

Nutritional status and reproductive performance of cattle agroecosystems in silvopastoralism in the Andean region of Ecuador

Hernán Rigoberto Benavides Rosales

hernan.benavides@upec.edu.ec

Universidad Politécnica Estatal del Carchi

Luis Rodrigo Balarezo Urresta

Universidad Politécnica Estatal del Carchi

Edison Marcelo Ibarra Rosero

Universidad Politécnica Estatal del Carchi

Rolando Martín Campos Vallejo

Universidad Politécnica Estatal del Carchi

Guillermo Alexander Jácome Sarchi

Universidad Politécnica Estatal del Carchi

Juan Ramón García Díaz

Universidad Central "Marta Abreu" de Las Villas

Research Article

Keywords: Silvopastoral systems, Agroecosystems, Body condition, reproductive indicators, Natality

Posted Date: June 16th, 2025

DOI: <https://doi.org/10.21203/rs.3.rs-6856634/v1>

License:   This work is licensed under a Creative Commons Attribution 4.0 International License. [Read Full License](#)

Additional Declarations: No competing interests reported.

Abstract

The goal of this study was to find out how silvopastoral systems with *Alnus acuminata* H.B.K. (Alder) and *Acacia melanoxylon* R.Br. (Acacia) along with the herbaceous layer affect the nutritional status and reproductive performance of agroecosystems (AES) in Ecuador's Andean region with silvopastoral cattle. AES 1 and 2 contained alder and Acacia, respectively, and AES 3 contained grasses only. We determined the effect of AES and year on reproductive indicators and body condition at calving (BCC) using multifactorial ANOVA and interaction. There was an energy deficit in the second year in AES 1 and 3, and in all three years in AES 2. There was an excess of crude protein in all three AES in all three years. The first service parity interval (FPSI) was lower ($P < 0.05$) in AES 1 and in years 2 and 3. The CCP was higher ($P < 0.05$) in AES 1, and the services per gestation were higher ($P < 0.05$) in the first year. Calving-conception (CCP) and calving-delivery (DDP) intervals were lower in AES1 and in years two and three. We conclude that Alder and Acacia favored nutrient balance in AES 1 and 2. In AES 1, CCP was higher, and IPPS was reduced; the interaction between AES and the year of study benefited CPI and IPP, which were better in AES 1, in the third year.

Introduction

Feeding of specialized cattle herds in the Andean region of Ecuador is based on extensive grazing, with a predominance of monoculture of tropical grasses and the absence of trees (Balarezo et al. 2018), like what happens in tropical areas of Latin America (Durand-Chávez et al. 2022). Under these conditions, soils are degraded, there is a low supply of shade, the quantity and quality of edible biomass are affected, and the bio-economic behavior of the animals is affected (Donaghy et al. 2022).

In the agro-ecosystems (AES) of the Carchi province, dairy cows don't get enough of the nutrients they need. As a result, they have high levels of blood urea nitrogen (BUN) and beta hydroxybutyrate (B-OH) in their serum, as well as low levels of phosphorus, potassium, and phosphorous (Balarezo et al. 2018). All of these changes were linked to worsening reproductive indicators.

La implementación de Sistemas Silvopastorales (SSP) es una alternativa para resolver problemas ecológicos causados por la ganadería extensiva (Amorim et al. 2023) y beneficiar la salud y producción animal (Buitrago et al. 2018; Wilkens et al. 2022; Thomsen et al. 2023; Poudel et al. 2024). In addition, these ESAs generate positive economic impacts through other marketable products or income diversification, reduce erosion, and benefit the environment (Amorim et al. 2023).

SSPs generate positive interactions among their components, with better reproductive performance for the animals and less negative environmental impact (Benavides et al. 2019). In addition, they reduce the use of external inputs in agricultural SSAs (Tzec-Gamboa et al. 2023).

Adding trees to the mix of soil, plants, and animals improves the nutritional value of the edible phytomass and the amount of DM and nutrients that are available to each animal every day. This lowers the nutritional deficit and, as a result, makes the cows healthier during labor and birth, and it also affects how they reproduce (Vargas-Hernández 2013).

In addition, SSPs contribute to animal comfort by reducing heat stress, resulting in improved production cycles and improved diet quality (Viñoles et al. 2022). Cattle placed under shade feel more comfortable and have less caloric stress; therefore, they will consume feed for a longer time, which increases their productivity and improves reproductive parameters (Arciniegas-Torres and Flórez-Delgado 2018; Thomsen et al. 2023; Poudel et al. 2025).

Silvopastoralism has many benefits, but most cattle producers don't use it because they don't know enough about it, don't have the resources to set up SSPs, and their animals' reactions vary from place to place because of differences in tree and pasture species, as well as soil and weather conditions (Poudel et al. 2021).

The impact of the introduction of SSP on the nutrient balance and reproductive behavior of dairy herds using low external inputs in the Andean region of Ecuador is unknown.

The point of this study was to look into what changes happen when you add SSP with *Alnus acuminata* H.B.K. (Alder) y *Acacia melanoxylon* R.Br. (Acacia), along with the herbaceous cover, to the nutritional status and reproductive performance of

ganaderos in silvopastoralism in Ecuador's Andean region.

Methods

Research scenario and its edaphoclimatic conditions

The research was carried out during the years 2020, 2021, and 2022 in dairy herds of the San Vicente farm, parish “El Carmelo,” Tulcán canton, Carchi province, Ecuador. The experimental area is in the hydrographic area 230, from latitude 0°39'33"N, longitude 77°36'20"W to latitude 0°38'55"N, longitude 77°36'25"W, with an altitude of 2916 to 3006 m.a.s.l. (INAMHI 2022).

The research site is 54.4 ha. Its soil is in the Andisol order, whose MO, pH, water retention, and effective depth fluctuate between 10 and 25%, 5.5 and 6.5%, 20 and 100%, and 20 and 70 cm, respectively. The relief undulates with a slope percentage that fluctuates between 10 and 40%, and N2 varies from medium to high values. The main limiting factor of the soils of the Andean region of Ecuador is acidity (Benavides et al. 2019).

La precipitación en los años del experimento varió de 892.50 a 1,317.50 mm. The average mean, maximum, and minimum temperatures during the study period were 12.12, 16.49, and 8.06°C, respectively (INAMHI 2022).

Agro-ecosystem characteristics (AES)

Three AES were used in a completely randomized experimental design. The predominant grasses in the three AES were Kikuyu (*Pennisetum clandestinum* L.), Ray grass (*Lolium perenne* L.), Holco (*Holcus lanatus* L.), and White clover (*Trifolium repens* L.). AES 1 (Fig. 1) was composed of grasses and *A. acuminata* trees, AES 2 (Fig. 2) of grasses and *A. melanoxylon* trees, and AES 3 of grasses only; the same was considered a control.

Trees in AES 1 and AES 2 were established in December 2019, at a planting density of 1000 trees ha⁻¹, in double rows, two meters apart, following contour lines (Figs. 1 and 2). We established double electric fences to protect the young trees from cow damage, which also served to divide the quarters. The practices used to design and establish the AES are consistent with those used in other countries (Poudel et al. 2025).

Time-restricted grazing was used for 18 hours per day. No protein energy concentrate was administered, but mineral salts were supplemented orally ad libitum. Mechanized milking of the cows was used twice a day, 5:00–7:00 am and 3:00–5:00 pm. The calf underwent artificial rearing from the third day of its birth.

Animals involved

Between 29 and 34 cows were used, and 9 to 12 cows were randomly assigned to each AES. The animals met the following criteria: Holstein cows between three and four years of age, with CC at calving (CCP) between 3.0 and 4.0 points on the five-point scale, were in third and fourth lactation with an average milk production of 10 ± 2 L cow⁻¹ day⁻¹, clinically healthy, not receiving medical treatment, and had an average milk production of 10 ± 2 L cow⁻¹ day⁻¹.

Methodologies of work

Health status

General health status was determined at the beginning of the experiment and followed throughout the study, using the functional invariants of the clinical method (Cuesta et al. 2007). The animals were dewormed and vaccinated according to the area's schedule.

Nutritional balance

The nutritional balance was calculated according to the feed offered (pasture mix, mineral salt, and the foliage of the trees in the third year), the requirements of the cows, and the contribution of each year. In addition, the average annual PV, PV increase, potential and actual milk fat percentage, locomotion expense, feed consumed, and number of lactations were considered. For this calculation, he used the software developed by Roche et al. (1999).

Indicators of reproductive performance and body condition

We used the methods explained by Brito et al. (2010) to find out the birth index (NI), the percentage of gestations at first service, the services per gestation (S/G), the calving-first service interval (IPPS), the calving-conception interval (CPI), and the calving-calving interval (CPI). Estrus detection was performed between 5:00–9:00 am and 3:00–7:00 pm by a trained man, using paint at the base of the cows' tails as an auxiliary method.

For artificial insemination, the semen was deposited in the uterus by an experienced technician, with a technical efficiency between 60 and 65% in the past four years. We used semen from Holstein bulls with proven fertility, which we contained in 0.25 c.c. straws at a concentration of 32 million per dose.

Body condition (CC) was estimated by physical examination of the animals that included inspection and palpation, classifying it on a scale of 1–5 points and divisions of 0.25 between them according to the methodology proposed by Rodenburg (2004). Due to the limited number of animals in the AES under study, we only determined CC at calving (CCP).

Statistical processing

Multifactorial analysis of variance (multifactorial ANOVA) was used to find out how AES and year affected reproductive indicators (IPPS, IPC, IPP, and S/G) and CCP. Means were compared using the Bonferroni test (Bonferroni 1936). We compared the birth rate within each AES year and between years within the AES using a multiple comparison of proportions. We used the statistical package Statgraphics Centurion version XV for statistical processing (Statistical Graphic Corp., USA 2006).

Results

The energy requirements of the cows in AES 1 were met at 107.37 and 103.34% in the first and third years, while in the second year 97.72% of the requirements were met and there was a deficit of 2.28 MJ; on the other hand, in AES 2 there was an energy deficit of 9.62, 15.48, and 1.25 MJ in years 1, 2, and 3, in that order. In AES 3, the energy demands were covered, except in the second year, where only 96.72% of the demands were covered, and the animals had a deficit of 2.93 MJ.

During the three years of the study, the crude protein requirements in all three AES exceeded their demands, ranging from 106.89–183.01%. Ca and P requirements were covered in all three AES and years between 100 and 152.35%.

For the IPPS, there are significant differences ($P < 0.05$) between the AES, being lower in AES 1 (Table 1). Following the study, the voluntary waiting period (Bruto et al. 2010) should not be longer than 18 days before the first service calving interval (IPPS). In the herds that were looked at, this was 45 days, so the postpartum anestrous period (PPA) was 64, 34, 87.09, and 134.77 days for AES 1, AES 2, and AES 3.

Table 1
Comparison of mean reproductive indicators (S/G and IPPS) and
body condition at calving (BCC).

Source	S/G	IPPS (Days)	CCP
	$\bar{x} \pm EE$	$\bar{x} \pm EE$	$\bar{x} \pm EE$
AES			
AES 1 (n = 21)	2,31 $\pm$ 0,17 ^a	127,34 $\pm$ 5,86 ^c	3,45 $\pm$ 0,07 ^a
AES 2 (n = 20)	2,48 $\pm$ 0,17 ^a	150,09 $\pm$ 5,98 ^b	3,05 $\pm$ 0,07 ^b
AES 3 (n = 17)	2,35 $\pm$ 0,19 ^a	197,77 $\pm$ 6,50 ^a	2,85 $\pm$ 0,08 ^b
Year			
1 (n = 17)	2,91 $\pm$ 0,19 ^a	174,94 $\pm$ 6,50 ^a	3,07 $\pm$ 0,08 ^a
2 (n = 20)	2,21 $\pm$ 0,17 ^b	147,99 $\pm$ 5,98 ^b	3,08 $\pm$ 0,07 ^a
3 (n = 21)	2,00 $\pm$ 0,17 ^b	152,28 $\pm$ 5,86 ^b	3,20 $\pm$ 0,07 ^a

^{abc} Different characters in the same column, within each source of variation, differ for $P < 0.05$, (Bonferroni 1936).

Table 2 shows that the CPI and PPI differed ($P < 0.05$) between AES and years, being lower in AES1 and years two and three. The AES's interaction with the year clearly influenced the CPI and PPI. AES 1 had the best results in year three, AES 2 in years two and three without differences between them, and in AES 3 the year had no influence. This is since the year's influence on the establishment of the AES was revealed.

Table 2
Comparison of CPI and PPI averages in the three SSAs and study years

Source		N	study years	
			IPC (Days)	IPP (Days)
			$\bar{x} \pm EE$	$\bar{x} \pm EE$
AES				
AES 1		21	172,69 $\pm$ 8.89 ^c	469,54 $\pm$ 4,69 ^c
AES 2		20	204,20 $\pm$ 9,07 ^b	484,01 $\pm$ 4,79 ^b
AES 3		17	256,82 $\pm$ 9,85 ^a	536,98 $\pm$ 5,20 ^a
Year				
1		17	247,10 $\pm$ 9,85 ^a	538,32 $\pm$ 5,20 ^a
2		20	199,46 $\pm$ 9,07 ^b	480,16 $\pm$ 4,79 ^b
3		21	187,16 $\pm$ 8,89 ^b	472,05 $\pm$ 4,69 ^b
AES	Año	N	$\bar{x} \pm EE$	$\bar{x} \pm EE$
AES 1	1	6	228,16 $\pm$ 16,52 ^a	545,83 $\pm$ 8,72 ^a
	2	7	163,28 $\pm$ 15,29 ^b	445,28 $\pm$ 8,08 ^b
	3	8	126,62 $\pm$ 14,31 ^c	417,50 $\pm$ 7,55 ^c
AES 2	1	6	266,33 $\pm$ 16,52 ^a	541,33 $\pm$ 8,72 ^a
	2	7	176,42 $\pm$ 15,29 ^b	458,71 $\pm$ 8,08 ^b
	3	7	169,85 $\pm$ 15,29 ^b	452,02 $\pm$ 8,08 ^b
AES 3	1	5	246,80 $\pm$ 18,10 ^a	527,80 $\pm$ 9,56 ^a
	2	6	258,66 $\pm$ 16,52 ^a	536,53 $\pm$ 8,72 ^a
	3	6	265,02 $\pm$ 16,52 ^a	546,66 $\pm$ 8,72 ^a

^{ab} Different characters in the superscripts of each variable in the same column, within each source of variation indicate significant differences * P < 0.05 (Bonferroni 1936). AES: Agroecosystem.

Discussion and conclusions

The cows didn't have enough energy in the second year of AES 1 and 2, and in all three years of AES 3. This means that the cows would have to find other ways to use their energy, even if they could produce 11.7 L cow⁻³ day⁻³ (Butler et al. 2013; Balarezo et al. 2018).

The increase in the PB content of the diet offered to animals is because SSPs increase the supply of forage to livestock, and the tree legumes in these agroecosystems provide more protein than grasses (Carvalho et al. 2017). In addition, cows in SSP have higher dry matter intake because they graze throughout the day, have less heat stress, show less competition and are better distributed, and spend much less time near the water trough. Consequently, cattle herds in silvopasture have higher productivity (Pent et al. 2020, 2021; Poudel et al. 2022; Thomsen et al. 2023; Poudel et al. 2025).

When there is too much CP and not enough energy, proteins are used as energy. This makes the liver use more N_2 and reaches its maximum capacity, which leads to more urea and NH_3 in the blood. This raises blood urea nitrogen (BUN) and causes the body to use more energy, making the energy balance even worse (Kananub et al. 2020).

In addition, dairy cows can compensate for the energy deficit by mobilizing and utilizing body reserves. When the capacity of Edelman rumen microorganisms to utilize NH_3 is saturated, it reaches the liver via the bloodstream and is converted to urea by the liver, whereby excess NH_3 leads to elevations in BUN, which harms reproductive behavior (Butler et al. 2013; Kananub et al. 2020).

There were lower IPPS levels in AES 1 because the CCP level was higher ($P < 0.05$) than in AES 2 and AES 3 (Table 1). This is especially true for cows in AES 3 who are in BEN because their CCP is less than 3.0. This makes them less fertile because insulin and leptin levels drop, which in turn affects the ovary or hypothalamus function and slows down the production of gonadotropic hormones. This leads to low fertility and a longer time for the ovarian activity to start up again after giving birth in dairy cows (Butler et al. 2013; Balarezo et al. 2018).

It has been shown that lower CCP affects fertility and that cows calving with CCP below three have higher postpartum anestrus and IPPS (Barletta et al. 2017). Similar results for these indicators were published by Balarezo et al. (2016) and Perez (2023) in AES, where a low body condition associated with increased IPPS was diagnosed.

Low CCP accentuates CC loss; early lactation is among the main factors associated with increased S/G in dairy cows, due to reduced gestation rate in the first AI (Gobikrushanth et al. 2019).

When there is too much loss of CC between giving birth and the first insemination, the IPG goes up (Carvalho et al. 2014) and the gestation rate goes down (Butler et al. 2013). Cows with low CC have lower postpartum ovulation rates due to Luteinizing Hormone (LH) deficiency that partially generates atypical waves of this hormone (Robson et al. 2008). Consequently, there is little development of the corpus luteum (CL) and little progesterone secretion (P4). This phenomenon explains the fertility disorders in cows with poor CC (Robson et al. 2007).

IPPS was lower in years two and three (Table 1), motivated because in these years AES 1 and AES 2 were more established and therefore animals were more efficiently taking advantage of their benefits.

BEN lowers the growth of dominant follicles and the production of estradiol because it lowers the amount of insulin and IGF-1 in the blood and the frequency of the LH pulse (Souissi and Bouraoui 2020). Thus, negative feedback, mediated by estradiol, is directly related to BE, and this physiological scenario delays first ovulation in cows with higher CC loss and lower nadir body condition (Barletta et al. 2017).

To sum up, Table 1 shows that the CCP didn't change over the study years, and the S/G didn't change over the AES either. However, it was higher in the first year ($P < 0.05$), which means that this indicator is poor since only 34.36% of pregnancies happened at the first artificial insemination service. The adequate value of the S/G should be ≤ 1.70 for an adequate fertility level, where more than 60% of the cows are gestated with an insemination (Brito et al. 2010).

To sum up, Table 1 shows that the CCP didn't change over the study years, and the S/G didn't change over the AES either. However, it was higher in the first year ($P < 0.05$), which means that this indicator is poor since only 34.36% of pregnancies happened at the first artificial insemination service. The adequate value of the S/G should be ≤ 1.70 for an adequate fertility level, where more than 60% of the cows are gestated with an insemination.

Excesses of CP and energy deficiency lead to an increase in BUN, which lowers the pH of the uterus and consequently affects semen and embryo survival. This results in low percentages of gestation at first service, increased need for repeat services, and a decline in reproductive indicators. The excess of CP in the diet of dairy cows decreases their fertility and worsens the reproductive efficiency of the herd, especially when the energy does not satisfy their needs (Kananub et al. 2020).

Dietary energy deficiencies are the main limiting factors for SSPs (Balarezo et al. 2018). In production conditions similar to those of this study, these authors showed that higher BUN levels were linked to S/G, IPC, IPP, and the return of ovarian activity.

However, increasing the PB content of the diet or its rumen degradability, especially when the energy is not sufficient to meet the animals' needs, leads to decreased fertility in dairy cows and, therefore, to a decrease in the reproductive efficiency of the herd (Kananub et al. 2020).

The PPI was different ($P < 0.05$) between AES and years (Table 2), but the birth rate wasn't significantly different ($P > 0.05$) between AES in the same year or between AES in the same year. This is likely because there were only nine animals in each group, which is a small sample size. However, in AES 1 in Year 3, the birth rate is very close to the target for optimum fertility potential, which is 90% (Brito et al. 2010).

As shown in Table 1, the animals in AES 3 had lower CCP than those in AES 2 and higher CPI than those in AES 2. This was true even though the animals in AES 2 ate the same amount of energy and protein and no year could meet their energy needs. This may be because the trees in AES 3 improve the animals' thermal comfort and welfare, protect them from solar radiation, and lower the effects of heat stress by making them work less to keep their systems in balance (Castaño et al. 2014). These results corroborate the beneficial effect of SSP on the CC of the cows, which had better reproductive performance (Vargas-Hernández 2013).

It has been documented that under the shade of trees, the ambient temperature can be reduced between 2 and 9°C during the hottest hours of the day (López et al. 2015). El bienestar animal es el factor determinante en la viabilidad técnica y económica de los sistemas de producción de leche (Arciniegas-Torres y Flórez-Delgado 2018; Thomsen et al. 2023; Poudel et al. 2025).

Alder and Acacia favored the nutrient balance in AES 1 and 2, with AES 2 showing an energy deficit. In AES 1, the CCP was higher, and the IPPS was reduced; the interaction of AES with the year of study benefited the IPC and IPP, which were better in AES 1 (Alder) in the third year.

Declarations

Acknowledgments

The authors of this work are grateful to the administration of the San Vicente Farm, the setting for this research, and to the authorities, teachers, and students of the Universidad Politécnica Estatal del Carchi (UPEC) for their disinterested contribution to its realization.

Authors' contributions

HRBR: research conception and design, data analysis and interpretation, and article writing. LRBU, EMIR, RMCV, GAJS, data analysis and interpretation, article writing JRGD: Research conception and design, statistical analysis, final review, and article approval.

Main financial source of the study

This research was financed with internal resources from the Universidad Politécnica Estatal del Carchi, through the cost center of the Research Department, within the framework of the project entitled "Management plan for the sustainable development of the San Francisco Experimental Center - UPEC". The authors and the University have no conflict of interest with the postulated contribution, since it is paid to the main institution UPEC.

Data availability

Primary research data are available.

Conflict of interest

The authors have no conflict of interest.

Institution responsible for the results

References

1. Amorim HCS, Ashworth AJ, O'Brien PL, Thomas AL, Runkle BRK, Philipp D (2023) Temperate silvopastures provide greater ecosystem services than conventional pasture systems. *Sci Rep*. <https://doi.org/10.1038/s41598-023-45960-0>
2. Arciniegas-Torres SP, Flórez-Delgado DF (2018) Estudio de los sistemas silvopastoriles como alternativa para el manejo sostenible de la ganadería. *Ciencia y Agricultura* 15 (2): 107–116. <https://doi.org/10.19053/01228420.v15.n2.2018.8687>
3. Balarezo LR, García-Díaz JR, Hernández-Barreto M, Vargas-Hernández S (2018) Uterine Involution in Holstein cows in the province of Carchi, Ecuador. *Rev. MVZ Córdoba* 23 (2): 6649–6659. <https://doi.org/10.21897/rmvz.1339>
4. Balarezo LR, García-Díaz JR, Hernández-Barreto MA, García López R (2016) Metabolic and reproductive state of Holstein cattle in the Carchi region, Ecuador. *Cuban Journal of Agricultural Science* 50 (3): 381–392. <http://cjas.science.com/index.php/CJAS/article/view/632/699>
5. Barletta RV, Maturana Filho M, Carvalho PD, Del Valle TA, Netto AS, Rennó F.P, Mingoti RD, Gandra JR, Mourão GB, Fricke PM, Sartori R, Madureira EH, Wiltbank MC (2017) Association of changes among body condition score during the transition period with NEFA and BHBA concentrations, milk production, fertility, and health of Holstein cows. *Theriogenology* 104:30–36. <https://doi.org/10.1016/j.theriogenology.2017.07.030>
6. Benavides HR, Vargas S, Caicedo D, Carvajal L, Gutiérrez DI, Mina J (2019) Effect of agro-ecosystem and periods of the year upon earthworm population density on silvopastoral systems. *Cuban Journal of Agricultural Science* 53 (1): 197–206. <http://scielo.sld.cu/pdf/cjas/v53n2/2079-3480-cjas-53-02-197.pdf>
7. Bonferroni CE (1936) Teoría estadística de clases y cálculo de probabilidades. Publicaciones del Instituto Superior de Ciencias Económicas y Comerciales de Florencia 8: 3–62.
8. Brito R, Blanco S, Calderón R, Preval B, Campo E (2010) Patología de la Reproducción Animal. 2da edición. La Habana, Cuba: Editorial “Félix Varela”. 1–41 pp.
9. Buitrago María E, Ospina-Daza, LA, Narváez-Solarte W (2018) Sistemas silvopastoriles: alternativa en la mitigación y adaptación de la producción bovina al cambio climático. Boletín Científico Centro de Museos. Museo de Historia Natural 22 (1): 31–42. <https://doi.org/10.17151/bccm.2018.22.1.2>
10. Butler S, Buckle F, Lewis Eva, Kavanagh S (2013) Nutritional management for fertility. International Conference. Dairy Cow Fertility. Reproductive performance for efficient pasture-based systems. Rochestown Park Hotel and Teagasc, Moorepark Research Centre, Cork, Ireland. p. 39–56. Disponible en https://www.teagasc.ie/media/website/2010/Dairy_Cow_Fertility_Proceedings.pdf. [Accedido: 25/10/2019].
11. Castaño FA, Rugeles CC, Betancur CA, Ramírez-López CJ (2014) Impacto del estrés calórico sobre la actividad reproductiva en bovinos y consideraciones para mitigar sus efectos sobre la reproducción. *Revista Biosalud* 13(2): 84–94. <http://www.scielo.org.co/pdf/biosa/v13n2/v13n2a07.pdf>
12. Carvalho PD, Souza AH, Amundson MC, Hackbart KS, Fuenzalida M.J, Herlihy MM, Ayres H, Dresch AR, Vieira LM, Guenther JN, Grummer RR, Fricke PM, Shaver RD, Wiltbank MC (2014) Relationships between fertility and postpartum changes in body condition and body weight in lactating dairy cows. *J. Dairy Sci* 97 (6): 3666–3683. <https://doi.org/10.3168/jds.2013-7809>
13. Carvalho WFD, Oliveira MED, Alves AA, Moura RLD, Moura RMD (2017) Energy supplementation in goats under a silvopastoral system of tropical grasses and leucaena. *Rev. Ciênc. Agron* 48 (1):199–207. <http://dx.doi.org/10.5935/1806-6690.20170023>
14. Cuesta, M, Montejo E, Duvergel J (2007) Medicina Interna Veterinaria. 1ra ed. La Habana, Cuba: Editorial Félix Varela. pp. 5–8.
15. Donaghy DJ, Pembleton KG, Barber DG (2022) Comparison of nutritive values of tropical pasture species grown in different environments, and implications for livestock methane production: A meta-analysis. *Animals* 12 (14):1806. <https://doi.org/10.3390/ani12141806>
16. Durand-Chávez LM, Vásquez-Pérez HV, Ushiñahua-Ramírez D, Carrasco-Chilón W, Depaz-Hizo BA, Saucedo-Uriarte JA (2022) Yield performance of forage shrubs and effects on milk production and chemical composition under the tropical climatic

- conditions of Peru. *Sustainability* 14: 12774. <https://doi.org/10.3390/su141912774>
17. Gobikrushanth M, Macmillan K, Behrouzi A, Hoff B, Colazo MG (2019) The factors associated with postpartum body condition score change and its relationship with serum analytes, milk production and reproductive performance in dairy cows. *Livest. Sci* 228:151–160. <https://doi.org/10.1016/j.livsci.2019.05.016>
 18. Google Earth (2019) Anexo 1. Ubicación del AES 1. <https://earth.google.com/web/@0,-1.16600013,0a,22251752.77375655d,35y,0h,0t,0r/data=CgRCAggBOgMKATBCAggBSg0I>
 19. INAMHI (2022) Instituto Nacional de Meteorología e Hidrografía. Datos meteorológicos de la estación meteorológica de Chalpatán, Carchi, Ecuador. Internet Disponible en: <http://www.inamhi.gob.ec>. [Accedido: 19 marzo 2023].
 20. Kananub S, Pechkerd P, VanLeeuwen J, Stryhn H, Arunvipas P (2020). Evaluation of influence of milk urea nitrogen on reproductive performance in smallholder dairy farms. *Aust. Vet. J* 98:375–379. <https://doi.org/10.1111/avj.12946>.
 21. López O, Lamela L, Montejo IL y Sánchez Tania (2015) Influencia de la suplementación con concentrado en la producción de leche de vacas Holstein x Cebú en silvopastoreo. *Pastos y Forrajes* 38 (1):46–54. <http://scielo.sld.cu/pdf/pyf/v38n1/pyf05115.pdf>
 22. López O (2023) Influencia del balance de energía en el desempeño productivo y reproductivo de vacas Mambí de Cuba en un sistema silvopastoril. Tesis presentada en opción al grado científico de Doctor en Ciencias Veterinarias. Universidad Agraria de la Habana. MES. Mayabeque, Cuba. 53 p.
 23. Pent GJ, Greiner SP, Munsell JF, Tracy BF, Fike JH (2020) Lamb performance in hardwood silvopastures, I: animal gains and forage measures in summer. *Transl Anim Sci* 4(1):385–399. <https://doi.org/10.1093/tas/txz154>
 24. Pent GJ, Fike JH, Kim I (2021) Ewe lamb vaginal temperatures in hardwood silvopastures. *Agrofor Syst* 95(1):21–32. <https://doi.org/10.1007/s10457-0180221-y>
 25. Poudel S, Pent G, Fike J (2024) Silvopastures: benefits, past efforts, challenges, and future prospects in the United States. *Agronomy* 14(7):1369. <https://doi.org/10.3390/agronomy14071369>
 26. Poudel S, Ely K, Fike J (2025). The potential of silvopasture in the mid-atlantic USA: insights from land managers on motivations, challenges, and production features. *Agrofor Syst* 99(3), 52. <https://doi.org/10.1007/s10457-025-01145-4>
 27. Robson C, Aller J, Callejas S, Cabodevila J, Alberio R (2007) Factores que afectan el anestro posparto en bovinos. *Taurus Olivos Pcia. Bs. As* 9 (33): 8–25. https://www.produccion-animal.com.ar/informacion_tecnica/cria/96-anestro.pdf
 28. Robson C, Aller, JF, Callejas, S Alberio RH (2008) Dinámica folicular y comportamiento del amamantamiento en razas Angus y criolla Argentina. *Arch. Zootec* 57 (220): 477–488. <https://www.redalyc.org/pdf/495/49515034009.pdf>
 29. Roche A, Larduet R, Torres V, Ajete A (1999) CALRAC. Programa de computación para el cálculo de raciones en rumiantes. *Revista Cubana de Ciencia Agrícola* 33 (1):13.
 30. Rodenburg J (2004) Body Condition Scoring of Dairy Cattle. OMAFRA Factsheet. [online] Order (92–122): 414–420. Disponible en: <http://www.omafra.gov.on.ca/english/livestock/dairy/facts/00-109.htm> [Accedido: 04/09/20].
 31. Souissi W, Bouraoui R (2020) Relationship between body condition score, milk yield, reproduction, and biochemical parameters in dairy cows. In: *Biology, physiological basis, nutritional requirements, and modelization*. M'Hamdi, Naceur (Ed.). National Agronomic Institute. ISBN: 978-1-78984-547-1. <https://doi.org/10.5772/intechopen.85343>
 32. StatPoint Technologies (2010) Statgraphics Centurion. (ser. Centurion), version 16.1 (XV), [Windows], Disponible en: <http://statgraphics-centurion.software.informer.com/download/> [Accedido: 15/04/2012].
 33. Thomsen SJ, Poudel S, Fike JH, Pent GJ (2023) Heifer performance and body temperatures in an open pasture versus silvopasture in the mid-Atlantic USA. *Agrofor Syst* 98:47–59. <https://doi.org/10.1007/s10457-023-00889-1>
 34. Tzec-Gamboa Magnolia del C, Álvarez-Rivera OO, Ramírez-Avilés L, Solorio-Sánchez FJ (2023) Decomposition and nitrogen release rates of foliar litter from single and mixed agroforestry Species under field conditions. *Agriculture* 13 (1): 222–238. <https://doi.org/10.3390/agriculture13010222>
 35. Vargas-Hernández S (2013) Producción de leche bovina tropical sostenible. Diseño, manejo y evaluación de agroecosistemas. Un enfoque integrado. Editorial Académica Española, AV Akademikerv Verlag GmbH & Co. KG Heinrich-Böcking-Str. 6–8 D – 66121 Saarbrücken. ISBN 978-3-639-55125-9. 158p.

36. Viñoles C, Fedrigo JK, Gonzalez VB, García L, Báez F (2022) Avances en el conocimiento sobre Sistemas Silvopastoriles en Uruguay. *Archivos Latinoamericanos de Producción Animal* 30 (Supl. 1), 43–53. <https://doi.org/10.53588/alpa.300505>
37. Wilkens P, Munsell JF, Fike JH, Pent GJ, Frey GE, Addlestone BJ, Downing AK (2022) Thinning forests or planting fields? Producer preferences for establishing silvopasture. *Agrofor Syst* 96(3):553–564. <https://doi.org/10.1007/s10457-21-00665-z>

Figures

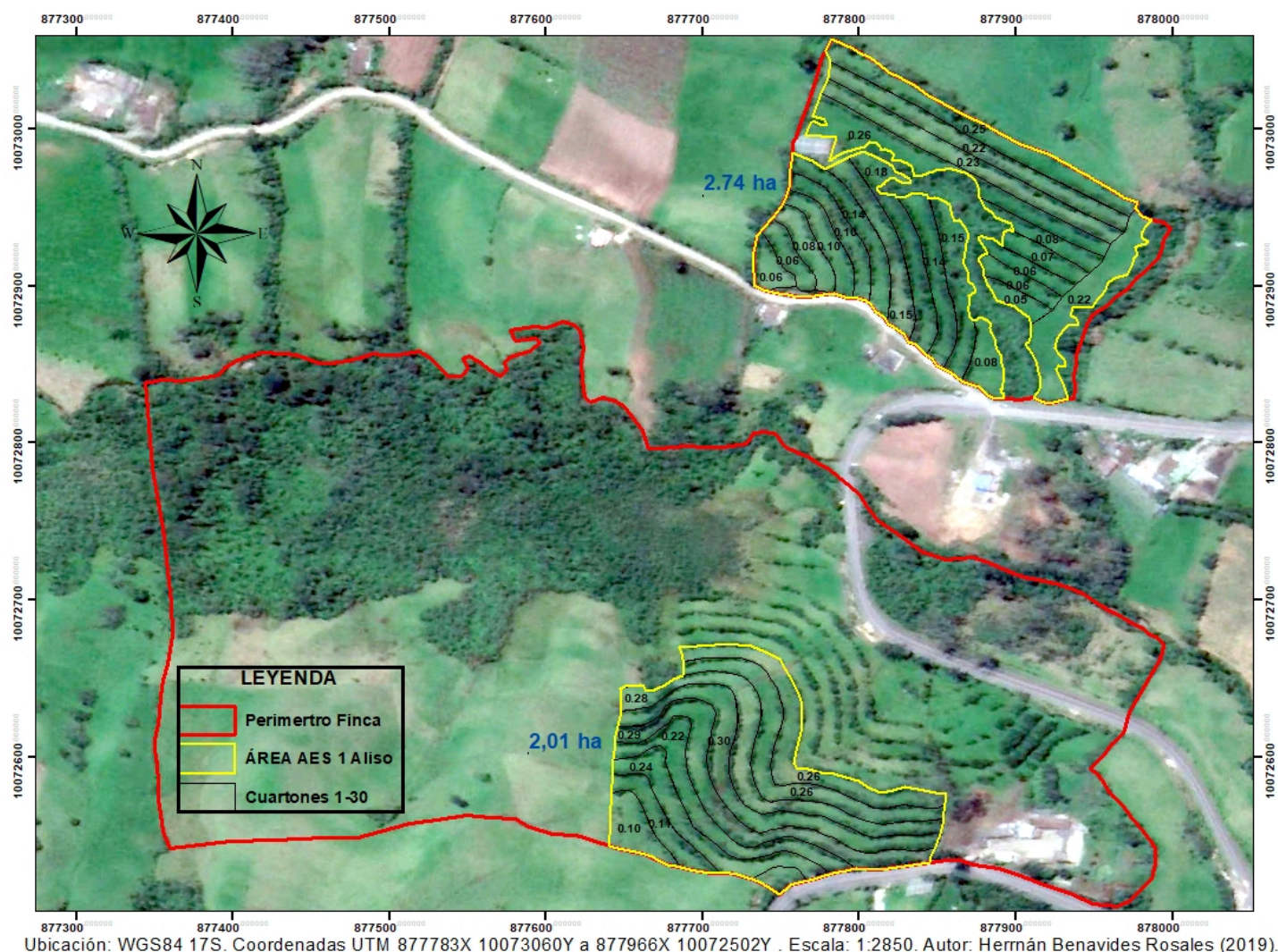


Figure 1

Location, establishment, and characteristics of AES 1, with Alder trees, which were planted following contour lines and protected with double electric fences (Google Earth, Anexo 1. Ubicación del AES 1, 2019)

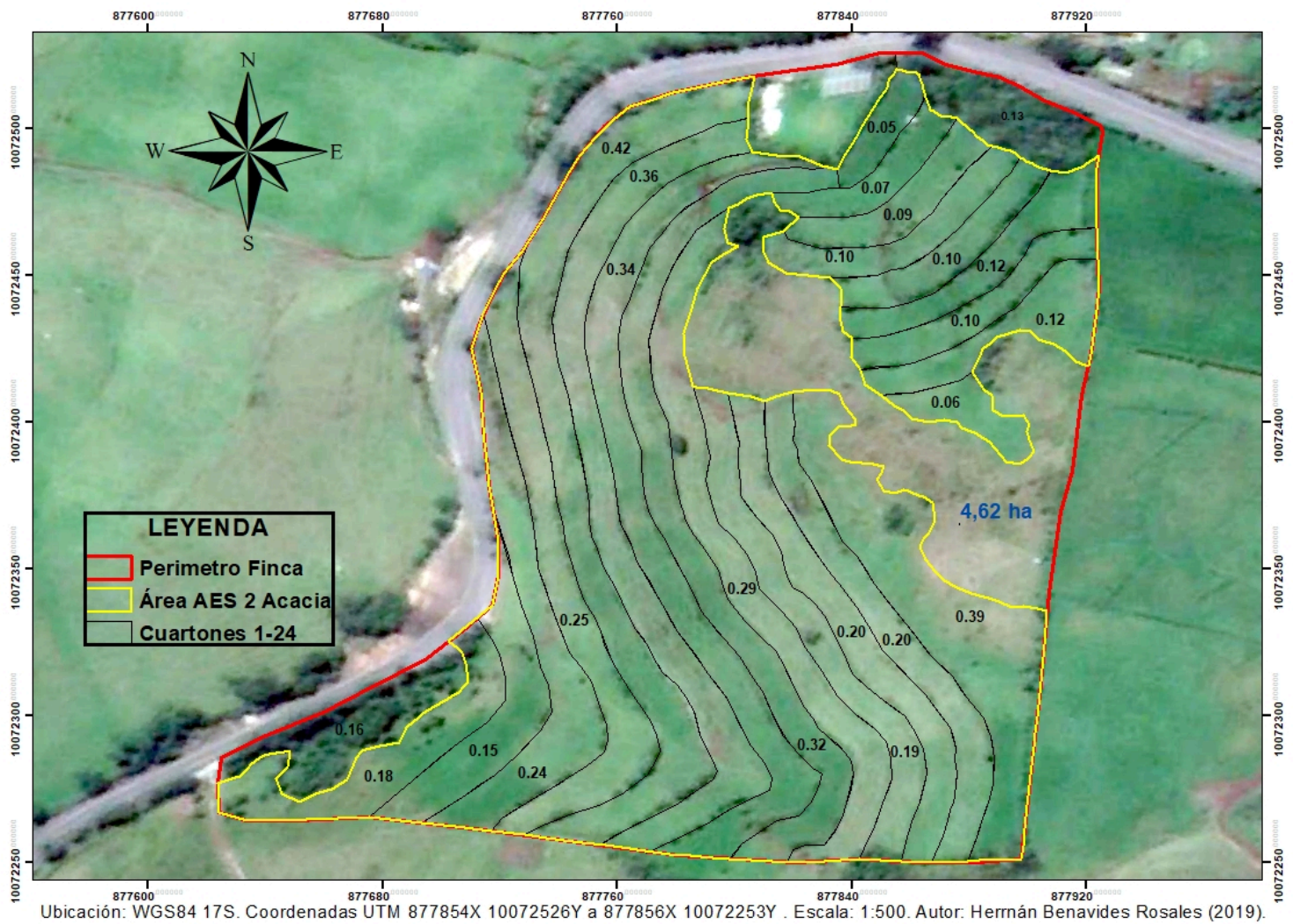


Figure 2

Figure depicts the location, establishment, and characteristics of AES 2, which features Acacia trees planted in accordance with contour lines and safeguarded by double electric fences. Imagen capturada desde Google (Google Earth, Anexo 1. Ubicación del AES 1, 2019)

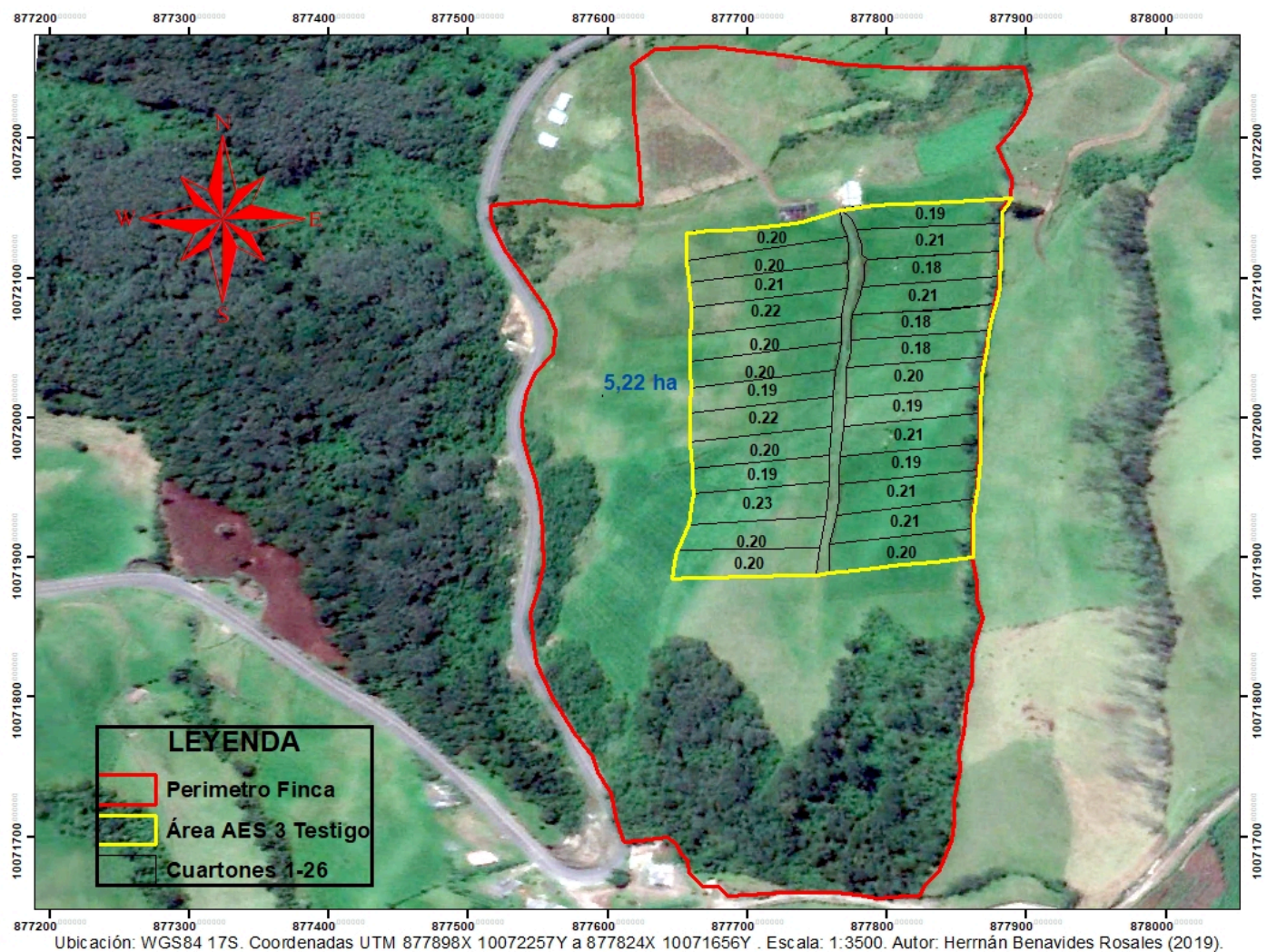


Figure 3

Ubicación y características de AES 3 (Control) Imagen capturada desde Google (Google Earth, Anexo 1. Ubicación del AES 1, 2019)