Journal of Agriculture and Rural Development in the Tropics and Subtropics
Vol. 121 No. 2 (2020) 233–241
https://doi.org/10.17170/kobra-202010191971 ISSN: 2363-6033 (online); 1612-9830 (print) – website: www.jarts.info

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

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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 grazing 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 grass-

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Published online: 11 November 2020 – Received: 26 August 2019 – Accepted: 14 August 2020

lands as socio-ecological systems that generate, beyond tangible provisioning services, jobs such as those related with the maintenance of the grasslands (Varela & Robles-Cruz 2016), and turning the Ecuadorian páramo grasslands into compensation centres destined to preserve hydrological services and carbon sequestration (Farley & Harden 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 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.*, 2014; Martínez-García *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 characterised by a strong volatility in prices (Popescu, 2017; Schulte *et al.*, 2018). This puts farmers, especially smallholders, 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), which confirms the importance of this sector in this part of the world in terms of land occupation (Gerssen-Gondelach *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 *et al.*, 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 grazing (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 *et al.*, 2011). For example, continuous grazing allows for stronger selectivity of animals than rotational grazing 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 extent the forage production season (Boserup, 2017), the resowing of pasture as well as the choice of pasture species (Chapman & Norriss, 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 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, 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 Páramos 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; MAGAP, 2016).

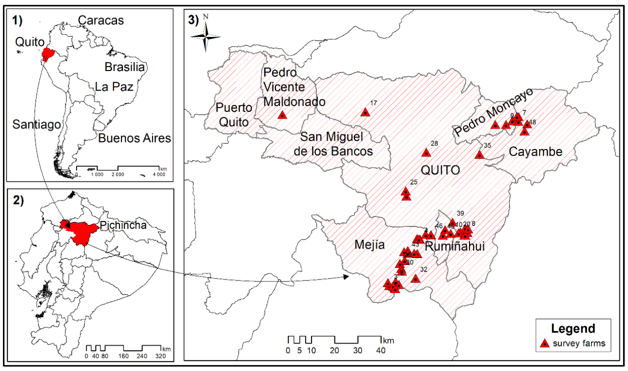

Fig. 1: *1) Location in South America, country Ecuador, 2) of the Pichincha province 3) and location surveyed farms.*

A list of all commercial dairy farms found in the Pichincha province was obtained from the undersecretary of Agroquality 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 %.

2.2 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 (Apollin & 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 paddock, resting time, pasture management, type of rotation, etc.). In addition, the milking parlour of the investigated farms was geolocated (Fig. 1) and information about the average slope of the pastures of the farms was collected from the GIS database of MAGAP (2017).

2.3 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 chi-square 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.

3 Results

3.1 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*)

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

in variable proportions. Likewise, some paddocks on some farms were sown with forage oats (*Avena sativa*) and vetch (*Vicia* sp.).

3.2 *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 ($p = 0.945$).

3.3 *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 grazing method is almost nonexistent over the whole area where almost all dairy farmers of the Province use some kind of rotational grazing, with a significant part using a movable

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

	Cayambe	*Mejía*	*Quito*	*Rumiñahui*	*P-value*[†]
Number of paddocks	$8.8^b \pm 8.0$	$26.4^a \pm 15.3$	$24.6^a \pm 18.9$	$30.0^a \pm 44.71$	0.035
Slope of pastures (mean %)	$12.5^b \pm 5.5$	$15.4^b \pm 13.1$	$26.1^a \pm 15.8$	$31.1^a \pm 17.2$	0.046
Cut and carry*	40	15	3.8	0	0.41
Vegetation resting time in rotational grazing (days)	45.0 ± 20.8	45.0 ± 12.0	45.0 ± 10.2	45.0 ± 12.2	0.17
Grazing 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

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.

4 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 grazing 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 Guaman & 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 & 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 grazing displayed the lowest average milk production per cow ($10.0\,\mathrm{kg\,d^{-1}}, p = 0.026$). In contrast, among the farms using rotational grazing, 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 Muñoz & Valarezo 2015; Balarezo *et al.*, 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, 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 grazing 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).

5 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 in dairy cows. The pasture management applied by most dairy farmers in the Ecuadorian Sierra based on rotational grazing with very short occupation times by means of a mobile electric fence seems relevant to maximize forage 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 grazing 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.

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 they have no conflict of interest.

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