LIÈGE université
Gembloux
Agro-Bio Tech

GRAZING MANAGEMENT STRATEGIES ADAPTED TO DAIRY CATTLE ON PASTURE IN THE ECUADORIAN SIERRA

Eloy CASTRO MUÑOZ

COMMUNAUTÉ FRANÇAISE DE BELGIQUE
UNIVERSITÉ DE LIÈGE – GEMBLOUX AGRO-BIO TECH

GRAZING MANAGEMENT STRATEGIES ADAPTED TO DAIRY CATTLE ON PASTURE IN THE ECUADORIAN SIERRA

Eloy CASTRO MUÑOZ

Dissertation originale présenté en vue de l'obtention du grade de docteur en sciences agronomiques et ingénierie biologique

Promoteurs: Jérôme Bindelle et Frédéric Lebeau
Année civile: 2023

Abstract

The Ecuadorian inter-Andean valley maintains large agricultural areas called haciendas whose main activity is milk production, surrounding these, we find small and medium producers also considered ranchers. Although both are oriented towards the same markets and implement a clear trend towards intensive production systems, they show a marked difference in the dynamics of productive activity despite sharing similar constraints in term namely of altitude and marked slopes for their pastures. To enhance productive yields, the most extensive and effective application of improved management is sought for by farmers. Options to reach this objective include the composition of herds, the size of the paddocks, the stocking rate and resting times of the meadows, the use of fertilizers, an efficient combination between agricultural crops and pasture renewal and stoking management methods, the latter being possibly one low cost short-term action lever to act upon in order to potentiate dairy farming productivity. However, it is difficult to predict the efficiency and profitability of such efforts, particularly when there is such a distant economic and cultural gap between ranchers in the same country. To the best of our knowledge, the link between grazing management and milk productivity has not been documented in high-relief situations. Our thesis aims to analyze the impact of stocking management methods on the productive performance of grazing cows, in intensive milk production in the Ecuadorian highlands. In addition to analyzing the influence of the relief in the decision making for the conformation of paddocks, in the context of different degrees of slope on the properties. We hypothesized that a grazing management system can be found that is better adapted to the organizational practices of dairy systems in the Ecuadorian tropical highlands, as well as identify some practices that better compensate for the detrimental effects of slopes on animal productivity. To do this, first, 42 milk-producing farms were characterized in different cantons of the rural area of the province of Pichincha (Quito, Mejía, Rumiñahui and Cayambe) of Ecuador. Through a questionnaire to identify the productive and management activities in the herds and evaluate the average slope of the pastures of the farms based on GIS data. The results showed that the farms had an average area of 40 ha, the herds were composed of 60 ± 63 milking cows, predominantly of the Holstein-Friesian breed (65 %), and the daily production of cows in milk reached 15.1 ± 3.4 kg. The highest productivity was found in the farms using rotational stocking with high intensity of instantaneous grazing with very short occupation times (< 12 h), cultural tasks in the meadows (reseeding, resting time, equalization cuts, soil aeration, fertilization, manure dispersion) and a flat topography of the pastures ($p < 0.05$). The steepness of the slopes was not a limitation to establish pastures for grazing animals since pastures were observed in the entire range of slopes, including very steep ones (up to 55 %). The daily production of individual cows was negatively correlated ($r = -0.323$, $p = 0.037$) with the average slope of the surveyed farms. Subsequently, we conducted two grazing experiments to determine the ingestive behavior of dairy cows, under the types of pasture rotation mostly used by farmers in the survey (from rotational stocking with long occupation time to grazing with very short occupation times of 3 hours), to test the relevance of rotations with shorter occupation times on the performance of the system. A first experiment was done on flat paddocks applying three rotational stocking contrasting treatments ranging from very short to long occupation times: three hours, 24 hours and seven days respectively of 7 days. Cows in the long occupancy time treatment spent more time eating, tended to have a higher average speed during forage intake, attributed to a greater displacement per exploration of the entire area assigned for the experimentation time. In the 3-h treatment, greater inactivity was perceived in anticipation of the opening of new areas for grazing during the day. Despite these differences in activity, milk production did not differ in quantity or quality (ie, fat, protein, non-fat solids, total solids). Showing that under grazing conditions with an intermediate forage allocation on flat paddocks and with low-producing cows, the application of a labor-intensive stocking method that requires opening new areas every 3 hours does not lead to a significant increase in the production. Next, we carried out a second grazing experiment in which two stocking methods (long occupancy and very short occupation) on a terrain with moderate relief and with up and downhill displacement of cows on the pastures to harvest the forage. Results showed that cows that grazed the very short time treatment moved more during meals than those placed in the long occupation time treatment. This is explained by the fact that the sub-paddocks 3 hours were designed horizontally to favor lateral walking and avoid the effect of the slope on displacement. While the herd that had freedom of movement throughout the paddock (long occupation time), traveled less (-27 %), leaving higher stubble height in postgrazing (7 cm). Higher volumes and concentration in solids were found in milk for the herd that grazed in the treatment with assignment of new sub-paddocks every three hours.

In conclusion, the combination of grazing management systems with operations that better compensate for the detrimental effects of slopes promote productive yields in dairy farms in the Ecuadorian highlands. The allocation of forage material must be based on a rotation with occupation times that adjust to the slope of the paddocks. Avoiding the unnecessary use of human and economic capital where it does not justify the implementation of shorter rotation times (flat paddocks), guaranteeing the optimization of resources, higher volumes and better quality of the milk produced. Finally, farmers can manage their agricultural processes using the proposals developed in this research according to the resources available in their environment.

Keywords: grazing rotation, tillage, occupation time, volume and quality of the milk, pasture rotation, slope

Résumé

La vallée interandine équatorienne abrite de grandes zones agricoles appelées haciendas dont l'activité principale est la production laitière, autour desquelles on trouve de petits et moyens producteurs également considérés comme des ranchers. Bien que tous deux soient orientés vers les mêmes marchés et mettent en œuvre une tendance claire vers des systèmes de production intensifs, ils présentent une différence marquée dans la dynamique de l'activité productive, bien qu'ils partagent des contraintes similaires en termes d'altitude et de pentes marquées pour leurs pâturages. Pour améliorer les rendements, les agriculteurs recherchent à améliorer leurs modes de gestion. Les options pour atteindre cet objectif comprennent la composition des troupeaux, la taille des parcelles, le taux de chargement et les temps de repos des prairies, l'utilisation d'engrais, une combinaison efficace entre les prairies et les cultures agricoles, le renouvellement des pâturages et les méthodes de gestion des pâturages, ces dernières étant peut-être un levier d'action à court terme le moins coûteux sur lequel agir pour potentialiser la productivité de l'élevage laitier. Cependant, il est difficile de prédire l'efficacité et la rentabilité de tels efforts, en particulier lorsqu'il existe un écart économique et culturel aussi important entre les éleveurs d'un même pays.

A notre connaissance, le lien entre la gestion du pâturage et la productivité laitière, exprimée à la fois en volume et en qualité, et en taux de charge, n'a pas été documenté dans les situations de haut relief. Notre thèse vise à analyser l'impact des méthodes de gestion du pâturage sur les performances productives des vaches au pâturage, en production laitière intensive dans les hautes terres équatoriennes. En plus d'analyser l'influence du relief dans la prise de décision pour la conformation des enclos, dans le contexte de différents degrés de pente dans les fermes bovines. Nous émettons l'hypothèse que nous pourrions trouver un système de gestion du pâturage mieux adapté aux pratiques organisationnelles des systèmes laitiers des hautes terres tropicales équatoriennes, ainsi qu'identifier certaines activités culturales dans les prairies qui compensent mieux les effets néfastes des pentes. Pour ce faire, dans un premier temps, 42 exploitations laitières ont été caractérisées dans différents cantons de la zone rurale de la province de Pichincha (Quito, Mejía, Rumiñahui et Cayambe) de l'Équateur. Cette caractérisation a été réalisée au travers d'une enquête avec questionnaire pour identifier les activités de production et de gestion dans les troupeaux et d'une évaluation de la pente moyenne des pâturages des exploitations à partir des données SIG. Dans un premier temps les enquêteurs ont été formés à l'utilisation du questionnaire et dans un second un tirage aléatoire des exploitations participantes a été réalisé, avec pour seul critère qu'elles produisent du lait. Les résultats d'enquête ont montré que les exploitations avaient une superficie moyenne de 40 ha, les troupeaux étaient composés de 60 ± 63 vaches laitières, majoritairement de race Holstein-Friesian (65 %), et la production journalière de vaches laitières individuelles atteignait 15.1 ± 3.4kg. La productivité la plus élevée a été constatée dans les exploitations utilisant le pâturage

tournant à forte intensité de pâturage instantané, avec des temps d'occupation très courts (< 12 h), les tâches culturales d'entretien dans les prairies (réensemencement, temps de repos, coupes d'égalisation, aération du sol, fertilisation, dispersion des matières fécales) et une topographie des pâturages plane ($p < 0,05$). La déclivité des pentes n'était pas une limitation pour établir des pâturages pour les animaux, puisque des prairies ont été observées dans toute la gamme des pentes, y compris les plus raides (jusqu'à 55 % de la pente). La production quotidienne des vaches individuelles était négativement corrélée ($r = -0,323$; $p = 0,037$) avec la pente moyenne de toutes les fermes enquêtées. Par la suite, nous avons mené une deuxième expérience au Centre Académique d'Enseignement Expérimental de La Tola (CADET), pour déterminer le comportement ingestif des vaches laitières, sous les trois types de rotation de pâturage les plus utilisés par les éleveurs (temps d'occupation long de 7 jours, temps d'occupation court de 24 heures et temps d'occupation très court de 3 heures). Cette expérience interroge la pertinence d'une pratique intensive, avec des temps de pâturage plus courts pour améliorer les performances du système. Pour cela, nous avons préparé trois enclos "plats" divisés en cinq sous-parcelles par une clôture électrique, permettant aux vaches de se comporter comme des troupeaux individuels, face au même disponible fourrager exprimé en hauteur d'herbe pré-pâturage dans les trois traitements. L'expérience a duré sept jours et a été répétée trois fois, en alternant le taux de charge à chaque répétition afin que les trois troupeaux aient la même opportunité de montrer leur comportement ingestif et leur potentiel productif à chaque traitement. Les vaches du traitement continu ont passé plus de temps à manger, ont eu tendance à avoir une vitesse moyenne plus élevée pendant l'ingestion, attribuée à un plus grand déplacement par exploration de toute la zone affectée à l'expérimentation. Dans le traitement de 3 h, une plus grande inactivité a été perçue en prévision de l'ouverture de nouvelles zones de pâturage pendant la journée. Malgré ces différences d'activité, la production de lait ne différait ni en quantité ni en qualité (c.-à-d. matières grasses, protéines, solides non gras, solides totaux), montrant qu'en conditions de pâturage avec une allocation fourragère intermédiaire sur des enclos plats et avec des vaches peu productrices, l'application d'un mode de charge à forte intensité de main-d'œuvre qui nécessite d'ouvrir de nouvelles zones toutes les 3 heures ne conduit pas à une augmentation significative de la production. Ensuite, nous avons réalisé une troisième expérience au Centre universitaire d'enseignement expérimental de Rumipamba (CADER), qui a décrit en détail le comportement d'ingestion et la production des bovins laitiers en terrain montagneux des Andes. Ceci à partir de deux modes de pâturage (temps d'occupation long au pâturage et des temps d'occupation très court), dans des enclos au relief modérément vallonné et avec déplacement de haut en bas de la montagne pour pâturer le fourrage. Les données obtenues ont été interprétées après deux répétitions du test, en faisant des coupes d'égalisation et en appliquant de l'engrais 30 jours avant le debut de chaque répétition. Cela a permis de répliquer les modes de gestion des prairies les plus utilisés par les éleveurs, promouvoir une allocation fourragère très similaire pour les deux traitements, favorisant un environnement contrôlé qui montrerait le potentiel productif de chaque troupeau. Les vaches qui

broutent dans le traitement horaire (3 heures) bougent plus pendant les repas que celles placées dans le traitement continu. Cela est dû au fait que les sous-enclos ont été conçus horizontalement pour favoriser la marche latérale et éviter l'effet de la pente sur le déplacement. Le troupeau qui disposait d'une liberté de mouvement dans tout l'enclos (long temps d'occupation), se déplaçait moins par vache (- 27 %), et révélait une hauteur d'herbe résiduelle plus important e(7 cm). Les essais montrent par ailleurs des volumes et une qualité de lait significativement plus élevés pour les troupeaux qui ont pâturé dans le traitement avec affectation de nouveaux sous-enclos toutes les trois heures.

En conclusion, la combinaison de systèmes de gestion des pâturages avec des opérations qui compensent mieux les effets néfastes des pentes favorise les rendements productifs dans les exploitations laitières des hautes terres équatoriennes. L'attribution du disponible fourrager doit être basée sur une rotation avec des temps d'occupation qui s'ajustent à la pente des enclos. Éviter l'utilisation inutile du capital humain et économique là où cela ne se justifie pas la mise en place de temps de rotation plus courts (paddocks plats), garantit l'optimisation des ressources, des volumes plus élevés et une meilleure qualité du lait produit. Enfin, les agriculteurs peuvent gérer leurs processus d’élevage à l'aide des propositions développées dans cette recherche en fonction des ressources disponibles dans leur environnement.

Mots-clés: rotation de pâturage, travail du sol, temps d'occupation, volume et qualité du lait, rotation de pâturage, pente

Acknowledgements

First of all, I want to thank my supervisors Prof. Jérôme BINDELLE and Prof. Frédéric LEBEAU for trusting me to carry out research in Latin America with such high standards of precision and scientific rigor. The masterful planning of my training induction in their research teams allowed me to absorb the technical knowledge, discipline and tenacity with which they do science. The combination of great demand with sublime motivation advice allowed me to reach levels of commitment and self-demand that brought out the best in me. Thank you for passing on all your experience with your good humor and boundless passion for research. The time difference between Ecuador and Belgium was another example of your infinite generosity and great commitment to my thesis project, thank you very much. It was an immense honor working with you, and we will surely continue working together.

I allow myself to thank Prof. Andriamasinoro Lalaina Herinaina ANDRIAMANDROSO who, in addition to having been a fundamental support for the collection and analysis of the data obtained in my experiments, was the colleague who, upon my arrival, showed me the dynamics of high-level research, the seriousness of meeting advance delivery times, and the friend who welcomed me into his home as part of his family during the training period at JUNIA ISA Lille, France. My sincere thanks to my colleague Gentil Da Silva NETO, who, thanks to the experience gained in the brilliant research group (DPFA-UFRGS, Brazil), represented a great help in interpreting my results, and in discussing in global terms the dynamics of the pastures.

I also thank the Gembloux Agro Bio Tech Precision Livestock and Nutrition Unit, led by Prof. Yves BECKERS, and made up of Prof. Nadia EVERAERT, Prof. Nicolas GENGLER and Prof. Martine SCHROYEN for integrating me into their wonderful team, for their advice and help. Many thanks to the group of colleagues and friends who have accompanied me in these six (6) years: Sylvie, Esther, Cécile, Emilie, Bienvenu, Patrick, Gaetan, Sophie, Julie LEBLOIS, Julie URLINGS, Hajer, Lauriane, Edvaldo, Arthur, Wail, Li, Yuxia, Gabriel, and Yannick. To the professors of the Faculty of Agricultural Sciences of the Central University of Ecuador,

I thank you for the collaboration and the advice I received during the achievement of my doctoral thesis. Prof. Jaime HIDROBO, Prof. Lenin RON, Prof. Carlos MONTUFAR, Prof. Juan BORJA were working by my side in the field experiments and the preparation of the scientific articles, dear colleagues, thank you very much. I thank all the members of the committee and the jury of my thesis: Prof. Yves BECKERS, Prof. Philippe LEJEUNE, Prof. Paulo C.F. CARVALHO, Prof. Andriamasinoro Lalaina Herinaina ANDRIAMANDROSO. All their experiences, reviews, advice and corrections contributed greatly to increase the quality of my experiments and work.

The conclusion of this work was achieved thanks to the financing of "Académie de Recherche et d'Enseignement Supérieur – Cellule de Coopération au Développement" (ARES-CCD, Brussels, Belgium), covered by the agreement of francophone universities, in particular Gembloux Agro -Bio Tech from the University of Liège and the Central University of Ecuador, thank you very much for your contribution. A very sincere thanks to my family for the help and patience in these long and exhausting years; your support, your love and your joy in the most difficult moments were my support, thank you very much.

Table of contents

List of figures

List of tables

List of photos

List of acronyms

°C, Celsius degree

ADF, Acid detergent fiber

AGDDs, growing degree days

AGROCALIDAD, Ecuadorian Agency for Quality Assurance

AGSO, Association of Ranchers of the Sierra and the East

ANOVA, analysis of variance

AOAC, Association of Official Analytical Chemists

ArcGis, software that allows handling and analyzing geographic information

ARES-CCD, Brussels, Belgium: Académie de Recherche et d'Enseignement Supérieur - Cellule de Coopération au Développement.

BW, body weight

CA, collection centers

Ca, Calcium

CADER, Experimental Academic Teaching Field "Rumipamba"

CADET, Experimental Academic Teaching Field "Tumbaco"

Cl, chlorine

cm, centimeter

CNRM-CM5, Centre National de Recherches Météorologiques

CP, crude protein

DIM, days in milk

DM, dry matter

EAP, economically active population

EAP, economically active population

ECLAC, Economic Commission for Latin America and the Caribbean

FAO, Food and Agricultur Organitation

FOAST, Statistics Division of the FAO

FM, Fresh matter

g, grams

GDP, Gross domestic product

GIS, Geographic information system

GNSS, Global navigation satellite system

GPS, Global Positioning Systems

Gx, Gy, Gz, Gravitational component of the acceleration on x, y and z-axis

ha, Hectare

HM, herbage mass

IMU, inertial measurement unit

INNEC, National Institute of Statistics and Censuses

K, Potassium

Kg d^{-1}, kilograms per day

Kg $ha^{-1}d^{-1}$, kilograms per hectare per day

Kg N ha^{-1}, kilograms nitrogen per hectare

LAI, Leaf area index

LW, live weight

m d^{-1}, meter per day

m s^{-1}, meter per second

m.a.s.l, meters above sea level

m^2, square meter

Mg, magnesium

MAGAP, Ministry of Agriculture, Livestock, Aquaculture and Fisheries

ml, milliliters

mm, millimeters

Na, Sodium

NDF, neutral detergent fibre

OM, organic matter

PLF, Precision livestock farming

RPM, Rasing plate meter

SAS, Statistical analysis software

SEM, standard error of the mean

SINAGAP, National Agricultural Information System MAGAP

Sp, species

ST, sward stick

STIR, short-term intake rate

UA/ha, animal units per ha

UAS, Unmanned aerial system

UCE, Central University of Ecuador

Uliege, University of Liège

UN, United Nations

UPA, Agricultural Production Unit

UPAs, Agricultural Production Unit

USD, United States Dollar

Chapter 1

General introduction

General Introduction

1. Context

Livestock contributes 40% of the value of world agricultural production and sustains the livelihoods and food security of almost 1,300 million people, in addition to guaranteeing employment for 150 million families in all countries and at all latitudes (FAO, 2019). Livestock production occupies an important part of the world's land area (Gamarra, 2001). Eighty percent of the land used for agriculture globally is dedicated to the production of feed for livestock, especially ruminants. Around 26% is covered by grassland and approximately one third of all cultivated area is occupied by seasonal forage material (FAO, 2019).

Climate effects complicate the future scenario of agriculture worldwide. These changes impact the life cycle of plants, imposing changes in agricultural and livestock production systems. According to Bárcena et al., (2020) there is a negative relationship between extreme weather events and the performance of agricultural production, the estimates of the “Centre National de Recherches Météorologiques”, based on the CNRM-CM5 model, consider an increase in the world temperature of 3.1 ºC and 3.6 ºC, as well as a change in precipitation of 18.9% and 3.1% in summer and winter, respectively.

The average marginal impact of temperature and precipitation on agricultural income per hectare shows a great dependence on temperature increases, while precipitation exhibits a mixed sensitivity, this depending on the farms that have or do not have access to irrigation sources (Dinar & Jammalamadaka, 2013; Bozzola, Massetti, Mendelsohn, & Capitanio, 2018). Additionally, the intensification of the use of non-renewable natural resources, excessive use of fertilizers, pesticides, new varieties of crops and other technologies of the well-known 'Green Revolution'. Implemented with the objective of increasing the world supply of food per capita, reducing hunger, and as Evenson & Gollin (2003) point out, improving nutrition. These extractivist practices had and still have terrible environmental consequences that cause most of the nine planetary boundaries to be transgressed by the world food system, each of which represents a vital system or process to regulate and maintain the stability of the planet (Willett et al., 2019). South America is no exception, while the countries of this continent face additional social challenges, according to data compiled by the Economic Commission for Latin America and the Caribbean (ECLAC) of the Organization of Nations. United Nations (UN), the economic progress of the region in the period 2014 - 2019 was barely 0.3 % on average, and in the current scenario it was aggravated by the confinements to prevent the spread of the global pandemic caused by the COVID-19. Recent history shows us the fragility of production systems in the face of catastrophic events such as the SARCOV pandemic_2. The closure of productive activities as caused a drop in access to basic basket products, as well as dairy products (ONU, 2020). In recent decades developing countries have increased their participation in world milk production, making dairy farming an important component for the future of South American food systems (FAO, 2017). Ecuador shows a very particular productive dynamic in dairy farms, for which ancestral practices have been complemented with innovative pasture management schemes, this in order to optimize production volumes and reduce the impact of the aforementioned adverse conditions. Being of vital importance to identify what are the forms of pasture management and how the criteria for forage allocation are established, as well as its influence in terms of sustainability and production. To the best of our knowledge, there is no information on the combination of the different management methods and even less, in the presence of high relief. By virtue of which our thesis aims to find the management methods that best fit the climatic, environmental and social conditions of the Ecuadorian highlands.

2. The dairy farming context in the Ecuadorian highlands

The Republic of Ecuador, located in South America owes its name to the equatorial line that crosses it. Extending between latitudes 1º30 'N and 5º S and longitudes 75º 20' W and 91º W, it is the smallest of the Andean countries with approximately 252,000 km². It borders Colombia to the north, Peru to the south and east, and the Pacific Ocean to the west. The Andes mountain range occupies the entire central belt of the country (as for Sierra region), which crosses from north to south, descending towards the west with lower lands appears the coastal region that borders the Pacific Ocean. Towards the east there are also lowlands in the form of plains that correspond to the Amazon or eastern zone (Pourrut, 1983; Jorgensen & León, 1999). The four regions are known as: Coast, Sierra, Oriente, and the Insular region (Figure 1). These actually correspond to political and neither climatic nor geographical limits; however, the topographic and climatic differences between them are very notable. The coastal region made up of very low plains and some hills (0 - 400) meters, with temperatures in the rainy months can reach 40 ºC and the driest months 14 ºC.

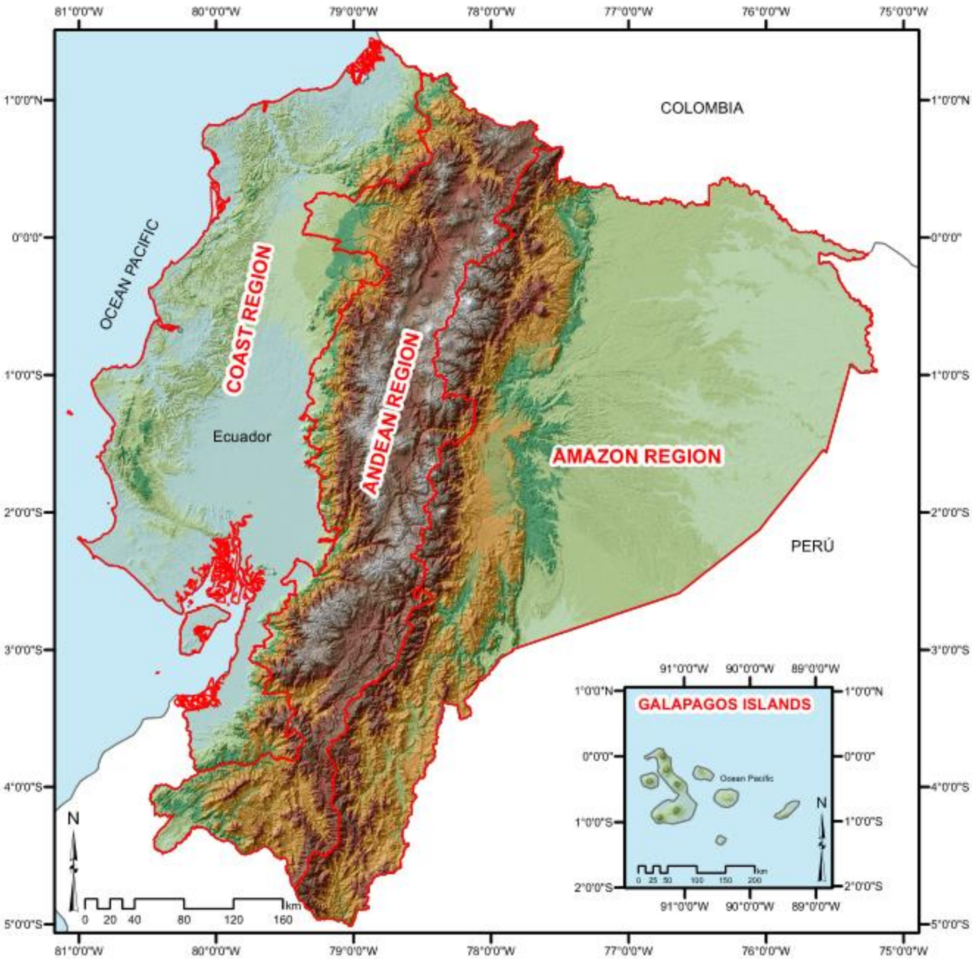


Figure 1: Ecuador regions location map. Taken from INGEOMATICA S.A

The rows of mountains of the inter-Andean corridor correspond to the sierra region where our study has taken place (Figure 2). Snow-capped mountains, volcanoes, peaks that exceed 6000 meters in height, with temperatures below zero in the mountain peaks with permanent ice, likewise, green and fertile valleys with average temperatures of 13 - 22 ºC that favor agricultural activities, but dominated by the highly framed geographical characteristics of the Andes Mountains (Lynch & Duellman, 1980; Cañadas, 1983).

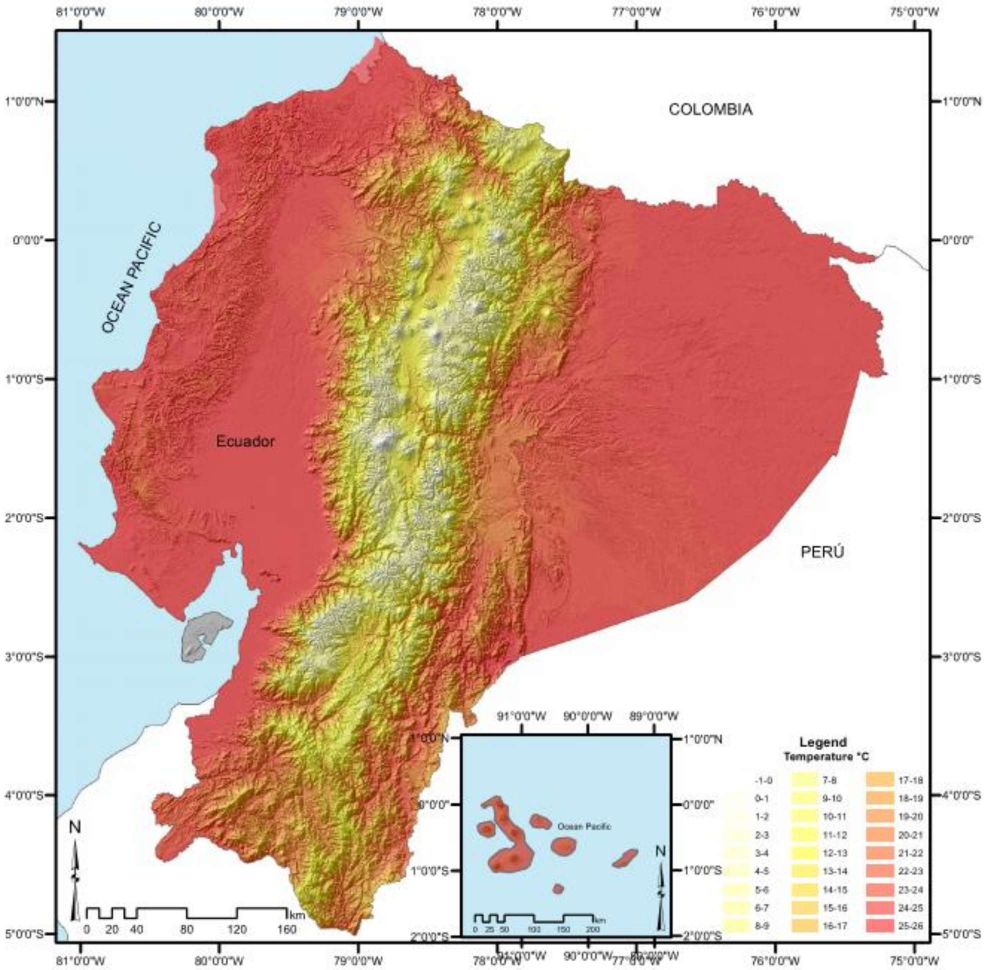


Figure 2: Temperature distribution in the different Ecuadorian regions. Taken from INGEOMATICA S.A

The Sierra zone shows little seasonal variation throughout the year, still two seasons are defined: wet or winter and dry or summer, this to its location on the equatorial line. The topography has probably the greatest influence on the climate.

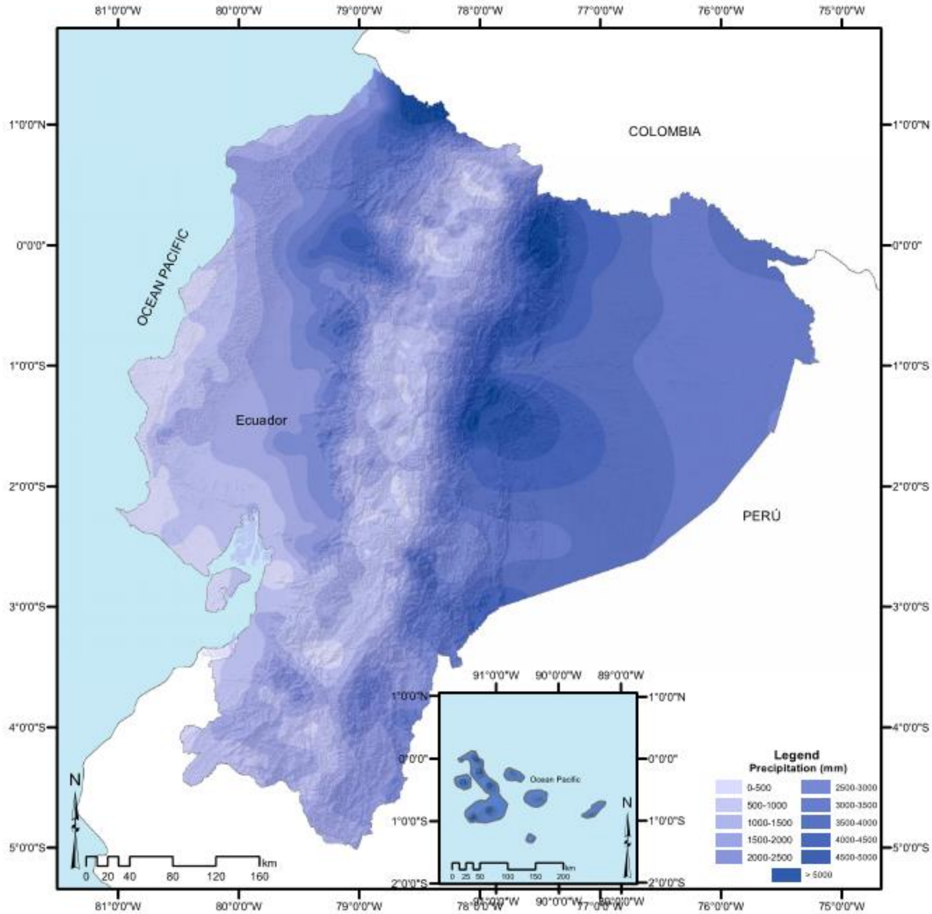


Figure 3: Precipitation distribution in the different Ecuadorian regions. Taken from INGEOMATICA S.A

Indeed, taking a more detailed look at the area where we did our work, we see that the Ecuadorian Inter-Andean corridor constitutes a natural mountainous barrier 100 to 120 km wide, with steep peaks that exceed 6,000 meters of altitude. The Sierra region is made up of ten of the twenty-four provinces that make up the republic: Carchi, Imbabura, Pichincha, Cotopaxi, Tungurahua, Chimborazo, Bolívar, Cañar, Azuay, Loja. As we would refer to above, this region is characterized by a great variety of climates and soils that make up four physiographic landscapes defined by geographical accidents: (1) plains, which cover a wide area located inside the mountain range that forms the Andes massif; (2) river valleys, formed by wide flat areas parallel to the river current; (3) variable sedimentary plain, formed by the combination of flat relief plains, with moderate undulation and strong undulation; and (4) Western and Eastern flanks of the Cordillera, located in the internal foothills of the cordillera and extending from north to south in the hydrographic basins, characterized by its very strong and irregular relief (SIGTIERRAS, 2018; Calvache, 2014). The material that gives rise to the soils is volcanic ash, determining certain special characteristics due to the existence of a wide climatic variation, which is responsible for the variety of altitude and wind currents such as Humboldt. Since the quaternary era, pyroclastic material has accumulated from volcanic activity; however, there is a difference in the characteristics of this material, depending on the formation of layers of different volcanoes and times of eruption, generating the existence of differences in the soils, such as: (a) coming from thick and permanent recent ash, (b) originated from recent fine ash, (c) originated from old hard and cemented ash (Franco et al., 2021).

The inter-Andean basin is located between two parallel mountain ranges (western and eastern), made up of a succession of subsidence basins of irregular topography with slopes of 10 – 50 %, in the flatter areas agricultural crops are developed on private properties (0 – 10 %) that take advantage of the inclination for the conformation of the irrigation canals. Between 2,400 and 3,200 meters of altitude, the presence of medium and large cattle ranches with fluctuating slopes in pastures is observed (Figure 4). In addition, there are a large number of small agricultural properties (minifundios), as well as a considerable number of indigenous milk-producing communities (Bernard, 1982; De Noni, Viennot, & Trujillo, 1997). In this diversity of dairy production systems, some extremely important factors that contribute to productive efficiency come together: management, feeding (nutrition), health and reproduction (genetic improvement); closely related factors that affect production in an interdependent manner. Approximately 24.89 million hectares that represent 19 % of the territory are found on very steep slopes (40 – 70 %), followed by 16 % or 20.90 million hectares in the range of 25 to 40 % and 18 % of the territory or 23.50 million hectares between 12 to 25 % slopes (Winckell, 1997).

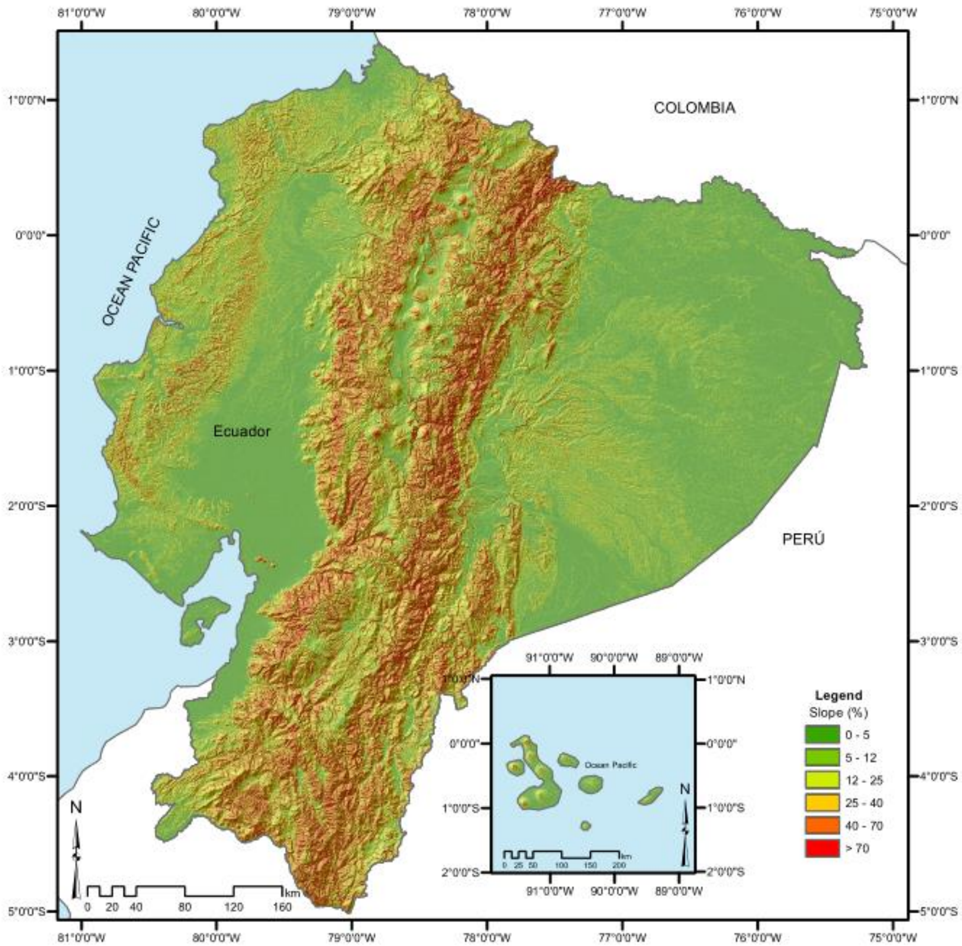


Figure 4: Distribution of the slope of the terrain in the different Ecuadorian regions. Taken from INGEOMATICA S.A

The Ecuadorian Andes mountain range presents several advantages, which makes this region interesting for dairy production compared to the other regions of Ecuador. It has important hydrological resources from volcanic mountain glaciers and páramos (high altitude area with little vegetation and extreme climate), being able to irrigate large agricultural areas through natural and artificial irrigation channels (Johansen et al., 2018). This condition allows abundant growth of a wide variety of forage material to feed the animals during the dry season. Conversely to typical intertropical climates, the temperate high-altitude climate allows the development of cool season grasses with high nutritional value (Bustamante, 2006; Franco, Peñafiel, Cerón, & Freire, 2016). It also facilitates the establishment of mixtures of grasses and legumes typical of temperate pastures that allow sustained milk production (Dumont, Clements, Huckle, & Wilkins, 1992; Ramírez, Izquierdo, & Paladines, 1996). However, the dairy farms located in the Andean region with altitudes of up to 4,000 meters above sea level present a significant decrease in the partial pressure of oxygen, translating into physiological problems commonly called altitude sickness, which leads to a decrease in the productive capacities of the animals (Will, Hicks, Card, & Alexander, 1975; Valenzuela, et al., 2017).

3. Grass-based dairy production systems in the Ecuadorian Sierra

According to the III National Agricultural Census (2002), more than 25 % of the Ecuadorian population is linked to agricultural activity, and that 31 % of the economically active population (PEA) around 1,313,000 people, works directly in the agricultural or livestock activity sectors. Both the largest number of cattle heads and natural pastures are concentrated in the Sierra (2,225,923 heads and 601,249 ha). The daily production of cow's milk at the national level amounted to 5,648,786 liters in 2019. The sierra region contributes 78% of the national daily production (5,165,222 liters), with averages close to 11 liters/cow per day, although dairy areas that reach daily averages higher than 18 liters/cow are reported.

Livestock systems are a set of elements in dynamic interaction organized by people in order to take advantage of resources through domestic animals (Lhoste, 1986; Dedieu, Faverdin, Dourmad, & Gibon, 2008). The three key components of livestock systems are (1) the animals, (2) the territory and the cultivation systems that provide food resources to the animals, under the organization of the third component, (3) the people who practice agricultural activities. There is a defined structure in the Sierra region depending on the size of the farms, according to Requelme and Bonifaz (2012) three production levels are identified between 1 - 5 ha, 5 - 20 and between 20 - 120 ha. There are cantons with good results based on the volume of milk production, in the first level (1 - 5 ha) it is 13.5 kg/cow/day (Mejía), in the second level (5 - 20 ha) it is 16 .1 kg/cow/day (Cayambe), and the third level (20 - 120 ha) is 21.4 kg/cow/day (Tulcán and Pedro Moncayo). Emphasizing that the production levels will depend not only on the size of the farms, but also on the management conditions that involve the dynamic components (animal resources, fodder and human capital), as well as the incorporation of modern technological tools (GPS, electric fence, RPM, 3D camera, drone, etc.) in the production process (Andriamandroso et al., 2017). Among these management conditions, the regulation of the price of milk plays a key role. This price was set in 2013 by the Ministry of Agriculture and Fisheries of Ecuador (MAGAP), through Ministerial Agreement 394 with the regulation of payment for milk quality, at a value of (0.42 USD) per liter of raw milk with additional bonuses for sanitary, quality and good livestock practices in dairy farming (Ministry of Agriculture, Livestock, Aquaculture and Fisheries, 2013). These bonuses served as incentives for dairy farmers to make required modifications to their practices and infrastructure, such as milk cooling tanks. However, given the high costs that these new demands implied, it was necessary for small and medium producers (<200 kg/day) to meet in collection centers that would allow them to access bank credits to acquire the most expensive inputs (Contero, 2008; De la Cruz, Simbaña, & Bonifaz, 2018). Despite these key structural, social, and agricultural differences, most farmers in the Ecuadorian highlands have in common the use grass as their main source of food, hence the focus on this resource and its management in the next section.

Pasture according Dillon et al. (2008) is the most economical feed for dairy cattle, especially when cattle graze on it. Most production systems in the Ecuadorian highlands are based on pastures grazed throughout the year to feed the animals. An adequate use of this resource requires that farmers adopt restocking methods that optimize the efficiency of the system, whatever the optimization objective may be: increase milk production per animal, per grazing area, provide additional ecosystem services, etc. The way in which animals harvest grass in terms of intensity and frequency, and how farmers can adequately provide for the animals will define the profitability of farms. It is fundamental to consider the pasture and its management as the starting point of all the actions and decisions of the cattle farm (Euclides & Euclides Filho, 1997; Silva & Sbrissia, 2010). For this purpose, a proper understanding of the mechanisms driving the growth dynamics of grazed pasture, on the one hand, and the grazing behavior of animals, on the other hand, is essential.

a) Dairy context and specialized breeds

Dairy production is shown as one of the main economic activities obtained from agricultural dynamics. This is due to the significant demand for milk and dairy products around the world and its irregular supply. It is increasingly imperative to achieve high levels of competitiveness by the dairy industry, the number of animals in relation to the volume and quality of the milk produced must show accounting income from the efficiency and effectiveness of the herds of specialized farmers (Barreto & Fajardo, 2018). To talk about the quality of milk, it is vitally important to highlight its nutritional components. This is constituted by a significant proportion of water (around 87 %), the rest, called dry extract that represents 130 grams (g) per kg, of which between 35 and 45 g are fat (Iglesias et al., 2015). In the proportion of total solids, organic components (carbohydrates, lipids, proteins, vitamins) and minerals (Ca, Na, K, Mg, Cl) are grouped. The productive potential for the volume and quality of milk shows values depending on the breed, stage of lactation, body condition (endogenous); while exogenous factors involve the environment where the animal interacts, climate, nutrition, zootechnical management, health management (Manterola, 2010). There are dairy breeds with different potentialities and productive attributes. The Jersey breed is a small animal that, although it requires less feed, uses 69 % of the energy consumed to produce milk. While the largest breeds allocate 61 % of the energy for this same purpose, showing greater efficiency (13 %) for the maintenance of the body. Although the Brown Swiss breed presents a greater rusticity and better adaptation to adverse environmental conditions, it does not neglect milk production in terms of volume, but especially in terms of milk quality. Norman cows, despite their dual-purpose origin (meat and milk), show a representative dairy character (28 kg/day), especially due to their high fat content (4.3 %) and (3.4 %) proteins. The Simmental breed originated to satisfy a triple productive purpose (meat, milk and draft). Currently, it is considered the breed with the best fertility, showing the lowest number of open days and the lowest number of days of calving-conception interval (IPC). Being a dual-purpose breed, it shows an average daily production of 18 kg in two milkings, the evaluation of milk quality produces 3.4 % protein and 3.9% fat (Çilek & Tekin, 2005). However, the Holstein Friesen breed is the most widespread in dairy farming in various regions of the world. This is because it holds the record for the highest production volume in a lactation period (Ahlborn-Breier & Hohenboken, 1991). The predominance of this race is evident in Ecuador; a survey carried out by Muñoz et al. (2020) in the Pichincha province, indicates that it represents 65 % of the composition of dairy herds.

b) Grazed grass growth dynamics

The art of grazing management relies on the making sure that both the requirements of the grazing herbivore and that of the grazed plant are met when grazing occurs. From the perspective of the plant, grazing constitutes a sudden reduction in the above-ground biomass and thus in leaf area allowing the interception of light for photosynthesis. Photosynthesis is considered optimal when light interception reaches 95 %, hence this value is often taken as a target to initiate the grazing from the plant perspective (Brougham, 1958). Whether the post grazing management targets should or not maintain a significant light interception capacity after defoliation will strongly influence the regrowth capacity of the plant, the need to use energy stores in the lower parts of the stubble and the time required to recover to pregrazing light interception (Matches, 1992). Razing management should aim at maintaining a high light interception capacity after a defoliation. Hence, pre and post grazing targets and resting times applied by the farmer combined to weather conditions and the phenology of the plant species present in each pasture, have impact to the productivity of the pastures as they determine the growth dynamics, the leaf elongation rate, leaf appearance, and the number and density of regrowth (Garcez et al., 2002). According to Briske (2011), the responses of individual plants to the intensity and frequency of defoliation imply important processes at the level of the plant-animal interface. In the short term, physiological responses related to reduced carbon supply resulting from loss of leaf area will limit leaf tissue production; in the long term, morphological responses allow the plant to adapt its architecture and avoid defoliation. This favors the development of creeping and stoloniferous species, capable of avoiding grazing, since they maintain their growth points at ground level and present an important area of photosynthetic tissue in the lower strata that makes regrowth possible (Carballo et al.,2005). Gregorini, (2012) states that the frequency of defoliation is defined as the number of defoliations per unit of time, and is controlled by adjusting the stocking rate and the grazing period. The various methods used to set animals to graze in a determined pasture area and the specific targets applied will have an impact on the severity of the defoliation, related to the harvest rate, the heterogeneity of the defoliation on the area and the regrowth potential of the pasture plant, related to the importance of the reliance on the contribution of energy reserves for the production of new leaves (Roche et al., 2017). Indeed, several studies have showed that continuous stocking and rotational stocking lead to different vegetation structures and harvest efficiencies (McMeekan & Walshe, 1963; Derner, 1993; Bailey & Brown, 2011). Namely, continuous stocking is more likely to display larger patches of ungrazed vegetation combined with patches of more heavily grazed areas with plants suffering from exhaustion on a same paddock, it could be considered as inducing what could be considered as higher levels of “wasted” herbage mass (Davis & Pratt, 1956; Sollenberger et al., 2012). This phenomenon also drives the vegetation to evolve differently in moderately to lighted grazed areas as opposed to heavily grazed ones. The stocking rate, i.e. the number of head of livestock that are set to graze on this determined area will also impact the magnitude of these effects. Defoliation is the variable that most influences the response of the plants, through selectivity, measured as frequency (number of times the plant is defoliated in a period) and intensity (amount of material removed); understanding that, with greater stocking rate, both variables increase (Hodgson & Ollerenshaw, 1969; Harris et al., 1997). Conversely, the rotational stocking of herbivores allows to offer to the grazed plants a resting period that allows for a more even spatial use of the forage during the grazing and increased harvest efficiencies compared to the total biomass production, especially if farmers let their animals graze the paddocks extensively during the occupation of the paddocks (Hancock, 1954; Undersander et al., 2002). Hence pregrazing targets should aim for a specific foliage development that allows for both a good light interception and the constitution of energy reserves for the plants and post grazing targets should avoid an excessive defoliation to allow for a quick recovery of the plants. For example, Fulkerson and Donaghy (2001) present Lolium perenne as a 3-leave grass that should be allowed to regrowth to the production of three leaves before experiencing a new defoliation. Inaddition to stocking methods, there are cultural methods that favor regrowth capacity, the equalization cut is a practice that allows the stimulation of phytohormones (auxins) with the capacity to induce the formation and elongation of stems, as well as promote cell differentiation and increase apical dominance (Alcantara et al., 2019). Studies carried out on the cutting season in pastures subjected to equalization cutting Eriochloa polystachya Kunth, suggest that the best nutritional contents are obtained after 25 days of rest time with 11 % of protein, compared with 9.57 % of protein in cuts made at 40 days

(Gómez et al., 2020). Equalization cuts are also used by farmers to retake control of heterogenuous pastures induced by selective grazing, especially in continuous stocking methods, although its use is more commonly carried out in rotational stocking (Castro et al., 2021). Other practices carried out by farmers is the dispersal of feces after the animals have been driven to other paddocks, respecting the alternation of "occupation times and rest times" of the paddocks (Franco, 2009). In this context, the rejection that the animals show to areas of the prairie where the aged manures are found is known, the feces are dispersed mechanically on the second or maximum on the third day to avoid dehydration. A 500 kg animal could produce 25 kg of feces and 20 liters of urine per day, containing high levels of nitrogen, phosphorous, potassium and calcium oxide (Dijkstra et al., 2013). Cárdenas & Garzón (2011) describe this practice as a fundamental and irreplaceable link in the regeneration of grasslands, allowing nutrients to be used by plants by spreading the smallest particles throughout the meadow. Likewise, an increase in the temperature of the upper layers of the soil is perceived as a result of fermentation, promoting the protection and renewal of microorganisms.

c) Grazing behaviour

Throughout the day, dairy cattle spend 3 to 7 h/day eating, consuming 9 to 14 meals per day. In addition, they ruminate from 7 to 10 h/d, while drinking they use 30 min/d, 2 to 3 h/d milking and they need about 10 h/d lying down and/or resting (Grant and Albright, 2000). The pasture is a clearly delimited area and composed mainly of plant material that can be native plants and/or natural pastures (naturalized or improved), where cattle feed and carry out most of their productive and reproductive activity. In this sense, an important indissoluble relationship with the soil, the vegetation, the climate and the animals that graze exists (Vásquez et al., 2017).

The way herbivores will explore the pastoral environment will be influenced on the one hand by their nutritional requirements and state of hunger, which vary with their physiological status but also along a grazing day over the course of several meals. On the other hand, factors that relate to the pasture, its structure and its vegetation will determine how the animal will explore their environment to fulfill the afore-mentioned requirements. The organization of the paddocks, i.e., surface, shape and distribution, as well as the distribution of key elements such as water troughs, milking parlor, access gates, mineral licks, shaded areas and shelters constitute attraction points that will alter the explorative behavior of the herbivores. Additionally, on sloppy terrain the orientation of the slopes will modify the microclimatic and soil environment altering the plants that grow on different parts of a paddock displaying a direct relationship with the amount of grass that can be produced, showing limitations in exposure to sunlight, thin soils, low fertility and leaching due to the presence of slopes in the meadows (Vargas et al., 2015). In the same order, Di Marco and Aello (2002) determined that the energy expenditure of cattle in grazing is related to the combined effect of the energy expenditure inherent to walking and grazing, as well as to the act of biting at harvest time. Thus, in rugged terrain, the slope of the paddocks is an important factor to take into account when analyzing energy expenditure, since when going up to collect forage in the highest areas, muscle activity requires greater energy expenditure, which is not compensated at the time of feeding. descend to lower areas (Holechek, 1988; Lachica et al., 1997). An increase in food consumption above 250 gr/DM/day is suggested, or in caloric terms, 18 kcal.km^{-1}.100kg^{-1} BW are needed in the presence of sloping pastures to complement maintenance energy requirements (Lachica & Aguilera, 2005; Maurya et al., 2012). As grazing herbivores can be seen as trying to optimize the balance between energy harvesting while eating and the energy expenditure, they are known to modify their behaviour and especially the degree of exploration of paddocks according to the topography. For their part, Senft et al. (1987) pointed out that the time dedicated to grazing in a certain area was closely related to the quantity and quality of its forage, concluding, in turn, that the probability that an animal returns to a site is proportional to the richness of the grass that this area has. When assigned to a pasture, herbivores must decide where to put their heads down and set up their feeding station in their grazing field. Within the feeding station, the animal must select which species and which parts of the plant it will consume. Thus the diet selection process has two levels: a spatial choice of where to graze and a choice of which species to consume (Stuth, 1991). The heterogeneity can be perceived by the animal at different levels and then the selection can be at the level of feeding site within a pasture, of species within a site, or of organs within a plant. The degree of selection depends on the characteristics of the bites that the animal will eat given by maturity, physical and biochemical characteristics of the grass and the selection capacity of the animal (identification and apprehension) (Laca, 2009). In general, cattle prefer to consume slices on stalks and live and young material over dead and mature ones. The selected material with respect to the rejected one generally has a higher amount of nitrogen, phosphate and gross energy, and a lower amount of fiber. Being the availability of forage the one that governs the factors that make the animals find different conditions in the pasture every day, understanding that its decrease causes an increase in grazing time, affecting the frequency of defoliation; while increasing grazing pressure also increases defoliation frequency (Hodgson & Ollerenshaw, 1969; Platero et al., 2022). Grazing intensity is defined as the amount of dry matter harvested in a grazing period and is determined by the number of cows and the duration of grazing. A higher intensity has a positive influence on the amount of forage harvested, but the frequency will be affected by the need to allow more rest time to the pasture, so that it reaches the same forage volumes as before. In turn, changes can occur in the botanical composition, where at high intensities prostrate species are favored over erect ones (Bryan & Prigge, 1994). Increasing the intensity of grazing decreases the possibility of selection, since the animals increase the consumption of species and parts of the most palatable plant and, consequently, the most susceptible species could progressively decrease. However, unlike the defoliation frequency, Hodgson and Ollerenshaw (1969) state that when the LAI decreases, the grazing intensity does not vary significantly, being around 40 – 50 % of the initial height. Grazing intensity is the main determinant of the morphogenetic variables characterized by leaf size and tiller density and, consequently, the resulting average LAI of the pasture (Nabinger & Carvalho, 2009). When animals are restricted to a limited area and graze for a short period of time, individual leaves or clumps are rarely completely defoliated in a single bite. Rather, the pasture is consumed in a series of steps, so that the stands will be grazed several times during the day (Hodgson, 1985). Taking longer or shorter periods of time to feed to cover the net energy requirement (Schoener, 1971; Hixon, 1982). In addition, it evaluates the morphological components of the plant to optimize the consumption of dry matter, in order to minimize energy costs (Carvalho, 2013). Recent studies show great advances in the understanding of the ingestive behavior of animals from the determination of optimal heights of forage species pre and post grazing (Fonseca et al., 2012; Amaral et al., 2013; Mezzalira et al., 2014), comparing different stocking methods in different climates (Gonçalves et al., 2009; Bremm et al., 2012). From this perspective, these works have shown that while short term grazing behavior is strongly influenced by the structure of the vegetation on offer. Plotting short-term intake rates against grass structure, mostly sward height, there appears to be a bell-shaped curve with a sward height that allows the herbivore to consume very efficiently the forage, minimizing both the exploratory and manipulation movements before severing a bite of grass and the chewing movement to swallow such a bite. Hence, herbivores optimizing the energy harvest efficiency as discussed before, will not only adapt their behavior to the topography and the associated energy expenditure, but they will also continuously be making a trade-off between the search for optimal grazing opportunities with adequate sward height and the locomotion cost to find search opportunities, especially in a rugged terrain.

d) Grazing management

Many authors agree that grazing management techniques, from the point of view of the pasture, should aim to maximize the efficiency of forage use without affecting its growth rate. While from the animal point of view it is about maximizing the efficiency of forage utilization without disturbing the rate of metabolic utilization of the nutrients consumed by the animals (Johnstone-Wallace & Kennedy, 1944; Kollmorgen & Simonett, 1965). In that same order, we saw in the previous section that the animals react based on the variation in the presentation of the grass structure and activate the grazing mechanism to achieve consumption that meets daily nutritional requirements. It is necessary to develop an optimum stocking method for the management of natural pastures or forage mixtures, which allows conserving forage for use in times when growth is limited by environmental factors (Berretta, 1996). In turn, the effect of grazing can favor or harm forage production, making it necessary to make combinations in intensity and frequency of defoliation so that there is adequate productivity without deteriorating pastures (Nabinger et al., 2007). With all these mechanisms in mind, the planning and management of a grazing operation for dairy cattle is based on making sure that the requirements of both the animal and the plants are met. The most important decision now of selecting the grazing scheme is to determine the appropriate endowment for each type of pasture to achieve the production objectives without altering the ecosystem. When the endowment is adjusted to the potential of the pastures and the grazing modality includes rest periods, the fields remain in good condition, with variations due to seasonal changes, achieving a highly stable ecosystem capable of recovering after violent impacts, such as the drought (Heady et al., 1961; Berretta, 1996; Holechek et al., 2001). Each pasture has a potential production that will determine the carrying capacity; that is, the maximum endowment to achieve an objective of animal performance, with a specific stocking method, which can be applied in a defined period without deteriorating the ecosystem (Mott, 1960). The continuous stocking method discussed above is based on keeping a certain number of animals in the pastureland, characterized by extensive areas, for a long period of time. In studies such as those by Campbel (1961) and Wheeler (1962) it was shown that when correcting the stocking rate per hectare (47 animals), the same animal defoliates the same plant with time intervals of up to 15 days, demonstrating that it is not necessarily always the same plant will be defoliated with high levels of intensity. However, in some tropical regions close to latitude 0°00'00″, it is reported that the use of continuous stocking in winter pastures are undergrazed, generating large volumes of plant material residues due to the mechanical action of trampling, urine and feces, considerably reducing the optimization of the use of meadows (Paladines, 1979; Ruiz, 1990). In the summer it is overgrazed due to low availability, causing forage deterioration due to the loss of botanical varieties susceptible to these extremes of intensity (Toro & Briones, 1995; Poppi et al., 1999). The tools that are currently available make it possible to manage differently than continuous stocking. This is the case of alternate grazing, which presents certain improvements in terms of its management, that is, it is an area delimited and divided on the perimeter into two paddocks where the animals graze on average half the time in each one. It means, that if the herd of animals is grazed in a pasture for a period of 5 to 6 months, the other pasture will be resting for the same time. Although the rest time was introduced in this system, it is not flexible in terms of duration, since it will only depend on the time that the other paddock reaches to feed the herd and vice versa. Analyzing its efficiency in terms of adjustment of the ococupation periods, it confers better tools than the continuous system depending on the time of use of a pasture, allowing greater efficiency in the ingestive behavior of the animal and accumulation of reserves by the plant. It provides a more efficient management and ease to apply fertilizers, conferring the necessary time for the absorption of the applied nutrients (Paladines, 1979; Grijalva et al., 1995). Other more widespread alternatives for pasture allocation methods are rotational stocking methods. They consist of an intensive management system where farmers subdivide the paddocks and take into account the supply of forage in each subpaddock and the number of animals assigned. Subsequently, they are moved to the next paddock and guarantee that the pastures have a period of resting days to reach their vigor (Müller & Wissel, 2007). According to O'Reagain et al. (2014) its application is only justified when working with improved high production pastures and having animals with very good performance, when agronomic practices are organized for pasture management and handling high animal loads. However, this practice, in which the animals are rotated from one pasture to another, makes it easier to make the most of the plant material, allowing the pastures to rest for periods of time long enough for them to recover their reserves and regrow healthily (Voisin et al., 1967; Hodgson, 1985). Strip grazing is an extreme variant of rotational stocking in which occupancy time is reduced to a day, or even hours, with the aim of increasing instantaneous stocking and minimizing forage waste. The need to fix the area to graze on a daily basis forces us to look for alternatives to delimit the subpaddocks, the use of fences, generally of the electric type, has managed to be very useful for farmers, sometimes two wires are used in front and one behind to prevent the animals from returning to consume the regrowth of the grass that is at rest (Balocchi et al., 2020; Álvarez & Gimenez, 2021). The farmers manage the grazing periods depending on the volume and quality of the forage supply, as well as the number and categories of animals in the lot. The rest periods are influenced by the degree of growth and production of the forage species, the time of year and the complementary tillage assigned to the paddock just after harvest (Guevara et al., 2018). Basically, the system seeks the maximum utilization of the pastures and at the optimum moment where it shows its highest percentage of nutrients, allowing it an adequate recovery period, and to accumulate sufficient reserves so that it can regrow vigorously (Barrera & Arce, 1993; Hughes, 2011). According to Korte et al. (1982), it is recommended to start grazing on a lawn when the foliage of the plant reaches 95% light interception (LI). Because gross photosynthetic rates coincide with high rates of net forage accumulation and low rates of senescence; being at the end of the linear phase of the sigmoidal forage growth curve as described by Brougham (1955), accepting the importance of determining the LAI as a critical parameter due to its positive relationship with the ability of the plant to intercept light (Gastal and Lemaire, 2015). However, measuring these parameters at the field level is not an easy task, unless they are carried out for research purposes. It has been possible to establish an indirect relationship between LAI and indicators that are easier to measure in the field, such as standing biomass or grass height. The biomass of the meadow refers to the instantaneous measurement at ground level of the total weight of the forage per surface unit, using a quadrat (e.g. 0.5 m by 0.5 m) that promotes the direct cutting of the fresh plant material and subsequent drying to determine the MD present at the cut site (Wilm et al., 1944; Hodgson, 1979). Although this represents the most expensive method for estimating herbage mass HM, it is dependent on sufficient paddock samples being taken (López-Guerrero, 2011). Therefore, it is classified as a destructive and expensive technique in labor and equipment, which also limits the intake of the forage resource that herbivores could consume (Mannetje, 2000). On the other hand, non-destructive techniques, such as the rasing plate mater RPM and sward stick ST are widely used to estimate HM due to their simplicity, speed of use and the ease of storing and processing large amounts of data (Castle, 1976; King & Barthram, 1986). Being very useful to connect a GPS to these tools, allowing to geolocate the exact point of sampling to characterize additional variables before and after grazing (Michez et al., 2019). It is essential to develop a high precision in the management of the calibration equations between collected plant material (g) and the instrument readings (cm) to obtain accurate estimates of biomass for each paddock (Sanderson et al., 2001). Determination of pasture heights before and after grazing are simple indicators or tools that farmers use to determine grazing management decisions (Amaral et al., 2013). This eventually allows that for rotationally stocked pastures, forage allowance be calculated as the relationship between the mean of each stocking period [(pre-grazing + post-grazing) / 2] and the stocking density. For continuously stocked pastures, be calculated as the relationship between the mean pasture pre and post-grazing recorded each period of assigned days and the stocking density. (Sollenberger et al., 2005). Recent studies supported that a specific turf structure, determined primarily by its height, allows dairy cows to maximize their short-term ingestion rate STIR, combining optimal bite mass and pasture horizon grasp, mow and swallow time selected (Penning & Hooper, 1985; Fonseca et al., 2012b). When plotting the data of ingestive behavior at STIR as a function of turf height, a bell-shaped curve is usually obtained, specific for each forage species. For example, in *Lolium multiflorum* and *Cynodon dactylon* the turf height that allows animals to maximize STIR is 19 cm. For *Avena strigosa*, it is 29 cm, while for Kikuyu (*Cenchrus clandestinus - Hochst. ex Chiov*) it is 20 cm. Likewise, the forage peanut (*Arachis glabrata*) is described with 18 cm as the optimal height to establish rotational stocking with maximum DM accumulation, being 9 cm for the mixture of *Lolium perenne L.* with *Trifolium repens L.* (Pyke et al., 1977; McClearn et al., 2019; da Rocha et al., 2020; Marin, 2021). A study conducted by Pembleton et al. (2016) indicates that with a higher volume of biomass (i.e. mixtures of *perennial ryegrass* and white clover and plantain), an increase in the volume and components of the milk was obtained, in the early lactation period; compared to a lower supply of monoculture (i.e. *perennial ryegrass*). A similar result was also found by Woodward et al. (2013), who noted an increase in autumn milk production from cows grazing on a mixed mix of six (6) species (including grasses and legumes) pastures in the Waikato region of New Zealand. Both recognize a greater digestibility, and lower fiber content of legume- or forb-containing pastures; thanks to a higher voluntary intake due to the concept of turf structure and palatability. However, establishing the grazing conditions of a pasture will not only depend on the volume of biomass or the structure of the turf that is shown to the animals. It is also about measuring how much remains after each meal, be it a patch under continuous stocking or a pasture under rotational stocking. This will determine the length of time, in terms of accumulated growing degree days AGDDs, the plant should be allowed to recover before experiencing a new defoliation event (Calvache et al., 2020). Delaby and Peyraud (1998) found that forage intake can be increased by 1 kg of cow per day when the residual pasture height is increased by 1 cm. While Hoden et al. (1991) argue that, although it had a similar result for continuous stocking 1 - 3 cm, in the case of rotational stocking the height of the residual layer was 5 - 6 cm. Coinciding with the data from Mayne et al. (1987) who argue that by increasing the stoking rate it would be possible to correct the volume of production, although sacrificing the frequency of defoliation per year of the paddocks.

In addition to the large social, economic, and topographical differences, dairy farms in the Ecuadorian highlands may differ in the loading methods used to handle their grazing animals. Indeed, some farms let their animals graze continuously in large areas of paddocks for long periods of time without allowing resting cycles for the stalls. While others spend a significant amount of time and energy to replant them every three or four years, applying rotational stocking of medium duration (1 day), and even as short duration (3 hours), where they move an electric fence wire that allows the advance of the animals to new strips of grass. Faced with this great diversity of traditional and innovative stocking methods, we perceive the importance of being able to fully understand the operation of farms, identify the conformation patterns of dairy herds, interpret the logic of the design of pasture rotation types, both in flat grasslands as well as those that show some percentage of slope, in order to find the type of rotation that best suits the productive characteristics of our country.

In this context, the University of Liège (ULiege) and the Central University of Ecuador (UCE), and thanks to the funding of the Académie de Recherche et d'Enseignement Supérieur - Cellule de Coopération au Développement (ARES-CCD, Brussels, Belgium) , have launched a project on the interpretation of dairy cattle grazing management strategies, with the aim of finding a pasture management scheme that best suits the practices of dairy farmers in the sierra zone of the Ecuadorian highlands, in whose framework our work develops.

Five research questions have been defined to achieve this goal:

- What are the forms of organization of the herd in the dairy farms of the Ecuadorian highlands?
- What are the management methods in the dairy farms of the Ecuadorian highlands?
- Does the size of the paddocks determine the choice of pasture rotation methods?

- What is the impact of pasture rotation types on the ingestive behavior of dairy cows?
- What influence do stocking methods have on the volume and quality of the milk produced?

4. Hypothesis and objectives

The aim of the thesis is to understand how stocking management methods used in intensive milk production in the Ecuadorian highlands influence the performance of grazing cows. With these objectives, we presume that we could find a grazing management system that better adapts to the organization practices of dairy systems in the Ecuadorian tropical highlands, as well as identify some operation practices that better compensate for the detrimental effects of topography.

5. Research strategy

For the successful achievement of this study, we present the answers to the main research questions in chapters based on the articles published or submitted for in different peer-reviewed journals. This first chapter included a review of the literature to interpret the evolution of dairy herd management from the diversity of pasture stoking rate practices, and to know the criteria for adopting their types based on the topographic characteristics of the paddocks, herd structure and efficiency of productive yields. Subsequently, a survey was conducted of 42 dairy farms in the rural area of the Pichincha province in the republic of Ecuador, to document the diversity of agricultural management practices and understand the influence of the slope of pastures on those practices. Based on the information obtained in the survey, an experiment was carried out for seven days and three repetitions that evaluated the ingestive and productive behavior of dairy cows that grazed in three types of pasture rotation, with different occupation times (seven days, 24 h and three hours), and in flat paddocks. Finally, an experiment was carried out with dairy cows in paddocks with mild slopes and with two types of pasture occupation times in the rotation (seven days and three hours), the study was carried out five days in a row with two repetitions, we evaluated the ingestive behavior of the animals with the same forage allowance, the energy expenditure required for grazing within the paddocks, depending on the volume and quality of milk produced. This document is made up of five chapters, as detailed below. In addition to the introduction, general discussion and perspectives, the other chapters have been published, submitted for publication or are currently under construction for submission in peer-reviewed international journals.

Chapter 1: General introduction.

Chapter 2: How do management practices and farm structure impact productive performances of dairy cattle in the province of Pichincha, Ecuador.

Eloy Castro Muñoz, Andriamasinoro L.H. Andriamandroso, Yannick Blaise, Lenin Ron, Carlos Montufar, Patrick Mafwila Kinkela, Frédéric Lebeau, Jérôme Bindelle. Journal of Agriculture and Rural Development in the Tropics and Subtropics Vol. 121 No. 2 (2020) 233–241.

Chapter 3: Analysis of the nutritional and productive behavior of dairy cows under three rotation bands of pastures, Pichincha, Ecuador.
Eloy Castro Muñoz, Andriamasinoro L.H. Andriamandroso, Yves Beckers, Lenin Ron, Carlos Montufar, Gentil F. Da Silva Neto, Juan Borja, Frédéric Lebeau, Jérôme Bindelle.
Journal of Agriculture and Rural Development in the Tropics and Subtropics. Vol.122 No. 2 (2021).289-298

Chapter 4 (*unpublished*): Evaluation of the productive behavior of dairy cow grazing on paddocks with a moderate slope with two different rotation method.
Eloy Castro Muñoz, Andriamasinoro L.H. Andriamandroso, Yves Beckers, Juan Borja, Carlos Montufar, Gentil F. Da Silva Neto, Frédéric Lebeau, Jérôme Bindelle.

Chapter 5: General discussion and perspectives.

References

Badgery, W., Millar, G., Broadfoot, K., & Michalk, D. (2017). Increased production and cover in a variable native pasture following intensive grazing management. *Animal Production Science, 57*(9), 1-55.

Aarts, H., Biewinga, E., & Van, H. (1992). Dairy farming systems based on efficient nutrient management. *Netherlands Journal of Agricultural Science, 40*(3), 285-299.

AGSO. (2017, Marzo 15). *Ecuador se proyecta incrementar la producción de leche*. Retrieved from http://www.agso.ec/ecuador-se-proyecta-incrementar-la-produccion-de-leche/

Aharoni, Y., Henkin, Z., Ezra, A., Dolev, A., Shabtay, A., Orlov, A., . . . Brosh, A. (2009). Grazing behavior and energy costs of activity: A comparison between two types of cattle. *Journal of Animals Science, 2009*(1), 2719–2731.

Alvarado, R. (2017, Octubre 18). *Estudio de Mercado "Sector de la leche en el Ecuador".* Retrieved from https://www.scpm.gob.ec/sitio/wp-content/uploads/2019/03/VP-ESTUDIO-DE-LA-LECHE.pdf

Andriamandroso, A., Bindelle, J., Mercatoris, B., & Lebeau, F. (2016). A review on the use of sensors to monitor cattle jaw movements and behavior when grazing. *Biotechnologie, Agronomie, Société et Environnement, 20*(1), 2-15.

Apollín, F., & Eberhart, C. (1999). *Análisis y diagnóstico de los Sistemas de Producción en el medio rural, Guía Metodológica.* Quito, Ecuador: Camaren.

Arce, M., & Pozo, W. (2015). Variabilidad en la producción lechera del agrosistema IASA, según las categorías de intensidad de lluvias de Trojer. *Boletín Técnico, Serie Zoológica, 10*(11), 1-10.

Arnold. (1985). *Bioenergetics of Wild Herbivores.* Florida, EE.UU: CRC Press.

Asamblea Nacional Constituyente. (2008). Constitución de la República del Ecuador. Registro Oficial 449.

Balarezo, L., García, J., Hernández, M., & García, R. (2016). Metabolic and reproductive state of Holstein cattle in the Carchi region, Ecuador. *Cuban Journal of Agricultural Science, 50*(3), 381-392.

Banco Central del Ecuador. (2020). *Reporte de coyuntura sector agropecuario.* Quito: Banco Central del Ecuador.

Bárcena, A., Samaniego, J., Peres, W., & Alatorre, J. (2020, Junio 01). *La emergencia del cambio climático en América Latina y el Caribe: ¿seguimos esperando la catástrofe o pasamos a la acción?* Retrieved from https://www.cepal.org/es/publicaciones/45677-la-emergencia-cambio-climatico-america-latina-caribe-seguimos-esperando-la

Bargo, F., Muller, L., Delahoy, J., & Cassidy, T. (2002). Milk response to concentrate supplementation of high producing dairy cows grazing at two pasture allowances. *Journal of Dairy Science, 85*(7), 1777-1792.

Barnes, M., Norton, B., Maeno, M., & Malechek, J. (2008). Paddock size and stocking density affect spatial heterogeneity of grazing. *Rangeland Ecology & Management, 61*(4), 380-388.

Bernard, A. (1982). *Diagnóstico socioeconómico del sector rural ecuatoriano.* Quito, Ecuador: Insitut de recherche pour de développement.

Bonifaz, N., & Gutiérrez, F. (2013). Correlación de niveles de urea en leche con características físico-químicas y composición nutricional de dietas bovinas en ganaderías de la provincia de Pichincha. *La Granja, 18*(32), 33-42.

Boserup, E. (1993). *The Conditions of Agricultural Growth.* París, Francia: Routledge.

Bozzola, M., Massetti, E., Mendelsohn, R., & Capitanio, F. (2018). The European Review of Agricultural Economics is searching for a book review editor. *European Review of Agricultural Economics, 45*(1), 57-59.

Briske, D., Nathan, F., Sayre, L., Huntsinger, M., Fernandez, B., Budd, J., & Derner, D. (2011). Origin, persistence, and resolution of the rotational stocking debate: integrating human dimensions into rangeland research. *Rangeland Ecology and Management, 64*(4), 325-334.

Bruinsma, J. (2017). *World Agriculture: Towards 2015/2030.* París, Francia: Routledge .

Bustamante, M. (2006). Adaptación de cuatro variedades de Alfalfa" Medicago Sativo en la zona de Cananvalle-Tabacundo, Cayambe-Ecuador 2004. *La Granja*, *5*(1), 11-19.

Caballero, D., & Hervas, T. (1985). *Producción lechera en la Sierra Ecuatoriana.* Quito, Ecuador: IICA Biblioteca Venezuela.

Calvache, M. (2014, Noviembre 5). El suelo y la productividad agrícola en la sierra del Ecuador. *XIV Congreso Ecuatoriano de la Ciencia del Suelo* . Esmeraldas, Ecuador.

Cañadas, L. (1983). *El mapa ecológico y bioclimático del Ecuador*. Retrieved from https://www.ipgh.gob.ec/portal/index.php/biblioteca-menu/novedades-bibliograficas/456-el-mapa-bioclimatico-y-ecologico-del-ecuador.

Carvalho, P. C.D.F. (2013). Harry Stobbs Memorial Lecture: Can grazing behavior support innovations in grassland management? *Tropical Grasslands-Forrajes Tropicales*, *1*(2), 1-137.

Carvalho, P., Bremm, C., Mezzalira, J., & Fonseca, L. (2015). Can animal performance be predicted from short-term grazing processes? *Animal Production Science*, *55*(3), 1-35.

Castro, E., Burgos, J., & Valarezo, L. (2015). Efectos de aditivos y levadura en el incremento de peso en terneras holstein-friesian, de tres a seis meses de edad. *Siembra, 21*(1), 29-33.

Cepeda, D., Gondard, P., & Gasselin, P. (2007). *Mega diversidad agraria en el Ecuador: disciplina, conceptos y herramientas metodológicas para el analisis-diagnóstico de micro-regiones.* Lima, Perú: IFEA.

Chapman, D., Bryant, J., Olayemi, M., Edwards, G., Thorrold, B., McMillan, W., . . . Norriss, M. (2016). An economically based evaluation index for perennial and short-term ryegrasses in New Zealand dairy farm systems. *Grass and Forage Science*, *72*(1), 1-21.

Chobtang, J., Ledgard, S., McLaren, S., & Donaghy, D. (2017). Life cycle environmental impacts of high and low intensification pasture-based milk production systems: A case study of the Waikato region, New Zealand. *Journal of Cleaner Production*, *140*(2), 664-674.

Contero, R. (2008). La calidad de la leche: un desafío en el Ecuador. *La Granja*, *7*(1), 25-28.

Crist, T., & Peters, V. (2014). Landscape and Local Controls of Insect Biodiversity in Conservation Grasslands: Implications for the Conservation of Ecosystem Service Providers in Agricultural Environments. *Land*, *3*(1), 693-718.

Cuchillo, M., Wrage, N., & Isselstein, J. (2017). Behavioral patterns of (co-) grazing cattle and sheep on swards differing in plant diversity. *Applied Animal Behaviour Science, 191*(1), 17-23.

De la Cruz, E., Simbaña, P., & Bonifaz, N. (2018). Milk quality management of small and medium cattle ranchers of collection centers and artisan cheese factories, for continuous improvement. case study: Carchi, Ecuador. *La Granja, 27*(1), 124-136.

De la Motte, L., Jérome, E., Mamadou, O., Beckers, Y., Bodson, B., Heinesch, B., & Aubinet, M. (2016). Carbon balance of an intensively grazed permanent grassland in southern Belgium. *Agricultural and Forest Meteorology, 1*(2016), 370-383.

De Noni, G., Viennot, M., & Trujillo, G. (1997). La erosion agricola de los suelos en el Ecuador. In *Geografia basica del Ecuador.* Quito, Ecuador: Fonds IRD.

De Oliveira , R., Barioni, L., Hall, J., Moretti, A., Fonseca, R., Alexander, P., . . . Moran, D. (2017). Sustainable intensification of Brazilian livestock production through optimized pasture restoration. *Agricultural Systems,* 201-211.

Dedieu, B., Faverdin, P., Dourmad, J., & Gibon, A. (2008). Système d'élevage, un concept pour raisonner les transformations de l'élevage. *INRAE Productions Animals, 21*(1), 45-58.

Dinar, A., & Jammalamadaka, U. (2013). Adaptation of irrigated agriculture to adversity and variability under conditions of drought and likely climate change : interaction between water. *International journal of water governance, 1*(2), 58 - 64.

Drackley, J. (1999). Biology of dairy cows during the transition period: The final frontier? *Journal of Dairy Science, 82*(11), 2259-2273.

Dumont, J., Clements, J., Huckle , C., & Wilkins, R. (1992). *Trébol blanco y producción de leche.* Osorno, Chile: INIA.

Esguerra, J., Cassoli, L., Múnera, O., Cerón, M., & Machado, P. (2018). Calidad de la leche: factores asociados al personal vinculado al ordeño. *Revista MVZ Córdiba, 23*(1), 6461-6473.

Espinoza, J. (1996). El Niño y sus implicaciones sobre el medio ambiente. *Acta Oceanográfica del Pacífico, 8*(1), 115-134. Retrieved from https://aquadocs.org/bitstream/handle/1834/2224/El%20Ni%c3%b1o%20y%20sus%20implicaciones%20sobre%20el%20medio%20ambiente.pdf?sequence=1&isAllowed=y

Evenson, R., & Gollin, D. (2003). Assessing the impact of the Green Revolution, 1960 to 2000. *Science, 300*(5620), 758-762.

FAO. (2017). *Producción pecuaria en América Latina y el Caribe*. Retrieved from https://www.fao.org/americas/prioridades/%20produccion-pecuaria/es/

FAO. (2019). *El estado mundial de la agricultura y la alimentación. Progresos en la lucha contra la pérdida y.* Roma, Italia: FAO.

FAO. (2021). *Producción animal*. Retrieved from https://www.fao.org/animal-production/en/

FAOa. (2017, Diciembre 1). *Milk and Milk Products: Price and Trade Update.* Retrieved from https://www.fao.org/3/i8326e/i8326e.pdf

FAOb. (2021). *Ecuador Production*. Retrieved from https://www.fao.org/faostat/es/#search/PRODUCCI%C3%93N%20DE%20ECUADOR

FAOSTAT. (2018, Noviembre 1). *The Statistics División of the FAO*. Retrieved from http://www.fao.org/faostat/en/\#data

Farley, K., Anderson, W., Bremer, L., & Harden, C. (2011). Compensation for ecosystem services: an evaluation of efforts to achieve conservation and development in Ecuadorian páramo grasslands. *Environmental Conservation, 38*(4), 393–405.

Flanders, F., & Gillespie, J. (2015). *Modern Livestock & Poultry Production.* Massachusetts, EE.UU: Cengage Learning.

Franco, W., Catucuago, C., Alvarez, W., & Bazantes, K. (2021). Uso pecuario intensivo, propiedades químicas del suelo y sostenibilidad en los andes al norte del Ecuador. *Ciencia del Suelo, 39*(1), 80-93.

Franco, W., Peñafiel, M., Cerón, C., & Freire, E. (2016). Biodiversidad productiva y asociada en el Valle Interandino Norte del Ecuador. *Bioagro, 28*(3), 181-192.

Fulkerson, W., & Donaghy, D. (2001). Plant soluble carbohydrate reserves and senescence-key criteria for developing an effective grazing management system for ryegrass-based pastures a review. *Australian Journal of Experimental Agriculture, 41*(2), 261-275.

Gamarra , M. (2001). Situación actual y perspectivas de la ganadería lechera en la cuenca de Lima. *Revista de Investigaciones Veterinarias del Perú, 12*(2), 1-13.

Garibaldi, L., Barbara, G., D'Annolfo, R., Graeub, B., Cunningham, S., & Breeze, T. (2017). Farming Approaches for Greater Biodiversity, Livelihoods, and Food Security. *Trends in Ecology & Evolution, 32*(1), 68-80.

Gerssen, S., Lauwerijssen, R., Havlík, P., Herrero, M., Valin, H., Faaij, A., & Wicke, B. (2017). Intensification pathways for beef and dairy cattle production systems: Impacts on GHG emissions, land occupation and land use change. *Agriculture, Ecosystems & Environment, 240*(1), 135-147.

Gondard, P. (2005). *Ensayo en torno a las regiones de Ecuador Herencias y reestructuraciones.* Quito, Ecuador: Centro Andino de Acción Popular.

Grant, R., & Albright, J. (2001). Effect of animal grouping on feeding behavior and intake of dairy cattle. *Journal Dairy Science, 1*(84), 156-163.

Grijalva, J., Espinosa, F., & Hidalgo, M. (1995). *Producción y utilización de pastizales en la región interandina del Ecuador.* Quito, Ecuador: Instituto Nacional Autónomo de Investigaciones Agropecuarias.

Guamán, G., Masaquiza, D., & Curbelo, L. (2017). Caracterización de Sistemas Productivos Lecheros en Condiciones de Montaña, Parroquia Químiag, Provincia Chimborazo, Ecuador. *Revista de Producción Animal, 29*(2), 14-24.

Hanrahan, L., McHugh, N., Hennessy, T., Moran, B., Kearney, R., Wallace, M., & Shalloo, L. (2018). Factors associated with profitability in pasture-based systems of milk production. *Journal of Dairy Science, 101*(6), 5474-5485.

Hofstede, R., Segarra, P., & Vásconez, P. (2003). *Los Páramos del Mundo.* Quito, Ecuador: IUCN.

Hofstetter, P., Frey, H., Gazzarin, C., Wyss, U., & Kunz, P. (2014). Dairy farming: indoor v.pasture-based feeding. *Journal of Agricultural Science, 152*(1), 994–1011.

Hostiou, N., & Dedieu, B. (2009). Diversity of forage system work and adoption of intensive techniques in dairy cattle farms of Amazonia. *Agronomy for Sustainable Development, 29*(4), 2-10.

INEC. (2020). *Estadísticas Agropecuarias*. Retrieved from https://www.ecuadorencifras.gob.ec/estadisticas-agropecuarias-2/

Ingvartsen, K. (2006). Feeding-and management-related diseases in the transition cow: Physiological adaptations around calving and strategies to reduce feeding-related diseases. *Animal Feed Science and Technology, 123*(4), 175-213.

Isbell, F., Gonzalez, A., Loreau, M., Cowles, J., Díaz, S., Hector, A., . . . Larigauderie, A. (2017). Linking the influence and dependence of people on biodiversity across scales. *Nature, 1*(546), 65-72.

Johansen, K., Alfthan, B., Baker, E., Hesping, M., Schoolmeeste, T., & Verbis, K. (2018, Febrero 4). *El Atlas de Glaciares Andinos de la UNESCO.* Arendal, Noruega: UNESCO.

Jordan, E., & Fourdraine, R. (1993). Characterization of the management practices of the top milk producing herds in the country. *Journal of Dairy Science, 76*(10), 3247-3256.

Jorgensen, P., & León, S. (1999). *Catalogue of the Vascular Plants of Ecuador*. Retrieved from Missouri Botanical Garden web site: http://www.mobot.org/MOBOT/Research/ecuador/results.shtml

Kay, G., Mortelliti, A., Ayesha, T., Philip, B., Florance, D., Cunningham, S., & David, L. (2017). Effects of past and present livestock grazing on herpetofauna in a landscape-scale experiment. *Conservation Biology, 1*(1), 1-13.

Krejcie, R., & Morgan, D. (1970). Determining sample size for research activities. *Educational and psychological measurement, 30*(3), 607-610.

Lascano, A., Arcos, A., Guevara, V., Torres, I., Guevara, V., Serpa, G., . . . Pedraza, O. (2017). Respuesta productiva de vacas lecheras neozelandesas sometidas a pastoreo rotacional en el trópico alto del norte de Ecuador. *Maskana, 8*(1), 153-155.

Lean, I. (1987). *Nutrition of dairy cattle.* Sydney, Australia: Postgraduate Committee in Veterinary Science.

Lhoste, P. (1986). Sur les systèmes d'élevage. *Revue d'élevage et de médecine vétérinaire des pays tropicaux, 39*(1), 11-12.
Lynch, J., & Duellman, W. (1980). *The Eleutherodactylus of the Amazonian slopes of the eciadorian Andes (Anura: Leptodactylidae).* Kansas, EE.UU: University of Kansas.
Martínez, C., Rayas, A., Anaya, J., Martínez, F., Espinoza, A., Prospero, F., & Arriaga, C. (2015). Performance of small-scale dairy farms in the highlands of central Mexico during the dry season under traditional feeding strategies. *Tropical Animal Health and Production, 47*(2), 2-8.
Mazoyer, M. (2001). *Protecting small farmers and the rural poor in the context of globalization.* Retrieved from https://www.fao.org/worldfoodsummit/msd/Y1743e.pdf
Mezzalira, J., Carvalho, P., Fonseca, L., Bremm, C., Cangiano, C., Gonda, H., & Laca, E. (2014). Behavioural mechanisms of intake rate by heifers grazzing swards of contrasting structures. *Applied Animal Behavior Science, 1*(153), 1-9.
Ministerio de Agricultura, Ganadería, Acuacultura y Pesca. (2013, Septiembre 4). Acuerdo 394. *Regular y controlar el precio del litro de leche cruda pagado en finca y/o centro de acopio al productor y promover la calidad e inocuidad de la leche cruda*.
Ministerio de Agricultura, Ganadería, Acuacultura y Pesca. (2016). *La política agropecuaria ecuatoriana: hacia el desarrollo territorial rural sostenible: 2015-2025.* Quito, Ecuador: Ministerio de Agricultura, Ganadería, Acuacultura y Pesca.
Ministerio de Agricultura, Ganadería, Acuacultura y Pesca. (2017, Noviembre 15). *Catálogo de objetos temáticos del Ministerio de Agricultura, Ganadería, Acuacultura y Pesca*. Retrieved from http://geoportal.agricultura.gob.ec/pdf/Catalogo_ Volumen_II.pdf
Moir, J., & Cameron, K. (2011). The spatial coverage of dairy cattle urine patches in an in- tensively grazed pasture system. *Journal of Agricultural Science, 179*(4), 473-485.
Noboa, S. (2010). Cambio climatico y pobreza en el Ecuador. *Brazilian Journal of Environmental Sciences, 1*(17), 54-64. Retrieved from http://rbciamb.com.br/index.php/Publicacoes_RBCIAMB/article/view/379/326
O'Brien, D., Shalloo, L., Joe, P., Buckley, F., Grainger, C., & Wallace, M. (2012). A life cycle assessment of seasonal grass-based and confinement dairy farms. *Agricultural Systems, 107*(1), 33-46.
ONU. (2020, Diciembre 16). *América Latina: En 2021 el crecimiento dependerá del control del COVID-19, no debemos relajar las medidas de protección*. Retrieved from https://news.un.org/es/story/2020/12/1485722
Ospina, P., Hollenstein, P., & Latorre, S. (2020). *Territorio, ruralidades, ambiente y alimentación en el Ecuador: un balance de la investigación*

(2000-2019). Quito, Ecuador: Universidad Andina Simón Bolívar, Sede Ecuador.
Palacios, F. (1977). *Pastizales de regadío para alpacas.* Lima, Perú: Instituto de Estudios Peruanos.
Partridge, T. (2015). Agua: vida y agricultura. *Leisa, 31*(3), 2-44.
Popescu, A. (2017). Trends in milk market and milk crisis impact in Romania. *Scientific Papers Series Management, 17*(2), 281-290.
Pourrut, P. (1983). *Los climas del Ecuador: fundamentos explicativos.* Quito, Ecuador: Programa Nacional de Regionalizacion Agraria del Ministerio de Agricultura y Ganaderia.
Ramirez, P., Izquierdo, F., & Paladines, O. (1996). *Producción y utilización de pastizales en cinco zonas agroecológicas del Ecuador.* Quito, Ecuador: EPN.
Requelme, N., & Bonifaz, N. (2012). Caracterización de sistemas de producción lechera de Ecuador. *La Granja, 15*(1), 55-68.
Saavedra, O. (2006). EI sistema agricola prehispanico de Camellones en la amazonia boliviana. In V. Francisco, *Agricultura ancestral: Camellones y albarradas.* Quito, Ecuador: Ediciones Abya- Yala.
Sánchez, Á., Savian, J., De Souza, W., Osorio, M., Marín, A., Bindelle, J., . . . De Faccio, P. (2020). Does grazing management provide opportunities to mitigate methane emissions by ruminants in pastoral ecosystems? *Science of The Total Environment, 754*(1), 1420-1429.
Schulte, H., Musshoff, O., & Meuwissen, M. (2018). Considering milk price volatility for investment decisions on the farm level after European milk quota abolition. *Journal of Dairy Science, 101*(8), 7531-7539.
SIGTIERRAS. (2018). *Mapa de Órdenes de Suelos del Ecuador*. Retrieved from http://www.sigtierras.gob.ec/mapa-de-ordenes-de-suelos/
SINAGAP. (2014). *VI Censo Agropecuario*. Retrieved from https://www.ecuadorencifras.gob.ec/estadisticas- agropecuarias-2/. Last accessed: June 2020
Solís, M. (1690). Los pastizales naturales del Ecuador. *Revista Geográfica, 27*(53), 93–105.
Solo, V. (2012). *Toacazo: en los Andes equinocciales tras la reforma agraria.* Quito: Flacso.
Sturaro, E., Marchiori, E., Cocca, G., Penasa, M., Ramanzin, M., & Brittante, G. (2013). Dairy systems in mountainous areas: Farm animal biodiversity, milk production and destination, and land use. *Livestock Science, 158*(3), 157-168.
Thomas, C. (2004). *Feed into milk: a new applied feeding system for dairy cow : an advisory manual.* Gotinga, Alemania: Biology, Engineering.
Valarezo, G. (1993). *Tierras y Manos Indias: La Recuperacion del Suelo En Las Comunidades Andinas de Chimborazo.* Quito, Ecuador: Comunidec.

Valdez, F. (2006). *Drenajes, camellones y organizacion social : usos del espacio y poder en La Tola, Esmeraldas.* Quito: Ediciones Abya- Yala.

Valenzuela, H., Baquerizo, M., Pantoja, C., Rojas , F., Huayre, R., Reina, J., . . . Rojas, E. (2017). Estudio de la prevalencia del mal de altura en ganado vacuno de la raza Brown swiss, de la Sierra Central de Perú, abril 2017. *Ciencia y Desarrollo, 20*(2), 17-23.

Varela, E., & Robles, A. (2016). *Ecosystem services and socio-economic benefits of Mediterranean grasslands.* Barcelona, España.

Villacís, B., & Carrillo, D. (2010). *Estadística Demográfica en el Ecuador: Diagnóstico y Propuestas.* Quito, Ecuador: Instituto Nacional de Estadística y Censos.

Will, D., Hicks, J., Card, L., & Alexander, A. (1975). Inherited susceptibility of cattle to high-altitude pulmonary hypertension. Journal of applied physiology. *Journal of applied physiology, 38*(3), 494-494.

Willett, W., Rockstrom, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., & Murray, C. (2019). Food in the Anthropocene: the EAT-Lancet Commission on healthy diets from sustainable food systema. *The Lancet, 393*(10170), 447-492.

Winckell, A. (1997). Los grandes rasgos del relieve en el Ecuador. In *Geografia basica del Ecuador.* Quito, Ecuador: Fonds IRD.

Zanzzi , F. (2007). *La división territorial político-administrativa con base en la participación ciudadana.* Milagro, Ecuador: Universidad Estatal de Milagro.

After the previous chapter introducing the context of the thesis and reviewing the literature on the evolution of dairy herd management based on the diversity of pasture load practices, the criteria for the adoption of its types, depending on the topographical, climatic characteristics and the size of the farms; as well as a small sketch of the national reality in terms of Gross Domestic Product (GDP) and the labor, social and economic impact of dairy production in the Ecuadorian countryside, the next chapter focuses on documenting the most used agricultural techniques by Andean dairy farmers. For this purpose, we carried out a survey in 42 milk-producing farms in different cantons of the province of Pichincha (Quito, Mejía, Rumiñahui and Cayambe) of Ecuador. The induction and training in the use of the questionnaire with its open and closed questions, prior to the deployment in the field of the professors and students of the agronomic engineering career of the Central University of Ecuador, allowed us to identify the wide range of types of management of dairy farms. In terms of herd organization, cultural work in the meadows, as well as pasture rotation methods, in its constant search for better animal performance from the occupation rate. However, although the slope of the land has a clear impact on the productive volumes of grazing animals, there are no reports on the influence of diversity on management practices and its consequences on animal performance, considering the slope. That is why we focus on documenting management practices in dairy systems in the tropical highlands of central Ecuador and understanding the influence of slope on production volumes and processes.

Chapter 2

How do management practices and farm structure impact productive performances of dairy cattle in the province of Pichincha, Ecuador?

Artícle 1

How do management practices and farm structure impact productive performances of dairy cattle in the province of Pichincha, Ecuador?

Eloy Castro Muñoz [a,b,c,], Andriamasinoro L. Andriamandroso [e], Yannick Blaise [b], Lenin Ron [a], Carlos Montufar [a], Patrick Mafwila Kinkela [b,d], Frédéric Lebeau [c], Jérôme Bindelle [b]*

a Universidad Central del Ecuador, Facultad de Ciencias Agrícolas, Jerónimo Leiton y Gato Sobral s/n. Ciudadela Universitaria. 170521, Quito, Ecuador
b Precision Livestock and Nutrition Unit, AgroBioChem, Gembloux Agro-Bio Tech, University of Liège, Passage des Déportés 2, 5030 Gembloux, Belgium
c Digital Energy & Agriculture Lab (DEAL), Biosystems Dynamics and Exchanges (BioDynE), Gembloux Agro-Bio Tech, University of Liège, Passage des Déportés 2, 5030 Gembloux, Belgium
d Animal Science Unit, University of Kinshasa, Democratic Republic of the Congo
e Department Agriculture and Landscape Teaching and Research Department, ISA Lille, Junia, 48 Boulevard Vauban, 59046 Lille, France

Corresponding author

CASTRO MUÑOZ Eloy, MSc, Universidad Central del Ecuador, Ecuador. Facultad de Ciencias Agrícolas, Ave. Universitaria, Qutio 170129. +593 22232402

The preliminary results of the study were presenting in the *1 rs International Congress of Agricultural Science and Technology (INIAP)*, Quito, Ecuador, (2018).

This chapter is adapted from an article submitted for publication in *Journal of Agriculture and Rural Development in the Tropics and Subtropics (JARST).* Vol.121 Nº 2 (2020) 233-241

Abstract

The combination of ancestral knowledge and modern agricultural techniques are increasingly used by Andes farmers, demonstrating its great importance as an ideal alternative to achieve international standards of productivity and sustainability. Pasture management has demonstrated its relevance in terms of milk volume and quality in farms located in the Ecuadorian highlands, showing a wide range of types of forage resource use, in its constant search for better animal yields from the occupancy rate. However, while inclination of land has a clear impact on energy expenditure of grazing animals, there are no reports on the influence of the diversity in management practices and their consequences on animal performance, considering the slope of pastures animals are grazing. The objective of the present investigation was to document management practices in dairy systems in the tropical highlands of central Ecuador and to understand the influence of the slope of pastures on those practices. A survey was carried out in the rural area of the province of Pichincha in 42 dairy farms using a questionnaire to identify the productive and management activities in the herds and to evaluate the average slope of the pastures of the farms based on GIS data. Results showed that farms had an average acreage of 40 ha, the herds were composed of 60 ± 63 cows in milk, predominantly Holstein (65 %), and the daily production of individual milking cows reached 15.1 ± 3.4 kg. Highest productivity was found on farms with the highest re-population rates using rotatory grazing with high intensity of instantaneous grazing with very short occupation times (<12 h) and a flat topography of the pastures ($p < 0.05$). The daily production of individual cows was negatively correlated ($r = -0.323$, $p = 0.037$) with the average slope of the farms. It is concluded that the use of rotational stocking with very short occupation times seems relevant to maximize individual yields. More research should clarify whether the specific pasture design and the rotation system can contribute to reducing the observed negative impact of high slopes on individual milk production.

Keywords: grazing rotation, tillage, slopes

1. Introduction

Grasslands are unique components of agroecosystems. They cover 26 % of total land and 69 % of agricultural areas in the world. Grazed pastures display multiple roles that can benefit the sustainability of dairy production, such as lower feeding costs (Bruinsma, 2017). Pastures can play a significant role in trapping atmospheric CO_2 through soil C sequestration (De la Motte et al., 2016). In addition, grasslands provide many social and environmental services. The selection of an adequate choice of more diverse grass and legume species and varieties with adequate management could support a wider range of micro-fauna and crop auxiliaries, from acting as filters for the composition of functional species of bees and beetles that enrich the coverage of the surrounding soil (Crist & Peters, 2014), through the recognition of grasslands as socio-ecological systems that generate, beyond tangible provisioning services, jobs such as those related with the maintenance of the grasslands (Varela & Robles, 2016), and turning the ecuadorian "paramo" grasslands into compensation centers destined to preserve hydrological services and carbon sequestration (Farley et al., 2011). But more importantly, adequate selection of grasses and a high biodiversity level could sustain more stable production services. It was demonstrated that biodiversity in grasslands is a key factor to either mitigate decreases in case of disturbances or even increase forage productivity (Isbell et al., 2017; De Oliveira et al., 2017). Indeed, grazing livestock was proved to be the least expensive way to feed ruminants such as cattle for both milk and meat production (Hofstetter et al., 2015). The share of cattle in milk production worldwide corresponds to 83 % (FAOSTAT, 2018). Because the demand is very high, the annual growth rate of milk production is 1.4 % globally, but the market is characterized by a strong volatility in prices (Popescu, 2017; Schulte et al., 2018). This puts farmers, especially small- holders, under great economic pressure and raises the acute question of the improvement of their livelihoods (Garibaldi et al., 2017). In Latin America, the dairy sector has been more dynamic in the past 20 years than in the rest of the world, with an average growth of 12.5 % for its 3.15 millions of milk producers (FAO, 2017). This confirms the importance of this sector in this part of the world in terms of land occupation (Gerssen, et al., 2017) as well as generation of employment (Cepeda et al., 2007).

Dairy production in Ecuador is concentrated mostly in the Andean highlands, the Sierra. The milk production in this region reaches 73 % of the national total production representing 3,869,000 kg per day (Grijalva, Espinosa, & Hidalgo, 1995). Within this area, dairy farms use diverse animal and pasture management systems in response to their specificities in terms of farm structure, available land, livestock, mechanisation and human resources. In this regard, methods of pasture management can range from mechanical cuts, to grazing using continuous or intensive rotational stocking (Kay et al., 2017). The proper management of pastures is of utmost importance for the stability and profitability of the dairy operations. It has repercussions on both the biomass production, feeding quality and regeneration capacity of the plant community, as well as livestock performance. The way cattle explore a pasture depends on several factors that will in the end contribute to the extra energy requirement they specifically need to move on the paddock. Among these factors, some are linked to the quality of the forage resource and the ease by which animals will be able to take their bites (Arnold, 1985). Others are related to the energy costs to move around the paddock, especially its topography (Aharoni et al., 2009).

Grazing is indeed a multiscale heterogeneous process in space and time involving a combination of one-time confined choices to perform bites on specific feeding stations to large movements of the animals across the whole pasture over meals, days and months. What happens at the bite level influences the whole grazing pattern and subsequent animal performance (Andriamandroso et al., 2016). Moreover, grazing management can influence the spatial uniformity of both plant removals and excreta depositions, which in turn affect plant diversity (Moir & Cameron, 2011). For example, continuous stocking allows for stronger selectivity of animals than rotational stocking, both in terms of location where bites are taken and in terms of which plant species or plant parts are consumed. Long term occupation times in rotations increase the chances for observing a second grazing event on a given feeding station as compared to innovative rotations where the optimal sward structure is offered to maximize animal intake (Carvalho et al., 2015). Hence, while milk production faces new challenges and there is a strong need to achieve greater efficiency with increasingly limited and more expensive resources (Hostiou & Dedieu, 2009). Farmers should be accompanied to adopt new management systems that include the proper use of new technologies and production techniques to increase stability and the global efficiency (Chobtang et al., 2017).

Hence, various management levers can be considered by the Andean dairy farmers in Ecuador: the number of harvests through grazing or cuts per year, the resting days attributed to the paddock taking into account the botanical composition, and the season (Hilario et al., 2017), as well as the control of frequency and intensity of defoliation (Badgery et al., 2017), the structure of the vegetation on offer (Carvalho, 2013), the use of irrigation to extend the forage production season (Boserup, 2017), the resowing of pasture as well as the choice of pasture species (Chapman, et al., 2017). However, to our knowledge, the link between grazing management and milk productivity expressed both per head and per pasture surface area has not been documented yet in situations with high variation in terrain relief. Farmers working in areas such as the Ecuadorian Sierra do not know which grazing system might be the most stable and sustainable. Therefore, we argued that we could find a grazing management system that best fits (1) management practices of dairy systems in the Ecuadorian tropical highlands, especially how grazing lands are used, differ between farms according to the slope of the farm area, (2) the average slope of the paddocks grazed by dairy cows impact their individual milk yields; and (3) some management practices compensate better for Requelme y Bonifaz (2012) such detrimental effects of slopes. Hence, we performed a survey in farms located in the province of Pichincha in the Ecuadorian Sierra to characterise their diversity in structure with a specific focus on herds and grazing management systems and link them to technical and productive indicators.

2. Materials and methods

2.1. Location of the farms

The survey was performed in the Province of Pichincha, considered the largest "milk producer par excellence" in Ecuador, in an area known as El Valle Inter-Andino with an agricultural area of 925,740 ha. The altitude varies from the northwest of Quito (1600 m), through the valleys of Machachi, Tabacundo and Cayambe (2500 m) to the "páramos" (3500 m), with very diverse climatic conditions. The paramos experience negative temperatures in the early morning, while the temperatures at 12 noon can be as high as 24 °C in the altiplano zones (January - May, October - November). Most areas also have a seasonal distribution of rainfall with 1500 mm in winter and 400 mm in summer (Arce & Pozo, 2015; Ministerio de Agricultura, Ganadería, Acuacultura y Pesca (MAGAP, 2016).

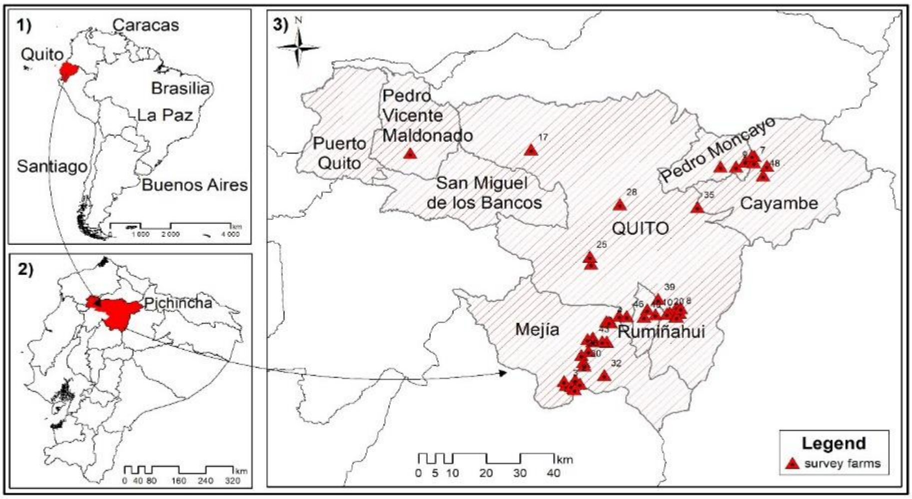


Figure 5: 1) Location in South America, country Ecuador, 2) of the Pichincha province 3) and location surveyed farms.

A list of all commercial dairy farms found in the Pichincha province was obtained from the undersecretary of Agro-quality of the Ministry of Agriculture, Aquaculture and Fisheries of Ecuador and cross-validated with the National Agricultural Census (SINAGAP, 2014). A total of 42 dairy farms were randomly selected among those selling their milk to a dairy plant. The selected farms belonged to 7 cantons and 22 parishes. The sample size complied with the equation proposed by Krejcie & Morgan (1970) in order to guarantee homogeneity and representativeness for a confidence level of 95 %.

3. Survey

The surveys were conducted by undergraduate university students of the Faculty of Agricultural Sciences of the Central University of Ecuador, under the supervision of three professors of the same institution. The owners or managers of the farms of four municipalities (Cayambe, Mejía, Quito & Rumiñahui) were interviewed in February 2017 based on a structured questionnaire collecting various technical indicators relevant to the predominant production systems in the province (Apollín & Eberhart, 1999). These indicators were divided into subsystems: characterisation of the structure of the farm (total and pasture area, average slope, animal load, etc.); structure of the dairy herd (size of dairy herds, breeds, herd categories, milk production, feeding system, etc.); grassland management methods (number of paddocks, resting time, pasture management, type of rotation, etc.). In addition, the milking parlour of the investigated farms was geolocated (Figure 1) and information about the average slope of the pastures of the farms was collected from the GIS database of Ministerio de Agricultura, Ganadería, Acuacultura y Pesca (MAGAP, 2017).

4. Data analysis

All the collected data were analysed with the mixed procedure of SAS 9.4, comparing the mean values of the quantitative data between category after testing distributions for normality and using each farm as experimental unit. The qualitative data were analysed by chisquare test to identify the dependence of frequency variables in relation with classification of the farms in the four municipalities. Analysis of variance was used to test for differences in quantitative data, while Pearson’s correlation was run to evaluate the influence of slope on milk yield parameters based on all individual farms in the dataset.

5. Results

5.1. Descriptive characteristics of the farms

Pichincha known as "milkmaid province" has different areas where dairy production is practiced. Of those, four were surveyed for a total of 42 farms: Mejia (20 farms); Quito (13); Cayambe (5); Rumiñahui (4). The size of the farms ranged from 5 to 700 ha, with a median value of 40 ha. Most of the area of the farms is used to produce forage, and 70 % of the area on average was used as pasture for milk production, with average pasture area of 24 paddocks per farm, in the range of 1.5 to 2 ha in size and a median of 8 pasture cycles per year. Pastures were all artificial, composed of a mixture of sown grasses (*Pennisetum clandestinum, Lolium multiflorum, Dactylis glomerata, Lolium perenne, Holcus lanatus*) and legumes (*Medicago sativa, Trifolium repens*) in variable proportions. Likewise, some paddocks on some farms were sown with forage oats (*Avena sativa*) and vetch (*Vicia sp.*).

Table 1. Average and standard deviation to characterise the structure by area, loading intensity and slope of farms surveyed in different municipalities in the province of Pichincha

	Cayambe	Mejía	Quito	Rumiñahui
n (numbers of farms by site)	5	20	13	4
Total area of farms (ha)	39.4 ± 51.4	56.6 ± 38.7	82.0 ± 84.1	182.8 ± 344.9
Pasture surface (ha)	14.4 ± 19.9	46.5 ± 32.3	48.8 ± 46.8	19.0 ± 20.8
Animal load (AU/ha)*	1.5 ± 0.7	1.9 ± 1.0	1.3 ± 0.7	2.3 ± 0.4
Inclination slope (%)	12.5 ± 5.5	15.4 ± 13.1	27.2 ± 15.7	31.1 ± 17.2

* AU/ ha = average number of animal units per ha, assuming year-round grazing (AU is defined here as an animal of 450 kg)

Table 2. Average and standard deviation to characterise the structure by area, loading intensity and slope of farms surveyed in different municipalities in the province of Pichincha

	Cayambe	Mejía	Quito	Rumiñahui	P-value
Dairy herd breed					
Total number of animals	45.0 ± 54.0	180.8± 153.1	162.5 ± 145.7	82.25 ± 83.4	0.19
Holstein	44.0 ± 54.2	121.6 ± 106.8	106.9 ± 105.86	43.7 ± 40.2	0.28
Others	0.6^{b} ± 1.34	14.1^{ab} ± 22.8	47.9^{a} ± 83.7	31.25^{a} ± 47.8	0.046
Crosses	0.4± 0.89	45.1± 94.07	7.31± 11.21	7.25 ± 11.41	0.067
Categories of dairy herd (%)					
Male calf	14	11	14	10	0.56
Female calf	9^{a}	1^{b}	5^{ab}	3^{b}	0.01
Heifer	12	18	18	15	0.34
Replacing female	11	11	11	7	0.92
Dry cattle	5^{c}	15^{ab}	14^{b}	18^{a}	0.00
Breeding male	3	0	1	1	0.12
Dairy cow	46	44	37	46	0.21
Milk production (kg ha^{-1} d^{-1})	9.76^{ab} ± 6.26	25.95^{a} ± 16.47	8.87^{b} ± 7.53	18.97^{a} ±14.92	0.018
Production per cow (kg d^{-1})	14.82 ± 2.13	16.09 ± 2.77	13.74 ± 3.89	12.77±2.97	0.11

ANOVA: abc = values followed by different letters differ significantly at the 0.05 level

5.2. Herds compositions

A total of 6277 animals were counted in the surveyed farms. Herds were composed of 60 ± 63 cows in milk, followed by heifers 24 ± 20 and breeding males with 1 ± 1. Adult cows, i.e. cows having calved at least one time, represented less than 60 % of the total herds of cattle, indicating a limited level of specialisation of the farms. It was found also that the farms were predominantly composed of Holstein-Friesian breed (65 %), with significant differences in the category (Table 1). Other breeds, such as crossings of Creole with Brown Swiss, Jersey, and Montbeliere were more present in the herds of Mejia, Quito and Rumiñahui than of Cayambe, where they were almost absent ($p = 0.046$). Milk production sold daily to the dairy plants reached 15.1 ± 3.4 kg per cow. The individual milk productivity of the cows was neither correlated to the size of the herd ($p = 0.189$) nor the total pasture area of the farms ($p = 0.945$).

5.3. Grass management and tillage

When considering grass management and tillage (Table 2), farms in Cayambe differed from the other three locations with a lower number of paddocks used in the grazing system ($p = 0.035$). Moreover, farms located in Quito and Rumiñahui had paddocks with steeper slopes than Cayambe and Mejía ($p = 0.046$). Other management operational parameters and practices such as resting time or the use of electric fences to practice fast rotation rates on the paddocks did not differ between the cantons. Additionally, the continuous stocking method is almost nonexistent over the whole area where almost all dairy farmers of the province use some kind of rotational stocking, with a significant part using a movable electric fence to open up new portions on the paddocks for grazing every 2 to 3 hours. Regarding the management of the vegetation itself, fewer farmers of Rumiñahui mentioned sowing their pastures as opposed to the other locations. The frequency of other practices such as reseeding, dispersion of manure or equalization cuts did not differ between locations.

Table 3. Structural characterisation and pasture management of farms surveyed in the Pichincha province

	Cayambe	Mejía	Quito	Rumiñahui	P-value†
Number of paddocks	8.8^{b} ± 8.0	26.4^{a} ± 15.3	24.6^{a} ± 18.9	30.0^{a} ± 44.71	0.035
Slope of pastures (mean %)	12.5^{b} ± 5.5	15.4^{b} ± 13.1	26.1^{a} ± 15.8	31.1^{a} ± 17.2	0.046
Cut and carry*	40	15	3.8	0	0.41
Vegetation resting time in rotational stocking (days)	45.0 ± 20.8	45.0 ± 12.0	45.0 ± 10.2	45.0 ± 12.2	0.17
Stocking methods (%)					
Rotation	100	100	90	100	X^2, 0.36
Continuous	0	0	10	0	X^2, 0.74
Electric fence	100	95	70	50	X^2, 0.51
Tillage measure (% of farmers)					
Sowing[1]	100	90	90	25	X^2, 0.012
Reseeding[2]	60	75	70	50	X^2, 0.23
Equalization cut[3]	80	65	20	50	X^2, 0.92
Aeration[4]	60	60	40	25	X^2, 0.16
Manure dispertion[5]	80	50	50	75	X^2, 0.33

† ANOVA test, and Chi-square tests;

abc= values followed by different letters differ significantly at the 0.05 level;
* Fresh grass placed in feeders in the waiting area of the milking parlour in percentage of all farms applying; 1−5 Tillage frequency: 1 once a year; 2,4 twice a year; 3,5 more than twice a year

6. Discussion

This study showed that farmers working in pasture-based milk production in the province of Pichincha, Sierra region of Ecuador, apply intensive pasture management practices such as very short-term rotational stocking with electric fences, reseeding, and equalisation cuts. This province has traditionally herds that contribute very important volumes to the regional dairy plant (Esguerra et al., 2018). In our case, 31% of the farms surveyed showed a production of > 1000 kg milk per day. However, 35% of the farms showed milk volumes of < 300 kg per day, which may be explained by the great diversity of management techniques found in this survey which was also reported by (Guamán, Masaquiza, & Curbelo, 2017). Milk sold to the dairy plants reached 15.1 ± 3.4 kg per cow per day, which is rather low for animals of specialised breeds. Nevertheless, these levels are in line with what could be expected from cows grazing on high quality pasture as confirmed by the botanical composition (Bonifaz y Gutiérrez, 2013) but receiving very little concentrate supplements (Bargo et al., 2002). The steepness of the slopes was not a limitation to establish pastures for grazing animals since pastures were observed on the whole range of slopes, including the very steep ones (up to 55% of steepness). Similar results were observed in the Italian eastern Alps (Sturaro et al., 2013), where dairy cows are grazing the steepest meadows and highland pastures in traditional low-input systems. However, the large range and the consecutively high SD in individual milk production were also explained by differences in topography (Table 3). Indeed, the high SD value indicated a high variability in pasture area use efficiency between farms. This showed that a margin of progression does exist for farmers in their production indicators. Three factors might explain this variability. One factor is related to the intensity of the pasture use. Individual cow production levels were positively correlated to stocking rate ($r = -0.455$, $p = 0.003$), which reached 1.7 ± 0.8 cow ha^{-1} of pasture. A second difference lies in the grazing management. All farms applied some kind of rotation on the pastures. Interestingly, the farms applying continuous stocking displayed the lowest average milk production per cow (10.0 kg d^{-1}, $p=0.026$). In contrast, among the farms using rotational stocking, those applying high instantaneous grazing intensity with very short occupation times (<12 h) moving the herd with an electric fence several times a day had higher individual milk production than those using longer occupation times (15.7 vs. 12.4 kg d^{-1}; $p = 0.019$). The third factor identified to explain the high SD in individual milk production is related to the topography of the pastures surrounding the farms. Interestingly, the daily production of individual cows was negatively correlated ($r = -0.323$, $p = 0.037$) to the average slope on the farms. Cows grazing in more rugged terrain of the Ecuadorian Sierra probably have to spend a greater amount of energy expenditure by walking up and down hill. Such an increase in energy requirements was estimated between 15 to 41%.

We noticed a considerable increase in the presence of the Holstein breed in the dairy herds compared to previous reports that showed the crossings of Creole cows with other specialized breeds such as Holstein, Brown Swiss, Jersey, and Montbeliere as the main racial group (Caballero & Hervas, 1985; Castro, Burgos, & Valarezo, 2015; Balarezo, García, Hernández, & García, 2016). This demonstrates the willingness of farmers to improve the genetic background of their herds and their possible receptiveness for further innovations in grazing management. A method that has been widely adopted for example is the use of electric fence to implement mob grazing practices (Requelme & Bonifaz, 2012) by moving a fence several times per day (3 to 5 times), due to its simple way of implementation and low cost, although moving the fence several times a day is more demanding in terms of labour, allowing to obtain higher forage harvest levels by limiting the feeding space (Barnes et al., 2008). Mob grazing allows for forage resources to be used in a more controlled manner, but the forage structure on offer over the whole grazing strip is probably far from the optimum that should allow a maximization of the intake (Mezzalira et al., 2014). Hence, other stocking methods maximizing individual performances rather than forage harvest would probably be more appropriate for those farms where very little concentrates are used. The length of the resting time between subsequent pasture periods, with an average of 45 days, is another indication that forage harvest is maximized requiring rather long recovery periods for the mixture of C3 and C4 grasses that are observed in the pastures (Fulkerson & Donaghy, 2001).

7. Conclusions

This study addressed the influence of management practices on productive performance in the milk production system in relation to the slope inclination of the paddocks. It clearly demonstrated that increased slopes reduce milk production, individual per cow. The pasture management applied by most dairy farmers in the Ecuadorian Sierra based on rotational stocking with very short occupation times by means of a mobile electric fence seems relevant to maximize for age harvest of each strip by cows. This method is time- consuming and a proper economical assessment considering both the labour and investment costs to implement such a strategy is required. Moreover, since this study did not find that many differences between farms in terms of grazing management, as few applied a continuous stocking management for example, further research is still needed to clarify if a specific pasture layout and the use of high rotation rates can effectively contribute to a better use of the forage resource and counteract the negative impact of high slopes on milk production per cow.

8. Acknowledgements

This work was designed and planned in the Precision Agriculture Unit of Gembloux Agro-Bio Tech, University of Liège, and was carried out thanks to the students and professors of the Faculty of Agricultural Sciences of the Central University of Ecuador; as well as the state entity of the Ecuadorian Agency for Quality Assurance (AGROCAL- IDAD) of the Ministry of Agriculture, Livestock, Aquaculture and Fisheries (MAGAP). Eloy Castro Muñoz was funded by the joint program of the Central University of Ecuador (Quito, Ecuador) and the Académie de Recherche et d’Enseignement Supérieu –Cellule de Coopération au Développement (ARES-CCD, Brussels, Belgium).

Conflict of interest

The authors declare that they have no conflict of interest.

References

Aharoni, Y., Henkin, Z., Ezra, A., Dolev, A., Shabtay, A., Orlov, A., Yehuda, Y., & Brosh, A. (2009). Grazing behavior and energy costs of activity: A comparison between two types of cattle. Journal of Animal Science, 87(8), 2719-2731. https://doi.org/10.2527/jas.2008-1505.

Andriamandroso, A., Bindelle, J., Mercatoris, B., & Lebeau F. (2016). A review on the use of sensors to monitor cattle jaw movements and behavior when grazing. Biotechnol. Agron. Soc. Environ., 20(S1).

Apollin, F., & Eberhart, C. (1999). Análisis y diagnóstico de los Sistemas de Producción en el medio rural, Guía Metodológica.

Arce-Carriel, M. R., & Pozo-Rivera, W. E. (2015). Variabilidad en la producción lechera del agrosistema IASA, según las categorías de intensidad de lluvias de Trojer. Serie Zoológica, 10(11), 1-10.

Arnold, G. W. (1985). Regulation of forage intake. In: Hudson, R. J., & White, R. G. (eds). Bioenergetics of wild herbivores. CRC Press, Boca Raton, pp 81–101.

Badgery, W. B., Millar, G. D., Broadfoot, K., Michalk, D. L., Cranney, P., Mitchell, D., & van de Ven, R. (2017). In- creased production and cover in a variable native pasture following intensive grazing management. Animal Production Science, 57(9), 1812-1823. https://doi.org/10.1071/ AN15861.

Balarezo, L. R., García-Díaz, J. R., Hernández-Barreto, M. A., & García López, R. (2016). Metabolic and reproductive state of Holstein cattle in the Carchi region, Ecuador. Revista Cubana de Ciencia Agrícola, 50(3), 381–391.

Bargo, F., Muller, L. D., Delahoy, J. E., & Cassidy, T. W. (2002). Milk response to concentrate supplementation of high producing dairy cows grazing at two pasture allowances. Journal of Dairy Science, 85(7), 1777-1792. https://doi.org/10.3168/jds.S0022-0302(02)74252-5.

Barnes, M. K., Norton, B. E., Maeno, M., & Malechek, J. C. (2008). Paddock size and stocking density affect spatial heterogeneity of grazing. Rangeland Ecology & Management, 61(4), 380-388. https://doi.org/10.2111/06-155.1.

Bonifaz, N., & Gutiérrez, F. (2013). Correlación de niveles de urea en leche con características físico-químicas y composición nutricional de dietas bovinas en ganaderías de la provincia de Pichincha. La Granja, 18(2), 33-42. https://doi.org/10.17163/lgr.n18.2013.02.

Boserup, E. (2017). The conditions of agricultural growth: The economics of agrarian change under population pressure. Routledge.

Bruinsma, J. (2017). World agriculture: towards 2015/2030: an FAO study. Routledge. http://www.fao.org/3/a-y4252e. pdf.

Caballero, D., & Hervas, T. (1985). Producción lechera en la Sierra Ecuatoriana. IICA Biblioteca Venezuela.

Carvalho, P. C. F. (2013). Harry Stobbs Memorial Lecture: Can grazing behavior support innovations in grassland management. Tropical Grasslands, 1,137–155. https://doi.org/10.17138/tgft(1)137-155.

Carvalho, P. D. F., Bremm, C., Mezzalira, J. C., Fonseca, L., Da Trindade, J. K., Bonnet, O. J. F., & Laca, E. A. (2015). Can animal performance be predicted from short-term grazing processes? Animal Production Science, 55(3), 319–327. https://doi.org/10.1071/AN14546.

Castro Muñoz, E., Burgos, J., & Valarezo, L. (2015). Efectos de aditivos y levadura en el incremento de peso en terneras holstein-friesian, de tres a seis meses de edad. Tumbaco, Pichincha. Siembra, 2(1), 29–33. https://doi.org/10.29166/siembra.v2i1.114.

Cepeda, D., Gondard, P., & Gasselin, P. (2007). Mega diversidad agraria en el Ecuador: disciplina, conceptos y herramientas metodológicas para el analisis-diagnóstico de micro-regiones. Mosaico agrario. SIPAE, IRD, IFEA, Quito, 29–54.

Chapman, D. F., Bryant, J. R., Olayemi, M. E., Edwards, G. R., Thorrold, B. S., McMillan, W. H., Kerr, G. A., Judson, G., Cookson, T., Moorhead, A., & Norriss, M. (2017). An economically based evaluation index for perennial and short-term ryegrasses in New Zealand dairy farm systems. Grass and Forage Science, 72(1), 1–21. https://doi.org/10.1111/gfs.12213.

Chobtang, J., Ledgard, S. F., McLaren, S. J., & Donaghy, D. J. (2017). Life cycle environmental impacts of high and low intensification pasture-based milk production systems: A case study of the Waikato region, New Zealand. Journal of Cleaner Production, 140, 664–674. https://doi.org/10.1016/j.jclepro.2016.06.079.

Crist, T. O., & Peters, V. E. (2014). Landscape and local controls of insect biodiversity in conservation grasslands: im- plications for the conservation of ecosystem service providers in agricultural environments. Land, 3(3), 693–718. https://doi.org/10.3390/land3030693.

De la Motte, L.G., Jérôme, E., Mamadou, O., Beckers, Y., Bodson, B., Heinesch, B., & Aubinet, M. (2016). Carbon balance of an intensively grazed permanent grassland in southern Belgium. Agricultural and forest meteorology, 228, 370–383. https://doi.org/10.1016/j.agrformet.2016. 06.009.

De Oliveira Silva, R., Barioni, L. G., Hall, J. J., Moretti, A. C., Veloso, R. F., Alexander, P., Crespolini, M., & Moran, D. (2017). Sustainable intensification of Brazilian live- stock production through optimized pasture restoration. Agricultural systems, 153, 201–211. https://doi.org/10.1016/j.agsy.2017.02.001.

Esguerra, J. C., Cassoli, L. D., Múnera-Bedoya, O. D., Cerón-Muñoz, M. F., & Machado, P. F. (2018). Calidad de la leche: factores asociados al personal vinculado al ordeño. Revista MVZ Córdoba, 23(1), 6461–6473. https://doi.org/10.21897/rmvz.1241.

FAO (2017). Producción pecuaria en América Latina y el Caribe. Available at: www.fao.org/americas/prioridades/ produccion-pecuaria/es/. Last accessed 01.11.2020.

FAOSTAT (2018). The Statistics Division of the FAO. Available at: http://www.fao.org/faostat/en/\#data. Last accessed 01.11.2020.

Farley, K. A., Anderson, W. G., Bremer, L. L., & Harden, C. P. (2011). Compensation for ecosystem services: an evaluation of efforts to achieve conservation and development in Ecuadorian páramo grasslands. Environmental Conservation, 38(4), 393–405. https://doi.org/10.1017/S037689291100049X.

Fulkerson, W. J., & Donaghy, D. J. (2001). Plant-soluble carbohydrate reserves and senescence-key criteria for developing an effective grazing management system for ryegrass-based pastures: a review. Australian Journal of Experimental Agriculture, 41(2), 261–275. https://doi.org/10.1071/EA00062.

Garibaldi, L. A., Gemmill-Herren, B., D'Annolfo, R., Graeub, B. E., Cunningham, S. A., & Breeze, T. D. (2017). Farming approaches for greater biodiversity, livelihoods, and food security. Trends in Ecology & Evolution, 32(1),68–80. https://doi.org/10.1016/j.tree.2016.10.001.

Gerssen-Gondelach, S. J., Lauwerijssen, R. B., Havlík, P., Herrero, M., Valin, H., Faaij, A. P., & Wicke, B. (2017). Intensification pathways for beef and dairy cattle production systems: Impacts on GHG emissions, land occupation and land use change. Agriculture, Ecosystems & Environment, 240, 135–147. https://doi.org/10.1016/j.agee.2017.02.012.

Grijalva, J., Espinosa, F., & Hidalgo, M. (1995). Producción y utilización de pastizales en la región interandina del Ecuador. INIAP Archivo Histórico.

Guamán, G., Adolfo, R., Masaquiza Moposita, D., & Curbelo Rodríguez, L. M. (2017). Caracterización de Sistemas Productivos Lecheros en Condiciones de Montaña, Parroquia Químiag, Provincia Chimborazo, Ecuador. Revista de Producción Animal, 29(2), 14–24.

Hilario, M. C., Wrage-Mönnig, N., & Isselstein, J. (2017). Behavioral patterns of (co-) grazing cattle and sheep on swards differing in plant diversity. Applied Animal Behaviour Science, 191, 17–23.

Hofstetter, P., Frey, H. J., Gazzarin, C., Wyss, U., & Kunz, P., 2014. Dairy farming: indoor v. pasture-based feeding. The Journal of Agricultural Science, 152(6), 994–1011. https://doi.org/10.1017/S0021859614000227

Hostiou, N., & Dedieu, B. (2009). Diversity of forage system work and adoption of intensive techniques in dairy cattle farms of Amazonia. Agronomy for Sustainable Development, 29(4), 535–544. https://doi.org/10.1051/agro/2009012.

Isbell, F., Gonzalez, A., Loreau, M., Cowles, J., Díaz, S., Hector, A., Georgina, M., David, A., O'Connor, M., Duffy, J., Turnbull, L., Thompson, P., & Turnbull, L. A. (2017). Linking the influence and dependence of people on biodiversity across scales. Nature, 546, 65–72. https://doi.org/10.1038/nature22899.

Kay, G. M., Mortelliti, A., Tulloch, A., Barton, P., Florance, D., Cunningham, S. A., & Lindenmayer, D. B. (2017). Effects of past and present livestock grazing on herpetofauna in a land scape-scale experiment. Conservation Biology,31(2), 446–458. https://doi.org/10.1111/cobi.12779.

Krejcie, R. V., & Morgan, D. W. (1970). Determining sample size for research activities. Educational and psychological measurement, 30(3), 607–610. https://doi.org/10.1177/001316447003000308.

MAGAP, 2016. La política agropecuaria ecuatoriana: hacia el desarrollo territorial rural sostenible: 2015-2025. Ministerio de Agricultura, Ganadería, Acuacultura y Pesca. Tech. Rep p. 25 Available at: https://fliphtml5.com/wtae/owkh/basic/51-52. Last accessed 01.11.2020.

MAGAP, 2017. Catálogo de Objetos Temáticos del Ministerio de Agricultura, Ganadería, Acuacultura y Pesca. http://geoportal.agricultura.gob.ec/pdf/Catalogo_ Volumen_II.pdf

Martínez-García, C. G., Rayas-Amor, A. A., Anaya-Ortega, J. P., Martínez-Castañeda, F. E., Espinoza-Ortega, A., Prospero-Bernal, F., & Arriaga-Jordán, C. M. (2015). Performance of small-scale dairy farms in the highlands of central Mexico during the dry season under traditional feeding strategies. Tropical Animal Health and Production, 47(2), 331–337.https://doi.org/10.1007/s11250-014-0724-0.

Mezzalira, J. C., Carvalho, P. C. D. F., Fonseca, L., Bremm, C., Cangiano, C., Gonda, H. L., & Laca, E. A. (2014). Behavioural mechanisms of intake rate by heifers grazing swards of contrasting structures. Applied Animal Behaviour Science, 153, 1–9. https://doi.org/10.1016/j. applanim.2013.12.014.

Moir, J. L., Cameron, K. C., Di, H. J., & Fertsak, U. (2011). The spatial coverage of dairy cattle urine patches in an intensively grazed pasture system. The Journal of Agricultural Science, 149(4), 473–485. https://doi.org/10.1017/S0021859610001012.

Popescu, A. (2017). Trends in milk market and milk crisis impact in Romania.nScientific Papers. Series "Management Economic Engineering in Agriculture and Rural Development". Univ.Agricultural Sciences & Veterinary Medicine, 17(2), 281–9.

Requelme, N., & Bonifaz, N., 2012. Caracterización de sistemas de producción lechera de Ecuador. La Granja, 15(1), 55–68. https://doi.org/10.17163/lgr.n15.2012.05.

Schulte, H. D., Musshoff, O., & Meuwissen, M. P. M. (2018). Considering milk price volatility for investment decisions on the farm level after European milk quota abolition. Journal of Dairy Science, 101(8), 7532-7539. https://doi.org/10.3168/jds.2017-14305.

SINAGAP-MAGAP. 2014. VI Censo Agropecuario. Available at: https://www.ecuadorencifras.gob.ec/estadisticas- agropecuarias-2/. Last accessed: June 2020.

Sturaro, E., Marchiori, E., Cocca, G., Penasa, M., Ramanzin, M., & Bittante, G. (2013). Dairy systems in mountainous areas: Farm animal biodiversity, milk production and destination, and land use. Livestock Science, 158(1-3), 157–168. https://doi.org/10.1016/j.livsci.2013.09.011.

Varela, E., & Robles-Cruz, A. B. (2016). Ecosystem services and socio-economic benefits of Mediterranean grasslands. In: Options Mediterraneennes, Serie A: Mediterranean Seminars (Vol. 114, pp. 13-27).

The previous chapter showed the diversity of management practices in dairy systems in the tropical highlands of the Andean Cordillera, identifying management practices that do not necessarily favor milk production and, on the contrary, promote intensive use of forage resources, with a high demand for labor. This chapter helps to understand the ingestive behavior of dairy cows grazing in the different types of pasture rotation systems mostly used by ranchers. Questioning the relevance of such an intensive practice, we hypothesized that shorter grazing times in a rotational stocking method would improve system performance. For this purpose, we designed an experiment that compares the ingestive behavior and the production of dairy cows that graze in a rotational stocking method with three contrasting occupation periods (long occupation time, short occupation time and very short occupation time) and compared the ingestive behaviours and the milk production of those cows.

Chapter 3

Analysis of the nutritional and productive behaviour of dairy cows under three rotation bands of pastures, Pichincha, Ecuador

Artícle 2

Analysis of the nutritional and productive behaviour of dairy cows under three rotation bands of pastures, Pichincha, Ecuador

Eloy Castro Muñoz [a,b,c,*], *Andriamasinoro Lalaina Herinaina Andriamandroso* [e], *Yves Beckers* [b], *Lenin Ron* [a], *Carlos Montufar* [a], *Gentil F. da Silva Neto* [d], *Juan Borja* [a], *Frédéric Lebeau* [c], *Jérôme Bindelle* [b]

a Universidad Central del Ecuador, Facultad de Ciencias Agrícolas, Jerónimo Leiton y Gato Sobral s/n. Ciudadela Universitaria. 170521, Quito, Ecuador
b Precision Livestock and Nutrition Unit, AgroBioChem, Gembloux Agro-Bio Tech, University of Liège, Passage des Déportés 2, 5030 Gembloux, Belgium
c Digital Energy & Agriculture Lab (DEAL), Biosystems Dynamics and Exchanges (BioDynE), Gembloux Agro-Bio Tech, University of Liège, Passage des Déportés 2, 5030 Gembloux, Belgium
d Department of Forage Plants and Agrometeorology, Federal University of Rio Grande do Sul, RS; Brazil
e Department Agriculture and Landscape Teaching and Research Department, ISA Lille, Junia, 48 Boulevard Vauban, 59046 Lille, France

Corresponding author

CASTRO MUÑOZ Eloy, MSc, Universidad Central del Ecuador, Ecuador. Facultad de Ciencias Agrícolas, Ave. Universitaria, Qutio 170129. +593 22232402

This chapter is adapted from an article submitted for publication in *the International Journal of Agriculture and Rural Development in the Tropics and Subtropics (JARTS)*. Vol.121 Nº 2 (2020) 233-241

The results of this study were presented in a poster at: *7th REDU Yachay Tech University*, Ibarra, Ecuador, (11-15 November, 2019)

The results of this study were presented in Book of Abstracts of the *71st Annual Meeting of the European Federation of Animal Science (EAAP)* Wageningen Academic Publishers, Oporto, Portugal (December, 2020). (p. 322).

Abstract

This research was carried out on *Pennisetum clandestinum*-based pastures to identify the effect of rotational stocking systems with similar forage allowance (8.2 kg of dry matter for 100 kg of live weight) but differing in their occupation times on the behaviour and the production of dairy cows. A long occupation time of seven days was compared to short (24 h) and very short (3 h) occupation times The experimental scheme consisted in three herds of four Holstein Friesian cows grazing three paddocks, one per occupation time, for one week and replicated three times in a cross-over design. Pasture height and biomass were measured before and after each grazing week and on a daily basis, two cows per herd were monitored during daytime with activity sensors and their milk production was recorded. The main results showed that in all treatments, the cows reduced the height of the sward by 40 % on average. The cows in the long occupation treatment spent more time in meals and tended to have higher average speed during the day than in the very short occupation treatment, ascribed to a higher exploration of the whole gradable area every day in the long occupation treatment and to more time idling animals in the very short occupation treatment in anticipation of the opening of new areas to graze over the course of day. Despite those difference in activity, milk production did not differ neither in quantity with an average of 12.4 ± 0.14 kg per day, nor in quality (i.e., fat, protein, non-fatty solids, total solids). We conclude that under our grazing conditions with an intermediate forage allowance and low producing cows, applying a labour intensive occupation time requiring to open new areas every 3 hours does not lead to a significant production increase.

Keywords: grazing time, milk production, pasture rotation, *Pennisetum clandestinum*, occupation time

1. Introduction

The Republic of Ecuador, located in South America owes its name to the equatorial line that crosses it. Extending between latitudes 1°30'N and 5° S and longitudes 75°20'W and 91°W, it is the smallest of the Andean countries with approximately 252,000 km2. It borders Colombia to the north, Peru to the south and east, and the Pacific Ocean to the west. The "Cordillera de los Andes" occupies the entire central belt of the country (Sierra region), which crosses from north to south, descending towards the west with lower lands appears the coastal region that borders the Pacific Ocean. It is in the area of the Sierra that dairy farming is concentrated in the area of the Sierra. Indeed, both the largest number of heads of cattle and natural pastures are concentrated in the Sierra (2,225,923 heads and 601,249 ha). Milk production in the Sierra reaches 5,165,222 liters and represents 78.5% of the national production national, with average yields close to 11 liters / cow per year (FAO, 2019; INEC, 2020). The Andean mountain range has several assets, making this region interesting for dairy production compared to the other regions of Ecuador. It has important hydrological resources from volcanic mountain glaciers and "páramos", being able to irrigate large agricultural areas through natural and artificial irrigation channels (Johansen et al., 2019) enabling a continuous forage growth during the dry season. The milder climate allows for cool-season grasses with higher nutritional value to grow (Bustamante, 2006; Franco et al., 2016), as well as the establishment of grass and legume mixtures typical from temperate pastures (Dumont et al., 1992; Ramírez et al., 1996; Gundel, 2008) that allow a sustained milk production (AGSO, 2017). Since there is a close relationship between the availability of forage and the productivity of dairy cattle (Montoya & Barahona-Rosales, 2017), pasture management practices are a fundamental pillar for the expression of the genetic potential of these animals (Reyes, 2016). The primary production of a fodder mix depends on the genetic growth capacity of the grass species and its interaction with the environment (Paladines, 1984). Moreover, Zúñiga et al. (2015) and Dörner et al. (2017), showed that several management practices can impact pasture yield and its stability beyond this intrinsic factors: equalization cut, stool dispersion, fertilisation, irrigation, and, last but not least, the stocking pressure. Rotational stocking is a stocking method based on alternating periods of use and rest on a same paddock. Its objective is to optimize the use of the grass that is produced and/or the production of the grazing livestock (Llangarí et al., 2013; Carvalho et al., 2017). Usually, rotational stocking is praised for its ability to increase forage production and reduce wastage induced by trampling, defecation, urination or selection (Kilgour, 2019). The pressure that animals exert in terms of frequency and intensity of defoliation is a very important factor affecting the production of a pasture. High frequencies of defoliation are associated with reduced plant growth (Caballero & Hervas, 1985; Chilibroste et al., 2015) as higher intensities result in the inability of optimum regrowth and low accumulation of dry matter (Badgery et al., 2017; de Moura Zanine et al., 2019).

A recent survey showed the extensive use of rotational stocking by farmers in the Ecuadorian highlands, but this practice varies a lot, mostly in grazing times since most farmers apply common residence times of one to several days, but some of them declared opening new strips for grazing as often as every 3 h to the cows (Muñoz et al., 2020). Questioning the relevance of such a labour-intensive practice, we hypothesized that shorter grazing times in a rotational stocking method would improve the performances of the system and we designed an experiment to compare the behaviour and production of dairy cows in rotational stocking with three occupation times (long, short and very short occupation times).

2. Materials and methods

2.1. Experimental pasture

This experiment took place from March to May 2018, in the experimental academic teaching field "La Tola" (CADET) of the Faculty of Agricultural Sciences, Central University of Ecuador, located in the sector La Morita parish Tumbaco, canton of Quito, in the province of Pichincha, Ecuador. The farm is located at 78°37'09" W longitude and 0°22'7" S latitude at an altitude of 2505 m.a.s.l.

The rainfall during the experiment was below the 10-year average (Table 4), with very low precipitation levels recorded in March (- 8 %), April (-59 %), and May (-11.7 %). Average daily temperatures were 0.2 °C lower than the 10-year average, with April and May being the coldest months (0.7 °C), compared to March, which was the warmest in the experiment, and in turn with 0.2 °C warmer than average for the previous 10 year.

Table 4. Temperature and rainfall data during the experimental period and mean data for the average of the previous 10-year at "La Tola" CADET.3

	Period	March	April	May
Rainfall (mm)	2018	114	85	70.3
	2008-2018	122	145	82
Mean Temperature (°C)	2018	16.9	16.2	16.2
	2008-2018	16.7	16.7	16.6

The 1.3 ha experimental pasture was situated on a clay soil and was dominated by kikuyu (*Pennisetum clandestinum* Hochst ex Chiov.), perennial ryegrass (*Lolium perenne L.*), white clover (*Trifolium repens L.*) and alfalfa (*Medicago sativa L.*), sowed six years before. The whole pasture was first subjected to an equalization cut, fertilised with 45 kg of N ha^{-1} and allowed to grow for approximately 30 days to reach the desired biomass (Leach et al., 2000). The experimental pasture was divided in three paddocks each provided similar forage allowance, one per occupation periods grazing: (long occupation time) grazing with seven days of grazing time; short occupation time grazing (daily) with 24 hours grazing time; and very short occupation time grazing (hours) with a three hours grazing time. Hence, the paddock in the short occupation time grazing treatment

was divided into seven 600 m^2 sub-paddocks, where the animals assigned to this treatment grazed for 24 hours. Similarly, the paddock of the very short occupation time grazing treatment was subdivided into 28 strips of 150 m^2. Animals were allowed to graze a new strip every 3 hours after reentering the paddock following the morning milking with an electric fence that was moved forward, increasing the size of the available area. At night, after the evening milking, the whole 600 m^2 was made available to the animals. In the case of the long occupation time grazing treatment, the assigned cows remained in the entire area of 4200 m^2 (42 m x 100 m) without restriction during the 7 days that each phase lasted. In all three grazing treatments, the first two days were used as habituation period for the animals to the new paddock and stocking method. The next five days were considered experimental. Once a 7-day grazing phase was completed, the sequence of equalisation and fertilisation cuts was repeated and a new 7-day grazing phase began, just after a 30-day rest of the paddocks. The procedure was repeated three times so that all cows and paddocks could undergo all treatments.

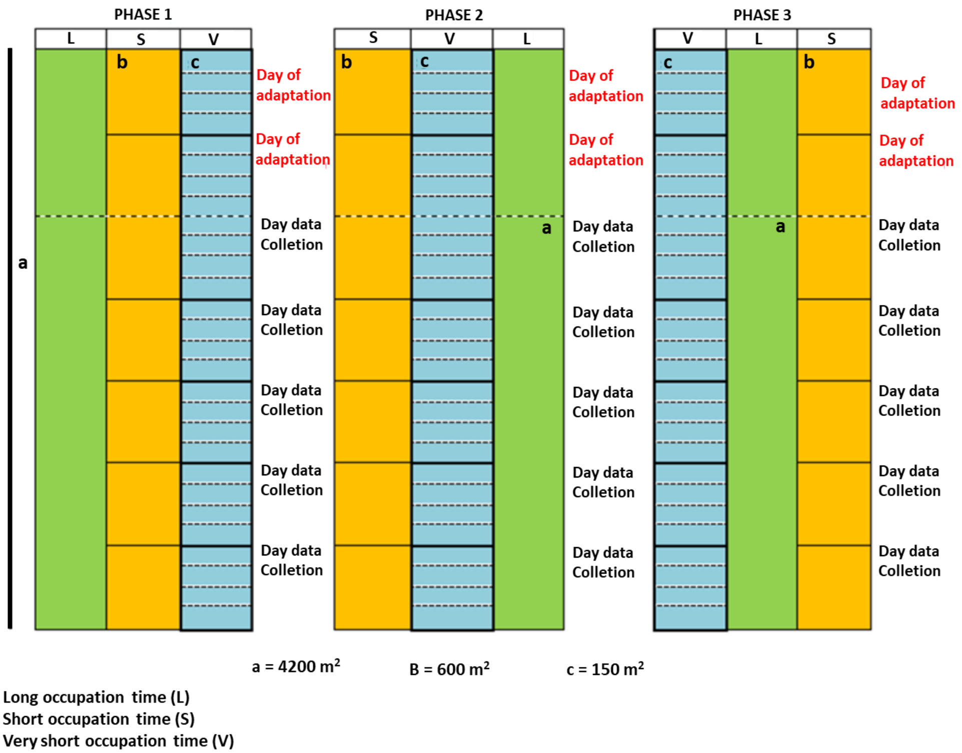


Figure 6: Distribution scheme of the three grazing occupation times (long , 7 d; short , 24 h, very short 3 h) in the three phases of the experiment.

2.2. Animals

A total of twelve Holstein Friesian cows of 3.8 years of age on average were used of which six cows (2 per treatment) were used as experimental animals to record milk quality and production as well as behaviour data. One week before the beginning of each phase, a halter was placed on each cow to be monitored so that they could adapt to its use. All procedures involving animals were approved by the Commission for Ethics in the Use of Animals of the Sector of Agricultural Sciences of the Central University of Ecuador (024/2016).

The halter was equipped with an iPhone 5S (Apple Inc., Cupertino, CA, USA) placed in a waterproof box. The iPhones had the Sensor Data 1.23 application installed to register the signals provided by the inertial measurement unit (IMU) of the smartphones. To have an additional power supply, an external Anker PowerCore 20000 mAh battery was connected to each iPhone 5S through an electric cable with a USB port. The batteries were carefully inserted into a waist bag and hung from the neck of the animals.

2.3. Determination of biomass

The height of the grass was measured daily with a grass stick (Barthram 1984), during the milking time, in thirty (30 cm x 30 cm) quadrats distributed along a fixed grid per paddock, in correspondence with the daily advance per treatment. Five turf heights per quadrat were taken and averaged. In addition, to determine the availability of pasture and consumption, four forage samplings were carried out per paddock per day. The fresh grass samples were placed in paper bags, weighed and put in an oven at 60 °C for 48 hours for dry matter (DM) determination.

2.4. Chemical analysis

The dried grass samples were ground to pass a 1 mm mesh screen. Subsequently and with the use of the Ankor Fiber Analyzer 2000® equipment, they were analysed for their content in acid detergent fibre (ADF, AOAC 973.18), neutral detergent fibre (NDF, AOAC 2002.04), crude fibre (CF, AOAC 978.10.) and crude protein (CP, N x 6.25, AOAC 2001.11.).

2.5. Milk production

Milking took place each day at 04:00 a.m. and at 4:00 p.m. Individual milk yield (in kg) was recorded at each milking with the help of individual aluminium drums and quantified with a decalitre. Milk samples were taken from each cow in sterile 20 ml bottles containing Bronopol, kept in an insulated flask at a temperature of 4 °C to 7 °C until sent to the laboratory of the Ecuadorian Agency for Quality Assurance AGROCALIDAD. The samples were subjected to composition analysis (protein, fat, total solids and non-fat solids) by infrared spectrophotometry using a MILKOSCAN FT 6200, PEE02 protocol (Wang et al., 2014).

2.6. Calculations and statistical analyses

IMU data from the iPhones were processed using the open algorithm proposed by Andriamandroso et al. (2017) to classify grass intake, rumination and other behaviour (behaviours that are neither grass intake nor rumination) while on paddocks based on 1second time windows. Using information on grazing, periods of meals were calculated as recommended by Gibb (1998): "periods of meals are sequences of grazing events and interruptions between two consecutive grazing events as long as these interruptions do not last longer that five minutes". In addition, the total distance travelled by the animals during the day as well their average speed during the different activities, especially meals, was computed from GPS data (latitude and longitude data recorded by the IMU).

Statistical analysis of the biomass, live weight and forage allowance was performed. The paddock was considered as the experimental unit for an analysis of variance and a means classification by the Differences of Least Squares Means method using the MIXED procedure of SAS® OnDemand for Academics (SAS Campus Drive, Cary, NC, USA) with the following general linear model:

$$Y = \alpha + T_i + \varepsilon$$

Where Y is the result, α the mean, Ti the fixed effect of the treatment (i varies from 1 to 3) and ε the error term. Pre- and post-grazing sward heights as well as forage quality were compared using each measurement as experimental unit with the following model:

$$Y = \alpha + Ti + Pj + \varepsilon$$

where Y is the result, α the mean, Ti the fixed effect of the treatment (i varies from 1 to 3), Pj the random effect of the period (j varies from 1 to 3), and ε the error term.

Animal behaviour data and milk quality were compared using each individual as experimental unit with the following model:

$$Y = \alpha + T_i + P_j + C_k + \varepsilon$$

where Y is the result, the mean, Ti the fixed effect of the treatment (i varies from 1 to 3), Pj the random e
effect of the period (j varies from 1 to 3), Ck the random effect of the cow (k varies from 1 to 6), and ε the error term.

3. Results

3.1. Sward characteristics and forage quality

As displayed in Table 5 we can see that the biomass and the live weights per hectare showed uniform values for the three treatments, yielding the expected similar forage allowances for the different treatments. The pregrazing sward height did not differ either, while the post-grazing sward height tended to be 1 cm higher (P = 0:066) in the long occupation time treatment than the other two rotational treatments.

Table 5 Biomass and sward heights (N = 90) and total stocking in the three occupation times treatments (N = 9) (long occupation time, short occupation time, very short occupation time) across the three experimental periods.

	Treatments					Variance parameter estimates	
Item	**Very short**	**Short**	**Long**	**SEM**	**P-value**	**Period**	**Residual**
Cattle live weight (kg)[†]	1943	1976	1851	27.3	0.150	-	475
Biomass (kg DM ha^{-1})[‡]	2610	2627	2665	111.7	0.984	-	149
Forage allowance (kg DM/100 kg LW d^{-1})	8.03	8.02	8.63	0.355	0.776	-	1.39
Pre-grazing sward height (cm)	16.7	16.5	17.0	0.22	0.505	7.38	4.52
Post-grazing sward height (cm)	10.2^{b}	10.2^{b}	11.2^{a}	0.22	0.066	7.36	4.13

[a˜b] Means within a row with different superscripts differ (P < 0:05). SEM (standard error of the mean).

[†] Mean live weight of the animals at the beginning of the experiment.

[‡] Average biomass available at the beginning of the experiment in each treatment.

3.2. Composition of the pasture and nutritional content

The nutritional value of the grass, represented by the chemical composition (CP, OM, ash, NDF and ADF) of the sampled grass did not differ between the treatments (P > 0:05; table 6).

3.3. Animal behaviour and performance

In the long occupation time rotation expresses a higher percentage of time devoted to meals during the day, showing significant differences in relation to short occupation time and very short occupation time treatments (Table 7). The percentage of time devoted to grazing shows more activity per animal in the long occupation time treatment + 18 % compared to the very short occupation time treatment, and + 8 % compared to the short occupation time treatment (p = 0.027). Differences were also observed in the time devoted to rumination, where cows in the very short occupation time treatment spend 3.5 % more-time ruminating compared to the general mean of the three treatments.

The total daily distance covered by the cows shows significant differences between the treatments, the long occupation time treatment being the one that reflects the greatest distance (+ 443 m / d) as compared to the general mean. Further, animals in the very short occupation time rotation tended to move more slowly (P = 0.010). The distance traveled during the meals shows a difference between the treatments, the cows that grazed in the very short occupation time treatment covered the lowest distance. Interestingly, the speed of the animal was not different during the meals (P = 0.156).

Table 6: Chemical composition of grass before grazing in the three occupation time treatments : long (7 d), short (24 h) and very short (3 h) occupation times across the three experimental periods (N = 12).

	Treatments					Variance parameter estimates	
Item	**Very short**	**Short**	**Long**	**SEM**	**P-value**	**Period**	**Residual**
CP%	14.3	13.6	14.6	0.91	0.772	6.88	2.73
OM%	88.7	89.0	88.9	0.09	1.000	0.000	0.000
ADF%	30.0	28.5	29.7	0.38	0.313	0.00	1.12
NDF%	48.6	48.2	48.3	4.57	0.474	250	0.18
Ash%	11.3	11.0	11.1	0.38	0.819	1.42	0.30

a˘b Means within a row with different superscripts differ (P < 0:05). SEM (standard error of the mean).
CP: crude protein; OM: organic matter; ADF: acid detergent fibre; NDF: neutral detergent fibre.

Table 7: Behaviour of dairy cows in the three occupation time treatments: long (7 d), short (24 h) and very short (3 h) occupation times across the three experimental periods (N = 30).

	Treatments					Variance parameter estimates		
Item	**Very short**	**Short**	**Long**	**SEM**	**P-value**	**Cow**	**Period**	**Residual**
Time dedicated to (in %)								
: meal*	80^{b}	88^{a}	87^{a}	0.012	0.012	<0.001	<0.001	0.004
grazing events	48^{b}	58^{a}	66a	0.027	0.027	0.016	0.002	0.009
ruminating	8^{a}	5^{ab}	4^{b}	0.0069	0.008	<0.0012	<0.001	0.001
other activities	44	37	31	0.025	0.165	0.0147	<0.001	0.009
Total distance covered per cow (m^{d-1})	2776^{b}	3582^{ab}	3622^{a}	1675	0.051	7.159E5	1.6862E6	8.775E6
Speed (m^{s-1})	0.10^{b}	0.14^{a}	0.13^{a}	0.006	0.010	8.80E-5	4.68E-4	8.700E-4
Distance during meals per cow (m^{d-1})	2630^{b}	3287^{a}	3140^{ab}	128	0.013	4.861E5	<0.001	5.874E6
Speed during meals (m^{s-1})	0.12	0.15	0.13	0.005	0.1563	8.65E-5	8.60E-4	8.390E-4

a˘b Means within a row with different superscripts differ (P < 0:05). SEM (standard error of the mean).

* Periods of meals are sequences of grazing and non-grazing events during which interruptions between two (2) consecutive grazing events last no longer than five (5) minutes.

The milk production shown in Table 8 does not present significant differences between the pasture rotation systems (p > 0:05), neither in quantity nor in quality.

Table 8: Milk production of dairy cows grazing the three occupation time treatments : long (7 d), short (24 h) and very short (3 h) occupation times across the three experimental periods (N = 18).

	Treatments Estimates					**Variance parameter estimates**		
Item	**Very short**	**Short**	**Long**	**SEM**	**P-value**	**Cow**	**Period**	**Residual**
Milk yield (kg/d)	12.8	12.5	12.3	0.709	0,68	6.40	1.92	1.23
Milk fat content (g/100ml)	4.21	4.05	4.02	0.169	0.12	0.16	0.10	0.03
Milk protein content (g/100ml)	3.38	3.46	3.25	0.370	0.09	0.07	0.02	0.06
Non-fatty solids content (g/100ml)	8.67	8.50	8.61	0.146	0.09	0.11	0.04	0.02
Total solids (g/100ml)	12.88	12.56	12.64	0.157	0.19	0.44	0.27	0.07

[a˘b] Means within a row with different superscripts differ (P < 0:05). SEM (standard error of the mean).

4. Discussion

The objective of this study has been to determine the effect of three contrasting occupation times for rotational stocking, on the productive behavior of dairy cows in terms of grass consumption and its impact milk production and quality. Strip grazing practices, by which animals are induced to move one or more times a day between predefined forage allowance grazing areas, are considered by some authors as interesting management practice for optimal use of grasslands and effcient productivity of dairy farms (Abrahamse et al., 2008; Umstatter, 2011; Koene et al., 2016). However, this system requires more labour to comply with predetermined area restrictions, and induces animals to consume less palatable plant parts (Flores et al., 1993). Dairy cows in the long occupation time treatment have greater freedom of movement and selection of the most palatable plant material, but they generate large volumes of pasture waste by the mechanical action of trampling, urine and faeces deposition that decreases the usable portion of the forage of pastures (Edmond, 1958; Paladines, 1978; Drewry & Paton, 2000). It could be postulated that animals with different productive performance would present different nutritional requirements, which would be expressed through differences in grazing behaviour. In our experiment the observations were made under conditions controlled by previous cuts that guaranteed some homogeneity and similarity in the forage on offer in the three treatments as confirmed by the similar chemical composition (Table 6). The results showed a higher percentage of meal in the time budget of the cows in the long occupation time and short occupation time treatments compared to the very short occupation time treatment. This finding is consistent with that referred to by Gibb et al. (1995), that longer grazing times in more productive cows can only be achieved at the expense of the time allocated to rest and rumination. However, our results differ with those obtained by Pulido et al. (2001) that the most productive cows compensate for this longer grazing time with a reduction of other activities that were not necessarily rumination. It should be noted that in the current experiment, we only measured the behaviour during the day. Hence rumination activities most likely took place after the evening milking after the sensors were dismounted from the halters. Although not ideal, with 16.7 cm on average, the sward height on offer was close to the 20 cm recommended for Pennisetum clandestinum, by Marín Gomez (2019) to let grazing heifers maximize their short-term intake rate. The very short occupation time treatment showed the highest defoliation intensity with 39 %, the short occupation time showed 38% and the long occupation time treatment the lowest defoliation rate with 34 %, this despite having a very similar pre-grazing height for all three treatments. Although these values showed a moderate forage harvest rate (Fonseca et al., 2012; Mezzalira et al., 2014; Schons et al., 2021). It is possible that in the case of the very short occupation time, this greater defoliation intensity caused the animals to access the lower canopy strata where the presence of stems is higher (Flores et al., 1993; Benvenutti, Gordon & Poppi, 2006). This also suggests that, faced with high levels of competition in restricted grazing areas, cows also modify their feeding behaviour to consume food in a shorter period of time and spend more of their time budget waiting to access new grazable areas, coinciding with the results obtained by Crossley et al. (2017). This could explain why the cows that grazed in the short occupation time and very short occupation time treatments consumed the lower layers of vegetation somewhat more, increasing the intensity of defoliation in these treatments (Gregorini et al.,2009; Benvenutti et al., 2016).

The ruminating percentage showed a longer period of time for the cows that grazed in the very short occupation time, in relation to the long occupation time treatment. In this same order, the speed shown by the movement of dairy cows in the long occupation time treatment was greater than those that grazed in very short occupation time and short occupation time treatments. The greatest daily traveled distance corresponded to the cows that grazed in the long occupation time treatment. This longer distance was favoured by the freedom of movement of the cows in the long occupation time treatment that encouraged the exploration of the whole area, inducing higher speeds and distances traveled. When questioning the accuracy of the GPS data obtained by the iPhones S5 (IMU) in the different treatments and repetitions, we agree with (Rempel & Rodgers, 1997; Chuvieco & Hantson, 2018) when they state that by performing a greater number of repetitions at different times of the year the readings obtained from the location of the satellites that triangulate the coordinates of the trajectory of the displacement of the cows can be contrasted. Although the mountainous nature of the Andean cordillera represents natural obstacles that affect the accuracy of the measurements obtained, and even more so if the sensors were in motion (Leptich et al., 1994). We believe that the readings obtained from the Sensor Data application resulted in geographic coordinates with good accuracy. Since, when contrasting the cvs data in the software that allows the management and analysis of geographic information

(ArcGis), with the coordinates generated from the satellite constellation (GNSS) for the limit points of the paddocks. It showed that the coordinates generated from the iPhones were located within the research area. Demonstrating that these modern smartphone sensors with multi-constellation and dual-frequency receivers estimate an accuracy range close to a few meters accuracy (Corria, 2001; Halachmi et al., 2019; Denis et al., 2021). In the very short occupation time treatment, animals were forced to graze the smaller area they were allowed to entirely in a limited period of time, leaving those areas as less interesting to the animals when a new strip is offered. Hence, cows did not return to previously grazed areas. A similar behaviour was observed for the short occupation time treatments. This is consistent with Laca et al. (1992) and Martínez-García et al. (2015) when they state that there is an effect on the ingestive behaviour of animals subjected to different times of rotation systems, especially if it restricts mobility and movement for selection of grasses, even in homogeneous pastures. Interestingly, we detected a disinterest of the animals in the very short occupation time treatment, to keep on grazing approximately fifteen to thirty minutes before the opening of a new area for the next three hours. This is because of the acquisition of previous experience in the adaptation days, as also suggested by Lopes et al. (2013) and Schmitt et al. (2019), probably the knowledge of signs that would announce that a new strip would be soon on offer (Rørvang & Nawroth, 2021), and that waiting for some time for the next strip would be better to optimize forage intake per unit of time, since the levels of depletion of the strips at the end of the 3 hours period are very close to the 40% of depletion that start seeing a drop in short term intake rate of the herbivores as stated above (de Faccio Carvalho, 2013; Savian et al., 2020).

When comparing the effect of the treatments for each occupation time on milk production, we did not find significant differences between treatments, neither in volume nor in milk quality. This coincides with the results shown by Hanson et al. (1998) for a survey conducted in 23,542 dairy farms in New York and Pennsylvania, where he compared the production of milk from the farms that used moderate intensive grazing with farms that used extensive grazing. Resulting in the production of milk was lower in the farms that used moderate grazing than in the farms that used extensive grazing. Discreply with the results obtained by Delaby et al. (2003), Flores-Llesama et al. (2006) and Pérez-Prieto et al. (2013). When they point out that the allocation of fodder that coincides with the high intensity of consumption, based on a more intense rotational stocking management, could contribute to higher volumes of milk production.

5. Conclusions

Under a moderate intensity of pasture management, intermediate forage allowance, the occupation times does not influence the productive performance of low producing dairy cows. A greater restriction of the grazing area increases the intensity of defoliation, over coming the vegetative areas of the plant until it reaches the stems, promoting the need for an increase in the time dedicated to rumination. We conclude that with a correct forage allowance (FA) based on the design of the pastures, the determination of the height of the pasture, the structure and the nutritional characteristics of the pasture before starting grazing, guaranteeing a better interaction between plant – animal it does not seem useful to apply labour intensive very short occupation time.

6. Acknowledgements

This work was designed and planned in the Precision Agriculture Unit of Gembloux Agro-Bio Tech, University of Liège, and was carried out thanks to the students and professors of the Faculty of Agricultural Sciences of the Central University of Ecuador; as well as the state entity of the Ecuadorian Agency for Quality Assurance (AGROCALIDAD) of the Ministry of Agriculture, Livestock, Aquaculture and Fisheries (MAGAP). Eloy Castro Muñoz was funded by the joint program of the Central University of Ecuador (Quito, Ecuador) and the Académie de Recherche et d'Enseignement Supérieur – Cellule de Coopération au Développement (ARES-CCD, Brussels, Belgium).

Conflict of interest

The authors declare that there is no conflict of interest associated with this publication.

References

Abrahamse, P. A., Dijkstra, J., Vlaeminck, B., & Tamminga, S. (2008). Frequent allocation of rotationally grazed dairy cows changes grazing behaviour and improves productivity. Journal of Dairy Science, 91, 2033–2045. https://doi.org/10.3168/jds.2007-0579

AGSO. (2017). Ecuador se proyecta incrementar la producción de leche. http://www.agso.ec/ecuador-se-proyectaincrementar-la-produccion-de-leche/ (accessed March 15,2020)

Andriamandroso, A. L. H., Lebeau, F., Beckers, Y., Froidmont, E., Dufrasne, I., Heinesch, B., ... & Bindelle, J. (2017). Development of an open-source algorithm based on inertial measurement units (IMU) of a smartphone to detect cattle grass intake and ruminating behaviors. *Computers and electronics in agriculture*, *139*, 126-137. https://doi.org/10.1016/j.compag.2017.05.020

AOAC Official Method 973.18 (2009a). Offcial Methods of Analysis of AOAC INTERNATIONAL, 18th Ed., AOACINTERNATIONAL, Gaithersburg, MD.

AOAC Official Method 2002.04 (2009b). Official Methods of Analysis of AOAC INTERNATIONAL, 18th Ed., AOACINTERNATIONAL, Gaithersburg, MD.

AOAC Official Method 978.10 (2009c). Offcial Methods of Analysis of AOAC INTERNATIONAL, 18th Ed., AOACINTERNATIONAL, Gaithersburg, MD.

AOAC Official Method 2001,11 (2009d). Official Methods of Analysis of AOAC INTERNATIONAL, 18th Ed., AOAC INTERNATIONAL, Gaithersburg, MD.

Badgery, W. B., Millar, G. D., Broadfoot, K., Michalk, D. L., Cranney, P., Mitchell, D., & Van de Ven, R. (2017). Increased production and cover in a variable native pasture following intensive grazing management. Animal Production Science, 57(9), 1812–1823. https://doi.org/10.1071/ AN15861

Barthram, G. T. (1984). Experimental techniques: the HFRO sward stick. Biennial report, 1985, pp. 29–30.

Benvenutti, M. A., Gordon, I. J., & Poppi, D. P. (2006). The effect of the density and physical properties of grass stems on the foraging behaviour and instantaneous intake rate by cattle grazing an artificial reproductive tropical sward. Grass and Forage Science, 61(3), 272–281. https://doi.org/10.1111/j.1365-2494.2006.00531.x

Benvenutti, M. A., Pavetti, D. R., Poppi, D. P., Gordon, I. J., & Cangiano, C. A. (2016). Defoliation patterns and their implications for the management of vegetative tropical pastures to control intake and diet quality by cattle. Grass and Forage Science, 71(3), 424–436. https://doi.org/10.1111/gfs.12186.

Bustamante, M. D. C. D. (2006). Adaptación de cuatro variedades de Alfalfa Medicago sativo en la zona de Cananvalle-Tabacundo, Cayambe-Ecuador 2004.La Granja, 5(1), 11–19. https://doi:10.17163/lgr.n5.2006.02.

Caballero, D., & Hervas, T. (1985). Producción lechera en la Sierra ecuatoriana. IICA Biblioteca Venezuela.

Carvalho, P. C. D. F. (2013). Harry Stobbs Memorial Lecture: Can grazing behavior support innovations in grassland management?. Tropical Grasslands-Forrajes Tropicales, 1(2), 137–155. https://doi.org/10. 17138/tgft (1)137-155.

Carvalho, P. C. D. F., Bremm, C., Savian, J. V., Zubieta, A.S., Leonardo, S., Marin, A., Neto, G. F. S. Schons, R. M. T., De Moraes, A., Santos, T., & Bindelle, J. (2017). Como optimizar a ingestão de forragem por vacas leiteiras em pastejo? https://repositorio.unal.edu.co/handle/unal/75736. Last accessed 15 June 2020.

Chilibroste, P., Gibb, M. J., Soca, P., & Mattiauda, D. A. (2015). Behavioural adaptation of grazing dairy cows to changes in feeding management: do they follow a predictable pattern? Animal Production Science 55(3), 328–338. https://doi.org/10.1071/AN14484.

Chuvieco, E., & Hantson, S. (2010). Plan Nacional de Teledetección de Media Resolución Procesamiento estándar de imágenes Landsat Documento técnico de algoritmos a aplicar. *Universidad de Alalá. España*.

Crossley, R. E., Harlander-Matauschek, A., & DeVries, T. J. (2017). Variability in behavior and production among dairy cows fed under differing levels of competition. Journal of Dairy Science, 100(5), 3825–3838. https://doi.org/10.3168/jds.2016-12108.

Correia, P. (2001). *Guía práctica del GPS*. Marcombo.

de Moura Zanine, A., Rebuffo, G. P. M., de Jesus Ferreira, D., de Souza, A. L., Ribeiro, M. D., Pinho, R. M. A., ...& Sprunk, M. (2019). The effects of herbage allowance on pasture characteristics and milk production of dairy cows. New Zealand Journal of Agricultural Research, 62(2), 200–209. https://doi.org/10.1080/00288233.2018.1473885.

Delaby, L., Peyraud, J. L., Foucher, N., & Michel, G. (2003). The effect of two contrasting grazing managements and level of concentrate supplementation on the performance of grazing dairy cows. Animal Research, 52(5), 437–460.https://doi.org/10.1051/animres:2003030.

Denis, D., Flores, D. D. C., Ferrer-Sánchez, Y., & Tamé, F. L. F. (2021). Potencialidades de los celulares inteligentes para investigaciones biológicas. Parte 2: Receptores GPS/GNSS. *Revista del Jardín Botánico Nacional*, 209-216. https://doi.org/10.1080/13683500.2019.1619674

Dörner, J., Horn, R., Dec, D., Wendroth, O., Fleige, H., & Zúñiga, F. (2017). Land-Use-Dependent Change in the Soil Mechanical Strength and Resilience of a Shallow Volcanic Ash Soil in Southern Chile. Soil Science Society of America Journal, 81(5), 1064–1073. https://doi.org/10.2136/sssaj2016.11.0378. (accessed on 26 April 2021).

Drewry, J. J., & Paton, R. J. (2000). Effects of cattle treading and natural amelioration on soil physical properties

and pasture under dairy farming in Southland, New Zealand.New Zealand Journal of Agricultural Research, 43(3), 377–386. https://doi.org/10.1080/00288233.2000.9513438.

Dumont et al. (1992). Trébol blanco y producción de leche. INIA. Citado por Francisco Lanuza en el III Seminario Aspectos Técnicos y perspectivas de la producción de leche INIA, Osorno-Chile, 1996.

Edmond, D. B. (1958). The influence of treading on pasture a preliminary study. *New Zealand Journal of Agricultural Research*, *1*(3), 319–328.

FAO. (2019). El papel de la FAO en la producción animal. http://www.fao.org/3/ca6030es/ca6030es.pdf. (accessed on 03 April 2020).

Flores, E. R., Laca, E. A., Griggs, T. C., & Demment,M. W. (1993). Sward height and vertical morphological differentiation determine cattle bite dimensions. *Agronomy Journal, 85*(3), 527–532. https://doi.org/10.2134/agronj1993.00021962008500030001x.

Flores-Lesama, M., Hazard, L., Betin, M., & Emile, J. C. (2006). Differences in sward structure of ryegrass cultivars and impact on milk production of grazing dairy cows. *Animal Research*, *55*(1), 25-36. https://doi.org/10.1051/animres:2005044.

Fonseca, L., Mezzalira, J. C., Bremm, C., Gonda, H. L., & Carvalho, P. D. F. (2012). Management targets for maximising the short-term herbage intake rate of cattle grazing in Sorghum bicolor. *Livestock Science, 145*(1-3), 205–211.https://doi.org/10.1016/j.livsci.2012.02.003.

Franco, W., Peñafiel, M., Cerón, C., & Freire, E. (2016). Biodiversidad productiva y asociada en el Valle Interandino Norte del Ecuador. Bioagro, 28(3), 181–192.

Gibb, M. J., Rook, A. J., Huckle, C. A., &NuthalL, R. (1995, March). The effect of sward surface height on grazing behaviour by lactating holstein-friesian cows. In: Proceedings of the British Society of Animal Science. Vol. 1995, pp. 26–26. https://doi.org/10.1017/S0308229600027951.

Gibb, M. J. (1998). Animal grazing/intake terminology and definitions. Pasture ecology and animal intake, 3, 21–37.

Gregorini, P., Gunter, S. A., Beck, P. A., Caldwell, J., Bowman, M. T., & Coblentz, W. K. (2009). Short-term foraging dynamics of cattle grazing swards with different canopy structures. *Journal of Animal Science, 87*(11) ,3817–3824. https://doi.org/10.2527/jas.2009-2094.

Gundel, P. (2008). Producir XXI, Bs.As. 16(2006), 24-32. IFEVA, FAUBA-CONICET. www.producciÃ¸snanimal.com.ar.

Halachmi, I., Guarino, M., Bewley, J., & Pastell, M. (2019). Smart animal agriculture: application of real-time sensors to improve animal well-being and production. *Annual review of animal biosciences*, *7*, 403-425. https://doi.org/10.1146/annurev-animal-020518-114851

Hanson, G. D., Cunningham, L. C., Morehart, M. J., & Parsons, R. L. (1998). Profitability of moderate intensive grazing of dairy cows in the Northeast. *Journal of dairy science*, *81*(3), 821-829.https://doi.org/10.3168/jds.S0022-0302(98)75640-1

INEC. (2020). Datos Estadísticos Agropecuarios. ESPAC Quito https://www.ecuadorencifras.gob.ec/estadisticasagropecuarias-2/.

Johansen, K. S., Alfthan, B., Baker, E., Hesping, M., Schoolmeester, T., & Verbist, K. (2019). El Atlas de Glaciares y Aguas Andinos: el impacto del retroceso de los glaciares sobre los recursos hídricos. UNESCO Publishing. doi:10.1016/j.earscirev.2019.04.001.

Kilgour, R. (2019). Livestock behaviour: A practical guide.CRC Press.

Koene, P., Hogewerf, P., & Ipema, B. (2016). Dairy cow welfare: Effects of a virtual fence on social behavior. In: Kamphuis C. (ed.). Precision dairy farming. Wageningen Academic Publishers pp.337–341. https://www.scopus.com/record/display.uri?eid=2s2.085074163723\&origin=inward\&txGid=fc4c128d471c9cee7b84b4f8717c64eb.

Laca, E. A., Ungar, E. D., Seligman, N., & Demment, M.W. (1992). Effects of sward height and bulk density on bite dimensions of cattle grazing homogeneous swards. Grass Forage Science, 47, 91–102. http://doi:10.1111/j.1365-2494.1992.tb02251.x.

Leptich, D. J., Beck, D. G., & Beaver, D. E. (1994). Aircraft-based LORAN-C and GPS accuracy for wildlife research on inland study sites. *Wildlife Society Bulletin*, 561-565. https://www.jstor.org/stable/3783080

Llangarí, B., Rodríguez, I., Luis, F., & Godoy, A. (2013). Experiencia en manejo y producción limpia de pasturas Cuenca alta del río Ambato. http://repositorio.iniap.gob.ec/handle/41000/2424.

Lopes, F., Coblentz, W., Hoffman, P. C., & Combs, D. K. (2013). Assessment of heifer grazing experience on shortterm adaptation to pasture and performance as lactating cows. Journal of Dairy Science, 96(5), 3138–3152. https://doi.org/10.3168/jds.2012-6125.

Marín Gomez, A. (2019). Sward heights for maximizing herbage and nutrient intake rate of dairy heifers grazing kikuyu grass and reduce in vitro methane production. Tesis Doctoral. Universidad Nacional de Colombia.https://repositorio.unal.edu.co/handle/unal/75736.

Martínez-García, C. G., Rayas-Amor, A. A., Anaya-Ortega, J. P., Martínez-Castañeda, F. E., Espinoza-Ortega, A., Prospero-Bernal, F., & Arriaga-Jordán, C. M. (2015). Performance of small scale dairy farms in the highlands of central Mexico during the dry season under traditional feeding strategies. Tropical Animal Health and Production,47, 331–337. https://doi.org/10.1007/s11250-014-0724-0.

Mezzalira, J. C., Carvalho, P. C. D. F., Fonseca, L., Bremm, C., Cangiano, C., Gonda, H. L., & Laca, E. A. (2014). Behavioural mechanisms of intake rate by heifers grazing swards of contrasting structures. Applied Animal Behaviour Science, 153, 1–9. https://doi.org/10.1016/j.applanim.2013.12.014.

Montoya, E. S., Chará, J. D., & Barahona-Rosales, R. (2017). The nutritional balance of early lactation dairy cows grazing in intensive silvopastoral systems. Ciência Animal Brasileira, 18 https://doi.org/10.1590/1089-6891v18e-40419.

Muñoz, E. C., Andriamandroso, A. L., Blaise, Y., Ron, L., Montufar, C., Kinkela, P. M.,Lebeau, F., & Bindelle, J. (2020). How do management practices and farm structure impact productive performances of dairy cattle in the province of Pichincha, Ecuador. Journal of Agriculture and Rural Development in the Tropics and Subtropics, 121(2), 233–241. https://doi.org/10.17170/kobra-202010191971.

Paladines, O., & Leal, J. A. (1978). Manejo y productividad de las praderas en los Llanos Orientales de Colombia. Available at: http://ciat-library.ciat.cgiar.org/Articulos_ Ciat/2013/10526_ES_Manejo_y_productividad_de_las_praderas_en_los_llano .pdf.

Paladines, O. (1984). Mediciones de la respuesta animal en ensayos de pastoreo: ganancia de peso. In: Lascano, C.& Pizarro, E. (eds.). Evaluación de pasturas con animales: Alternativas metodológicas, pp. 99–126.

Pérez-Prieto, L. A., Peyraud, J. L., Delagarde, R. (2013). Does pre-grazing herbage mass really affect herbage intake and milk production of strip-grazing dairy cows? Grass and Forage Science, 68, 93–109. https://doi.org/10.1111/j.1365-2494.2012.00876.x.

Pulido, R. G., Balocchi, O., & Fernandez, J. (2001). Efecto del nivel de producción de leche sobre el comportamiento ingestivo en vacas lecheras en pastoreo primaveral. Archivos de Medicina Veterinaria, 33(2), 137-144.http://dx.doi.org/10.4067/S0301-732X2001000200002.

Ramírez, P., Izquierdo, F., Paladines, M., & Osvaldo, L. (1996). Producción y utilización de pastizales en cinco zonas agroecológicas del Ecuador, [Pasture production and use in five agroecological regions in Ecuador]. http://www.sidalc.net/cgibin/wxis.exe/?IsisScript=GREYLIT.xis\&method=po st\&formato=2\&cantidad=1\&expresion=mfn=016146. (accessed on 18 October 2020).

Rempel, R. S., & Rodgers, A. R. (1997). Effects of differential correction on accuracy of a GPS animal location system. *The Journal of Wildlife Management*, 525-530. https://www.jstor.org/stable/3802611

Reyes, J. J. (2016). Principal results of the studies carried out at the Instituto de Ciencia Animal on bovine milk production. Cuban Journal of Agricultural Science, 49(2)., 153–159. http://cjascience.com/index.php/CJAS/article/view/529.

Rørvang, M. V., & Nawroth, C. (2021). Advances in understanding cognition and learning in cattle. In Understanding the behaviour and improving the welfare of dairy cattle (pp. 17-35). Burleigh Dodds Science Publishing.

Savian, J. V., Schons, R. M. T., Mezzalira, J. C., Neto, A.B., Neto, G. D. S., Benvenutti, M. A., & Carvalho, P. D. F. (2020). A comparison of two rotational stocking strategies on the foraging behaviour and herbage intake by grazing sheep. Animal, 14(12), 2503–2510. https://doi.org/10.1017/S1751731120001251.

Schmitt, D., Padilha, D. A., Medeiros-Neto, C., Ribeiro Filho, H. M. N., Sollenberger, L. E., & Sbrissia, A. F. (2019). Herbage intake by cattle in kikuyugrass pastures under intermittent stocking method. Revista Ciência Agronômica, 50(3), 493–501. https://10.5935/1806-6690.20190058.

Schons, R. M. T., Laca, E. A., Savian, J. V., Mezzalira, J.C., Schneider, E. A. N., Caetano, L. A. M., Zubieta, A. S.,Benvenutti, M. A., & Carvalho, P. D. F. (2021). 'Rotatinuous' stocking: An innovation in grazing foster both herbage and animal production. Livestock Science, 245, 104406. https://doi.org/10.1016/j.livsci.2021.104406.

Umstatter, C. (2011). The evolution of virtual fences: a review. Computers and Electronics in Agriculture, 75(1), 10–22. https://doi.org/10.1016/j.compag.2010.10.005.

Wang, H., Liu, Z., Liu, Y., Qi, Z., Wang, S., Liu, S., Dong, S., Xia, X., & Li, S. (2014). Levels of Cu, Mn, Fe and Zn in cow serum and cow milk: Relationship with trace elements contents and chemical composition in milk. Acta Scientiae Veterinariae, 42(1), 1–14. https://www.redalyc.org/pdf/2890/289029240024.pdf.

Zúñiga, F., Ivelic-Sáez, J., López, I., Huygens, D., & Dörner, F. J. (2015). Temporal dynamics of the physical quality of an Andisol under a grazing system subjected to different pasture improvement strategies. Soil and Tillage Research,145, 233–241. https://doi.org/10.1016/j.still.2014.09.014.

From the previous chapter, the relevance of the use of rotational stocking with short and very short occupation times for dairy cows in flat paddocks was questionned, based on the absence of any significant impact on milk production and quality. Indeed, when comparing the one stocking method with three different occupation periods (long occupation time, short occupation time and very short occupation time) there was no productive differences in terms of volume or milk quality. Nevertheless, the Ecadorian farmers who apply very short occupation times (Chapter 2) are faced in some cases with significant slopes on their pastures which might in their view justify the use of such rotation scheme. Within the framework of an ARES-UCE research project, a third experiment was designed (chapter 4) to investigate the ingestive behaviors and the production of milk when paddocks present a significant slope. In this case a stocking method with two different occupation periods (long occupation time and very short occupation time) was compared in paddocks with a slope.

Chapter 4

Evaluation of the behavior of dairy cows grazing on paddocks with a moderate slope with two different rotation methods

(unpublished)

Artícle 3

Evaluation of the behavior of dairy cows grazing on paddocks with a moderate slope with two different rotation methods

Eloy Castro Muñoz [a,b,c], Andriamasinoro Lalaina Herinaina Andriamandroso [e], Yves Beckers [b], Juan Borja [a], Carlos Montufar [a], Gentil F. da Silva Neto [e], Frédéric Lebeau [c], Jérôme Bindelle [b]*

a Universidad Central del Ecuador, Facultad de Ciencias Agrícolas, Jerónimo Leiton y Gato Sobral s/n. Ciudadela Universitaria. 170521, Quito, Ecuador
b Precision Livestock and Nutrition Unit, AgroBioChem, Gembloux Agro-Bio Tech, University of Liège, Passage des Déportés 2, 5030 Gembloux, Belgium
c Digital Energy & Agriculture Lab (DEAL), Biosystems Dynamics and Exchanges (BioDynE), Gembloux Agro-Bio Tech, University of Liège, Passage des Déportés 2, 5030 Gembloux, Belgium
d Department of Forage Plants and Agrometeorology, Federal University of Rio Grande do Sul, RS; Brazil
e Department Agriculture and Landscape Teaching and Research Department, ISA Lille, Junia, 48 Boulevard Vauban, 59046 Lille, France

Corresponding author

CASTRO MUÑOZ Eloy, MSc, Universidad Central del Ecuador, Ecuador. Facultad de Ciencias Agrícolas, Ave. Universitaria, Qutio 170129. +593 22232402

The preliminary results of this study were presenting in the oral presentation at: 7th *REDU Yachay Tech University, Ibarra, Ecuador*, 11-15 November 2019.

The results of this study were shown in Book of Abstracts of the *72st Annual Meeting of the European Federation of Animal Science (EAAP).* Davos, Switzerland (30 August- 03 september 2021)

Abstract

The importance of studying the behavior of dairy cattle lies in knowing the ability to take advantage of the forage contribution that each cow shows depending on the occupation period to which it is subjected. This research was carried out at the Rumipamba Experimental Teaching Academic Center, with the objective of evaluating feeding behavior and milk production volume in paddocks with slope moderate. The methodology used for the research was designed from one stocking method with two different occupation periods (long occupation time and very short occupation time), in each system four Holstein Friesian dairy cows were placed, three with sensors and one as a control, in two periods of five consecutive days, where the first two days corresponded to an adaptation period. Each cow with sensors was monitored in real time with the use of a data sensor, traditional methods were used to measure the forage offer and its characteristics. The results showed that in the very short occupation treatment the cows reduced the height of the pasture 5 % more than the long occupation treatment, showing significant differences for post-grazing ($P < 0.05$). The ingestive behavior, despite not showing significant differences, indicates that the cows that grazed the treatment for very short occupation moved 73 % more during meals than those that were long occupation treatment. The displacement shows that the cows without restraint moved more up (+ 48.73 m) and down (+ 52.71 m), while the cows in the very short occupation treatment moved more (+ 799.33 m) laterally ($P < 0.05$). The energy expenditure shows a numerical difference of (+ 0.38 J/kg $BW^{0.75}$) for the cows that selected the grass in long occupation treatment. The cows that harvested the forage in the very short occupation treatment reached 2.6 kg/day more milk than those that remained in the long occupation treatment, in the same order the quality of the milk for the protein parameter was higher, with statistical significance for both. cases. ($P < 0.05$). This is due to the fact that the sub-paddocks were designed horizontally to favor lateral walking, and avoid the effect of the slope on displacement. We conclude that, with an intermediate forage allocation for medium production cows, in paddocks with moderate slopes, grazing rotation with very short occupation times does significantly favor the productive parameters of dairy cows.

Keywords: pasture rotation, volume and quality of the milk, grazing time, slope

1. Introduction

Mountainous areas are characterized by their unfavorable topography, typically described by adverse elevation and/or slope, remoteness, and climate, which can vary significantly between regions and countries. Mountain agriculture represents 16 % of the agricultural area used in the 27 member states of the European Union (European Commission, 2013). Livestock production represents the dominant activity with about 54 % of mountain turnover. The main products originate from dairy products obtained from dairy cows, but with an important part of sheep's milk and goat's milk (Santini et al., 2013; Coppa et al., 2019). The mountainous regions of northern Chiapas in the United States of Mexico show sustained growth in the raising of dairy and beef cattle since the 1970s and 1980s. The indigenous communities develop their livestock production at altitudes ranging from 300 to 2300 masl, who practice a mixed production system, called the mountain livestock system (forest-cattle system, grazing in forest rangelands and mixed mountain agriculture). Considered a dynamic food allocation model, in which grazing in the forest is combined with the consumption of stubble in the cultivation areas. However, a strong pressure on natural resources is reported in this area due to not having economic resources for the implantation of improved pastures (Villafuerte et al., 1997; López et al., 2001). The number of cattle that graze in the mountainous areas of the Ecuadorian highlands has shown a sharp increase in recent years. The stability generated by the sale of cow milk, as well as the implementation of public policies that set the base price of the raw milk at $ 0.42 (Ministerio de Agricultura, Ganadería, Acuacultura y Pesca [MAGAP], 2013), has prompted a regained interest in dairy farming by peasants. The use of agricultural land in the country shows that out of 3.5 million hectares dedicated to pastures, the Sierra region, the Andean highlands, holds the largest share (75 %), followed by the Coastal area with 14 % and the Amazon with 11 % (Grijalva, J. 2011; Barahona & Mariano, 2018).

It is well known that herbivores that graze in mountainous areas must perform greater muscular activity due to the increased energy expenditures when climbing uphill to collect forage that are not fully compensated by reduced energy expenditure when moving downhill. As referred to by Lachica et al. (1997) the energy cost of lifting 1 kg of body weight one vertical meter reaches 32 J, while in the vertical descent the energy cost was estimated at 13 J/kg per meter. Hence, since herbivores spend most of their day walking and collecting forage, the intensity of this activity is variable due to different factors that affect the behavior of the animal in grazing, specifically about the time they spend to move around the grazable area selecting the forage to harvest. Some of these factors are specific to the animal itself, such as the age, its physiological and nutritional status (Allison, 1985; Bonnet et al., 2015; Zubieta et al., 2021). Several methods are available to determine the energy cost of milk production. Most of them use multiple regression techniques deriving energy costs from milk production and composition. Tyrrell and Reid (1965) obtained the energy cost from the components of milk (fat, protein, casein). Additionally, Aharoni et al. (2005) incorporates the data generated from the body physiology of each dairy cow into the equations, placing sensors such as heart rate to determine heart rate and a thermocouple that, in addition to body temperature, measures O_2 blood flow of thanks to the high sensitivity to measure changes in peripheral blood flow. Other factors are related to the grazed vegetation such as the forage allowance, the botanical composition of the grazed vegetation and its developmental stage and structure and the distribution of the forage resources across the land (Sanderson et al., 2004; Sollenberger et al., 2005). Some factors are related to the environmental conditions such as the weather conditions and the topography of the pastureland, which can show important variations in the pattern of vegetation and the distribution of species over distances of a few meters, depending on the solar radiation that is reached by the degree of steepness of the slope (Bennie et al., 2008). While most stocking methods consider factors inherent to the vegetation in order to maximize forage collection or provide the best grazing condition to the animals (de Faccio Carvalho, 2013), the physical work inherent to locomotion that depends on the distance traveled, the speed and the slope on which it is carried out is seldom considered (Miwa et al., 2017; Koczura et al., 2019). Knowing how stocking method would influence the ability for an animal to adjust its exploration of the grazable area when a forage resource is distributed across a pasture with a marked relief, and hence how the animal is still able to deal with the constraint of increase energy expenditure. As shown in Muñoz et al. (2020), many dairy farms located in the Sierra are characterized by having pastures that present a well-marked relief, with slope ranges between 12 and 27 % in the surveyed areas. In order to explore the whole area homogeneously is important to propose adequate management methods for farmers working in such areas, as those of the Sierra region of Ecuador. The results obtained in a recent survey show that dairy farms located at high altitudes in the Ecuadorian highlands, which apply labor-intensive methods that require opening new areas every 3 hours, do not lead to a significant increase in milk production (Muñoz et al., 2021), especially on farms where paddocks are mostly flat or with little slopes. We hypothesize that in the presence of marked slopes, the stocking methods of very short occupation times, the dairy cows will show better performance than a long occupation time stocking. In this context, we designed an experiment with the objective of determining the ingestive and productive behavior of dairy cows that graze in two types of rotation in paddocks with similar slopes.

2. Materials and methods

2.1. Experimental pasture

This experiment took place from March to December 2019, in the Experimental Academic Teaching Field "Rumipamba" (CADER) of the Faculty of Agricultural Sciences, Central University of Ecuador, located in the sector San Miguel parish Rumipamba, canton of Salcedo, in the province of Cotopaxi, Ecuador. The farm is located at 78°35'32" west longitude and 01°01'05" south latitude at an altitude of 2680 m.a.s.l

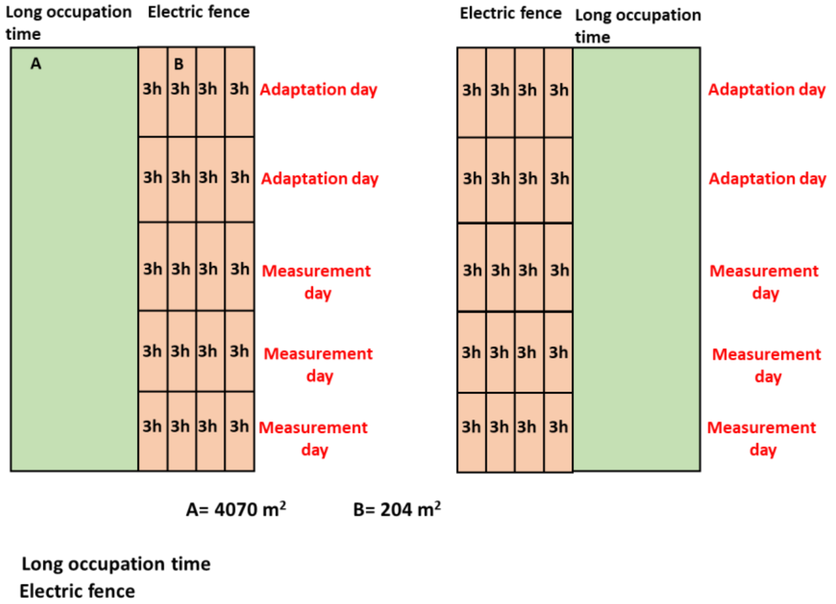


Figure 7: Distribution scheme of grassland rotation in the two phases of the experiment.

The experimental grassland of 0.814 ha was with sandy clay soil, with an average slope of 9.20 % in the paddocks. It was dominated by 60 % kikuyu (*Pennisetum clandestinum Hochst*), 30 % perennial ryegrass (*Lolium perenne* L.), 10 % alfalfa (*Medicago sativa* L.), and 5 % white clover (*Trifolium repens* L.) sown nine years before. All vegetation was first subjected to a homogenization cut at 5 cm, fertilized with 90 kg of nitrogen/ha and allowed to grow for 30 days to reach the desired biomass. The experimental pasture was divided into two paddocks (experimental unit), one by each stocking method: long occupation time stocking with 5 days of period of duration and very short occupation time, with a permanence time of 3 hours per strip. Therefore, the paddock of the very short occupation time treatment was subdivided into twenty 204 m² strips. The animals assigned to this treatment were allowed to graze a new strip every 3 hours, after re-entering the paddock after morning milking, with an electric fence that moved forward and closed behind, preventing re-entry to the area previously consumed, assigning the same size of the subpaddock available and moving the water trough together with the animals to their new grazing areas each time. In the evening, after the evening milking, the whole daily 816 m² were made available to the animals without restriction. In the case of the long occupation time grazing treatment, the assigned cows remained in the entire 4070 m² area without restriction during the five days that each phase lasted. All animals were grazing similar pastures before the beginning of the experiment and in both treatments, the first two days were used as adaptation period. The next five days were considered experimental. Once a grazing phase of five days was completed, the sequence of equalization and fertilization cuts was repeated and a new grazing phase of five days began, assigning both the paddocks and the groups of cows to a new treatment. In total, the procedure was performed twice. During the experiment, the mean temperature was 12.8 ºC and total precipitation 741 mm, compared to the 10 year climatic averages of 13.3 ºC and 584 mm.

2.2. Animals and milk sampling

Eight Holstein Freisian lactating cows with an average body weight (BW) 486 ± 33 kg, age of 3.8 ± 0.4 years, parity number of 1.8 ± 0.4, and a daily production of 15.3 ± 1.8 kg were selected. Four dairy cows were placed for each rotation system as an independent herd. Twice a day, the cows were led to the milking parlor (4:00 am and 4:00 pm), where the milk production data and samples were taken. A glass decaliter incorporated into the individual milking equipment allowed individual volumes to be recorded. Milk samples were taken from each cow in sterile 20 ml bottles with Bronopol, kept in a thermo flask at a temperature of 4 °C to 7 °C until it was sent to the chemistry laboratory of the Ecuadorian Agency for Quality Assurance AGROCALIDAD. The samples were subjected to composition analysis (protein, fat, total solids and non-fat solids), by infrared spectrophotometry, in the MILKOSCAN FT 6200 equipment, PEE02 protocol.

2.3. Monitoring of the grazing behaviour

Six (three per treatment) cows were equipped with sensors during the grazing experiments. One week before the start of each phase, the halter was placed on each cow that would be monitored so that they could adapt to its use. The halter was fitted with an iPhone 5S (Apple Inc., Cupertino, CA, USA) placed in a waterproof case. The iPhones had the Sensor Data 1.23 app installed to record the signals provided by the inertial measurement unit (IMU) of the smartphones. For an additional power source, an Anker PowerCore 20000 mAh external battery was connected to each iPhone 5S via an electrical cable with a USB port so that measurement could last for 24 h.

2.4. Sward and slope measurements

The sward height on the grazed paddocks was measured daily during the morning milking of the cows using a sward stick on twenty-eight places distributed along a fixed grid per paddock, (Barthram, 1984). Five grass stick heights were averaged per location. In addition, to determine the availability of grass and the consumption (pre-grazing and post- grazing), four forage samplings were carried out per subpaddock per day for the treatment of the electric fence, while for the long occupation time treatment four samples were taken before and four samples after the five-day experimental period. The samples were weighed and placed in an oven at 60°C for 48 hours for the determination of the dry matter content.

To determine the slope in the paddock, SOKKIA GCX3 Receiver GNSS RTK equipment was used with a horizontal precision of 10 mm and a vertical precision of 15 mm. A total of 280 measurement points were taken to determine the average slope of the experimental area. The vertical and horizontal displacement of the cows in the treatments was determined from the tracking of the sensors in the latitudinal and longitudinal position, and then synchronized with the ArcGis software.

2.5. Chemical analysis

The dried forage samples were ground to pass a 1 mm mesh screen. Subsequently and with the use of the Ankor Fiber Analyzer 2000® equipment, they were analyzed for their content in dry matter (DM, 105°C), acid detergent fiber (ADF, AOAC 973.18), neutral detergent fiber (NDF, AOAC 2002.04), crude fiber (CF, AOAC 978.10.) and crude protein (CP, N×6.25, AOAC 2001.11.).

2.6. Calculations and statistical analyses

IMU data from the iPhones were processed using the open algorithm proposed by Andriamandroso et al. (2017) to classify forage intake, rumination and other behaviours (behaviours that are neither forage intake nor rumination) while on paddocks based on 1second time windows. Meals were measured as grazing sequences that were not interrupted for more than 5 minutes (Gibb et al., 1998). In addition, from GPS data based on latitude and longitude data, the total distance traveled and the perpendicular or lateral displacement of the animals during the day, as well as their average speed during the different activities, were calculated (Brosh et al., 2010).

The energy cost coefficients were derived from data on 8 cows throughout 5 days of measurement at 5-minute intervals. Each record in the data set included the following variables: cow identification (8 levels); stoking rate method (2 levels: long occupation time and very short occupation time); hours of the day (12 levels); activity (3 levels: grazing, ruminating, walking, and others); horizontal and uphill or downhill locomotion distances. Even though locomotion energy cost per movement of 1 m was directly measured per second (i.e., at a speed of 1 m/sec). The energy concentration in milk was calculated according to Tyrrell and Reid (1965) from fat and protein. Energy milk production output was calculated as milk energy (MJ/kg milk) multiplied by milk yield (kg/day).

Statistical analysis of the biomass, bodyweight and forage allowance was performed. The paddock was considered as the experimental unit for an analysis of variance and a means classification by the Differences of Least Squares Means method using the MIXED procedure of SAS® OnDemand for Academics (SAS Campus Drive, Cary, NC, USA) with the following general linear model:

$$Y = \alpha + T_i + \varepsilon$$

Where Y is the result, α the mean, Ti the fixed effect of the treatment (i varies from 1 to 2) and ε the error term. Pre- and post-grazing sward heights as well as forage quality were compared using each measurement as experimental unit with the following model:

$$Y = \alpha + T_i + P_j + \varepsilon$$

Where Y is the result, α the mean, Ti the fixed effect of the treatment (i varies from 1 to 2), Pj the random effect of the period (j varies from 1 to 3) and ε the error term. Animal behaviour data and milk quality were compared using each individual as experimental unit with the following model:

$$Y = \alpha + T_i + P_j + C_k + \varepsilon$$

Where Y is the result, α the mean, Ti the fixed effect of the treatment (i varies from 1 to 2), Pj the random effect of the period (j varies from 1 to 2), Ck the random effect of the cow (k varies from 1 to 8) and ε the error term.

3. Results

3.1. Sward characteristics and animal bodyweight

As shown in Table 9, similar biomass densities (2367 kg DM / ha) were obtained in both treatments during the course of the experiment as well as average bodyweight (486 ± 33 Kg) of the dairy cows. Similarly, the pre-grazing sward height in both treatment was close to the target height designed for the experiment, namely 15 cm. Nevertheless, the forage allowance showed slight differences, with the long occupation time treatment having more forage than the very short occupation time treatment (+ 0.16 kg / DM kg BW / d). Consequently, the post-grazing sward height resulted in a slightly lower value for the rotational stocking (-0.7 cm on average).

Table 9: Average sward characteristics and total stocking in the two occupation times across the two experimental periods

Item	Treatments			SEM	P_value	Variance parameter estimates	
	N	Very short (3 h)	Long (7 d)			Period	Residual
Biomass[1] (kg DM ha) †	28	2364	2369	4.099	0.551	304.4	1199.78
Body weight (kg) ‡	8	489	483	9.333	0.7335	-	1135.82
Slope (%)	280	9.20	9.20	0.302	1.000	0.000	7.3977
Forage allowance (kg DM/100 kg LW d)	16	9.74[b]	9.90[a]	0.701	0.0014	0.6766	0.0456
Pre-grazing sward height (cm)	28	15.3	15.4	0.27	0.1219	0.0243	0.4043
Post-grazing sward height (cm)	28	9.7[b]	10.4[a]	0.34	<.0001	0.0106	0.5412

[a – b] Means within a row with different superscripts differ ($P < 0.05$). SEM (standard error of the mean).
† Average biomass available at the beginning of the experiment in each treatment.
‡ Mean live weight of the animals at the beginning of the experiment.

3.2. Chemical composition of the forage and nutritional content

The forage composition did not show any statistical differences (Table 10). The crude protein content averaged 155 g / kg DM, 907.9 g / kg DM for the organic matter, 313.0 g / kg DM for the acid detergent fiber and 569.0 g / kg DM for the neutral detergent fiber.

Table 10: Chemical composition of forage before grazing in the two occupation times across the two experimental periods (N = 28).

	Occupation time				**Variance parameter estimates**	
Item	**Very short (3 h)**	**Long (7 d)**	**SEM**	**P- Value**	**Period**	**Residual**
CP (g/kg DM)	145	166	13.15	0.338	919.8	48.30
OM (g/kg DM)	908	908	1.42	0.937	3.105	9.000
ADF (g/kg DM)	316	310	6.50	0.732	0.00	231.1
NDF (g/kg DM)	568	571	4.57	0.832	923.1	103.0
Ash (g/kg DM)	92.2	92.0	1.42	0.937	3.105	9.000

[a – b] Means within a row with different superscripts differ (P < 0.05). SEM (standard error of the mean). CP: crude protein; OM: organic matter; ADF: acid detergent fiber; DNF: neutral detergent fiber.

3.3. Animal behavior in grazing

Despite some numerical differences between the treatments, the cows grazing in the long occupation time and the very short occupation time treatment did not display any statistical differences neither in the time they dedicated to each activity, nor in the distance they covered or the speed.

Table 11: Behavior of dairy cows in the two occupation times across the two experimental periods (N =12)

Item	Occupation time		SEM	P_value	Variance parameter estimates		
	Very short (3 h)	Long (7 d)			Cow	Period	Residual
Time dedicate to (in minutes):							
Meal *	655	567	0.0387	0.233	<0.001	<0.001	0.0109
Grazing events	288	376	0.0601	0.388	0.0053	0.1022	0.2353
Ruminating	226	363	0.0801	0.327	<0.001	<0.001	0.0236
Other activities	410	317	0.0620	0.275	0.0097	0.0162	0.0183
Total distance covered per cow (m d^{-1})	3748	2738	315.6	0.238	<0.001	<0.001	734297
Speed (m s^{-1})	0.12	0.08	0.0117	0.166	<0.001	<0.001	0.0009
Distance during meals per cow (m d^{-1})	3664	2664	295.5	0.212	<0.001	<0.001	612580
Speed during meals (m s^{-1})	0.12	0.09	0.0114	0.389	<0.001	<0.001	0.0012

[a – b] Means within a row with different superscripts differ (P < 0.05). SEM (standard error of the mean).
* Periods of meals are sequences of grazing and non-grazing events during, which interruptions between two (2) consecutive grazing events last no longer than five (5) minutes.

Table 12 shows the movement of dairy cows in the paddock, divided in two groups of the occupation time. The result shows a significant difference for the downhill between the treatments, being the lower descent (- 52.71 m) in the animals that grazed with very short occupation time. Significant differences were also obtained in the displacement uphill, being the group of cows that grazed in the long occupation time treatment the one that reached the greatest ascent in favor of the slope (+ 48.73m). In the case of horizontal displacement, the cows that grazed with mobility restriction with movement of the electric fence every 3 hours, was greater (+ 799.33m) than the cows that remained with freedom of movement in the long occupation time treatment. Although no significant difference was shown for energy expenditure, a numerical difference (+ 0.38J/kg $BW^{0.75}$) in higher energy requirement was obtained for cows that grazed without mobility restriction.

Table 12: Displacement in the paddock of dairy cows in the two occupation times across the two experimental periods (N =17)

Item	Occupation time		P- value	SEM	Variance parameter estimates		
	Very short (3 h)	Long (7 d)			Cow	Period	Residual
Downhill (m /12 h)	37.64 [b]	90.35 [a]	<.0001	6.5687	18.77	<0.001	48.33
Uphill (m /12 h)	42.66 [b]	91.39 [a]	<.0001	6.1650	<0.001	<0.001	74.56
Displacement horizontal (m /12 h)	2883.17 [a]	2083.54 [b]	0.0141	161.99	53057	<0.001	271117
Energy expenditure (J/kg $BW^{0.75}$/12 h)	3.53E6	3.88E6	0.2100	2.36E5	6.11E11	3.50E11	2.00E11

[a – b] Means within a row with different superscripts differ (P < 0.05). SEM (standard error of the mean). The data reflects the average displacement of dairy cows per treatment in 5-minute intervals.

The milk yield of the cows grazing in both treatment (Table 13) showed significant differences with higher volume of milk produced by the cows that rotated in the very short occupation time treatment (+ 2.6 kg / day). The fat content was also higher for the very short occupation time (+ 0.24 g / 100 ml), than in the long occupation time treatment. Likewise, higher protein content (+ 0.4 g / 100 ml) were obtained in the cows that grazed in the very short occupation time treatment, with significant differences in this parameter. Non-fatty and total solids contents did not differ according to the stocking method.

Table 13: Milk production of dairy cows grazing under two occupation times across the two experimental periods (N = 12)

Item	Occupation time		P- value	SEM	Variance parameter estimates		
	Very short (3 h)	Long (7 d)			Cow	Period	Residual
Milk yield (kg/d)	16.6[a]	14.0[b]	0.0134	0.5511	0.4902	0.3903	1.1792
Milk fat content (g/100ml)	3.80	3.56	0.3608	0.1900	0.2265	0.1299	0.1559
Milk protein content (g/100ml)	3.49[a]	3.09[b]	0.0432	0.1047	0.0298	0.0225	0.0548
Non-fatty solids content (g/100ml)	8.90	8.52	0.770	0.1400	0.0967	0.0728	0.0759
Total solids (g/100ml)	12.7	12.0	0.924	0.2303	0.6686	0.0000	0.0215

[a – b] Means within a row with different superscripts differ (P < 0.05). SEM (standard error of the mean).

4. Discussion

Stocking methods are techniques used to manipulate the distribution of animals in space and time in order to achieve specific goals (e.g. efficiency of forage use). In this study we used one stocking method with two different occupation periods, with the presence of slopes in the paddock. Replicating the pasture allocation techniques carried out by farmers after analyzing the results obtained by our survey (Muñoz et al., 2020).

The similarity of the sward height between the two occupation times is important because it indicates that the sward was a factor that provided the same exploitation opportunities and did not influence the ingestive behavior of the cows as such (Table 9). In addition, the nutritional composition of the forage was similar for both occupation times during the realization of the experiment (Table 10). The highest grazing down was obtained in the very short occupation time (+ 6 %), however, the sward height was a consequence since in this study we controlled only forage allowance. On the other hand, the forage allowance was statistically different and long occupation time treatment present + 0.16 kg / DM kg BW / d, despite the values being numerically rather close in terms of sward height (9.74 and 9.90) for the very short occupation time and long occupation time treatments, respectively. By restricting the grazing area, the animals perceive limits in the selection capacity, therefore they need to make better use of the leaf area of the plant, accessing the deeper and less palatable parts (Flores et al., 1993; Parsons and Dumont, 2003; Chapman et al., 2007). This coincides with what has been published by Flores-Lesama et al. (2006) when they state that making equalization cuts of the paddocks at the end of grazing will be very useful to remove the lignified stems and pseudostems that reduce palatability and quality of grazing forage for the next harvest, and also allowing sufficient resting time to allow it to grow back to grazable height (Paladines, 1984; Henning et al., 2000). The ingestive behavior despite not showing significant differences indicates curious data: the cows that grazed the very short occupation time treatment moved 73 % more during meals than those that were in the long occupation time one. We suggest that this is due to the fact that the strips placed in the very short occupation time treatment were designed horizontally, that is, perpendicular to the mountain to favor lateral walking and avoid greater energy expenditure due to the effect of the slope (Lachica & Aguilera, 2005; Brosh et al., 2010).

Additionally, we observed that cows were more active reducing grass height in the first hour, just after allowing them to access a new range of grazing for the next three hours. We consider that this is due to the fact that the upper layer of the plant has a higher leaf: stem ratio and the difficulty of grasping and the number of chews decreases (Parsons et al., 1994, Tharmaraj et al., 2003), encouraging the animals to increase the rate of reduction of the height of the pasture in less time (Table 11). When consulting the scientific literature for the determination of the energy cost in milk production, we identified the use mainly of multiple regression techniques, deriving milk production as a coefficient, or relationship between coefficients, from calorimetric data. Establishing the comparison of models that analyze values obtained from the energy contribution of the diet (MJ/kg of metabolizable energy), the total heat generated during the day (kJ·kg of $BW^{-0.75}/d^{-1}$); as a function of the activities (grazing, ruminating and others) and the horizontal and vertical displacement (kJ kg of $BW^{-0.75}$ /d^{-1} /km^{-1}). When we analyze the movement of the cows in the paddock (Table 12), a clear preference for lateral movement is obtained in both experiments (76 %), this despite the fact that the long occupation time treatment did not pose up- and downhill mobility restrictions (Shine et al., 2020).

We observed that the cattle chose to avoid the extra physical effort that traveling uphill represents, since they spent more time in the lower part or only accessed the upper part of the paddock once or twice a day (3.8 %) to select less grazed pastures. However, the overall average of our study shows energy costs per grazing displacement 17 % higher than those reported by Brosh et al. (2006) for beef cows (6.14 J/kg of $BW^{0.75}$/m). We believe that this could be related to the average energy values for milk production (0.820) reported by previous research, Schiemann et al. (1974), Vermorel et al. (1982) and Kirkland and Gordon (1999), Van Es et al (1970) reported values of 0.808, 0.795, 0.778 and 0.900, respectively. Consulting the postulate of Di Marco and Aello (2002) when using the radiocarbon technique to determine the energy expenditure of walking, we find that we are in 90% agreement. In our case, and considering the novel method to determine the efficiency of the use of body tissue for milk production (Kirkland et al., 2002), 18 Kcal/km/100kg are needed in the presence of sloping paddocks, compensating the difference with flatter areas with an increase in consumption of 250 gr/MS/day of maintenance energy. This agrees with what Vavra & Ganskopp described (1987) when they stated that cows prefer to graze on gently sloping paddocks, especially in the warmer months. In that same order Lachica & Aguilera (2005); Maurya et al. (2012) they raise the energetic cost that ruminants represent to adapt to the physiological changes that the displacement of long distances implies in grazing, being even more critical in the presence of slope in the paddocks. The differences in milk production between the treatments are probably related to the differences in the energy requirements of the cows when performing activities such as walking on the pasture and selecting forage, especially in the presence of slopes (Brosh et al., 1998; Eastridge et al., 1998; Agnew and Yan., 2000). With highly significant differences for milk production volume (Table 13), the cows that harvested the forage in the very short occupation time treatment reached 2.6 kg / day more milk than the cows that grazed in the long occupation time treatment, this represented a daily difference of more than 16 % between occupation times methods. Our results coincide with those obtained by Bedoya et al. (2018), where it confirms that farms located in the Colombian Andes mountain range and with high percentages of undulations 63 %, reach averages of production per cow of 18.4 kg / day, and with the use of rotational stocking by bands. Likewise, Benavides (2016) and Barrios et al. (2019) report that forage management programs are similar in more than 88 % of the dairy farms in their study areas, being rotational stocking in strips with the use close to electricity and several daily strips the most implemented. The quality of the milk shows for protein an increase of 11.5 % daily for the cows that grazed in the very short occupation time treatment. This in economic terms and based on the price policies for raw cow's milk adopted by Ministerial Agreement No. 394 (MAGAP, 2013), for an increase in bonuses for milk quality, which can reach up to $ 0.50 per kg of milk produced (Cervantes et al., 2013; Alvarado, 2017; Larrea et al., 2020; Contero et al., 2021).

5. Conclusions

We obtained that, under a moderate grazing intensity with restricted mobility in sloping paddocks, deeper defoliation of the vegetative area of the sward is favored. Milk production and quality of the milk produced are influenced by the occupation times methods. We conclude that stocking methods with very short occupation times in pastures with moderate slopes do significantly favor the productive parameters of dairy cows.

Conflict of interest

The authors declare that there is no conflict of interest associated with this publication.

Acknowledgements

This work was designed and planned in the Precision Agriculture Unit of Gembloux Agro-Bio Tech, University of Liège, and was carried out thanks to the students and professors of the Faculty of Agricultural Sciences of the Central University of Ecuador; as well as the state entity of the Ecuadorian Agency for Quality Assurance (AGROCALIDAD) of the Ministry of Agriculture, Livestock, Aquaculture and Fisheries (MAGAP). Eloy Castro Muñoz was funded by the joint program of the Central University of Ecuador (Quito, Ecuador) and the Académie de Recherche et d'Enseignement Supérieur – Cellule de Coopération au Développement (ARES-CCD, Brussels, Belgium).

References

Agnew, R. E., & Yan, T. (2000). Impact of recent research on energy feeding systems for dairy cattle. Livestock Production Science, 66(3), 197-215. https://doi.org/10.1016/S0301-6226(00)00161-5

Aharoni, Y., Brosh, A., & Harari, Y. (2005). Night feeding for high-yielding dairy cows in hot weather: effects on intake, milk yield and energy expenditure. *Livestock Production Science*, *92*(3), 207-219. https://doi.org/10.1016/j.livprodsci.2004.08.013

Allison, C. D. (1985). Factors affecting forage intake by range ruminants: a review. Rangeland Ecology & Management/Journal of Range Management Archives, 38(4), 305-311. https://journals.uair.arizona.edu/index.php/jrm/article/viewFile/7864/7476

Alvarado, R. (2017). Estudio de mercado “Sector de la leche en el Ecuador”. Superintendencia de control del poder de Mercado. Ecuador. scielo.senescyt.gob.ec/scielo.php?script=sci_nlinks&pid=S1390-85962021000100031000002&lng=en

Andriamandroso, A. L. H., Lebeau, F., Beckers, Y., Froidmont, E., Dufrasne, I., Heinesch, B., ... & Bindelle, J. (2017). Development of an open-source algorithm based on inertial measurement units (IMU) of a smartphone to detect cattle grass intake and ruminating behaviors. Computers and Electronics in Agriculture, 139, 126-137. https://doi.org/10.1016/j.compag.2017.05.020

AOAC Official Method 973.18 (2009a) Official Methods of Analysis of AOAC INTERNATIONAL, 18th Ed., AOACINTERNATIONAL, Gaithersburg, MD.

AOAC Official Method 2002.04 (2009b) Official Methods of Analysis of AOAC INTERNATIONAL, 18th Ed., AOACINTERNATIONAL, Gaithersburg, MD.

AOAC Official Method 978.10 (2009c) Official Methods of Analysis of AOAC INTERNATIONAL, 18th Ed., AOACINTERNATIONAL, Gaithersburg, MD.

AOAC Official Method 2001,11 (2009d) Official Methods of Analysis of AOAC INTERNATIONAL, 18th Ed., AOACINTERNATIONAL, Gaithersburg, MD.

Barahona, A., & Mariano, J. B. (2018). Ecuador Livestock Annual 2015–Cattle Numbers Up. https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Ecuador%20Livestock%20Annual%202015_Quito_Ecuador_9-21-2015.pdf (viewed on 26/04/2020)

Barrios, D., Restrepo-Escobar, F. J., & Cerón-Muñoz, M. F. (2019). Adopción tecnológica en agronegocios lecheros. Livestock research for rural development, 31(8), 116. http://lrrd.cipav.org.co/lrrd31/8/cero31116.html

Barthram, G. T. (1984). Experimental techniques: the HFRO sward stick. Biennial report, 1985, 29-30.

Bedoya, O. D. M., Cassoli, L. D., Ángel, M. O., & Muñoz, M. F. C. (2018). Caracterización de sistemas de producción lechera de Antioquia con sistemas de ordeño mecánico. Livestock Research for Rural Development, 30, 5. http://www.lrrd.org/lrrd30/5/ceron30086.html

Benavides Patiño, L. M. (2016) Análisis energético y balance de nitrógeno a escala predial en sistemas ganaderos de lechería especializada en el norte de Antioquía con niveles de intensificación alto, medio y bajo. Tesis de Maestría en Ciencias Agrarias de la Facultad de Ciencias Agrarias, Universidad Nacional de Colombia.http://www.bdigital.unal.edu.co/55912/1/1090387550.2017.pdf

Bennie, J., Huntley, B., Wiltshire, A., Hill, M. O., & Baxter, R. (2008). Slope, aspect and climate: spatially explicit and implicit models of topographic microclimate in chalk grassland. Ecological modelling, 216(1), 47-59. https://doi.org/10.1016/j.ecolmodel.2008.04.010

Bonnet, O. J., Meuret, M., Tischler, M. R., Cezimbra, I. M., Azambuja, J. C., & Carvalho, P. C. (2015). Continuous bite monitoring: a method to assess the foraging dynamics of herbivores in natural grazing conditions. Animal Production Science, 55(3), 339-349. https://doi.org/10.1071/AN14540

Brosh, A., Aharoni, Y., Degen, A. A., Wright, D., & Young, B. (1998). Estimation of energy expenditure from heart rate measurements in cattle maintained under different conditions. Journal of animal science, 76(12), 3054-3064. https://doi.org/10.2527/1998.76123054x

Brosh, A., Henkin, Z., Ungar, E. D., Dolev, A., Orlov, A., Yehuda, Y., & Aharoni, Y. (2006). Energy cost of cows' grazing activity: Use of the heart rate method and the Global Positioning System for direct field estimation. Journal of animal science, 84(7), 1951-1967. https://doi.org/10.2527/jas.2005-315

Brosh, A., Henkin, Z., Ungar, E. D., Dolev, A., Shabtay, A., Orlov, A., ... & Aharoni, Y. (2010). Energy cost of activities and locomotion of grazing cows: a repeated study in larger plots. Journal of animal science, 88(1), 315-323. https://doi.org/10.2527/jas.2009-2108

Chapman, D. F., Parsons, A. J., Cosgrove, G. P., Barker, D. J., Marotti, D. M., Venning, K. J., ... & Thompson, A. N. (2007). Impacts of spatial patterns in pasture on animal grazing behavior, intake, and performance. Crop Science, 47(1), 399-415. https://doi.org/10.2135/cropsci2006.01.0036

Cervantes Escoto, F., Cesín Vargas, A., & Mamani Oño, I. (2013). La calidad estándar de la leche en el estado de Hidalgo, México. Revista mexicana de ciencias pecuarias, 4(1), 75-86. http://www.scielo.org.mx/scielo.php?script=sci_arttext&pid=S2007-11242013000100006

Contero, R., Requelme, N., Cachipuendo, C., & Acurio, D. (2021). Calidad de la leche cruda y sistema de pago por calidad en el Ecuador. LA GRANJA. Revista de Ciencias de la Vida, 33(1), 31-43. https://doi.org/10.17163/lgr.n33.2021.03

Coppa, M., Chassaing, C., Sibra, C., Cornu, A., Verbič, J., Golecký, J., ... & Martin, B. (2019). Forage system is the key driver of mountain milk specificity. *Journal of dairy science, 102*(11), 10483-10499.https://doi.org/10.3168/jds.2019-16726

Di Marco, O., & Aello, M. (2002). Costo energético de la actividad de vacunos en pastoreo y su efecto en la producción. Disponible en: *Instituto Nacional de Tecnología agropecuaria (INTA*). http://www. anterior. inta. gob. ar/f.

de Faccio Carvalho, P. C. (2013). Harry Stobbs Memorial Lecture: Can grazing behavior support innovations in grassland management?. Tropical Grasslands-Forrajes Tropicales, 1(2), 137-155. https://doi.org/10.17138/tgft(1)137-155

Eastridge, M. L., Bucholtz, H. F., Slater, A. L., & Hall, C. S. (1998). Nutrient requirements for dairy cattle of the National Research Council versus some commonly used ration software. *Journal of dairy science, 81*(11), 3049-3062. http://jds.fass.org/cgi/reprint/81/11/3049

European Commission. (2013). Rural Development in the EU; Statistical and Economic Information Report 2012.

Flores, E. R., Laca, E. A., Griggs, T. C., & Demment, M. W. (1993). Sward height and vertical morphological differentiation determine cattle bite dimensions. Agronomy Journal, 85(3), 527-532. https://doi.org/10.2134/agronj1993.00021962008500030001x

Flores-Lesama, M., Hazard, L., Betin, M., & Emile, J. C. (2006). Differences in sward structure of ryegrass cultivars and impact on milk production of grazing dairy cows. Animal Research, 55(1), 25-36. https://doi.org/10.1051/animres:2005044

Gibb, M. J., Huckle, C. A., & Nuthall, R. (1998). Effect of time of day on grazing behaviour by lactating dairy cows. Grass and Forage Science, 53(1), 41-46. https://doi.org/10.1046/j.1365-2494.1998.00102.x

Grijalva, J. (2011). La Industria lechera en Ecuador: un modelo de desafío. Retos.Obtenidode http://retos.ups.edu.ec/documents/1999140/2025183/Entrevista.pdf

Henning, J., Lacefield, G., Rasnake, M., Burris, R., Johns, J., Johnson, K., & Turner, L. (2000). Rotational stocking. University of Kentucky Cooperative Extension Service ID-143. Available at:(accessed 24 June 2013).

Kirkland, R. M., & Gordon, F. J. (1999). The metabolisable energy requirement for maintenance and the efficiency of use of metabolisable energy for lactation and tissue gain in dairy cows offered a straw/concentrate ration. *Livestock Production Science, 61*(1), 23-31. https://doi.org/10.1016/S0301-6226(99)00046-9

Kirkland, R. M., Yan, T., Agnew, R. E., & Gordon, F. J. (2002). Efficiency of use of body tissue energy for milk production in lactating dairy cows. *Livestock Production Science*, *73*(2-3), 131-138 https://doi.org/10.1016/S0301-6226(01)00259-7

Koczua, M., Martin, B., Bouchon, M., Turille, G., Bérard, J., Farruggia, A., ... & Coppa, M. (2019). Grazing behaviour of dairy cows on biodiverse mountain pastures is more influenced by slope than cow breed. animal, 13(11), 2594-2602. https://doi.org/10.1017/S175173111900079X

Lachica, M., Prieto, C., & Aguilera, J. F. (1997). The energy costs of walking on the level and on negative and positive slopes in the Granadina goat (Capra hircus). British Journal of Nutrition, 77(1), 73-81. https://doi.org/10.1017/S0007114500002890

Lachica, M., & Aguilera, J. F. (2005). Energy expenditure of walk in grassland for small ruminants. Small Ruminant Research, 59(2-3), 105-121. https://doi.org/10.1016/j.smallrumres.2005.05.002

Larrea Izurieta, C. O., Hurtado, E. A., Macías Andrade, J. I., Vera Loor, L. E., & More Montoya, M. J. (2020). Estimación del valor genético predicho en bovinos lecheros mestizos en un hato en la sierra alta de Chimborazo, Ecuador. Revista de Investigaciones Veterinarias del Perú, 31(4). http://dx.doi.org/10.15381/rivep.v31i4.17519

López-Carmona, M., Jiménez-Ferrer, G., de Jong, B., Ochoa-Gaona, S., & Nahed-Toral, J. (2001). Livestock system in the highlands of tzotzil-northern Chiapas, Mexico. *Veterinaria México, 32*(2), 93-102. https://www.medigraphic.com/cgi-bin/new/resumenI.cgi?IDARTICULO=5976

Maurya, V. P., Sejian, V., Kumar, K., Singh, G., & Naqvi, S. M. K. (2012). Walking stress influence on livestock production. In Environmental stress and amelioration in livestock production (pp. 75-95). Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-29205-7_4

MAGAP. Ministerio de Agricultura, Ganadería, Acuacultura y Pesca. (2013). Acuerdo Interministerial N° 394. Quito. http://www.agrocalidad.gob.ec/documentos/dcz/acuerdo-394.pdf

Miwa, M., Oishi, K., Anzai, H., Kumagai, H., Ieiri, S., & Hirooka, H. (2017). Estimation of the energy expenditure of grazing ruminants by incorporating dynamic body acceleration into a conventional energy requirement system. Journal of Animal Science, 95(2), 901-909. https://doi.org/10.2527/jas.2016.0749

Muñoz, E. C., Andriamandroso, A. L. H., Blaise, Y., Ron, L., Montufar, C., Mafwila Kinkela, P., Lebeau, F., & Bindelle, J. (2020). How do management practices and farm structure impact productive performances of dairy cattle in the province of Pichincha, Ecuador. https://doi.org/10.17170/kobra-202010191971

Muñoz, E. C., Andriamandroso, A. L. H., Beckers, Y., Ron, L., Montufar, C., da Silva Neto, G. F., Borja, J., Lebeau F., & Bindelle, J. (2021). Analysis of the nutritional and productive behaviour of dairy cows under three rotation bands of pastures, Pichincha, Ecuador. Journal of Agriculture and Rural Development in the Tropics and Subtropics (JARTS), 122(2), 289-298. https://doi.org/10.17170/kobra-202112035148

Parsons, A. J., & Dumont, B. (2003). Spatial heterogeneity and grazing processes. Animal research, 52(2), 161-179. https://doi.org/10.1051/animres:2003013

Parsons, A. J., Thornley, J. H., Newman, J., & Penning, P. D. (1994). A mechanistic model of some physical determinants of intake rate and diet selection in a two-species temperate grassland sward. Functional ecology, 187-204. https://doi.org/10.2307/2389902

Sanderson, M. A., Skinner, R. H., Barker, D. J., Edwards, G. R., Tracy, B. F., & Wedin, D. A. (2004). Plant species diversity and management of temperate forage and grazing land ecosystems. Crop Science, 44(4), 1132-1144. https://doi.org/10.2135/cropsci2004.1132

Santini, F., Guri, F., & Gomez y Paloma, S. (2013). Labelling of agricultural and food products of mountain farming. *Proyecto encargado por la Dirección General de Agricultura*. https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=420242b00be64f6a85af8fe63eab3e89b8e3e425

Schiemann, R., Henseler, G., Jentsch, W., & Wittenburg, H. (1974). Utilization of feed energy for milk production. 8. Determination of energy metabolism in high-yielding cows in the early stage of lactation. *Archiv fur Tierernahrung, 24*(2), 105-137. https://europepmc.org/article/med/4441277

Shine, P., Upton, J., Sefeedpari, P., & Murphy, M. D. (2020). Energy consumption on dairy farms: A review of monitoring, prediction modelling, and analyses. *Energies*, *13*(5), 1288. https://doi.org/10.3390/en13051288

Sollenberger, L. E., Moore, J. E., Allen, V. G., & Pedreira, C. G. (2005). Reporting forage allowance in grazing experiments. Crop Science, 45(3), 896-900. https://doi.org/10.2135/cropsci2004.0216

Tharmaraj, J., Wales, W. J., Chapman, D. F., & Egan, A. R. (2003). Defoliation pattern, foraging behaviour and diet selection by lactating dairy cows in response to sward height and herbage allowance of a ryegrass-dominated pasture. Grass and Forage Science, 58(3), 225-238. https://doi.org/10.1046/j.1365-2494.2003.00374.x

Tyrrell, H. F., & Reid, J. T. (1965). Prediction of the energy value of cow's milk. *Journal of Dairy science*, *48*(9), 1215-1223.

Van Es, A.J.H., Nijkamp, H.J., Vogt, J.R. (1970). Feed evaluation for dairy cows In: Schurch, A., Wenk, C. (Eds.), Energy Metabolism of Farm Animals, European Association For Animal Production, Publication No. 13, pp. 61–64.

Vavra, M., & Ganskopp, D. (1987). Slope use by cattle, feral horses, deer, and bighorn sheep.

Vermorel, M., Remond, B., Vernet, J., & Liamadis, D. (1982). Utilization of body reserves by high-producing cows in early lactation; effects of crude protein and amino-acid supply. In European Association for Animal Production. Agricultural Univ. of Norway. Dep. of Animal Nutrition. https://agris.fao.org/agris-search/search.do?recordID=NO8300522

Villafuerte Solís, D., García, M. D. C., & Meza, S. (1997). *La cuestión ganadera y la deforestación: viejos y nuevos problemas en el trópico y Chiapas* (No. HD 9433. M63. C758 1997).

Zubieta, A. S., Marín, A., Savian, J. V., Bolzan, A. M. S., Rossetto, J., Barreto, M. T., ... & Carvalho, P. C. D. F. (2021). Low-intensity, high-frequency grazing positively affects defoliating behavior, nutrient intake and blood indicators of nutrition and stress in sheep. Frontiers in Veterinary Science, 8. http://doi: 10.3389/fvets.2021.631820

Chapter 5

General discussion and perspectives

Chapter 5. General discussion and perspectives

"A good dairy farmer must first be a genuine forage supplier."

1. Overview

The role of pasture management practices in the efficiency of milk production is essential, since pastures are the nutritional and most economical base for feeding cattle, they constitute the fundamental pillar of the sustainability and productive and reproductive efficiency of the herd. The balance between forage production and nutritional quality impacts the DM, fiber, protein and lignin content, which allows ruminants to better obtain the necessary nutrients for feed conversion. The hypothesis of this research was to find a grazing management system that is better adapted to the management practices of dairy systems in the Ecuadorian tropical highlands and that efficiently compensates for the detrimental effects of topography on pastures. Although there is abundant literature that characterizes agricultural production systems, they essentially describe social, productive and ecological aspects (Requelme and Bonifaz, 2012; Torres et al., 2014; de Córdoba & Cruz, 2017), however, at the beginning of this research very little was known about the impact on the ingestive behavior of dairy cows based on the stocking methods mainly used by dairy farms in the Ecuadorian highlands. The objective of this thesis was to understand how the stocking management methods used in intensive milk production influence the performance of grazing cows in the Ecuadorian highlands. This objective was achieved by answering several research questions, which we will now discuss, namely:

- What are the forms of organization of the herds in the dairy farms of the Ecuadorian highlands?
- What are the management methods in the dairy farms of the Ecuadorian highlands?
- Does the size of the paddocks determine the choice of pasture rotation methods?
- What is the impact of pasture rotation types on the ingestive behavior of dairy cows?
- What influence do stocking methods have on the volume and quality of milk produced?

2. Management and organization practices of dairy farming in the Ecuadorian inter-Andean valley

When we examine the functioning and forms of organization of the herds in the tambos of the Ecuadorian highlands, province of Pichincha, the survey we carried out shows us a great variety in form and structure (Muñoz et al., 2020). The size of the dairy farms surveyed shows a range from 5 to 700 ha, the municipalities visited (Cayambe, Mejía, Quito and Rumiñahui), present variations of 39.4 ± 51.4, 56.6 ± 38.7, 82.0 ± 84.1, 182.8 ± 344.9 ha, respectively. However, it shows an average of 40 ha, coinciding with what was stated by Requelme and Bonifaz (2012) who affirm that in the Sierra we will find three categories of dairy farms depending on their respective surface: a) the category of small farm that goes from 1 to 5 ha with an average of 3 ha, especially in the provinces of Cotopaxi, Chimborazo and Bolívar; b) the category of intermediate farms with 5 to 20 ha; and, c) the category of more than 20 ha, where some farms have up to 120 ha, especially in the provinces of Pichincha and Carchi. It should be noted that the province of Pichincha has an area in the northwest that houses very large farms with greater dual-purpose livestock production (milk and meat), reversing the geographical limits of the inter-Andean valley, so it was necessary to include nearby farms. to the coastal zone in our study, to comply with the complete characterization of the province of Pichincha (Torres et al., 2014; de Córdoba & Cruz, 2017).

The average area dedicated to pastureland is in the order of 70 % of the total farm size, which shows that most of the area is dedicated to establishing paddocks to guarantee a year-round feeding of dairy cows. The number of such paddocks reaches an average of 24 per farm, while the size range of paddocks ranges from 1.5 - 2 hectares to an average of 8 pasture grazing cycles per year. There are other areas such as the milking parlors with large fenced areas with a cement floor, drinkers, and feeders that offer the possibility of supplying additional feed (cut grass and silage) to the cows (Table 3). At the same time, farms are found that allocate part of their land to other agricultural activities that are sometimes integrated with dairy farming. The most representative association is the cultivation of potatoes in the provinces of Carchi and Cotopaxi that represents a very important economic activity for the peasants, and that they can perfectly go hand in hand with dairy farming. Ranchers, agronomists, and many authors (Arce & Paladines, 1997; Crissman et al., 2002; Pérez, 2014), recognize that alternating grasslands with potato cultivation before sowing a new forage mixture greatly favors root rupture and stolons of very old creeping grasses such as kikuyo (*Pennisetum clandestinum*) and the grama (*Cynodon dactylon*). Allowing a considerable reduction in the use of highly toxic herbicides and pesticides, mitigating the environmental impact and promoting agroecological sustainability (Altieri, 1989; Campaña, 2011).

The dairy farms show an organization of the herd for the surveyed area of approximately (43 %) of the animals corresponding to dairy cows. The Andean term to call this group is "rejo". In order to achieve the highest productive and reproductive yields, these animals receive the best nutritional care (grass, silage, balanced feed, mineral salts, molasses, bypass fat, etc.), and sanitary control (prevention, control and/or eradication of diseases), trying to reach a calf/cow/year to guarantee the highest economic returns (AGSO, 2017). Next in importance are heifers (15 %), this number, in terms of dynamics and reproductive performance of the herd, shows good management of dairy cows with low replacement requirements thanks to the genetic and sanitary control programs implemented (Stevenson et al., 2008; Castro Muñoz et al., 2015). Dry cattle represent (13 %) of the herd and are made up of multiparous cows that are 2 months or less before calving, and replacement females (18 - 24 months of age) that after being inseminated and diagnosed as pregnant become part of this group. The surveyed farmers recognize the importance of allowing cows to dry for at least 60 days before calving, for the prevention of postpartum metabolic diseases, higher colostrum quality, better newborn weight, deworming and treatment to prevent clinical mastitis and subclinical, until conferring greater longevity of the reproductive stage (Frías et al., 2011). Such a proportion of dry cows is consistent with the proportion of the total herd animals, and when they give birth they move to the herd of cows producing milk (Marini & Di Masso, 2019). Next, we find the male calves (12 %), which are usually sold after 15 days because their fattening is of little interest to specialized dairy herds that also perform artificial insemination. Calves follow with (5 %), these represent one of the activities with the highest priority for the farms, beginning with the selection of artificial insemination straws based on catalogs with valuable information on the genetic information of the mother and the dairy attitude of the descendants. Curiously, the result of our survey shows a greater number of male calf (+ 7 %) in the period in which we carried out the sampling, which does not coincide with the information shown in the catalogs of bulls with pedregree proven, when they speak of descendants in the order of 50 % female calf and 50 % male calf in unsexed straws (Nebel & DeJarnette, 2011). The producers know that the calves born and raised on each farm receive an added value in terms of adaptation to the climate, physiological conditioning due to the altitude and steep slopes of the dairy areas. They recognize that the cost of raising, feeding and prophylaxis of common diseases in calves is very low compared to the value (US$ 1,800 - 2,400) of a calf on the market to replace discarded dairy cows (Castro Muñoz et al., 2015; Balarezo et al., 2016). Breeding males with (1 %) are the least represented category on our farms. The latter are less and less present due to the increasing use of artificial insemination and embryo transfer (Nasser et al., 2011).

The Holstein-Friesian dairy breed is the predominant one in the surveyed farms (65 %). This is probably explained by the high production volumes (> 25 kg/dairy cow) achieved by this breed in Ecuador, as well as the high number of companies that sell artificial insemination straws that import the genetic material of highly recognized bulls from the United States of America, Canada, New Zealand among others. It is followed by the Jersey breed (8 %), being a less heavy and smaller animal, which consumes less feed, but is very efficient in proportion to the volume and fat content of the milk produced and adapts very quickly to the environmental conditions of the farms. farms (Kong et al., 2019). Then there is the Brown Swiss breed (5.3 %), which is characterized for being an animal very well adapted to altitude and that, although its production volumes do not reach those of the Holstein, its quality (fat, protein, total solids and not fatty solids) is greater, a particularity conferred thanks to its genetic character as a dual-purpose breed (Bart et al., 2008; Quispe et al., 2016). The Normande (4.1 %) and Montbeliarde (3.2 %) breeds come from France and are highly appreciated by farmers for their robustness, rusticity and the high quality of the milk they produce (Cruz et al., 2013;

Mihai et al., 2019); however, crosses between the aforementioned breeds or with criollo cows are much more common (14.4 %) than purebreds (Table 2). Coinciding with what was published by Galarza et al. (2017) in the inter-Andean region there are several breeds of cattle intended for dairy production, for which pure breeds such as New Zealand Holstein are initially used and eventually crosses are made with Creole breeds, resulting in mixed breeds. Alvarado et al. (2020) define that the ancestors of Creole bovines are mostly linked to the Iberian populations, however, the high frequency of crossing has drastically decimated their population. In other studies, such as those carried out by Guapi et al. (2017), establish that, when crossing Creole cows with bulls of dairy breeds, the daughters will produce more milk than the mothers and these in turn will transmit resistance to certain diseases. Notably, the best breed of cattle intended for milk production is the Holstein, showing better adaptation to a diet sustained mainly by grazing paddocks with a moderate incline, although they also show excellent conversion when supplemented with balanced feed, sacrificing their own body condition from maintaining high milk volumes (Cardona et al., 2021). The reproductive walls, although they were not deeply analyzed in this research, it should be noted that this breed shows the best results regarding fertility, reaching the desired paradigm of all dairy farms (Ordoñez et al., 2022). For Contero et al. (2021) the type of feeding in the herd must contain an adequate forage mixture which, in combination with the balanced and hay, increases the percentages of fat and protein in the milk, they also mention that another factor that intervenes corresponds to the breed, due to that Holstein and crossbred cows (Creole x Holstein) maintained fat values of 3.4-3.7 g/100 ml Within this framework it should be noted that milk production systems generally seek high-yield breeds, for which the majority of the population corresponds to pure Holstein cows, taking into account that the most common dairy breeds come from temperate climates (El Tarabany et al. 2018).On the other hand, crossbreeding The relationship between criollas and dairy breeds results in a variety of animals that adapt to environmental conditions, since they take advantage of this complementarity and at the same time mitigate fertility and longevity problems (Ramírez et al. 2019). We currently know that purebreds promote a limited number of genetic traits that favor, above all, productive and reproductive parameters. Modern techniques to remove, modify or add genes to a DNA molecule as developed by genetic engineering and biotechnology, confer characteristics such as hardiness to animals that prevent the appearance of severe symptoms of some recurrent diseases (Thompson-Crispi et al., 2014; Jacob et al., 2020). However, in the inter-Andean valley we find dairy farms located at altitudes that exceed 3,500 meters above sea level. This causes a decrease in oxygen pressure and very cold temperatures, severe alveolar-pulmonary hypertension, circulatory disorders with generalized edema: the so-called “altitude sickness”, which leads to a decrease in the productive capacities of the animals (Pelouch et al., 1997; González et al., 2020). For this reason, farmers replicate the crosses between dairy breeds (Holstein, Jersey, Brown Swiss, Montbeliere, etc.), proposed by research carried out at the National Institute of Agricultural Research (INIAP), and by universities with agricultural faculties, which transfer their results in genetic matter, depending on the adaptation of the new individuals to extreme environmental conditions (Toalombo et al., 2019; Clavijo et al., 2020; Larrea et al., 2020).

3. Grazing management in dairy farms in the Andean highlands of Ecuador

The pastures in the surveyed farms were all artificial, composed of a mixture close to the proportion of 60 % - 70 % grasses and 20 % - 30 % legumes with mostly temperate species: *Pennisetum clandestinum, Lolium multiflorum, Dactylis glomerata, Lolium perenne, Holcus lanatus* for grasses and *Medicago sativa, Trifolium repens* for the legumes. We also found some paddocks from sown with forage oats (*Avena sativa*) and peas (*Vicia sp.*) for cut and carry.

Many authors agree that grazing management techniques from the point of view of the pasture is to maximize the efficiency of forage utilization without affecting its growth rate; as well as from the animal point of view, it is to optimize the efficiency in the use of forage by promoting the consumption of cows during meals and allowing an efficient metabolism of the nutrients consumed (Johnstone-Wallace & Kennedy, 1944; Kollmorgen & Simonett. 1965; Paladines & Leal, 1979). Chapters 3 and 4 of our thesis show how animals react depending on the variation in rotation frequency when offered a similar initial grass structure (Figures 6 and 7), activating the grazing mechanisms to reach the consumption that meets the daily nutritional requirements based on the feeding time periods, to cover the net energy requirement (Schoener, 1971; Hixon, 1982). Grazing herbivores also evaluate plant morphological components to optimize nutrient intake, minimizing energy costs (Cevallos, 1969). Our study showed that pasture-based dairy herds in the Sierra region of Ecuador apply intensive pasture management practices with some variant of rotational stocking (97 %), and particularly very short-term rotational stocking by bands with the use of of electric fences (80 %). On the other hand, continuous stocking (3 %) has decreased in use and is now almost non-existent, perhaps because it is simply seen as outdated. Additionally, Table 3 shows how the farms located in the dairy areas surveyed structure the number of paddocks based on the size of the properties ($p = 0.035$), but above all based on the geographical characteristics of the Andes mountain range ($p = 0.046$). The coincidence with other reports on the large number of herds that use this rotary grazing system stands out (Barrera & Arce, 1993; Cruz, 1993; Grijalva et al., 1995; Guevara-Freire et al., 2019). In this intensive pasture management system, the ranchers subdivide the paddocks considering the supply of forage in each subroom and the number of animals, assigning the cattle the necessary time for harvesting and then they are herded to the next subroom. In this way, it is guaranteed that the pastures have a rest period (30 - 45 days) long enough to achieve regrowth and energy accumulation until the next harvest (Müller & Wissel, 2007; Bowman et al., 2009). However, this long rest period clarifies a series of problems that originate from the lack of understanding of the plant-animal interface, being the animal "perspective" very important in the definition of grazing management goals (de Faccio Carvalho, 2013). In fact, if the plants require such a long rest period, it means that the defoliation intensity has probably been too high to allow a rapid recovery (Fulkerson & Donaghy, 2001). It probably means, that the animals at the end of the occupation time of the subpastures are forced to eat lower parts of the grass structure, which differs a lot from the optimal intensity of the intake rate. Indeed, awareness of the variations in the structure of the grass that is offered to grazing herbivores especially in terms of plant height is key in this respect (Hodgson, 1985; Cavalho & Moraes, 2005; Bailey & Provenza, 2008). Based on the ingestive behavior of grazing animals and with the purpose of understanding what optimal pre-grazing and post-grazing sward structure targets are for grazing management strategies, several studies have been developed under continuous and rotational stocking methods and with tropical and temperate climate grasses (Gonçalves et al., 2009; Bremm et al., 2012; Mezzalira et al., 2014). Coinciding with Fonseca et al. (2013) and Mezzalira et al. (2014), each forage species has an optimal structure to be grazed and an optimal structure in which the animals should leave it, which would correspond to it was very common in our survey period to find medium and large farms that assign forage according to the nutritional needs of the herd categories. Giving priority to the grate that corresponds to dairy cows, with higher nutritional requirements, allowing them to make better use of the higher quality pasture in the plots. Immediately afterwards, they introduce a second group called "seco" composed of dry cows and heifers close to the first calving with lower nutritional requirements, so that they carry out an activity known as "repelo", promoting the consumption of less palatable parts of the plant, evidencing in some farms and with the use of tractors that carry out an equalization cut (5 - 7 cm) after the departure of the second group (Paladines, 1992; Grijalva et al., 1995). This practice explains the recurrent need for long rest times that paddocks require to achieve the recovery of plant material, as we have presented throughout this investigation. However, in small properties inequality and lack of competitiveness of the agricultural sector are perceived, the management methods of dairy cattle are limited to keeping the animals in a single group for grazing. The paddocks show irregularity in their design, so the rotation is empirical, promoting resting times that reach up to 60 days far from what an adequate management with appropriate grazing target as discussed above would allow. It is basically the consequence of overgrazing due to lack of planning in terms of forage allowance per animal. The national reality shows the absence of public agricultural policies that protect the most vulnerable producers is the fundamental cause of this inequality. The lack of access to bank credits with fair interest rates (< 5 %), linked to the lack of schooling of the indigenous population close to 5.6 years in Basic General Education (EGB), compared to 10.9 years of culmination of the urban population (Tamayo, 2019) elucidates the lack of financial capital and qualified labor to access measurement tools and / or novel management practices that allow them to analyze productive parameters such as: 1) the determination of fresh forage mass, 2) the determination of the structure of the meadow, 3) determination of the leaf area index of the plant after defoliation, etc. However, the ingenuity of the smallholders is admirable, to calculate the average height of the pasture they use the measurement of the "boots" and this, they adjust it to the number of animals to define the time of occupation of the pasture. On many occasions and even being neighbors, we find small and irregular pastures in the foothills of the valleys alternated with agricultural crops belonging to smallholders; while in the valley floors there are larger producers that have agricultural machinery and inputs that allow them to carry out livestock practices with higher profitability rates (Zapatta, 2006; Chiriboga & Wallis, 2010).

Forage cultivation practices (Table 3) based on ancestral knowledge and in combination with modern techniques are usually carried out to benefit pasture production, considering several factors: topography, soil depth, fertility levels, climate, forage species, from the level of technology. Depending on the specific needs of each farm and its variations by area and from one paddock to another. The dispersal of feaces (64 %) is an operation widely used by farmers (Muñoz et al., 2020), since it brings great benefits to pastures, from the uniformity of fertilizer distribution, the exposure of larvae and eggs of parasites to the sun's rays, interrupting their biological cycle, until the homogenization of the "closure of the canopy" through ground cover and the regular consumption of all the plant material of the meadow. It also avoids bad smell and abnormal elongation of plants in the area where the cow deposited the manure in previous grazing (White et al., 2001; Connor et al., 2011). The equalization cut (54 %) is a task that eliminates the remains of the plants not consumed by the cattle during grazing, prevents the seeds of the weeds from sprouting and allows the light to penetrate to the base of the pasture, stimulating the young regrowth of grasses and legumes. It is known by the farmers who practice it, that the ideal is to connect the tractor to a cutting or brush cutting machine and moisten the paddocks immediately afterwards to avoid smaller plants to suffer from dehydration. However, and as we mentioned earlier, the practice of "repelo" is more common especially on larger farms with greater economic resources, where a second group of animals with less nutrient requirement is set to graze the day after a pasture has been harvested by the milk-producing cows. According to some technicians and producers, this practice is mostly recommended in the rainy season to avoid soil compaction due to the weight of the tractor in soils of volcanic origin in the Andean mountain range. Studies carried out in three cattle farms on the slopes of the Valle del Cauca in Colombia showed that the compaction index had a 70 % influence on the productive potential of the evaluated volcanic soils (Rojas et al., 2009). In that same order, the compaction of the soil induced by livestock is assumed by the "plow foot" or "hoof foot" type and depending on the origin of the soil and the location in the profile, an approximate pressure of 9 kg per cm^2 for the latter (Russell and Russell, 1968; Muñoz, et al., 2018). Much less frequently, twice a year, due to the slight impact observed at the first regrowth of the pasture, aeration (46.2 %) is practiced with reference to pre-hispanic origins, the breaking of the most exposed compacted layers of the soil with hoes by the natives, it was carried out with the objective of hydrating the deepest layers of the earth, today we know that it additionally favors the flow of nutrients and facilitates the efficient development of the root system and soil microbiota (Ceballos, 1969; Reategui et al.,2019). Our research found that the addition of macro and micro elements (fertilization 86 %) in its various variants (chemical or organic, solid or liquid) is carried just after harvest depending on the animal load, the forage mix, and the intensity of grazing guarantees, the restoration of nutrients to the soil extracted by the plant, as well as the optimal assimilation of new nutrients by the current growth of the pasture (Guevara et al., 2018). There is a high demand for biological fertilizers in the different livestock areas of the Sierra for several years, the high price of chemical fertilizers (55.00 USD per quintal of urea, (Portal Primicias, 2021), added to the harmful effects on health, and the proven environmental impact resulting from the indiscriminate use of technologies derived from the green revolution, are the main reasons why farmers use other edaphic sources that provide nutrients such as chicken manure. Likewise, a varied population of microorganisms whose metabolism can enrich soils with a high rate of mineralization (Cordovil et al., 2007; Rivero, 1999; Arias-Alemán et al., 2021). Complementing the fertilization and softening of the soil, the replanting of pastures (64 %) is an operation that allows to rehabilitate botanical species that, due to the intensity and frequency of the harvests, disappear with each growth of the pastures. On dairy farms of the Ecuadorian Sierra, it is carried out with a frequency of two to three years, simply dropping the seeds just before grazing with the aim that the hoofs of the cows consolidate the seed in the ground. Although the farms with greater economic resources use resowing machinery that is adjusted to the tractors and penetrates the soil between 10 - 15 cm to deposit the grass seeds (Franco et al., 2016).

Although it is true, conventional tillage practices are widely used for pasture production on the surveyed farms, arguing that their use favors soil aeration, improves water movement, optimizes root development, and promotes microbial activity. However, there are studies that question its long-term effects, especially when they refer to the indiscriminate use of disc plows, causing considerable degradation of the grass and changes in physical properties, with compaction producing mechanical resistance to germination, seed and root extension. Consequently, there are changes in the state of aeration and exchangeable gas between the soil-atmosphere and the moisture content of the soil (Macedo et al., 2005; Sanabria et al., 2006). We believe, as Sanabria et al. (1995) and Soares et al. (1992) that grass-legume associations under intensive tillage promote pasture degradation and decrease biomass production, favoring the implantation of weeds that support high levels of mechanical stress. The data obtained by Gómez et al. (2018), corroborate that the excessive implementation of conventional tillage causes the compaction of the arable layers of the soil, this directly caused by the passage of machinery. In addition, as previously stated, the compaction caused by the animals is one of the most important factors to take into account, since the degree of compaction will depend on the grazing system used, when the grazing system is intensive, the trampling of the animals for 2 to 3 years produces a compaction similar to that caused by extensive livestock with a time of use greater than 15 years (Murgueitio, 2003). Therefore, when implementing grazing systems that preserve the biotic and abiotic components of the soil in dairy production systems, it should be the priority of all producers, as mentioned by Terán & Cobo (2017).

The success of the exploitation of livestock farms in the Ecuadorian highlands depends on considering the pastures as true crops, being essential the compliance with the protocol of establishment and maintenance of the pastures. The first thing the producer must do is to measure the area of the paddock and make the corrections based on the topographical conditions and the expected stocking rate of his dairy herd. Additionally, he must carry out a soil analysis that allows him to know the physical, chemical, and microbiological characteristics of the lot, identify the productive capacity from the available nutrients and support the fertilization programs at optimal times and quantities (Espinosa, 1999; Gutiérrez et al., 2017). Next, the forage material to be sown must be chosen, based on the species and varieties appropriate for the area. It is vital to consider the climatic conditions in terms of luminosity that we have at latitude close to 0°- 00'- 00", and the competition that is generated between the most used species (alfalfa, ryegrass, bluegrass, kikuyu, oats, corn, rye, white clover, red clover, lotus and vetch), by establishing mixtures of grasses and legumes to achieve a better use of grass resources (Martínez et al., 2003; León et al., 2018). The optimal moment of the first cut, the frequency of the rotation methods, the intensity of the harvest per round will show, the best focused on achieving the greatest perenniality of the forage mixtures. The management of water from mountain glaciers and páramos is used 80 % to irrigate agricultural crops and 20 % for consumption as drinking water (Gaybor, 2008). However, only 10.5 % of the cultivated area of the country receives this benefit, it is clear to understand the inflection point between the cattle ranches that have access through the canalization network known as "acequias" for the use of the different techniques irrigation and drainage (77 % private and 23 % state), and those that only have their own reservoir or the climate to have access to this important natural resource to manage their pastures (Partridge, 2015).

Based on the data obtained in the survey carried out in 42 dairy farms, the intensive use of rotational stocking by the farms was identified. However, these practices vary a lot, especially in occupation times, since most farmers apply common residence times of one to several days, but some of them declared opening new strips for grazing every 3 hours for grazing cows. Questioning the relevance of such an intensive practice in labor, tools and equipment (electric fence), waterthroughs, salt licks in the field, etc. We hypothesized that shorter grazing times in a rotational stocking method would improve system performance. For this reason, we designed an experiment to evaluate the effect of three occupation times of pasture rotation on the productive behavior of dairy cows in terms of grass consumption and its impact on grazing time (Chapter 3). The use of electric fencing makes it possible to delimit an area where the cows feed at established times, based on the forage allowance. Although the cost of implementing electric fencing is high, it is quickly offset by the time and labor saved by establishing subppadock boundaries. So, this type of delimitation is superior to conventional and fixed methods (Grumett & Butterworth, 2022). Regarding the management in the pastures, Foot & Line (1960) indicated that it is impractical to increase the stocking rate without the use of electric fencing, since this allows its control, increasing productivity and profitability, without the need to drastically influence the prairie, for permanent delimitation concept. In studies based on the rotation of pastures established with an electric fence, they indicated that its use allows the cows to feed on the grass that the producer provides them, but not on the grass that they select, since the grazing area is delimited (Peñuela & Fernandez, 2010). The ranchers divide the property into paddocks with barbed fences, while for the allocation of pastures they subdivide the areas with the use of the electric fence. This allows them to rationalize the volume of food and promote the plant-animal relationship based on space-time interaction (Balarezo et al., 2015). Additionally, electric fences can adapt to topographically irregular terrain, on steep slopes, and flooded areas, guaranteeing notable flexibility in the delimitation of rugged areas with availability of forage for livestock feeding (Miles, 1951).

The height of the canopy was offered to the animals with a mean height of 16.7 cm, close to the 20 cm recommended for *Pennisetum clandestine Hochst* described by Marín et al. (2021), allowing cows to maximize their consumption rate in the short term. The results of the ingestive behavior of the cows come from the analysis of the data recorded by the iPhones with the SensorData application and the processing with the free algorithm developed by Andriamandroso et al. (2017). The means for the animals that grazed in each treatment are shown in Table 7, elucidatinga higher percentage of time spent eating by the cows that remained in the long occupation time treatments (+ 18 %) compared to the very short occupation time treatment, and with + 8 % when compared to short occupation time treatment (p = 0.027). Feeding periods were considered for grazing and non-grazing events, during which the interruptions between two consecutive grazing events did not last more than five minutes. As stated by Gibb et al. (1995), longer grazing times for cows can only be achieved at the expense of reducing the time spent resting and ruminating. However, our results differ from those obtained by Pulido et al. (2001) who affirm that the most productive cows compensate for this longer grazing time with a reduction in other activities that are not necessarily rumination. In addition to the fact that might grazing by anaimals was not monitored, we believe that, in the case of very short occupation time, the animals had to increase the intensity of defoliation (39 %) and access lower strata of the canopy to complete their food requirements due to the restriction of the area with the electric fence. This also led to a significant increase in the percentage of time spent ruminating compared to the general mean of the three treatments. The reason for this behavior is related to the unpleasant and indigestible characteristics of the portion of the plant that is induced to consume (Illius & Gordon, 1991). Additionally, we detected an unusual disinterest of the cows that grazed in the very short occupation time treatment in maintaining the grazing rhythm (- 7.5 % of meal), approx. 15 minutes before the opening of a new subppadock. For this behavior we have two possible explanations: 1) the cows after depleting the upper strata of the pasture had to maintain consumption, but already from the lower stratum where the palatability of the stems is lower, so the intake rate decreases (Benvenutti et al., 2017); 2) to acquisition of previous experience in the adaptation days, as also suggested by López et al. (2013) and Schmitt et al., (2019).

Additionally, we believe that we could be in the presence of the asymptotic relationship between pasture utilization and daily forage consumption or consumption rate in rotational stocking systems, described by several previous studies with tropical grasses (Silva 2004; Da Silva & Carvalho 2005; Fonseca 2012). This is a tangible result of the ingestive behavior of the cows to the change of the structure of the pasture as we decrease the height of the canopy. Our thesis found that milk production does not show any change in relation to pasture rotation systems. It coincides with the results obtained by Flores-Lesama et al. (2006) in kg/cow/day of milk, asserting that when harvesting the most intermediate layers of a meadow they contain a greater presence of pseudostems, hindering digestibility and palatability. We believe that this result may be influenced by the relatively low productivity of dairy cows (12 kg of milk per day on average) in the “La Tola” Experimental Academic Teaching Field. We agree with Delaby et al. (2003) when they state that a genetic potential of the dairy herd would show better individual yields of grazing cows, also incorporating balanced supplements in proportion to the individual volume produced per day. In addition to replicating pasture-based dairy production systems, our research analyzed quality and availability as a key factor (Dillon et al., 2005). Grazing management using long occupation time, short occupation time and very short occupation time grazing rotations became a fundamental factor to show how feeding behavior and the rate of forage consumption could be affected when the pre-grazing herb mass is not controlled regularly by farmers, penalizing production volume and milk quality (Ungar, E.D., 1996; Pérez-Prieto et al., 2013).

4. Management of paddocks and high relief in milk production

The number of paddocks and the slope in the pastures of the surveyed farms reflect significant differences ($p < 0.05$) among the surveyed areas. This is due to the morphological and topographic conditions of the terrain with slope ranges between (12 - 27 %), influencing the areas dedicated to grazing on the farms, the intensity and frequency of grazing, and the number of animals per farm. A second period of experiments in the highlands of Ecuador was carried out in 2019, this to strengthen our interpretation of the management techniques most used by dairy farmers in the presence of slopes (Chapter 4).

Increasing the efficiency of the forage harvest and improving the productive performance of the animals should focus on several factors. On the one hand, those that refer to the behavior of cattle based on the time they spend moving through the grazing area selecting the forage; and, on the other hand, the factors of the animals such as age, physiological and nutritional status (Bonnet et al., 2015; Zubieta et al., 2021). Additionally, factors associated with grazed vegetation such as forage allocation, botanical composition, vegetative stage of the plants, as well as the structure and distribution of the meadow were evaluated. All this in a mountainous area (2680 masl) and with moderate slopes greater than 9.2 %, where physical activity for the mere fact of collecting fodder implies a greater energy expenditure when going up than when going down. However, it is well known empirically by producers and demonstrated by some experiments, that there is no trade-off between the energy cost of lifting 1 kg of body weight in a vertical meter that involves spending 32 J, compared to the lowering that requires 13 J/kg. Despite obtaining a difference of -19 J per kg in each meter traveled down the paddock (Holechek, 1988; Lachica et al., 1997).

Thanks to the exhaustive selection process of animals with similar physiological characteristics (breed, age, calving, weight, etc.) of the cattle participating in the experiment, from the dairy herd of the Academic Teaching Experimental Field (CADER) "Rumipamba" of the Faculty of Agricultural Sciences, Central University of Ecuador. An experiment was carried out with the objective of evaluating the productive behavior of grazing dairy cows, in paddocks with a moderate slope with two different occupation times for rotational stocking. Two herds of dairy cows were established that grazed on paddocks with moderate slopes 9.2 %, and with a controlled occupation time for each treatment. The results show that the cows that graze on slopes in the very short occupation time treatment spent a little (0.12 %) more time eating than the cows in the long occupation time treatment. The total distance covered, and the speed were higher for the cows that grazed in the very short occupation time treatment (1010 m and 0.04 m/s) respectively. However, the greatest time dedicated to grazing and ruminating corresponded to the cows that grazed in the long occupation time treatment (0.11 % and 0.02 %). Despite not finding significant differences in the parameters analyzed for ingestive behavior, it was identified that the cows in the very short occupation time treatment consumed most of the grass height in the first hour of assignment, just after they were allowed to eat, access a new range of grass for the next three hours. We believe that this is due to the fact that the upper layer of the plant has a higher leaf: stem ratio and favors the size of the bite, decreasing the number of bites, and stimulates the animals to increase the rate of reduction of the height of the bite, meadow in less time (Parsons et al., 1994, Tharmaraj et al., 2003). Additionally, we agree with Lopes et al. (2013) when they talk about the prior experience that cows need when undergoing variations in stocking methods. We believe that when animals are subjected to changing subpaddocks in shot-term, they will need an adaptation time to establish an adjustment of the dynamics of the bite. Based on the movements of the lips, tongue and jaws in the act of apprehension, with head movements that cause tension in the mass of selected grass and break the forage (Carvalho et al., 2013). A wide variety of models have been developed by prestigious scientific research groups around the world in order to more accurately determine the energy cost in milk production. As a coefficient, multiple regression techniques are analyzed that process data obtained from the use of increasingly sophisticated sensors, and many others derived from milk components. Although our thesis did not focus on the elaboration of these models, we did take some bibliographical references that allowed us to evaluate some of the results of our research and, above all, to be able to contrast these magnificent works with our Latin American reality in the Andes. The general average of our study shows energy costs per grazing displacement (17 %) higher than those reported by Brosh et al. (2006) for beef cows (6.14 J/kg of BW $^{0.75}$ /m). We believe that the average height of the pastures where we developed our study (2680 masl), compared to the average height of the Sea of Galilee in Israel (115 masl), could have evidenced this increase in energy cost (Kreuzer et al., 1998). In addition, we see differences in the breeds of the animals that participated in the studies (Holstein Friesian & Simford cross and Simmental × Hereford cross). Analyzing experiments carried out in the Andes with cattle of different breeds, an increase in fat in the milk produced by the animals best adapted to altitude was obtained, postulating that altitude did not seem to cause any additional maintenance energy requirement (Bartl et al., 2009). Therefore, we assume that animals specialized in producing milk at this height could respond to the difference in values obtained by our thesis. Milk production was significantly higher (+ 2.6 kg/day) for the cows that rotated on very short occupation time grazing, showing a daily increase of (16 %). We believe that the design of the rectangular paddocks (Figure 7) facilitated the placement of the temporary sub-paddocks with the use of the mobile electric fence, and in the presence of a slope, which allowed the animals to move perpendicular to the mountain avoiding the increase in energy expenditure (Cárdenas, & Garzón, 2011). More productive results (18.4 kg/day) were found by Bedoya et al. (2018) in farms located in the Colombian Andes, and with high percentages of undulations over 63 % in their pastures. The quality of the milk presents an increase of 11.5 % daily in proteins in the cows that rotated in the very short occupation time treatment. We know that pasteurizers (milk processors) constantly evaluate production costs (0.28 USD/kg/milk/day) to achieve the best profitability for each liter produced (0.21 USD/kg/milk/day). This protein yield will mean an increase in milk quality bonuses, which can reach up to $0.50 per kg of milk produced (price per liter), following Ministerial Agreement No. 394 (MAGAP, 2018) on milk price policies for raw milk in Ecuador (Larrea et al., 2020; Contero et al., 2021). Interestingly, when analyzing the total distance covered by the cows that grazed in the long occupation time treatment, it was - 27 % lower than those that rotated in the treatment that moved the electric fence. Apparently, and despite not having restrictions on their mobility, they chose to avoid extra physical effort, since they spent more time in the lower part of the pasture where they selected the grass to eat. It is also observed that, although we offered practically the same pasture height in both treatments (average pre-grazing pasture height 15.35 cm), the cows that grazed in the long occupation time treatment used (0.7 cm) less than those that very short occupation time in the schedule treatment. This is consistent with what Vavra & Ganskopp (1987) described when they stated that cows prefer to graze on gently sloping pastures, especially in the warmer months, because the temperature and movement cause greater fatigue in the animals.

Future decision making on the efficient management of dairy production will depend on the timely adoption of technological tools that best suit agricultural needs. The use of sensors will enable real-time data acquisition and faster information transfer and storage to achieve true precision livestock farming systems. This involves live or near live observation and data transmission of animal behavior using these sensors as everyday tools. Achieving continuous and precise automation of real observations that currently with the use of traditional tools consume a lot of time and effort, and in the best of cases are supported by complex classification and modeling methodologies, that, although they appear to be efficient and precise, they need a good correspondence with what really happens in the field in each of the components that intervene in productive activity such as animals, plants, soil, climate, altitude, and topography. This thesis showed an IMU adaptation, placement and adjustment protocol that allowed continuous monitoring of animal behavior under different rotation methods (photo 1). Revealing how the gyroscope and accelerometer yield measurable and quantifiable data on how cows regulate their speed of movement during feeding, the change of season to select more appetizing plants based on the relief, and preferences for displacement (lateral or up and down) below. However, if our experiment had been able to count on a larger economic budget, it could have incorporated other tools that would allow contrasting the physiological activity (heart rate, temperature, reproductive activity, digestion, etc.) of the cow while grazing. As well as the acquisition of longer-lasting lithium batteries (24 - 48 hours) that would guarantee to sustain the electrical charge of the measurement devices and record the circadian rhythm of feeding, depending on the variations between day and night. We believe that images of the pasture obtained with a UVA with a 3D camera would have allowed us to characterize grass height and biomass at a much more precise spatial scale, before and after grazing. Additionally, we believe that there were topics in the research methodology that it was not possible to control, due to the limitations of the time assigned to carry out the work. It would have been more conclusive and robust to take data for a whole lactation period of a group of cows (305 ± 6.4 days), determining the influence of stocking methods on the rate of increase in milk production, until reaching peak production, and interpret the degree of productive persistence close to the lactation peak, which manages to sustain a given forage allowance. The dairy components suffer great variations depending on the breed and the stage of lactation or days in DIM milk. Had the necessary economic resources been available, breeds and/or crossbreeds commonly used by Andean producers would have been incorporated into the research, as well as the incorporation of milk quality analysis throughout the lactation curve, through its three periods and four main components: 1) initial production; 2) ascending phase or increase in production; 3) maximum point or peak of production; and, 4) decreasing rate or reduction of production, called persistence. Contrasting variations in the change of paddocks and in the botanical composition of plant material, distance traveled from and to the milking parlor; as well as the incorporation of climatic variables of temperature, luminosity.

Although the costs of these tools initially appear high for farmers, our results elucidate benefits in economic terms that are perceived by the volume and quality of the milk, through the design of inclined paddocks that encourage the lateral movement of the animals, favoring the proportional consumption of plant material with less energy expenditure for displacement concept. A more detailed investigation where it is possible to monitor twenty-four hours a day, throughout the lactation period of cows subjected to rotational stocking methods, could validate the results obtained. Incorporating canopy height diversity into research could reveal the impact of spatial heterogeneity on the foraging activity of dairy cows in grasslands on the slopes of the Ecuadorian highlands. In conclusion, management strategies for dairy cow grazing in high relief, as practiced in the Ecuadorian highlands, still present great challenges before achieving optimization in the use of forage resources. Based on the findings presented by this thesis, it is clear that dairy farms are adopting time-consuming grazing rotation methods without solid criteria in terms of production, where limiting access to grazing areas is not justified, especially in flat pastures (Castro Muñoz et al., 2021). It is essential that, within the annual planning of the acquisition of inputs for the maintenance or renewal of pastures, special attention is paid to the determination of the level of undulations and/or percentage of inclination in each paddock. Based on these results, farmers could adopt rotation methods with shorter occupancy times where the animals have movement limitations due to selection, but guaranteeing that the forage allocation corresponds to the nutritional requirement. Favoring the best ingestive activity of the animals, which means that the intensity and frequency of grazing would be more precisely adjusted on a spatio-temporal scale.

Reference

AGSO. (2017). Ecuador se proyecta incrementar la producción de leche. http://www.agso.ec/ecuador-se-proyecta-incrementar-la-produccion-de-leche/ (accessed March 15, 2020)

Altieri, M. A. (1989). Agroecology: A new research and development paradigm for world agriculture. *Agriculture, Ecosystems & Environment, 27*(1-4), 37-46.

Amaral, M.F., J.C. Mezzalira, C. Bremm, J.K. Da Trindade, M.J. Gibb, R.W.M. Suñe, and P.C. de F. Carvalho.2013. Sward structure management for a maximumshort-term intake rate in annual ryegrass. Grass Forage Sci. 68:271–277. https://doi:10.1111/j.1365-2494.2012.00898.x

Andriamandroso, A. L. H., Lebeau, F., Beckers, Y., Froidmont, E., Dufrasne, I., Heinesch, B., ... & Bindelle, J. (2017). Development of an open-source algorithm based on inertial measurement units (IMU) of a smartphone to detect cattle grass intake and ruminating behaviors. *Computers and electronics in agriculture*, *139*, 126-137. https://doi.org/10.1016/j.compag.2017.05.020

Arce, B., & Paladines, O. (1997). Análisis y opciones de desarrollo sostenible del ecosistema húmedo altoandino de la Provincia del Carchi, Ecuador. In Conferencia Electrónica “Estrategias para la Conservación y Desarrollo Sostenible de Páramos y Punas en la Ecorregión Andina. CDCPP (p. 3). https://core.ac.uk/download/pdf/48035486.pdf

Arias-Alemán, L., Vaca-Zambrano, E., Huebla-Concha, V., Shañay-Rea, S., & Abad-Rivadeneira, J. (2021). Evaluación productiva del maralfalfa verde Pennisetum SP con el uso de fertilizantes orgánicos e inorgánicos en la provincia de Morona Santiago. Polo del Conocimiento, 6(6), 1390-1401. https://doi:10.23857/pc.v6i6.2835

Bailey, D. W.; Provenza, F. D.(2008). Mechanisms Determining Large-Herbivore Distribution. In: PRINS, H. H. T.; VAN LANGEVELDE, F. (ed.). Resource ecology.
Dordrecht: Springer. p. 7–28. E-book. Available in: http://dx.doi.org/10.1007/978-
1-4020-6850-8_2. 13. Access in: 01 December. 2021.

Balarezo, L. R., García-Díaz, J. R., Hernández-Barreto, M. A., & López, R. G. (2016). Metabolic and reproductive state of Holstein cattle in the Carchi region, Ecuador. Revista Cubana de Ciencia Agrícola, 50(3), 381-392. https://www.redalyc.org/pdf/1930/193049037006.pdf

Barrera, V. H., & Arce, B. (1993). Análisis de la información previa de los sistemas de producción alrededor de ganadería de leche en los cantones de Tulcán, Montúfar y Espejo de la provincia del Carchi. https://repositorio.iniap.gob.ec/handle/41000/4239

Bartl, K., Gomez, C. A., García, M., Aufdermauer, T., Kreuzer, M., Hess, H. D., & Wettstein, H. R. (2008). Milk fatty acid profile of Peruvian Criollo and Brown Swiss cows in response to different diet qualities fed at low and high altitude. Archives of Animal Nutrition, 62(6), 468-484. https://doi.org/10.1080/17450390802453450

Bartl, K., Gómez, C. A., Aufdermauer, T., Garcia, M., Kreuzer, M., Hess, H. D., & Wettstein, H. R. (2009). Effect of diet type on performance and metabolic traits of Peruvian local and introduced cow types kept at 200 and 3600 m of altitude. *Livestock Science*, *122*(1), 30-38. https://doi.org/10.1016/j.livsci.2008.07.022

Bedoya, O. D. M., Cassoli, L. D., Ángel, M. O., & Muñoz, M. F. C. (2018). Caracterización de sistemas de producción lechera de Antioquia con sistemas de ordeño mecánico. Livestock Research for Rural Development, 30, 5. http://www.lrrd.org/lrrd30/5/ceron30086.html

Benvenutti, M. A., Pavetti, D. R., Poppi, D. P., Mayer, D. G., & Gordon, I. J. (2017). Ingestive behaviour and forage intake responses of young and mature steers to the vertical differentiation of sugarcane in pen and grazing studies. The Journal of Agricultural Science, 155(10), 1677-1688. https://doi.org/10.1017/S0021859617000673

Bonnet, O. J., Meuret, M., Tischler, M. R., Cezimbra, I. M., Azambuja, J. C., & Carvalho, P. C. (2015). Continuous bite monitoring: a method to assess the foraging dynamics of herbivores in natural grazing conditions. Animal Production Science, 55(3), 339-349. https://doi.org/10.1071/AN14540

Bowman, A. M., Alemseged, Y., Melville, G. J., Smith, W. J., & Syrch, F. (2009). Increasing the perennial grass component of native pastures through grazing management in the 400–600 mm rainfall zone of central western NSW. The Rangeland Journal, 31(4), 369-376. https://doi.org/10.1071/RJ08032

Bremm, C., E.A. Laca, L. Fonseca, J.C. Mezzalira, D.A.G. Elejalde, H.L.Gonda, and P.C. de F. Carvalho. (2012). Foraging behaviour of beef heifers and ewesin natural grasslands with distinct proportions of tussocks. Appl. Anim. Behav. Sci.141:108–116. https://doi:10.1016/j.applanim.2012.08.008

Campaña, A. (2011). Los agroquímicos: un tóxico para el campo ecuatoriano. ¿Agroindustria y Soberanía Alimentaria?, 131. http://biblioteca.clacso.edu.ar/gsdl/collect/ec/ec-010/index/assoc/D12927.dir/pdf_427.pdf#page=131

Cardona Iglesias, J. L., Avellaneda Avellaneda, Y., & Castro Rincón, E. (2021). Estimación del consumo de forraje para dos biotipos bovinos lecheros en el trópico altoandino de Nariño, Colombia. *Revista de Investigaciones Altoandinas*, *23*(4), 220-228. http://dx.doi.org/10.18271/ria2021.301

Carvalho, P. C. F.; Moraes, A. (2005). Comportamento ingestivo de ruminantes: bases para o manejo sustentável do pasto. In: CECATO, U.; JOBIM, C. C. (org.).
Manejo sustentável em pastagem. Maringá: UEM. v. 1, p. 1-20.

Carvalho, P. D. F., Trindade, J. K., Bremm, C., Mezzalira, J. C., & Fonseca, L. (2013). Comportamento ingestivo de animais em pastejo. *Forragicultura: Ciência, Tecnologia y Gestão dos Recursos Forrageiros. Jaboticabal, SP, Brasil: Gráfica Multipress*, 525-545. (FUNEP: Jaboticabal, BR)

Cárdenas, A., & Garzón, J. P. (2011). Guía de manejo de pastos para la sierra sur ecuatoriana. https://repositorio.iniap.gob.ec/bitstream/41000/2318/1/BD407.pdf

Castro Muñoz, E., Burgos, J., Pazmiño, J., & Valarezo, L. (2015). Efectos de aditivos y levadura en el incremento de peso en terneras holstein-friesian, de tres a seis meses de edad. Tumbaco, Pichincha. Siembra [online]. 2015, vol. 2, n. 1. https://doi.org/https://doi.org/10.29166/siembra.v2i1.114.

Castro Muñoz, E., Ron, L., Montufar, C., da Silva Neto, G. F., Borja, J., Lebeau, F., & Bindelle, J. (2021). Analysis of the nutritional and productive behaviour of dairy cows under three rotation bands of pastures, Pichincha, Ecuador. *Journal of Agriculture and Rural Development in the Tropics and Subtropics, 122*(2). https://doi.org/10.17170/kobra-202112035148

Cevallos, F. (1969). Manual para el manejo de pastos tropicales en el Ecuador. https://repositorio.iniap.gob.ec/handle/41000/1626

Chiriboga, M., & Wallis, B. (2010). Diagnóstico de la pobreza rural en Ecuador y respuestas de política pública. Grupo de Trabajo sobre pobreza rural. https://rimisp.org/wp-content/files_mf/1366317392Diagnosti...pdf

Clavijo, F. E., Rodríguez, L. F., Yánez, I., Godoy, G. A., Garzón, J. P., Pinargote, L., ... & Marini, P. R. (2020). Mejoramiento genético de especies bovinas en el INIAP. https://repositorio.iniap.gob.ec/handle/41000/5483

Connor, D. J., Loomis, R. S., & Cassman, K. G. (2011). Crop ecology: productivity and management in agricultural systems. Cambridge University Press.

Contero, R., Requelme, N., Cachipuendo, C., & Acurio, D. (2021). Calidad de la leche cruda y sistema de pago por calidad en el Ecuador. LA GRANJA. Revista de Ciencias de la Vida, 33(1), 31-43. https://doi.org/10.17163/lgr.n33.2021.03

Cordovil, C. M., Cabral, F., & Coutinho, J. (2007). Potential mineralization of nitrogen from organic wastes to ryegrass and wheat crops. Bioresource Technology, 98(17), 3265-3268. https://doi.org/10.1016/j.biortech.2006.07.014

Crissman, C., Espinosa, P., & Barrera, V. H. (2002). El uso de plaguicidas en la producción de papa en Carchi. https://doi.org/10.32645/13906925.348

Cruz, J. F., Rodríguez, D. D., Benavides, A. C., & Clavijo, J. A. (2013). Caracterización de parámetros productivos y reproductivos de ganado Normando en Colombia. Archivos de zootecnia, 62(239), 345-356.https://dx.doi.org/10.4321/S0004-05922013000300003

Da Silva, S. C., & Carvalho, P. D. F. (2005). Foraging behaviour and herbage intake in the favourable tropics/sub-tropics. Grassland: a global resource. Wageningen: Wageningen Academic Publishers, 81-95.

de Córdoba, M. B. F., & Cruz, L. V. (2017). El ordenamiento territorial y el urbanismo en el Ecuador y su articulación competencial. https://recyt.fecyt.es/index.php/CyTET/article/view/76591

de Faccio Carvalho, P. C. (2013). Harry Stobbs Memorial Lecture: Can grazing behavior support innovations in grassland management?. Tropical Grasslands-Forrajes Tropicales, 1(2), 137-155. https://doi.org/10.17138/tgft(1)137-155

Delaby, L., Peyraud, J. L., Foucher, N., & Michel, G. (2003). The effect of two contrasting grazing managements and level of concentrate supplementation on the performance of grazing dairy cows. Animal Research, 52(5), 437–460. https://doi.org/10.1051/animres:2003030.

Espinosa, J. (1999). *Acidez y encalado de los suelos* (No. 631.42 E8A2).

Flores-Lesama, M., Hazard, L., Betin, M., & Emile, J. C. (2006). Differences in sward structure of ryegrass cultivars and impact on milk production of grazing dairy cows.

Animal Research, 55(1), 25–36. https://doi.org/10.1051/animres:2005044

Frias, M., Landi, H., Montes, D., & Parodi, F. P. (2011). Análisis comparativo de la salud y costo en el período vaca parida en rodeos lecheros. InVet, 13(2), 17-23. https://www.redalyc.org/pdf/1791/179122770003.pdf

Fulkerson, W.J. and Donaghy, D.J., 2001. Plant-soluble carbohydrate reserves and senescence-key criteria for developing an effective grazing management system for ryegrass-based pastures: a review. Australian journal of experimental agriculture, 41(2), pp.261-275. https://doi.org/10.1071/EA00062

Gaybor, A. (2008). El Despojo del Agua y la necesidad de una transformación urgente, Cuadernos Populares del Agua, Quito-Ecuador, Foro de los Recursos Hídricos. pp. 81.

Gibb, M. J., Rook, A. J., Huckle, C. A., & NuthalL, R. (1995, March). The e_ect of sward surface height on grazing behavior by lactating holstein-friesian cows. In: *Proceedings of the British Society of Animal Science*. Vol. 1995, pp. 26–26. https://doi.org/10.1017/S0308229600027951.

Gonçalves, E. N., Carvalho, P. C. D. F., Kunrath, T. R., Carassai, I. J., Bremm, C., & Fischer, V. (2009). Plant-animal relationships in pastoral heterogeneous environment: process of herbage intake. Revista Brasileira de Zootecnia, 38(9), 1655-1662. https://doi.org/10.1590/S1516-35982009000900003

Gonzales Aparicio, G. W., Gutiérrez Reynoso, G. A., Ponce de León, F. A., & Chauca Francia, D. (2020). Estudio hematológico de bovinos criollos y Brown Swiss criados en los Andes de Perú. Revista de Investigaciones Veterinarias del Perú, 31(4). http://dx.doi.org/10.15381/rivep.v31i4.19032

Grijalva, J., Espinosa, F., & Hidalgo, M. (1995). Producción y utilización de pastizales en la región interandina del Ecuador. INIAP Archivo Histórico.

Guapi Guamán, R. A., Masaquiza Moposita, D., & Curbelo Rodríguez, L. M. (2017). Caracterización de sistemas productivos lecheros en condiciones de montaña, Parroquia Químiag, Provincia Chimborazo, Ecuador. Revista de Producción Animal, 29(2), 14-24. http://scielo.sld.cu/scielo.php?pid=S2224-79202017000200003&script=sci_arttext&tlng=en

Guevara-Freire, D., Montero-Recalde, M., Rodríguez, A., Valle, L., & Avilés-Esquivel, D. (2019). Calidad de leche acopiada de pequeñas ganaderías de Cotopaxi, Ecuador. Revista de Investigaciones Veterinarias del Perú, 30(1), 247-255. http://www.scielo.org.pe/scielo.php?script=sci_arttext&pid=S1609-91172019000100025

Gutiérrez, F., Alcoser, R., Macías, G., Portilla, A., & Espinosa, J. (2017). Omisión de nutrientes y dosis de nitrógeno en la acumulación de biomasa, composición bromatológica y eficiencia de uso de nitrógeno de raigrás diploide perenne (Lolium perenne). *Siembra, 4*(1), 81-92. https://doi.org/10.29166/siembra.v4i1.503

Hixon, M. A. (1982). Energy maximizers and time minimizers: theory and reality. The American Naturalist, 119(4), 596-599.https://doi:10.1086/283937

Hodgson, J. (1985). The control of herbage intake in the grazing ruminant. *Proceedings of the Nutrition Society*, *44*(2), 339-346. https://doi.org/10.1079/PNS19850054

Holechek, J. L. (1988). An approach for setting the stocking rate. *Rangelands Archives*, *10*(1), 10-14.

Illius, A. W. & Gordon, I. J. (1991). Prediction of intake and digestion in ruminants by a model of rumen kinetics integrating animal size and plant characteristics. Journal of Agricultural Science, Cambridge 116, 145–157. https://doi.org/10.1017/S0021859600076255

Jacob, K. K., Radhika, G., & Aravindakshan, T. V. (2020). An in silico evaluation of non-synonymous single nucleotide polymorphisms of mastitis resistance genes in cattle. Animal biotechnology, 31(1), 25-31. https://doi.org/10.1080/10495398.2018.1524770

Johnstone-Wallace, D. B., & Kennedy, K. (1944). Grazing management practices and their relationship to the behaviour and grazing habits of cattle. The Journal of Agricultural Science, 34(4), 190-197. https://doi.org/10.1017/S0021859600023649

Kollmorgen, W. M., & Simonett, D. S. (1965). Grazing operations in the Flint Hills–bluestem pastures of Chase County, Kansas. Annals of the Association of American Geographers, 55(2), 260-290. https://doi.org/10.1111/j.1467-8306.1965.tb00518.x

Kong, Z., Zhou, C., Li, B., Jiao, J., Chen, L., Ren, A., ... & Tan, Z. (2019). Integrative plasma proteomic and microRNA analysis of Jersey cattle in response to high-altitude hypoxia. Journal of dairy science, 102(5), 4606-4618.https://doi.org/10.3168/jds.2018-15515

Kreuzer, M., Langhans, W., Sutter, F., Christen, R. E., Leuenberger, H., & Kunz, P. L. (1998). Metabolic response of early-lactating cows exposed to transport and high altitude grazing conditions. *Animal Science*, *67*(2), 237-248. https://doi.org/10.1017/S1357729800009991

Lachica, M., Prieto, C., & Aguilera, J. F. (1997). The energy costs of walking on the level and on negative and positive slopes in the Granadina goat (Capra hircus). British Journal of Nutrition, 77(1), 73-81. https://doi.org/10.1017/S0007114500002890

Larrea Izurieta, C. O., Hurtado, E. A., Macías Andrade, J. I., Vera Loor, L. E., & More Montoya, M. J. (2020). Estimación del valor genético predicho en bovinos lecheros mestizos en un hato en la sierra alta de Chimborazo, Ecuador. Revista de Investigaciones Veterinarias del Perú, 31(4). http://dx.doi.org/10.15381/rivep.v31i4.17519

León, R., Bonifaz, N., & Gutiérrez, F. (2018). Pastos y forrajes del Ecuador: *Siembra y producción de pasturas*.

Lopes, F., Coblentz, W., Hoffman, P. C., & Combs, D. K. (2013). Assessment of heifer grazing experience on short-term adaptation to pasture and performance as lactating cows. Journal of dairy science, 96(5), 3138-3152. https://doi.org/10.3168/jds.2012-6125

Macedo, M. C., Zimmer, A. H., Miranda, C., & Costa, F. P. (2005). Agropastoril production in no tillage systems in the cerrado. In *Workshop "Advances in improving acid soil adaptation of tropical crops and forages, and management of acid soils" Brasilia, Brasil. Resúmenes* (p. 9).

Marini, P. R., & Di Masso, R. J. (2019). Age at the first calving and efficiency indicators in dairy cows with different productive potential in grazing systems. La Granja, 29(1), 84. https://orcid.org/0000-0003-4873-5156

Marín Gómez, A., Bindelle, J., Zubieta, A., Correa, G., Arango, J., Chirinda, N. and De Faccio Carvalho, P.C., (2021). In vitro fermentation profile and methane production of Kikuyu grass harvested at different sward heights. Frontiers in Sustainable Food Systems, p.463. https://doi.org/10.3389/fsufs.2021.682653

Martínez, A. M., Bonjoch, N. P., & Palacio, J. A. (2003). *Siembra de praderas*. Serida.

Mezzalira, J.C., P.C. De Faccio Carvalho, L. Fonseca, C. Bremm, C. Cangiano, H.L. Gonda, and E.A. Laca. (2014). Behavioural mechanisms of intake rateby heifers grazing swards of contrasting structures. Appl. Anim. Behav. Sci. 153:1–9. https://doi:10.1016/j.applanim.2013.12.014

MIHAI, R., MIHALASCU, C., MĂRGINEAN, G. E., MARIN, M. P., CĂRĂTUȘ, M. A., & VIDU, L. (2019). The dynamics of milk production in Montbeliarde breed on a farm in southern Romania. Scientific Papers. Series D. Animal Science, 165-169. http://animalsciencejournal.usamv.ro/pdf/2019/issue_2/Art27.pdf

Ministerio de Agricultura, Ganadería, Acuacultura y Pesca. (2018). Acuerdo Interministerial N° 394. Quito. http://www.agrocalidad.gob.ec/documentos/dcz/acuerdo-394.pdf

Muñoz, C., Barros Henriquez, J., Cajas Girón, S., Martinez Atencio, J., Sánchez Vega, C., & Mateus Echeverría, H. M. (2018). Procesos tecnológicos para la renovación de praderas degradadas en las regiones Caribe y Valles Interandinos.

Muñoz, E. C., Andriamandroso, A. L. H., Blaise, Y., Ron, L., Montufar, C., Mafwila Kinkela, P., ... & Bindelle, J. (2020). How do management practices and farm structure impact productive performances of dairy cattle in the province of Pichincha, Ecuador.https://doi.org/10.17170/kobra-202010191971

Müller, B., Frank, K., & Wissel, C. (2007). Relevance of rest periods in non-equilibrium rangeland systems–a modelling analysis. Agricultural systems, 92(1-3), 295-317. https://doi.org/10.1016/j.agsy.2006.03.010

Nasser, L. F., Penteado, L., Rezende, C. R., Sá Filho, M. F., & Baruselli, P. S. (2011). Fixed time artificial insemination and embryo transfer programs in Brazil. *Acta Scientiae Veterinariae*, *39*(1), s15-s22. https://www.redalyc.org/pdf/2890/289060016003.pdf

Nebel, R., & DeJarnette, M. (2011). Anatomía y fisiología de la reproducción bovina. *SELECT SIRES INC*, *6*. https://www.produccion-animal.com.ar/informacion_tecnica/inseminacion_artificial/97-fisiologia.pdf

Paladines, O., & Leal, J. A. (1979). Manejo y productividad de las praderas en los Llanos Orientales de Colombia.

Paladines, O. (1992). Metodología de pastizales para trabajar en fincas y proyectos de desarrollo agropecuario (No. 32203 caja (439)). MAG, GTZ.

Parsons, A. J., Thornley, J. H., Newman, J., & Penning, P. D. (1994). A mechanistic model of some physical determinants of intake rate and diet selection in a two-species temperate grassland sward. Functional ecology, 187-204. https://doi.org/10.2307/2389902

Partridge, T. (2015). El páramo. AGUA: vida y agricultura, 8. https://www.leisa-al.org/web/images/stories/revistapdf/vol31n3.pdf#page=8

Pelouch, V., Kolář, F., Ošt'ádal, B., Milerova, M., Čihák, R., & Widimský, J. (1997). Regression of chronic hypoxia-induced pulmonary hypertension, right ventricular hypertrophy, and fibrosis: effect of enalapril. Cardiovascular drugs and therapy, 11(2), 177-185. https://doi.org/10.1023/A:1007788915732

Pérez, L. A. C. (2014). La asociatividad en el sector agropecuario del Carchi y su potencial de producir y comercializar semielaborados de papa y leche. SATHIRI, (7), 153-163. https://doi.org/10.32645/13906925.348

Pérez-Prieto, L. A., Peyraud, J. L., Delagarde, R. (2013). Does pre-grazing herbage mass really affect herbage intake and milk production of strip-grazing dairy cows? Grass and Forage Science, 68, 93–109. https://doi.org/10.1111/j.1365-2494.2012.00876.x

Portal Primicias. (2022). El precio de los agroquímicos, como la urea, se duplicó en el último año e incidió en la inflación que registraron los alimentos en enero de 2022. (Consulted 15/04/2022) https://www.primicias.ec/noticias/economia/aumento-precio-agroquimicos-urea-alimentos-ecuador/

Pulido, R. G., Balocchi, O., & Fernandez, J. (2001). Efecto del nivel de producción de leche sobre el comportamiento ingestivo en vacas lecheras en pastoreo primaveral. Archivos de Medicina Veterinaria, 33(2), 137-144. http://dx.doi.org/10.4067/S0301-732X2001000200002.

Quispe Coaquira, J., Belizario Quispe, C., Apaza Zúñiga, E., Maquera Marón, Z., & Quisocala Carita, V. (2016). Desempeño productivo de vacunos Brown Swiss en el altiplano peruano. *Revista de Investigaciones Altoandinas, 18*(4), 411-422. http://dx.doi.org/10.18271/ria.2016.216

Reategui, K., Aguirre, N., Oliva, R., & Aguirre, E. (2019). Presión de pastoreo sobre la disponibilidad de forraje Brachiaria decumbens. Scientia Agropecuaria, 10(2), 249-258. http://dx.doi.org/10.17268/sci.agropecu.2019.02.10

Requelme, N., & Bonifaz, N. (2012). Caracterización de sistemas de producción lechera de Ecuador. La Granja, 15(1), 55-69. https://doi.org/10.17163/lgr.n15.2012.05

Rivero, C. (1999). Efecto del uso de gallinaza sobre algunos parámetros de fertilidad química de dos suelos de pH contrastante. Rev. Fac. Agron.(Maracay), 25, 83-93. https://ci.nii.ac.jp/naid/10020226667/

Rojas Palomino, A., Madero Morales, E., Ramírez Náder, L. M., & Zúñiga Escobar, O. (2009). Índice de potencial productivo del suelo aplicado a tres fincas ganaderas de ladera en el Valle del Cauca, Colombia. Acta Agronómica, 58(2), 85-90. http://www.scielo.org.co/scielo.php?script=sci_arttext&pid=S0120-28122009000200004

Russell, J. E.; Russell, E. W. 1968. Condiciones del suelo y desarrollo de las plantas. 4ta ed. España: Aguilar. 434 p.

Sanabria, V. D., Manrique, U., Rodríguez, M., de Gil, A., & Argel, P. (1995). Siembra de leguminosas en un pastizal establecido de Brachiaria decumbens. *Zootecnia Trop.,(13),* 2, 245-260.

Sanabria, D., Silva-Acuña, R., & Marcano, M. (2006). Evaluación de tres sistemas de labranza en la recuperación de una pastura degradada de Brachiaria humidicola. Evaluation, 24(4).

Schoener, T. W. (1971). Theory of feeding strategies. Annual review of ecology and systematics, 2(1), 369-404. https://doi:10.1146/annurev.es.02.110171.002101

Schmitt, D., Padilha, D. A., Medeiros-Neto, C., Ribeiro Filho, H. M. N., Sollenberger, L. E., & Sbrissia, A. F. (2019). Herbage intake by cattle in kikuyugrass pastures under intermittent stocking method. Revista Ciência Agronômica, 50(3), 493-501.DOI: 10.5935/1806-6690.20190058

Silva, G. P., Fialho, C. A., Carvalho, L. R., Fonseca, L., Carvalho, P. C. F., Bremm, C., & Da Silva, S. C. (2018). Sward structure and short-term herbage intake in Arachis pintoi cv. Belmonte subjected to varying intensities of grazing. The Journal of Agricultural Science, 156(1), 92-99. https://doi.org/10.1017/S0021859617000855

Soares, F. C. V., Monteriro, A. F., & Corsi, M. (1992). Recuperação de pastagens degradadas de Brachiaria decumbens. 1. Efeito de diferentes tratamentos de fertilização e manejo. Pasturas Trop, 14(2), 2-6.

Stevenson, J. L., Rodrigues, J. A., Braga, F. A., Bitente, S., Dalton, J. C., Santos, J. E. P., & Chebel, R. C. (2008). Effect of breeding protocols and reproductive tract score on reproductive performance of dairy heifers and economic outcome of breeding programs. *Journal of dairy science*, *91*(9), 3424-3438. https://doi.org/10.3168/jds.2007-0804

Tamayo, T. M. (2019). El sistema educativo de Ecuador: un sistema, dos mundos. Revista Andina de Educación, 2(1), 8-17. https://doi.org/10.32719/26312816.2019.2.1.2

Tharmaraj, J., Wales, W. J., Chapman, D. F., & Egan, A. R. (2003). Defoliation pattern, foraging behaviour and diet selection by lactating dairy cows in response to sward height and herbage allowance of a ryegrass-dominated pasture. Grass and Forage Science, 58(3), 225-238. https://doi.org/10.1046/j.1365-2494.2003.00374.x

Thompson-Crispi, K., Atalla, H., Miglior, F., & Mallard, B. A. (2014). Bovine mastitis: frontiers in immunogenetics. Frontiers in Immunology, 5, 493.https://doi.org/10.3389/fimmu.2014.00493

Toalombo, P. A., Almeida, F. A., Diaz, H., & Trujillo, J. V. (2019). Estudio de las correlaciones entre valores genéticos de producción–reproducción y tipo de los toros Jersey en Ecuador. Archivos de zootecnia, 68(264), 588-593.https://doi.org/10.21071/az.v68i264.5000

Torres, Y., Rivas, J., Pablos-Heredero, D., Perea, J., Toro-Mujica, P., Angón, E., & García, A. (2014). Identificación e implementación de paquetes tecnológicos en ganadería vacuna de doble propósito: Caso Manabí-Ecuador. Revista mexicana de ciencias pecuarias, 5(4), 393-407. http://www.scielo.org.mx/scielo.php?pid=S2007112420140004000002&script=sci_arttext

Ungar E.D. (1996). Ingestive behaviour. In: Hodgson J. and Illius A.W. (eds) The ecology and management of grazing systems, pp. 185–218. Wallingford: CAB international.

Vavra, M., & Ganskopp, D. (1987). Slope use by cattle, feral horses, deer, and bighorn sheep.

White, S. L., Sheffield, R. E., Washburn, S. P., King, L. D., & Green Jr, J. T. (2001). Spatial and time distribution of dairy cattle excreta in an intensive pasture system. Journal of environmental quality, 30(6), 2180-2187. https://doi.org/10.2134/jeq2001.2180

Zapatta, A. (2006). Cotopaxi: dinámicas agrarias y modificación de las condiciones agro ecológicas.

Zubieta, A. S., Marín, A., Savian, J. V., Bolzan, A. M. S., Rossetto, J., Barreto, M. T., ... & Carvalho, P. C. D. F. (2021). Low-intensity, high-frequency grazing positively affects defoliating behavior, nutrient intake and blood indicators of nutrition and stress in sheep. Frontiers in Veterinary Science, 8. http://doi: 10.3389/fvets.2021.631820

Publications and conference abstracts

Accepted publications (peer-reviewed)

Muñoz, E. C., Andriamandroso, A. L. H., Blaise, Y., Ron, L., Montufar, C., Mafwila Kinkela, P., Lebeau, F., & Bindelle, J. (2020). How do management practices and farm structure impact productive performances of dairy cattle in the province of Pichincha, Ecuador. *Journal of Agriculture and Rural Development in the Tropics and Subtropics* (JARTS), 121(2), 233-241.

Muñoz, E. C., Andriamandroso, A. L. H., Beckers, Y., Ron, L., Montufar, C., da Silva Neto, G. F., Borja, J., Lebeau F., & Bindelle, J. (2021). Analysis of the nutritional and productive behaviour of dairy cows under three rotation bands of pastures, Pichincha, Ecuador. *Journal of Agriculture and Rural Development in the Tropics and Subtropics* (JARTS), 122(2), 289-298.

Submitted

Muñoz, E. C., Andriamandroso, A. L. H., Beckers, Y., Montufar, C., da Silva Neto, G. F., Borja, J., Lebeau F., & Bindelle, J. (under review). Evaluation of the productive behavior of dairy cows grazing on paddocks with a moderate slope with two different rotation methods. Submitted to Journal of Agriculture and Rural Development in the Tropics and Subtropics (JARTS)

Poster presentations at international conferences (peer-reviewed)

Andriamandroso, A *., Castro Muñoz, E., Blaise, Y., Bindelle, J., & Lebeau, F. (2017). Differentiating pre-and post-grazing pasture heights using a 3D camera: a prospective approach. Oral presented at: *Precision Livestock Farming* '17, 238-246.

Blaise, Y *., Andriamandroso, A., Heinesch, B., Beckers, Y., Castro Muñoz, E., Lebeau, F., & Bindelle, J. (2017). Influences of feeding behaviour and forage quality on diurnal methane emission dynamics of grazing cows. 2017). Oral presented at: *Precision Livestock Farming* '17, 759-769.

Castro Muñoz E *., Andriamandroso, A., Blaise, Y., Ron, L., Montufar, C., Lebeau, F., & Bindelle, J. (2018). Characterization of productive management in dairy farms, Pichincha, Ecuador. Oral presented at: *1 rs International Congress of Agricultural Science and Technology*, Quito, Ecuador.

Castro Muñoz E *., Andriamandroso, A., Blaise, Y., Ron, L., Montufar, C., Lebeau, F., & Bindelle, J. (2019). Analysis of the productive behavior of dairy cows under three types of pasture rotation in Tumbaco, Pichincha. Oral presented at: 7th *REDU Yachay Tech University, Ibarra, Ecuador*, 11-15 November 2019.

Castro Muñoz E *., Andriamandroso, A., Artos, D., Pinto, G., Ron, L., Montufar, C., Lebeau, F., & Bindelle, J. (2019).Feeding behavior of dairy cows under three types of pasture rotation. Poster presented at: 7th REDU Yachay Tech University, Ibarra, Ecuador, 11-15 November 2019.

Castro Muñoz, E *., Da Silva Neto, G. F., Andriamandroso, H. A., Ron, L., Montufar, C., Debauche, O., & Lebeau, F. (2020, December). Influence of paddock occupation time on the grazing activity of dairy cows in rotational systems. *In Book of Abstracts of the 71st Annual Meeting of the European Federation of Animal Science* (p. 322). Wageningen Academic Publishers.

Castro Muñoz, E *., Da Silva Neto, G. F., Andriamandroso, H. A., Ron, L., Montufar, C., Lebeau, F., & Bindelle, J. (2021). Evaluation of the ingestive behaviour of the dairy cow under two systems of rotation with slope. *In Book of Abstracts of the 72st Annual Meeting of the European Federation of Animal Science* (p. 615). Wageningen Academic Publishers.

* Speaker

APPENDIX

Apendix 1, Survey Questionnaire

ESTUDIO DE CASO	**Nro.**	**Fecha**

DATOS DEL GANADERO			
Nombre			
Nivel de Educación		Edad	

DATOS DE LA PROPIEDAD			**PARROQUIA**	**CANTÓN**	**PROVINCIA**
Nombre					
Extensión m2	Propio ( )	Arrienda ( )	Otro ( )		

MANO DE OBRA FAMILIAR		**A.AGRÍCOLA**	**NO AGRÍCOLA**	**TIEMPO**	**EDAD**
Cónyuge					
Hijo 1					
Hijo 2					
Hijo 3					

MANO DE OBRA EXTERNA EMPLEADOS No	
Hombre ( )	
Mujer ( )	
Matrimonio ( )	

CRIANZA ANIMALES						
Ganado Leche	**Número**	**RAZA**	**BALANCEADO/kg**	**SALES/kg/día**	**COMPRA/ÉPOCA**	**VENTA/ÉPOCA**
Terneros						
Terneras						
Vacona Media						
Vacona Fierro						
Vacona Vientre						
Vaca Producción						
Vaca Seca						
Toro						

PRODUCCIÓN DE LECHE		**ÉPOCA DE VERANO**	**ÉPOCA DE INVIERNO**
Producción lt/día			
Promedio lt/vaca/día			
Total Producción Anual			
Ordeño Manual ( ) Mecánico ( )			

PASTOS			
Hectáreas No ( )	Pendientes de Inclinación % ( )	Tiempo de Descanso/días ( )	

PASTOREO CONTROLADO						
Estacional ( )	Rotación ( )	Cerca Eléctrica ( )	Corte ( )	Sogueo ( )	Estabulado ( )	Semiestabulado ( )

MEZCLA FORRAJERA						
Natural ( )	Introducido ( )	Anual ( )	Bianual ( )	Perenne ( )	Otros ( )	mezcla de forraj

PROCEDIMIENTOS DE LABRANZA POTREROS					
	VERANO	**INVIERNO**	**ANUAL**	**BIANUAL**	**OTROS**
Siembra					
Resiembra					
Cortes de Igualación					
Aireación					
Dispersión de Heces					

MÉTODOS DE CONSERVACIÓN DE FORRAJE					
Ensilaje ( ) solo de maiz	Henolaje ( )	Pacas ( )	Fardos ( )	Otros ( )	pasto Natural fresco

RIEGO					
Lluvia ( )	Reservorio ( )	Goteo ( )	Acéquia ( )	Inundación( )	Aspersión ( )

FERTILIZACIÓN				
Análisis de Suelo ( )		Química ( )	Orgánica ( )	Biológica ( )

EQUIPOS, HERRAMIENTAS Y SERVICIOS						
Herramientas ( )	Tractor ( )	Bomba Fumigar ( )	Equipo riego ( )	Arados ( )	Ing. Agrónomo( )	Dr. Veterinario( )

INSTALACIONES					
Cuyera ( )	Conejera ( )	Chanchera ( )	Establo caballos ( )	Galpón Pollos ( )	Hidropónico ( )

De acuerdo a su experiencia, ¿Cuáles son los principales problemas que enfrenta a lo largo del año en cuanto al manejo de recursos forrajeros?

¿En qué porcentaje afectan estos problemas, anualmente a su producción de forraje?

Apendix 2, Supplementary data

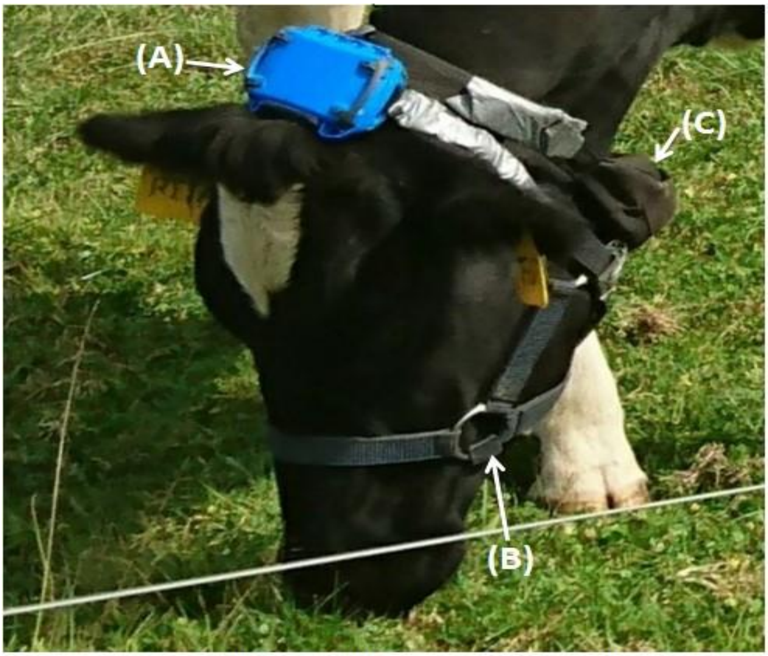
Supplementary Data (Annex to the Chapter 3 and 4): Program code and procedure for cattle grazing behaviors detection using data collected from iPhone 5S inertial measurement unit (IMU) under MatLab

```
function [output]=icowdetector_2020 (imu_useful, fs)%Fixed
data
%fs=100;sampling frequency of the IMU (100Hz)
global window
window = 1*fs; %window size
[b,a]=butter(2,[1/(fs/2) 4/(fs/2)],'bandpass'); %filter
design to allow frequencies between 1Hz and 4Hz pass.
 %List of signals thresholds for the behavior detection:
 %mGx: mean of gravitational acceleration on x-axis
 %sGx: standard deviation of gravitational acceleration on
 x-axis
 %sRx: standard deviation of rotation rate on x-axis
 %sRy: standard deviation of rotation rate on y-axis
 %mingraze and maxgraze: minimum and maximum thresholds for
 grazing
 %minrum and maxrum: minimum and maximum thresholds for
 ruminating.
mGx_maxgraze=0.95;
mGx_mingraze=0.6;
mGx_maxrum=0.4905;
mGx_minrum=0.1;
sGx_maxgraze=0.06;
sGx_mingraze=0.0052;
sGx_maxrum=0.0176;
sGx_minrum=0.0025;
sRx_maxgraze=0.7933;
sRx_mingraze=0.1336;
sRx_maxrum=0.1851;
sRx_minrum=0.032;
sRy_maxgraze=0.7337;
sRy_mingraze=0.1156;
sRy_maxrum=0.1445;
sRy_minrum=0.025;

%List of parameters of interest for the detection
Gx=imu_useful(:,1); %gravitational acceleration on x axis
Rx=imu_useful(:,2); % rotation rate on x axis
Ry=imu_useful(:,3); %rotation rate on y axis
detection_parameters=[Gx Rx Ry];

%Variable initialization
```

```
norm_Gx = [];%normalized gravitational acceleration on x-
axis
mGx = [];%normalized mean of gravitational acceleration on
x-axis
sGx = [];%normalized standard deviation of gravitational
acceleration on x-axis
fRx = [];%filtered rotation rate on x-axis
fRy = [];%filtered rotation rate on y-axis
sRx = [];%standard deviation of filtered rotation rate on z-
axis
sRy = [];%standard deviation of filtered rotation rate on y-
axis

%Variable pre-processing
norm_Gx = normalize_var(Gx,0,1);
fRx = filter(b,a,Rx);
fRy = filter(b,a,Ry);

%Mean and standard deviation calculation
mGx=calculate_mean(norm_Gx,window);
sGx=calculate_std(norm_Gx,window);
sRx=calculate_std(fRx,window);
sRy=calculate_std(fRy,window);

%mGxsGxsRx is the signals combination giving the best
detection accuracies.
%The algorithm is a simple Boolean algorithm in the respect
to the
%thresholds mentioned previously.

detected_behaviors =[];%Matrix of detected behaviors at 1Hz
frequency
for n=1:length(mGx);
    if mGx(n,1)<=mGx_maxgraze && mGx(n,1)>=mGx_mingraze &&
sGx(n,1)<=sGx_maxgraze && sGx(n,1)>=sGx_mingraze &&
sRx(n,1)<=sRx_maxgraze && sRx(n,1)>=sRx_mingraze;
        detected_behaviors(n,1)=1;%behaviour is grazing
        detected_behaviors(n,2)=0;
        detected_behaviors(n,3)=0;
    elseif mGx(n,1)<mGx_maxrum && mGx(n,1)>=mGx_minrum &&
sGx(n,1)<=sGx_maxrum && sGx(n,1)>=sGx_minrum &&
sRx(n,1)<=sRx_maxrum && sRx(n,1)>=sRx_minrum;
        detected_behaviors(n,2)=1;%behaviour is rumination
        detected_behaviors(n,1)=0;
        detected_behaviors(n,3)=0;
    else detected_behaviors(n,3)=1;%behaviour is others
        detected_behaviors(n,1)=0;
        detected_behaviors(n,2)=0;
```

```
    end
end
%Avoid ruminating and grazing behaviors which duration is
less than 2s
for n=2:length(detected_behaviors)-1;
    if detected_behaviors(n,2)==1;
        if detected_behaviors(n-1,2)~=1 &&
detected_behaviors(n+1,2)~=1;
            detected_behaviors(n,3)=1;
            detected_behaviors(n,2)=0;
        end
    end
end
for n=2:length(detected_behaviors)-1;
    if detected_behaviors(n,1)==1;
        if detected_behaviors(n-1,1)~=1 &&
detected_behaviors(n+1,1)~=1;
            detected_behaviors(n,3)=1;
            detected_behaviors(n,1)=0;
        end
    end
end
for n=2:length(detected_behaviors)-1;
    if detected_behaviors(n,1)==1;
        if detected_behaviors(n-1,1)~=1 &&
detected_behaviors(n+1,1)~=1;
            detected_behaviors(n,3)=1;
            detected_behaviors(n,1)=0;
        end
    end
end
%detection of meals i.e. grazing with interuptions <5min

meal=zeros (length(detected_behaviors),1);
if length(detected_behaviors)<300
    disp = ('error: recording too short (<5 min) to measure
meals')
else for n=1:length(detected_behaviors)-300;
        for i=1:300
            if detected_behaviors(n+i,1)==1;
            meal(n,1)=1;
            end
        end
     end
end
output = [detected_behaviors meal];
end
```

Apendix 3, Pictures of the thesis process



(A) Otterbox contains the iPhone; (B) Halter; (C) Bag that it contains of the supplementary battery

Photo 1. Sensors located in the center of the head, powered by long-lasting external batteries

Photo 2. Cow sampled at the time of rumination

Photo 3. Paddock with a slope

Photo 4. Milk samples for quality tests

Photo 5. Smart phone used with the Sensor Data app

Photo 6. Sampled cows grazing in flat paddocks

Photo 7. The height of the grass we take in a 30 × 30 cm² quadrant with a rising plate meter

Photo 8. Sampling of fresh matter within the quadrant

Photo 9. Record of production of each cow with the help of individual aluminum drums and a decaliter.

Photo 10. Fresh grass samples to determine dry matter after oven drying.