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Intensive clean livestock production system with rational Voisin grazing Case study: Bendavales farm–Versalles–Colombia

Sistema de producción ganadero intensivo limpio con pastoreo racional Voisin Estudio de caso: Finca Bendavales–Versalles–Colombia

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RESUMEN

This research tested the impact on the soil when implementing a Clean Intensive Livestock Production System (CILPS) via Voisin Rational Grazing (VRG). The methodology consists of the characterization of soil-grass-cattle management, including the soil chemical and biological analysis in the case study farm and reference land (comparison between extensive and CILPS-VRG systems). In addition, the VRG impact on agroecological management was evaluated by calculating the Soil Organic Matter Indicator (SOMI). Once the samples were processed, the T-Student test was applied, verifying the homogeneity of variances (F-Fischer) for the chemical variables and the Kruskal-Wallis test for the biological variables. The results identified substantial differences in some edaphic parameters such as organic matter, percentage of organic carbon, nitrogen, sulfur, and calcium. Moreover, to diversify nematodes and differences in the *Rhabdhitids* sp., the process characterized products from the natural organic fertilization in the soil with VRG. Finally, the calculation of the SOMI with a value of 41.6 for VRG indicates soil with no alteration or natural balance.

KEY WORDS: Clean Intensive Livestock Production System; Extensive Livestock Production System; Voisin Rational Grazing; good farming practices; soil management.

ABSTRACT

Este trabajo evaluó los resultados de la implementación de un Sistema de Producción Ganadero Intensivo Limpio (SPGIL) en el suelo, con Pastoreo Racional Voisin (PRV). La metodología se plantea desde la caracterización del manejo del suelo-pasto-ganado hasta el análisis químico y biológico del terreno en la finca estudio de caso y predio de referencia (comparación entre sistemas extensivo y SPGIL-PRV). Además, se evaluó el impacto del PRV en el manejo agroecológico, calculando el Indicador Acumulativo del Suelo (IAS). Una vez procesadas las muestras, se aplicó la prueba T-Student verificando la homogeneidad de varianzas (F-Fischer) para la variables químicas y la prueba Kruskal-Wallis para la variables biológicas. Los resultados identificaron diferencias significativas en algunos parámetros edáficos como materia orgánica, porcentaje de carbono orgánico, nitrógeno, azufre y calcio; además, mayor diversidad en nematodos y contrastes relevantes en la especie *Rhabdhitids* sp., resultados de la fertilización orgánica natural producida en el suelo con PRV. Por último, se estableció el cálculo del IACS con un valor de 41,6 para PRV, lo que indica un suelo inalterado y equilibrado naturalmente.

PALABRAS CLAVE: Sistema de Producción Ganadero Intensivo Limpio; Sistema Extensivo de Ganadería; Pastoreo Racional Voisin; buenas prácticas ganaderas; sostenibilidad de suelos.

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Introduction

In specific hillside zones of Colombia, livestock production has been linked to land degradation due to overgrazing and soil compaction. In addition, 98% of cattle production systems in the tropics are based on pasture and forage, worsening climate change, which makes it necessary the development of easily adoptable and profitable sustainable technologies: processes to vault an efficient use of available resources. In the country, there are projects such as the Colombia Mainstreaming Sustainable Cattle Ranching (CMSCR), sponsored by the World Bank, the Colombian Livestock Federation (Fedegan), the Center for Research on Sustainable Agriculture (CIPAV), the Colombian NGO Fondo-Acción and the Nature Conservancy, which promote Silvopastoral Systems (SPS), enhancing biological diversity and the provision of environmental services at local, regional and global levels. Unfortunately, according to experts, some of these attempts have failed, i. e., transfer of species incompatible with the environment, poor management of animal stocking, pest attacks, lack of training, and extreme climates. However, there is another endogenous, ecological, easy-to-assume, and economic model: it is the System of Intensive Clean Livestock Production (SICLP), which addresses proper livestock practices, with Intensive Rotational Grazing or Voisin Rational Grazing (VRG), based on pasture management where cattle is rotated to favor soil recovery. It also prohibits plowing, agrochemical fertilizers, amendments, and chemical veterinary drugs for livestock (Voisin, 2008). Therefore, the VRG seeks the profitability of the livestock system by relying on adequate pasture management; it conceives an agroecology technology to obtain economic benefits thanks to the absence of fertilizers or chemical amendments and commercial veterinary drugs for livestock. Moreover, as an environmental benefit for biodiversity and soil fertility, the VRG generates ecological and healthy dairy or meat production for consumers.

VRG has shown its efficacy in documented livestock production in countries such as Cuba, Brazil, Argentina, and Costa Rica. Research by Ojeda et al. (2014) indicates the benefits of VRG in increasing land fertility and animal carrying capacity over Mollisol soil in a 230-hectare production. The study was conducted on three properties: VRG, Soybean Farming (SF), and Natural Fallow (NF). The SF and NF include all crop years, soil plowing, fertilization, and glyphosate applications. Before and after 18 years of VRG use, the most significant changes were a 0.4 pH reduction in soil acidity, a 48% reduction in electrical conductivity, a 58% increase in organic carbon, and a 26% increase in total N. Hence, SF and NF treatments improved soil conditions via animal management and pasture promotion.

A study published by Ojeda et al. (2019) in a production unit in Barinas, Venezuela, shows the benefits of VRG on the soil, where experiments were conducted in different plots, whose results conclude that VRG provides high phosphorus fertility. Another research realized by Zin et al. (2018) in the state of Santa Catarina, Brazil, analyzed soil samples from four systems: VRG with trees, VRG without trees, primary forest, and secondary forest, whose results indicated that VRG combined with trees promises as a production system to enhance soil chemical attributes, with high content of organic matter, carbon, nitrogen, phosphorus, potassium, calcium magnesium, and pH.

In Colombia, projects are implemented on farms in the *Eje Cafetero*[1] zone, Valle del Cauca, Atlantic Coast, Cundinamarca, Meta, Tolima, Huila, Santander, and Boyacá as productivity practices; however, there is scarce research related to soil improvement. Jaramillo (2002) cites Perea et al. (1991), who studied the time effect when using a grazing system on sandy clay loam in a steep relief of the department of Huila. The results from this study for the first 5 cm indicate that as long as grazing is used correctly and time is dedicated to pasture recovery, substantial improvements are obtained in the physical properties of soils subjected to livestock exploitation. Sadeghian (2000) explored the impact of livestock and some sustainable alternatives for land management through a multidisciplinary analysis. The results made it possible to propose specific

1 Colombian coffee region.

practices and actions for viable soil management in the department of Quindío, a reasonable attempt for other regions with similar characteristics.

Linares (2006) established the sensitivity of some physical, chemical, and biological properties of the soil, identifying sustainability indicators for the livestock production system. So, during two seasons (summer – winter), this research measured bulk density, mechanical resistance to penetration, aggregate stability, organic matter, pH, soil respiration, and macroinvertebrates' biodiversity. In conclusion, the reaction of the soils in the different treatments was acidic or slightly acidic without significant statistical differences between treatments, horizons, or the two climatic seasons. The organic matter for the first 10 cm showed considerable differences since the properties of organic matter change, especially at the soil surface, where the maximum biological activity takes place.

Patiño et al. (2006) used the chemical analysis of historical records of 39 settlements of Valle del Cauca in the Eje Cafetero area; in the case of Versalles, 351 samples are related. These results —compared with those of other settlements and analyzing them descriptively— identified low organic matter and aluminum. However, the area holds much phosphorus due to soils composed of volcanic ash, characteristic of a high fixation capacity. Like calcium, the high potassium content is explained by the cartographic unit called Fondesa, whereas magnesium is at a medium level.

In Colombia, there is no pertinent research on managing soils with VRG aimed at the sustainability and balance of the environment and its habitat. The chemical and biological characteristics in Versalles' soil show the existing difficulties that make the VRG use essential for quality improvement. The objective relates the implementation and characteristics of the VRG system in the Bendavales' farm soil and the traditional extensive technique in the surroundings, in which a laboratory process takes the samples for obtaining the chemical and biological features to statistically evaluate the property conditions and, finally, conclude on their status according to the results.

Materials and methods

The research was completed in the Bendavales farm —El Diamante rural settlement (*vereda in Spanish*) in the municipality of Versalles, in the north of the department of Valle del Cauca, on a slope of the Western cordillera, bordered to the north by the municipalities of El Cairo and Argelia, to the south by El Dovio, to the west by Los Paraguas mountain range and the municipality of Sipi in the department of Chocó, and to the east by Toro and La Unión. Its altitude is 1860 masl, with an average temperature of 20°C. Its geographical coordinates are 4°34'43" N latitude and 76°12'23" W longitude. The soil origin or parental material comes from volcanic ash; the land is located in a geomorphological position of high hills with a 25% to 50% slope and a cartographic unit of consolidation Fondesa (Alcaldía Municipal de Versalles Valle del Cauca, 2016). Bendavales' total area comes to 22 hectares, 4 are forested, and 18 have used SICLP for more than 10 years. The impact on the resulting soil was evaluated, considering the quality as an essential factor to chemical, biological, and microbiological features that become an environmental benefit for biodiversity and fertility.

The methodology applied, soil characterization, pasture, and livestock management were obtained by gathering qualitative information from personnel knowledgeable about the property (Figure 1). Soil samples were also taken from the Bendavales farm and the nearby property for chemical and biological analysis. T-Student processed and analyzed the soil samples through a hypothesis test for the chemical variables. F-Fisher tested the previous homogeneity variance, and the Kruskal–Wallis one-way analysis of variance compared the biological data. Thus, the results of conventional production methods (extensive) were compared and, finally, the impact of the VRG agroecological management was evaluated by calculating the Soil Organic Matter Indicator (SOMI).

The property covers 22 hectares. A grazing system is applied with trees planted on 18 hectares and 60 paddocks nearly 2500 m^2 in size. The paddocks are mainly composed of a mixture of star grass

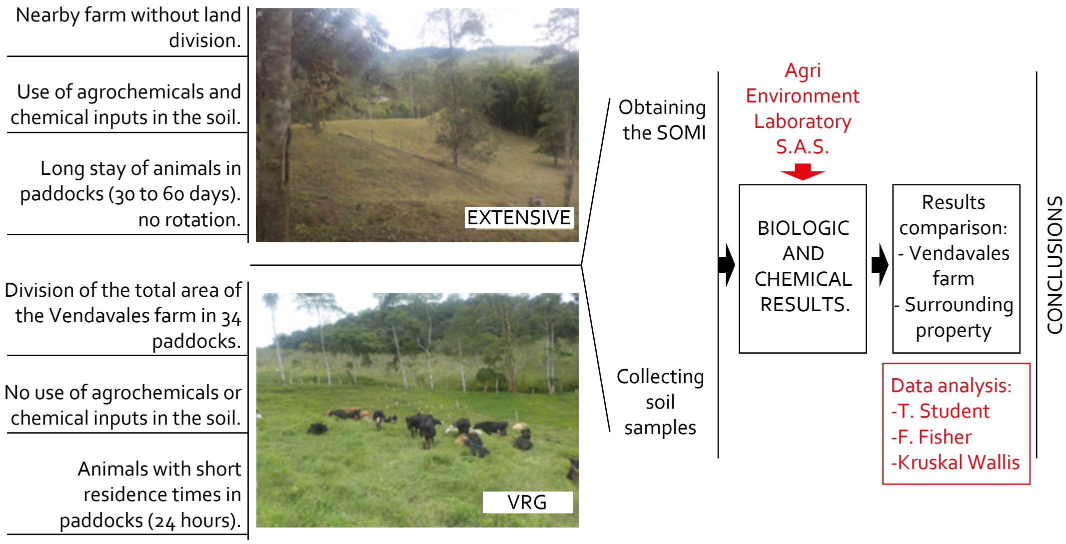

Figure 1. Methodology

(*Cynodon nlemfuensis* Vanderyst), kikuyu grass (*Cenchrus clandestinus* Chiovenda), Morrone or *Pennisetum clandestinum* Chiovenda), braquiaria (*Urochloa eminii* Mez) Davidse or *Brachiaria decumbens* Stapf), as well as some species of herbaceous legumes cacahuete pinto (*Arachis pintoi* Krapovickas & W. C. Gregory), ramie (*Boehmeria nivea* L. Gaudichaud-Beaupré), maize (*Zea mays* L.), canavalia bean (*Canavalia ensiformis* L. Candolle), and wild bushes Mexican bush-daisy (*Tithonia diversifolia* [Hemsley] Gray).

For soil and pasture management, the paddocks were divided: the grazing area was small but with enough space available, and the animals could rotate, occupying little time. It reduces the trampling on the soil and facilitates animal management. The cattle spent in the paddock (stocking rate: 35 cattle for milk production) 24 hours to recover the pastures in 60 days. Therefore, with the VRG, the paddocks are only occupied for 6 days out of 365, thus giving rest time to other pastures (359 days). For the recovery of each paddock, a rotation is sought in which the one with the most pasture is chosen, taking care that undesirable grasses do not flourish or pests grow. The use of chemical fertilizers, chicken or pig manure, or any other type of amendment is not allowed in the paddocks since these elements interfere with the biological activity of soil microorganisms.

In addition, there is no chemical weed control on the pastures, the remaining grass is not scythed because the twelve (12) horses do this work, and planting appears with the seeds provided by the manure. However, the most relevant contribution to the soil is the gradual restoration of the levels of organic matter and natural balance, which makes it more productive by improving its fertility. Three conditions are required to achieve these benefits: instantaneous load (a large number of animals in a given space, with enough trampling in a short time), biological factors (intense work of transformation of manure and urine into beneficial substances), and clear soil (no application of substances). For the analysis of the degree of soil disturbance, the Soil Organic Matter Indicator (SOMI) was implemented, comparing the effects of different management systems on soil quality through the evaluation of a minimum set of selected indicators according to the specific conditions of the farm (Obando & Montes, 2007). For this purpose, ten soil quality indicators were chosen according to the samples taken and the observation; each one taking a value between 1 to 5, where 1 is extreme, 2 is severe, 3 is moderate, 4 is mild, and 5 is none. The rating sum of the 10 selected indicators is the SOMI of each sample, represented by the equation of Obando and Montes (2007).

$$SOMI = \sum_{i=1}^{n} I_i \qquad (1)$$

Table 1. Alteration qualification and degree of soil quality

Cumulative index	Percentage (%)	Quality/Sustainability diagnosis	Degree of alteration
>40	>80	High	None
30–40	60–80	Healthy/Sustainable	Mild
25–29	50–58	Healthy/Sustainable with remediation measures	Moderate
20–24	40–48	Healthy with other land use (for example, less demanding or stress-tolerant crops)	Severe
<20	<40	Unhealthy (irreversible short-term degradation) / unsustainable	Extreme

Source: adapted from Obando and Montes (2007).

Where I_i is the i-th quality indicator and n is the total of indicators which for this work takes the value of 10. That is how the SOMI oscillates between the minimum value of 10 and the maximum value of 50 in Table 1. To evaluate the SOMI in percentage, 100% corresponds to 50, the maximum value.

Ten indicators were selected to calculate the SOMI, as shown in Table 2, eight are based on soil analysis, and the other two indicate the cover and height of the grass. With the SOMI results and by comparing them with the data in Table 1, the degree of soil disturbance of each sample can be known.

For the chemical and biological analysis, samples of approximately 1 kg each were taken at a depth of 30 cm, zigzagging through both properties (Vendavales farm and neighboring property), taking approximately 150 data. The analysis included the following determinations: texture by Bouyoucos, pH by a potentiometer, organic matter (OM) by the Walkey-Black method, available phosphorus (P) by the Bray II method, total nitrogen (N) by the Kjeldahl method, potassium (K), calcium (Ca) and magnesium (Mg) by the 1 N pH 7 ammonium acetate method, aluminum by the KCl method, iron (Fe), copper (Cu), zinc (Zn), manganese (Mn) by DTPA extraction, the electrical conductivity of the saturation extract (EC) by electrometric, effective cationic exchange capacity-ECEC, carbonates, bicarbonates, sulfate chlorides. Each of these farm variables was compared with those of another conventional system using fertilization or amendments.

Samples were taken in the morning to obtain representative information on soil biota, as it is a biological indicator of quality (Feijoo and Knapp, 1998): diversity, number, and functions are sensitive to stress and environmental changes in soil conditions associated with tillage, fertilizer, and pesticide

Table 2. Evaluation of soil quality indicators

Indicator	Results (1-5)		
	Poor (1-2)	Regular (3-4)	Good (5)
pH	pH 5 or lower	pH 5.1 to 5.9 and greater than 7	pH between 6 and 7
Organic matter (%)	Less than 7	7 to 9.9	Greater than 10
Carbon (%)	Less than 4	4 to 5.9	Greater than 6
Nitrogen (%)	Less than 0.2	0.2 to 0.29	Greater than 0.3
Potassium (cmol kg^{-1})	Less than 0.32	Between 0.32 and 0.5	Greater than 0.5
Calcium (cmol kg^{-1})	Less than 4.4	4.5 to 6.9	Greater than 7
Sulfur (cmol kg^{-1})	Less than 5.5	5.5 to 6.9	Greater than 7
Soil cover and grass height/direct observation	Soil cover is less than 50% and grass height is less than 10 cm	Coverage between 50% and 80% and grass height between 10 and 20 cm	Soil covers more than 50% and grass height more than 10 cm
Root development/direct observation	Few fine roots on the surface	Some fine roots on the surface	Many fine roots on the surface
Shannon index's diversity of species/calculated	Less than 1	Between 1 and 2	Greater than 2

Source: own elaboration based on soil analysis.

application, burning, logging, and other activities subject to agricultural systems (Blair et al., 1997).

The measurement of the microfauna and mesofauna in the soil was conducted through the methods LBC-200 and 201: confidential internal protocols validated by themselves related to the number of individuals found in 250 cm^3 of soil. These bioedafic data were subjected to quantitative analysis applied to the variable of diversity and abundance for the biotic community. We used the Shannon-Wiener proposal to calculate the diversity index (Krebs, 1999).

$$H = -\sum\left(\frac{n}{N}\right) \times log_2\left(\frac{n}{N}\right) \quad (2)$$

Where H is the Shannon-Wiener diversity index, n is the number of individuals in the morph group, and N is the total number of individuals in the sample. The index includes the number of species present in the study area (species richness) and the relative number of individuals of each species (abundance). In the laboratory, we elaborated a database using calculation software, exporting it then to the statistical program SAS. v. 7. The soil chemical variables were analyzed employing hypothesis tests with T-Student after homogeneity of variance study via F-Fisher. The above indicates representative differences concerning the means of the samples with the variance comparison whose interpretation is presented according to the significance criterion for values lower than 5%. On the other hand, it was impossible to normalize the SOMI and the biological indicators by applying the Kruskall-Wallis non-parametric test to detect differences between medians ($p<0.05$) in both treatments (Daniel, 2010).

Results

The soil analysis identified considerable differences between the traditional or extensive system and the VRG in the chemical-edaphic factors. This research achieved its results through the T-Student test (lower limit, average, upper limit, standard deviation, coefficient of variation, %), whose results must be $p<0.05$ to demonstrate the difference.

According to the process specified in Figure 2, the variables organic matter (OM) and organic carbon percentage (OC%) showed notable differences between the extensive system and the VRG, whereas the pH, electrical conductivity (EC), and efficient cation exchange capacity variables (ECEC) did not reveal substantial differences.

Regarding macronutrients (N, K, Ca, Mg, and S), Figure 3 shows the significant difference in the variable calcium (Ca), and those results were higher in nitrogen (N) and sulfur (S). Also, in the analysis of the minor elements (Fe, Mn, Cu, Zn, and B) and the cation relationships (Ca/Mg, Ca/K, Mg/K, (Ca+Mg)/K, and Ca: K), we did not find significant differences between the extensive system and the VRG.

Likewise, for the case of microbiological indicators in Figure 4, no significant statistical differences were detected since the following species were distributed in each treatment: *Trichoderma* sp., *Penicillium* sp., *Mucor* sp., *Fusarium* sp., yeasts, aerobic mesophilic bacteria, *Pseudomonas* sp., and *Cladosporium* sp. In contrast, nematodes were the representative group for the mesofauna, where only one species (*Rhabditis*) showed significant differences between the two treatments.

On the one hand, according to the average SOMI score of the reference system represented by extensive cattle ranching and chemical management, an average score of 28.6 was obtained based on the methodology of Obando and Montes (2007), summarized in Table 1: the soil presents a moderate degree of alteration. On the other hand, the values shown with the VRG system implemented on the farm yielded an average SOMI of 41.6, representing soil with no degree of alteration.

When analyzing the data statistically with the Kruskall-Wallis test (Daniel, 2010) presented in Figure 5, it was observed that the variables of organic matter, calcium, sulfur, root development, vegetative cover, and even the SIMO showed significant differences, indicating that agroecological management via VRG improves soil conditions. However, the percentage of carbon and nitrogen, although not relevant because they were above 5%, did not exceed 10%. Unlike pH, phosphorus and Shannon index did not show notable differences between both production systems, which is consistent with the T-Student test.

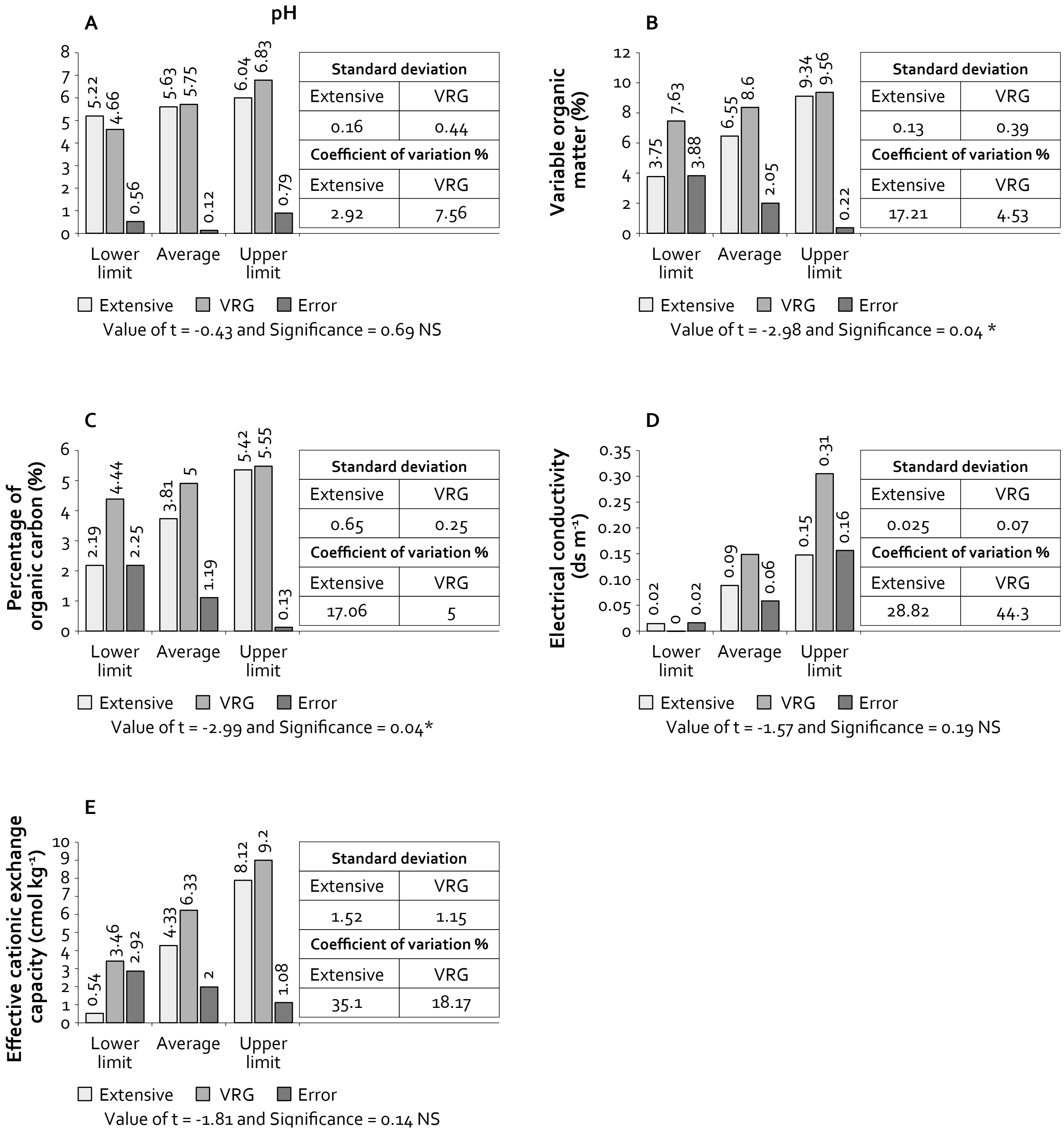

Figure 2. Soil chemical properties of both farms: A: pH; B: organic matter; C: organic carbon; D: electrical conductivity, and E: effective cationic exchange capacity. *NS* means no significant difference between the extensive system and VRG, and * means significant difference. *Source:* own elaboration

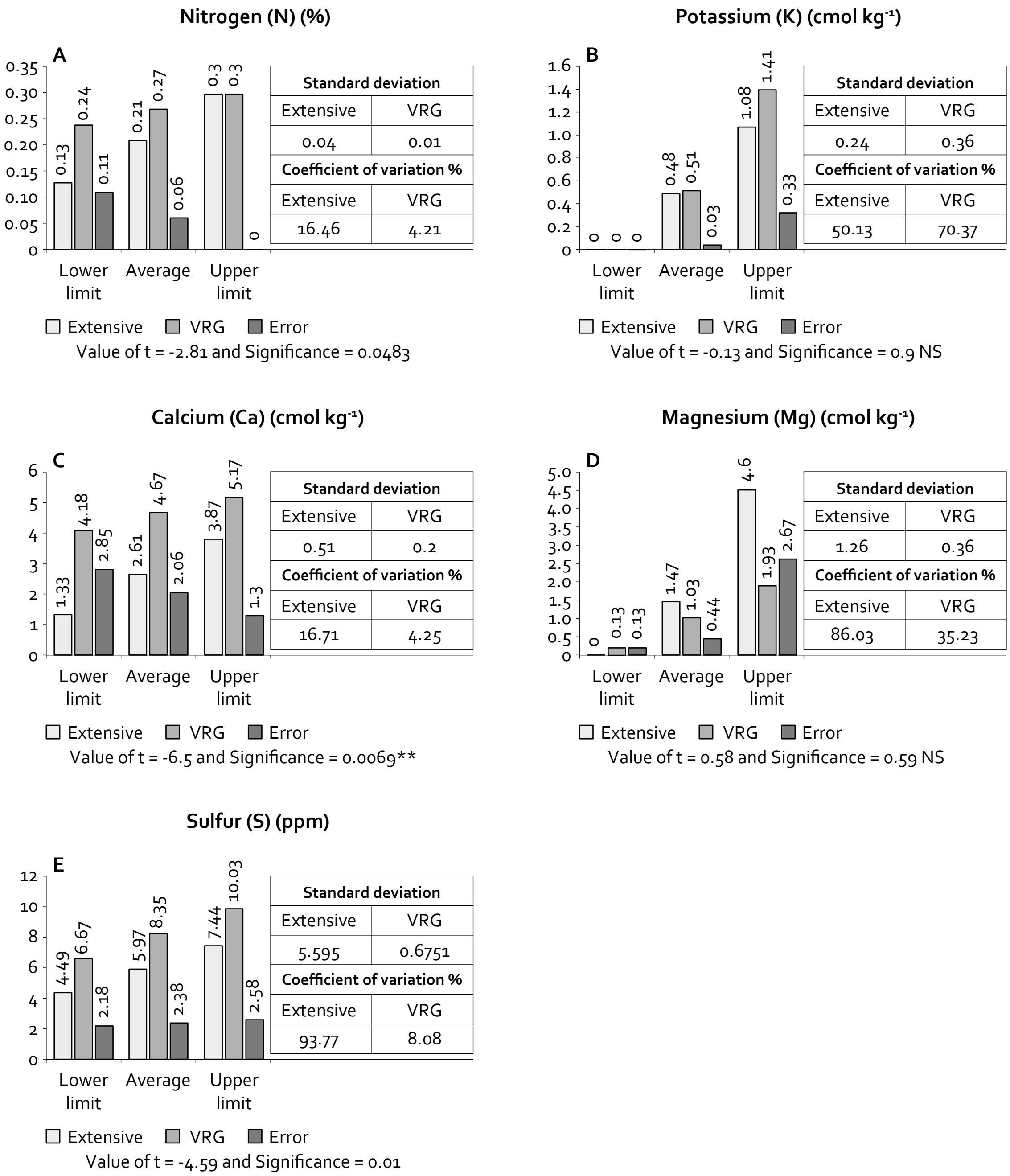

Figure 3. Comparison of soil macronutrients in both farms: A: nitrogen; B: potassium; C: calcium; D: magnesium, and E: sulfur. *NS* means no significant difference between the extensive system and VRG; * means a significant difference, and ** means a very significant difference. *Source:* own elaboration

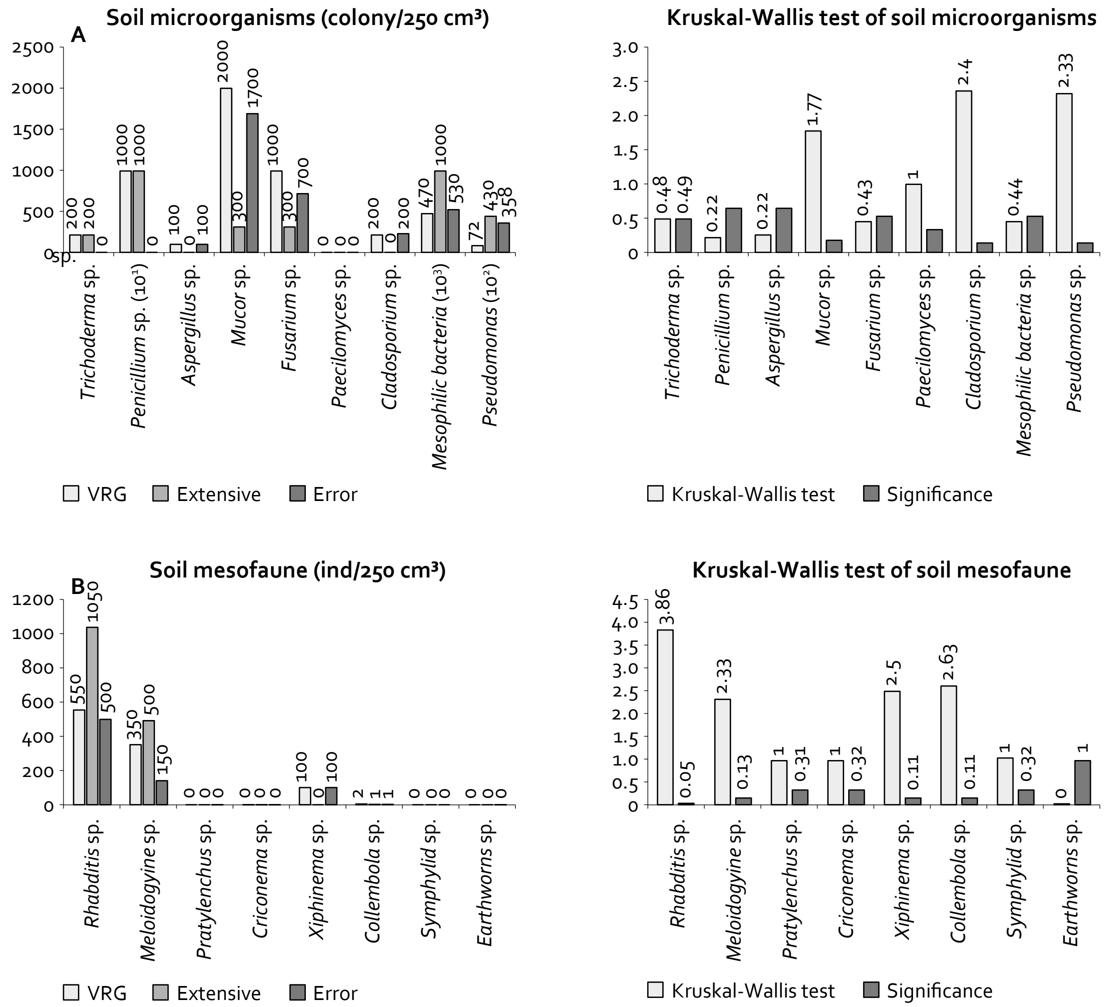

Figure 4. Soil microorganisms (A) and mesofauna (B) on both farms with the Kruskal-Wallis test. *NS* means no significant difference between the extensive system and VRG. *Source:* own elaboration

Table 3. Indicator qualification and SOMI soil quality index for the VRG and the extensive system

Indicator	VRG			Extensive		
	Repetition			Repetition		
	1	2	3	1	2	3
pH	5	4	4	4	4	4
Organic matter (%)	4	4	4	2	3	2
Carbon (%)	4	4	3	2	2	3
Nitrogen (%)	4	4	3	3	3	2
Potassium (cmol kg^{-1})	5	3	2	2	4	5
Calcium (cmol kg^{-1})	4	4	4	3	3	3
Sulfur (cmol kg^{-1})	5	5	5	2	3	3
Soil cover and grass height/direct observation	5	5	5	2	2	3
Root development/direct observation	5	5	5	2	3	3
Shannon index's diversity of species/ calculated	3	4	4	3	2	4
TOTAL	44	42	39	25	29	32

Source: own elaboration.

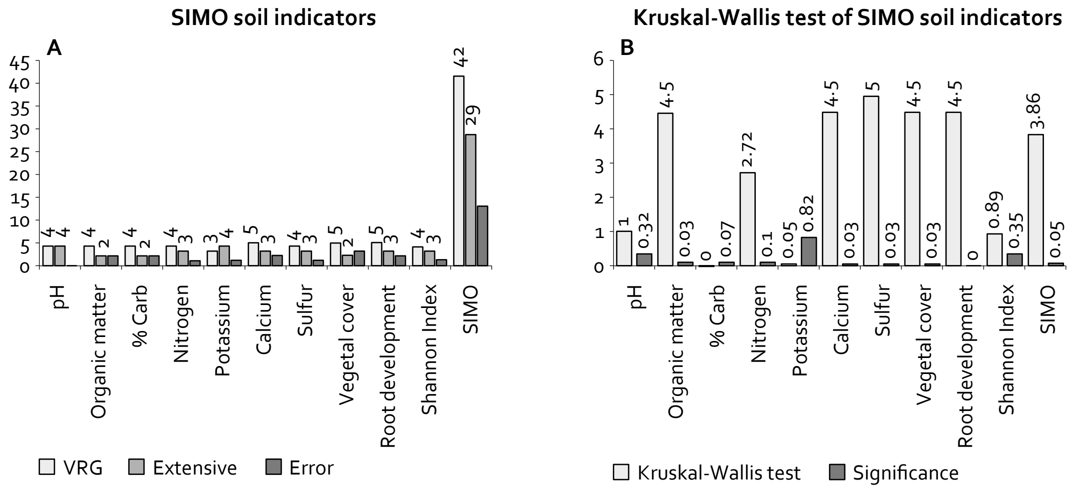

Figure 5. SIMO soil indicators in both farms. *Source:* own elaboration

Discussion

There is a very significant difference in Ca, coinciding with the study of Flores (1996), who concludes that animals can return nutrients to the soil through their excretions: up to 90% of N, K, and Ca, 80% of the P, and 50% of the OM they consume in their diet. Likewise, manure depositions increase the content of Ca, organic matter, and other minerals. According to Mejía et al. (2019), in addition to cow excreta (urine and feces), other components participate in the return of nutrients to the soil; in this case, the grazing system generates senescent material from trees grass and leaf litter present in the pasture. Likewise, Martínez et al. (2014) expose results where trees planted in silvopastoral systems raise or maintain soil pH and nutrient availability (phosphorus, potassium, and calcium).

Consequently, organic matter was significantly different, as seen throughout this paper: higher in the VRG than in the extensive system. Several authors confirm it, among them Perea (1991), cited by Jaramillo (2002), who compares traditional and intensive grazing at different times, verifying the increase in OM over the years with intensive 24-hour grazing, as well as Pinheiro (2004). It is also noteworthy that there is a relationship between organic matter and the percentage of carbon (% CO), where soil humus represents 85% of the OM, and the blackish color comes from the amount of carbon composing it (Velasco, 2015). Therefore, if there is a significant OM content, there will be in the % CO, as evidenced in this study, as well as in other research: Borie et al. (1999) and Martínez et al. (2008) describe organic carbon as essential for soil biological activity and serves as an energy source for organisms. Ojeda et al. (2014) conclude that besides carbon, nitrogen and sulfur improve substantially with the VRG system when combined with animal management.

As for biological indicators, the identified mesofauna included nematodes, constituting the largest population, associated with two functional groups of bacteriophages (genus *Rhabditis*) and fitoparásitos (género Meladogyne). Further, the bacteriophage nematodes (genus *Rhabditis*) showed significant differences between the two treatments, with a lower population in the VRG than in the extensive treatment, a similar result to the studies on nematofauna by Ibáñez et al. (2005) and Leguízamo and Parada (2008) comparing high Andes forests and pastures. In the forests, 67% of bacteriophages with high adaptive capacity was reported, in addition to easy colonization and survival because its food is bacteria and only 3% of phytoparasites; while in the pastures, bacteriophages increased by 76% and phytoparasite nematodes by 48%, due to the increase in organic matter.

The result of the statistical analysis of the SOMI proves the state of the soil without a degree of alteration due to agroecological management with a CILPS coupled with VRG, hence the convenience of implementing soil conservation activities to enhance its quality. Moreover, it agrees with Obando and Montes (2007) and their publications on different systems (forest, coffee, and pasture) in the soils of Caldas and with the soil sustainability indicator in the coffee plantations of the municipality of Rovira, Tolima (Lozano, 2014).

Conclusions

Agroecological management of livestock with the VRG system associated with clean production favors the increase of organic matter (OM) in the soil due to natural fertilization, achieving good pasture cover and height, as well as the biodiversity of forage species. In this way, a healthy pasture supply is maintained despite climatic variability.

From the environmental point of view, there are positive impacts since the VRG betters some soil factors, represented not only in increasing organic matter but also other elements such as organic carbon, nitrogen, and calcium thanks to the organic natural fertilization of manure and animal urine without the need for chemical fertilization.

Although no significant differences were identified in the biological indicators, it should be noted that the predominant taxonomic group was the nemotofauna. The information provided by the SOMI —with agroecological management of a CILPS accompanied by VRG— provides another relevant aspect: it allowed the evaluation of the lower degree of soil alteration by checking whether the PRV is a remedy or improver of the specific soil conditions.

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