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Dairy Cattle under Grazing Systems: An Estimate of the Carbon Footprint in the Northern Andes of Ecuador †

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Abstract: Border production systems are a threat to biodiversity hotspots. This is due to the dilemma of conservation or economic maximization, while the amount of carbon footprint (CF) generated by the management of border grazing and livestock is an uncertainty. The objectives of this study were to determine the socio-demographic characteristics of households, to describe animal and pasture management on farms and to estimate the CF generated by dairy cattle. The study was performed between two protected areas, being the El Ángel and La Bonita reserves, which are located in the Eastern Andean Cordillera of northern Ecuador. While the sampling was performed by conglomerate, the corresponding survey was conducted on the head of the households concerned. A total of 333 farmers from 86 rural households were surveyed. We identified an average of seven individuals per household with no education, while the average pasture area was about 45.3 ha. There was no association of forage species and the modernization of animal management is precarious. In the CF, the Cool Farm Tool program was used. The CF generated indicated that 79% is enteric fermentation of cattle, followed by management of pasture residues. The results of the current study encourage measures focusing on diet management, spread of livestock manure and reuse of grass as compost to reduce the CF of livestock systems.

Keywords: carbon footprint; greenhouse effect gases; grazing management; livelihoods

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1. Introduction

Nowadays multifunctional agriculture has become a key element in the fight against climate change. In recent decades, the increase in the size of livestock productions has been linked to the modernization and intensification of farms [1]. Although this leads to a problem associated with the contamination of water, soil and the contribution to global warming through the emission of greenhouse gases (GHG) such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), each of these gases have become a global challenge due to their possible effects and their useful life in the environment [1,2]. In Ecuador, thirty percent of the population is dedicated to agriculture, livestock, fishing, hunting and forestry. This is a population that mostly lives in the Agricultural Production Units

(APU's) also known as family farms, which can be of less than 50 ha who have Creole cattle managed with artisanal practices or farms with more than 50 ha with a more technical livestock production [3,4] For the year 2018, about 4.1 million head of cattle were reported, with the highest number of animals found in the Highland region with 48.4%, with dairy cattle representing the most head of cattle with 76.5% [5].

Livestock has been identified as one of the contributors to GHG emissions, since it is estimated that it can generate between 18 and 20% of the total GHG emissions of anthropogenic origin, a figure that is able to vary according to the countries. Among the three GHGs in livestock, their contribution is uneven since CO_2 accounts for 9%, CH_4 for 37% and N_2O for 65% [6–8]. Within the livestock sector, ruminants are the main contributors to the production of CH_4 product of enteric fermentation with 80 to 95% and only a small part 5 to 15% is generated by the fermentation of manure and the use of nitrogen fertilizers [9–12]. One of the determining factors for the mitigation of GHG produced in livestock is the feeding given to the animals, ranging from nutritional quality of the diet, level and pattern of ingestion, factors that have their effect on the ruminal environment and on the food transit speed. That determine the development of the microbial flora and the time available to ruminal microorganisms to ferment the food [9,13,14].

The carbon footprint (CF) is a relatively new term that determines the amount of GHG generated and emitted into the atmosphere derived from production activities, referring to the amount in tons or kilos of carbon dioxide equivalent to GHG produced on the day to day, becoming a recognized indicator to understand the dynamics of gases and that allows identifying routes to control, reduce or mitigate their emissions and impact. Based on the aforementioned context, the predominant aims of the current study were to determine the sociodemographic characteristics of households, describe the management of animals and pastures on farms, and estimate the carbon footprint generated by the dairy cattle.

2. Materials and Methods

2.1. Geographic Setting

The study area is located within the northern Ecuadorian Andes, in the productive landscape between: (1) the Area of Conservation and Sustainable Use (ACUS for its acronym in Spanish), created in 2016 with the aim of protecting water sources, moorlands and forests, having an area of 175.6 km^2, where the protected area belongs to the hydrographic basin of the Mira River [15] and (2) the El Angel Ecological Reserve, which has an area of 164.51 km^2, which was created in 1992, being part of the Ecuadorian System of Protected Areas, whose objective is to conserve mainly Hesperian moorlands (Figure 1).

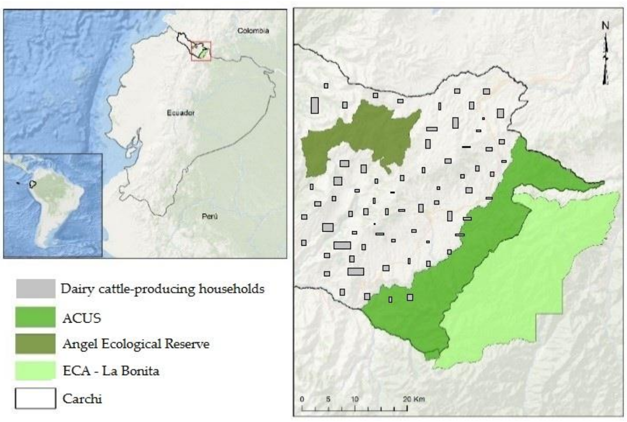

Figure 1. Productive landscape between the El Angel ecology area and the Conservation and Sustainable Use Area (ACUS).

The existing ecosystems in the productive landscape are grassland of the moorland (Hesperian) (RsSn01), high montane evergreen forest of the Western Andean Cordillera (BsAn03), high montane evergreen forest of the northern part of the Western Andean Cordillera (BsAn01), grassland of the moorland (HsSn02) [16]. The productive landscape is superimposed in the province of Carchi (Figure 1), which is an area of great importance for the production of bovine milk in the Andean region [17].

2.2. Data Collection and Sampling System

Our research involved 333 members of 85 dairy cattle-producing households. The data were collected through visits to the site and from interviews with the heads of mestizo peasant households, with a duration of 55 min, between the months of January and February of 2020. The non-probabilistic sampling technique used was for convenience following the criteria: (i) producers maintain subsistence systems (ii) milk production in the area is a source of economic income, (iii) the selected places are representative for the region and ethnicity. The questionnaire was adapted from the Poverty and Environment Network (PEN) template [18]. The descriptive statistics calculated were discrete and continuous quantitative multidimensional variables, using the SPSS 22 program [19].

2.3. Socio-Demographic Characteristics of Households and Management of Animals and Pastures on Farms

We studied the structure of the mestizo peasant population and its distribution by gender and age from a population pyramid (statistical representation). The indices were calculated by (1) Proportions of young population (<14 years), (2) adult population (between 15 to 64 years), (3) child/woman ratio, defined as the number of children under 5 years of age for each woman of reproductive age, (4) masculinity rate, which consists of the ratio of men to 100 women, where in a certain population it is considered the first indicator for the analysis of the distribution by sex in the population, (5) the youth dependency index, which is the relationship between the potentially dependent population (<15 years) and the population of potentially active age (between 15–64 years), (6) the index of the structure of the working-age population, which is the ratio between the population aged 40 to 64 and the population aged 15 to 39, and (7) the replacement rate of the working-age population, which is the ratio among the population n from 60 to 64 years and the population from 15 to 19 years [20,21]. The variables studied in the management of animals and pastures were (1) the experience in milk production (years) and years of schooling (2) total area of the farm (ha), (3) the area dedicated to pasture for milk production (ha), (4) Number of cows in production, (4) Total herd, (5) Number of months that the cows are in production, (6) Total milk production in liters per day, (7) Price of milk, which is expressed as average in dollars per liter.

2.4. Quantification of Greenhouse Gas Emissions

In order to estimate the carbon footprint (CF) in the selected livestock systems, the methodology started with the insertion of the data from each survey in the Cool Farm Tool software, in order to obtain CF data for each farm [32]. The software, through a series of data (inputs) collected in the surveys, estimates the emissions (outputs) of each livestock system studied, based on two criteria, being the per area used (hectares) and the per unit of product (tons) [22].

- Variable inputs: (1) General information, which includes data on the location of the farm, pasture area, climate. (2) Pasture management, which Includes information on the type of soil, fertilizers and pesticides used, waste management. (3) Cattle management, which includes cattle breed, weight, number of animals per category (young, productive, non-productive, feed supplied, amount of milk produced per day, fat/protein content in milk, type of grazing, management of manure.

- Variable outputs: (1) CF from pasture, which comprised of direct and indirect emissions from pasture and emissions from pasture residue management. (2) CF from livestock, which includes emissions from enteric fermentation, manure management, livestock feed emissions, $CH_4/N_2O/CO_2$ emissions.

The survey collected information related to pasture and livestock management. Simultaneously, additional information was obtained in a participatory workshop performed with a group of five experts from the National Autonomous Institute for Agricultural Research (INIAP) who conducted studies in the area. The information regarding soil and climate characteristics of the selected places was collected through secondary sources. With the information generated from the CF estimation, critical points were defined, from which action plans were developed in order to improve the management of the livestock systems in the study area and, in turn, reduce the footprint of carbon.

3. Results and Discussion

3.1. Sociodemographic Characterization and the Management System of Animals and Pastures

In the population stratum studied, there are 46.55% men and 53.45% women. The type of population pyramid resulting from regressive (Figure 2), as there is less population at the base than in the intermediate sections, while at the summit there is a significant number of establishment [23], being contrary to the population dynamics reported by Heredia-R et al. [24]. The mean age of the mestizo peasant men and women was 33.1 and 35.8 years, respectively. The young population was 5.41% in men and 8.41% in women, while the adult population was 37.84% and 42.64% in men and women respectively. The ratio of children per woman was 0.10, while the male ratio was 47%. The proportion of the young dependent population was 17% and the working-age population was 75%, while the replacement population was 9%, being a lower value than those reported with mestizo milk producers in the central highlands of Ecuador [25].

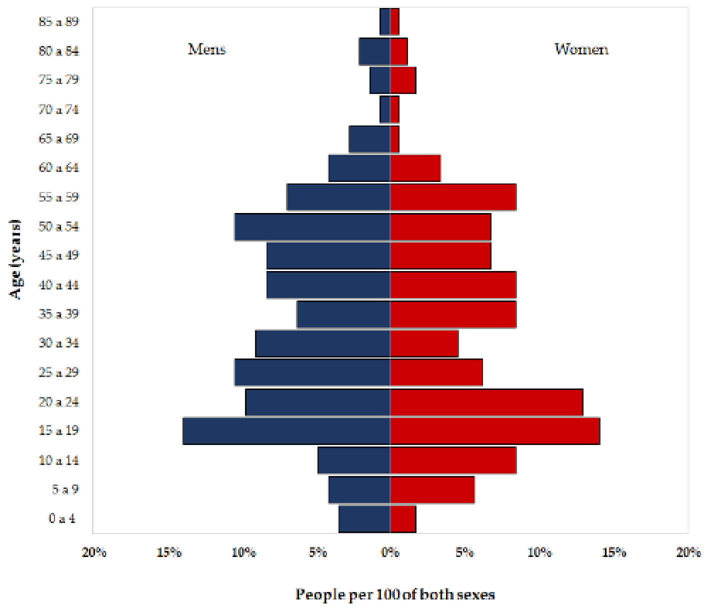

Figure 2. Population pyramid (regressive type) of mestizo milk producers in January 2020.

The experience of the heads of household in milk production is 20.66 years (Max: 50; Min: 2; SD: 11.84) with an average schooling of 3.3 years (Max: 6; Min: 1; DS: 1.06), which is why it is important to implement field schools to promote knowledge innovation [26]. The average area of the farms is of about 6 ha (Max: 27; Min: 0.1; SD: 3.46), being higher than the properties reported in the Ecuadorian central highlands [25]. The area dedicated to pasture for milk production is of 16 ha (Max: 28; Min: 1; DS: 4.05). The number of cows in average production is 4 UPA's (Max: 15; Min: 1; DS: 2.36). In terms of herd, there are 8 average animals (Max: 37; Min: 1; DS: 4.62). The relation to the number of months (average) that the cows are in production are of about 7.03 (Max: 12; Min: 4; SD: 1.21), while the total milk production is of 37.61 L per day (Max: 200; Min: 6; DS: 29.93), while the average price of milk in dollars per liter is 0.36 US dollars (Max: 0.44; Min: 0, 25; DS: 0.03).

3.2. Calculation of the Carbon Footprint in Livestock Systems

Calculation of the carbon footprint in livestock systems dairy farming developed in the ACUS, presents a carbon footprint equivalent to 10.91 tonCO_{2^e} ha^{-1} (Table 1). These values are similar to the CF of intensive mixed systems in three sites study according to the research of Cayambe et al. [17] who report between 10 and 11 ton.kgCO_{2^e} ha^{-1}. Additionally, a low annual CF farm system per finished product is observed, equivalent to 364,689 kgCO_{2^e} ton^{-1}. These results are significantly lower than those presented in the study by González-Quintero et al. [27] in the Colombian Andes, being between 2100 and 4200 kgCO_{2^e} ton^{-1}. However, as mentioned by Figueiredo et al. [28] in other CO_2 quantification studies, the comparison of CF`s between studies is complicated due to the diversity in the limits of the analysis.

Table 1. Variable output: CO_2 emissions from dairy farming systems in rural livelihoods in Ecuador.

Output Variables	A	B	C	D	E	F	G	H	I	J
Unit	kgCO2e ha-1	kgCO2e ton-1	kgCO2e ha-1	kgCO2e ton-1	kgCO2e ton-1	kgCO2e ton-1	kgCO2e ton-1	kg CH4 ton-1	kg N2O ton-1	kg CO2 ton-1
Average	10,915.5	364.68	149.3	192.2	133.31	29.22	2.88	288.8	5.09	152.8
SD	3581.69	117.99	0.16	0	93,52	24.77	2.5	132.99	3.09	93.06
CV (%)	33%	32%	3%	0%	70%	85%	87%	0,46	0,6	0,6

A: Annual farm system emissions by area; B: Emissions Annual farm system per finished product; C: Direct and indirect emissions field N_2O; D: Emissions from crop residue management; E: Livestock enteric emissions; F: Livestock manure management; G: Livestock feed; H: CH_4 emissions; I: N_2O emissions; J: CO_2 emissions.

Annual farm system emissions per ton of milk in Ecuador's subsistence dairy farming systems represent less than 80% of Colombia's emissions in dual-purpose cattle systems (milk and meat). There are several reasons that explain these differences in emissions such as improved pastures [10] higher fertilizer application rates and livestock feeding [29].

In our study, the direct and indirect emissions field N_2O are equivalent to 149.3 kgCO_{2^e} ha^{-1}, which is equivalent to half of the footprint generated in Colombia [27], whose emissions amount to 306.94 kgCO_{2^e} ha^{-1}. This may be due to the different feeding in dual-purpose cattle compared to subsistence dairy farming.

The management of pasture residues generates the greatest contribution to the pasture's carbon footprint, due to the fact that producers abandon the residues in the field [30], The proposed measure consists of directly incorporating these residues or making compost and applying it to the soil or to fertilize other nearby crops. No emissions from fertilizers were observed, due to the almost non-existing application of these.

The carbon footprint estimate indicated that 80.96% of livestock emissions derive from enteric digestion. Methane from enteric digestion is the gas in the highest proportion according to the study, equivalent to 288.80 kgCH_4 ton^{-1}. This is confirmed by many other studies where enteric fermentation is responsible for the highest percentage of emissions [10–12]. Food management alternatives are the main identified mitigation proposal, as stated by Wilkes et al. [14], offering balanced amounts of feed and feed according to the needs of the cattle according to age or production phase could reduce the CF of the conservation area.

Emissions from livestock manure management were 29.22 $kgCO_{2^e}$ ton^{-1}. This is due to the fact that most subsistence livestock systems in the Andes do not handle excreta, which has a greater carbon footprint. In the study performed by Cayambe et al. [17], one of the recommended measures to reduce the carbon footprint in livestock was the dispersal of feces, incorporating it into the soil as compost. In Brazil [31], manure waste is converted into bioenergy. In this way, profits are obtained and costs are reduced, and simultaneously the environment is protected. However, in the ACUS such practice would be relatively difficult to implement, due to the lack of biofuel policies.

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