2,0 ^{ab}	59,8 ^a	34,0 ^{ab}	61,1 ^b	1,3 ^b
T3 US, 45 days	22,4 ^a	2,1 ^{ab}	53,2 ^b	32,6 ^{bc}	67,1 ^a	1,4 ^a
T4 US, 35 days	23,7 ^a	2,2 ^a	53,3 ^b	31,5 ^c	68,5 ^a	1,4 ^a
SE ±	1,456	0,567	0,996	1,012	0,989	1,013
P - value	<0,01	<0,01	<0,001	<0,01	<0,01	<0,001

FSE: free sun exposure; US: under shade; CP: crude protein, NDF: neutral detergent fiber, ADF: acid detergent fiber, IVDMD: digestibility of dry matter and NLE: net lactation energy.
 a, b and c: means with different letters within the same column differ from each other according to Tukey's test ($p \leq 0,05$).

The mean CP contents in *C. clandestinus* of this research in pasture at free sun exposure were higher than those found by Insuasty-Santacruz *et al.* (2011) in the same area (monoculture 10,20 and SPS 11,4 %). However, they were lower than those reported by Portillo-López *et al.* (2019) in the Sapuyes locality, where *C. clandestinus* showed 18,7 % of CP, a lower value than that obtained in the SPS and higher than that found in T1 and T2.

Agrosavia's AlimenTro digital platform reported an average CP of 17,4 % in *C. clandestinus* for the Pasto municipality (Agrosavia, 2022). This result was higher than that obtained in this study for T1 and T2, and lower than T3 and T4. In Costa Rica, Villalobos-Villalobos and WingChing-Jones (2020) also reported higher values than those recorded in T1 and T2, at 28 days of cutting (18,5 %), but lower than those found in T3 and T4.

Avellaneda-Avellaneda and Mancipe-Muñoz (2020) in the Bogotá dairy basin in rainy seasons and with harvesting frequency at 35 days, reported a CP content of 21,5 % for *C. clandestinus*. When this value was compared with the treatments in the same period, it was higher than T2 and lower than T4. The above-cited authors, at 42 days, found 19,2 % CP, which was higher than T1 and lower than T3. Vargas *et al.* (2014) in the Colombian high tropics recorded 25,4 %, which was better than that described in this research.

Silva-Parra *et al.* (2017) in associated systems, in an arrangement with *A. acuminata*, and herbaceous utilization at 30 and 45 days, reported CP contents of 15,1 and 10,6 % in each season. Meanwhile, Tafur-Sánchez (2021), in two SPS with the same species, at different sowing distances, obtained a value of 17,8 and 17,0 %, lower results than those of this research.

Regarding EE, statistical differences were established between T4 and T1, with better performance in T4. Statistically, T2, T3 and T4 were similar, as were T1, T2 and T3. For this variable, the results in T1 (1,8) and T2 (2,1 %) were higher than those described in the highlands of the Nariño department, in Colombia by Insuasty-Santacruz *et al.* (2011) in monoculture (1,52 %). These authors reported 1,8 % of EE in *C. clandestinus* grass associated with trees, a lower value than that obtained in this research for T3 and T4.

The lowest fiber records were found in treatments 3 and 4, where the grass grew under the shade of the tree canopy. This corroborates the importance of SPS, if it is considered that lower NDF values lead to higher DM intake; while the decrease in ADF implies higher DM intake.

The NDF results of the silvopastoral treatments (T3 and T4) of this research were better than those reported by Tafur-Sánchez (2021) in two SPS of scattered *A. acuminata* trees-*C. clandestinus* (56,68 and 54,46 %), although the ADF content found by this author was better (27,0 and 28,7 %). They were similar to the result obtained by Navas-Panadero *et al.* (2020) in an *Acacia melanoxylon*-*C. clandestinus* association, with two cutting times (30 and 45 days), in which values of 58,0 and 57,0 % for NDF and 33,0 and 32,0 % for ADF were recorded.

In the silvopastoral treatments, the highest values were found in the digestibility and NLE indicators, related to the chemical composition of the pasture of these associated systems. The cutting age (less than or equal to 45 days) is also a factor that could have influenced, since the longer the regrowth period, the lower the digestibility and nutritional value of the pasture. It is for this reason that grazing at short

intervals constitutes an alternative for farmers to compensate higher nutritional and energy demands of dairy cattle (Correa *et al.*, 2008).

Regarding digestibility, the range of values published by AlimenTro (Agrosavia, 2022) varies between 59,6 and 70,1 % for the Pasto municipality, for which the results of this research are in the range reported in the municipality. However, when comparing these values with those of other authors, they were higher (52,5 % with 30 days of regrowth) than those reported by Correa *et al.* (2008), and were also higher than those obtained by Navas-Panadero *et al.* (2020) in two *A. acuminata*-*C. clandestinus* associations with 30 and 45-day cutting (63 and 64 %, respectively). Yet, they were lower than those obtained by Villalobos-Villalobos and WingChing-Jones (2020) in Costa Rica (73,3 %).

Portillo-López *et al.* (2019) in the Pasto locality referred an NLE of 1,45 Mcal kg DM⁻¹. In Sapuyes they recorded 1,33, higher values than those of the monoculture; while those of the SPS were above the results of Sapuyes and below those of Pasto. The NLE data, at 35 and 42 days, recorded by Avellaneda-Avellaneda and Mancipe-Muñoz (2020), in the Bogotá dairy basin, averaged 1,40 for the two cuts, which is above the average of T1 and T2 and below the average of T3 and T4.

Conclusions

In the treatments with trees, the best results were obtained in production and forage quality of *C. clandestinus*, which indicates the positive impact of the tree species on the evaluated indicators. The inclusion of trees in animal husbandry operations, in addition to improving productivity, allows the development of a more sustainable animal husbandry system.

Acknowledgments

The authors thank AGROSAVIA, attached to the Ministry of Agriculture and Rural Development of Colombia, to its Obonuco Research Center, to the Government of Nariño, which through the General System of Royalties has financed the project "Improvement of forage supply, optimization of feeding systems and assurance of milk quality and safety in the high tropics of the Nariño department", identified with BPIN code 2013000100279.

Conflict of interest

The authors declare that there is no conflict of interest among them.

Authors' contribution

- Bayron Giovanni Obando-Enríquez. Elaborated the methodology, conducted the research, data processing and writing of the original draft.
- Filadelfo Hernandez-Oviedo. Carried out the research, processed the data and wrote the original draft.
- Paola Andrea Portillo-López. Conducted the research, data processing and writing of the original draft.
- Edwin Castro-Rincón. Carried out the conceptualization, elaborated the methodology and supervised the research.

Bibliographic references

- Agrosavia. *AlimenTro-Agrosavia*. Colombia: Agrosavia. <https://alimentro.agrosavia.co/Home/Index?ReturnUrl=%2F>, 2022.
- Arcos-Álvarez, C. N.; Lascano-Armas, Paola J. & Guevara-Viera, R. V. Manejo de asociaciones gramíneas-leguminosas en pastoreo con rumiantes para mejorar su persistencia, la productividad animal y el impacto ambiental en los trópicos y regiones templadas. *RECA*. 2 (2):1-31. <http://revistaecuadorianadecienciaanimal.com/index.php/RECA/article/view/72/71>, 2018.
- Ariza-Nieto, C.; Mayorga, O. L.; Mojica, B.; Parra, D. & Afanador-Tellez, G. Use of LOCAL algorithm with near infrared spectroscopy in forage resources for grazing systems in Colombia. *J. Near Infrared Spectrosc.* 26 (1):44-52, 2018. DOI: <https://doi.org/10.1177/0967033517746900>.
- Avellaneda-Avellaneda, Y.; Mancipe-Muñoz, E. A. & Vargas-Martínez, J. de J. Effect of regrowth period on morphological development and chemical composition of kikuyu grass (*Cenchrus clandestinus*) in Colombian's highlands. *Rev. CES Med. Zootec.* 15 (2):23-37, 2020. DOI: <https://doi.org/10.21615/cesmvz.15.2.2>.
- Buitrago-Guillen, María E.; Ospina-Daza, L. A. & Narváez-Solarte, W. Sistemas silvopastoriles: alternativa en la mitigación y adaptación de la producción bovina al cambio climático. *Bol. Cient. Mus. Hist. Nat. U. de Caldas*. 22 (1):31-42, 2018. DOI: <https://doi.org/10.17151/bccm.2018.22.1.2>.
- Cardona-Iglesias, J. L.; Urbano-Estrada, María F. & Castro-Rincón, E. Evaluación de sólidos solubles en recursos forrajeros del trópico alto en el departamento de Nariño. *Ces. Med. Vet. Zootec.* 15 (2):8-22, 2020. DOI: <https://doi.org/10.21615/cesmvz.15.2.1>.
- Correa, H. J.; Pabón, M. L. & Carulla, J. E. Valornutricional del pasto kikuyo (*Pennisetum clandestinum* Hoechst Ex Chiov.) para la producción de leche en Colombia. *LRRD*. 20 (59). <https://lrrd.cipav.org.co/lrrd20/4/corra20059.htm>, 2008.

- Foss. El análisis de la fibra en el pienso animal: Fibra cruda, fibra detergente neutra (FDN) y fibra detergente ácida (FDA)-los estándares y las opciones de automatización. Denmark. <https://www.fossanalytics.com/-/media/files/documents/papers/laboratories-segment/ebook-fibre-analysis-of-animal-feed-es.pdf>, 2018.
- Giraldo, L. A. & Bolívar, Diana M. Evaluación de un sistema silvopastoril de *Acacia decurrens* asociada con pasto kikuyo *Pennisetum clandestinum*, en clima frío de Colombia. En: M. D. Sánchez y M. Rosales-Méndez, eds. *Agroforestería para la producción animal en América Latina*. Estudios FAO. Producción y sanidad animal. Roma: FAO. http://bibliotecadigital.agronet.gov.co/bitstream/11348/6692/1/20061127115335_Sistema%20silvopastoril%20acacia%20decurrens%20y%20kikuyo.pdf, 1999.
- Holdridge, L. R. *Ecología basadas en zonas de vida*. San José, Costa Rica: IICA. <http://repositorio.iica.int/bitstream/handle/11324/7936/BVE19040225e.pdf?sequence=1&isAllowed=y>, 1978.
- IDEAM. *Promedios mensuales de brillo solar para todas las estaciones del país (horas de sol al día)*. Bogotá: Instituto de Hidrología, Meteorología y Estudios Ambientales. <http://dhime.ideam.gov.co/atencionciudadano/>, 2018.
- IDEAM. *Consulta y descarga de datos hidrometeorológicos*. Bogotá: Instituto de Hidrología, Meteorología y Estudios Ambientales. <http://dhime.ideam.gov.co/atencionciudadano/>, 2022.
- IGAC. *Estudio general de suelos y zonificación de tierras del departamento de Nariño*. https://www.academia.edu/38164592/Estudio_General_de_suelos_y_zonificaci%C3%B3n_de_tiemras_del_departamento_de_Nari%C3%B3, 2004.
- Insuasty-Santacruz, E. G.; Apráez-Guerrero, J. E. & Navia-Estrada, J. F. Efecto del arreglo silvopastoril aliso (*Alnus acuminata* K.) y kikuyo (*Pennisetum clandestinum* H.) sobre el comportamiento productivo en novillas Holstein en el altiplano del departamento de Nariño. *Agroforestería Neotropical*. 1:1-8. <https://revistas.ut.edu.co/index.php/agroforesteria/article/view/13/13>, 2011.
- Mendiburu, F. de. *Package 'agricolae'. Statistical Procedures for Agricultural Research*. Version 1.3-5. <https://cran.r-project.org/web/packages/agricolae/agricolae.pdf>, 2021.
- Muñoz, D.; Calvache, D. & Yela, J. Especies forestales con potencial agroforestal para las zonas altas en el departamento de Nariño. *Revista de Ciencias Agrícolas*. 30 (1):38-53. <http://sired.udenar.edu.co/495/>, 2013.
- Muñoz-Guerrero, D. A.; Navia-Estrada, J. F. & Solar-te-Guerrero, J. G. *El conocimiento local en los sistemas silvopastoriles tradicionales. Experiencias de investigación en la región andina*. Pasto, Colombia: Universidad de Nariño. DOI: <http://dx.doi.org/10.22267/lib.udn.003>, 2018.
- Murgueitio-Restrepo, E.; Barahona-Rosales, R.; Flores-Estrada, Martha X.; Chará-Orozco, J. D. & Rivera-Herrera, J. E. Es posible enfrentar el cambio climático y producir más leche y carne con sistemas silvopastoriles intensivos. *Ceiba*. 54 (1):23-30, 2016. DOI: <https://doi.org/10.5377/ceiba.v54i1.2774>.
- Navas-Panadero, A.; Aragón-Henao, L. F. & Triana-Valenzuela, J. F. Efecto del componente arbóreo sobre la dinámica de crecimiento y calidad nutricional de una pradera mixta en trópico alto. *Rev. Med. Vet.* 1 (41):71-82, 2020. DOI: <https://doi.org/10.19052/mv.vol1.iss41.7>.
- Pizzio, R. M.; Bendersky, D.; Barbera, P. & Maidana, C. E. *Caracterización y manejo de los pastizales correntinos*. Argentina: Ediciones INTA. <https://repositorio.inta.gob.ar/handle/20.500.12123/8899>, 2021.
- Portillo-López, Paola A.; Meneses-Buitrago, D. H.; Morales-Montero, Sonia P.; Cadena-Guerrero, Máryory M. & Castro-Rincón, E. Evaluación y selección de especies forrajeras de gramíneas y leguminosas en Nariño, Colombia. *Pastos y Forrajes*. 42 (2):93-103. http://scielo.sld.cu/scielo.php?script=sci_arttext&pid=S0864-03942019000200093&lng=es&tling=es, 2019.
- R Core Team. *R: A language and environment for statistical computing*. Vienna: The R Foundation. <https://www.r-project.org/>, 2020.
- Silva-Parra, Amanda; Garay-Rodríguez, Seydyss & Gómez-Insuasti, A. S. Impacto de *Alnus acuminata* Kunth en los flujos de N₂O y calidad del pasto *Pennisetum clandestinum* Hochst. ex Chiov. *Colombia Forestal*. 21 (1):47-57, 2017. DOI: <http://doi.org/10.14483/2256201X.11629>.
- Soriano-Robles, R.; Arias-Margarito, L.; Carbajal-de-Nova, M.; Almaraz-Buendía, I. & Torres-Cardona, M. G. Cambio climático y ganadería: el papel de la agroforestería. *Agroproductividad*. 11 (2):70-74. <https://mail.revista-agroproductividad.org/index.php/agroproductividad/article/view/122>, 2018.
- Tafur-Sánchez, B. Efecto del sistema silvopastoril con *Alnus acuminata* en el valor agronómico y nutricional de *Pennisetum clandestinum*. *Revista de Investigación Científica UNTRM: Ciencias Naturales e Ingeniería*. 3 (3):9-14, 2020. DOI: <http://dx.doi.org/10.25127/ucni.v3i3.630>.
- Toledo, M. & Schultze-Kraft, R. Metodología para la evaluación agronómica de pastos tropicales. En: M. Toledo, ed. *Manual para la evaluación agronómica*. Serie CIAT 07sG-I. Cali, Colombia: Red Internacional de Evaluación de Pastos Tropicales. p. 91-110, 1982. DOI: <https://doi.org/10.7910/DVN/DYR7KS>.

- Vargas, J.; Pabón, M. & Carulla, J. Producción de metano *in vitro* en mezcla de gramíneas-leguminosas del trópico alto colombiano. *Arch. Zootec.* 63 (243):397-407. <https://scielo.isciii.es/pdf/azoo/v63n243/articulo1.pdf>, 2014.
- Vargas-Martínez, J. de J.; Sierra-Alarcón, Andrea M.; Mancipe-Muñoz, E. A. & Avellaneda-Avellaneda, Y. El kikuyo, una gramínea presente en los sistemas de rumiantes en trópico alto colombiano. *Ces. Med. Vet. Zootec.* 13 (2):137-156, 2018. DOI: <https://doi.org/10.21615/cesmvz.13.2.4>.
- Villalobos-Villalobos, L. & WingChing-Jones, R. Los pastos estrella africana, kikuyo y “rye grass” en Cartago, Costa Rica: biomasa, composición botánica y nutrientes. *UNED Research Journal.* 12 (1):e2811, 2020. DOI: <https://doi.org/10.22458/urj.v12i1.2811>.