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

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Abstract

This research was carried out on *Pennisetum clandestinum*-based pastures to identify the effect of three (3) types of stocking methods with similar forage allowance (8.2 kg of dry matter for 100 kg of live weight) but differing by the occupation times of the rotations (3 h, 24 h, and continuous) on the behaviour and the production of dairy cows. The experimental scheme consisted in three herds of four Holstein Friesian cows grazing three paddocks, one per rotation type, 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 continuous treatment spent more time in meals and tended to have higher average speed during the day than in the 3-h rotation ascribed to a higher exploration of the whole gradable area every day in the continuous treatment and to more time idling animals in the 3-h 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 stocking method 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 vol-

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canic 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 grazing 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 grazing 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 grazing 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 grazing method would improve the performances of the system and we designed an experiment to compare the behaviour and production of dairy cows grazing in three types of pasture rotation differing in their grazing time (continuous, 24 h and 3 h).

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 asl.

The rainfall during the experiment was below the 10-year average (Table 1), with very low precipitation levels recorded in March (−8 %), April (−59 %), and May (−11.7 %). Average daily temperatures were (0.2 °C) degrees 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 1: *Temperature and rainfall data during the experimental period and mean data for the average of the previous 10-year at "La Tola" CADET.*

	Period	*March*	*April*	*May*
Rainfall (mm)	2018	114	86	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 approx. 30 days to reach the desired biomass (Leach *et al.*, 2000). The experimental pasture was divided in three (3) paddocks each provided similar forage allowance, one per grazing method: (continuous) grazing with seven (7) days of grazing time; medium rotation grazing (daily) with a 24-hour grazing time; and short-term rotation grazing (hours) with a 3-h grazing time. Hence, the paddock in the medium rotation grazing treatment was divided into seven (7) 600-m^2 sub-paddocks, where the animals assigned to this treatment grazed for 24 hours. Similarly, the paddock of the short rotation grazing treatment was subdivided into 28 strips of 150 m^2. Animals were allowed to graze a new strip every 3-h 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-m² was made available to the animals. In the case of the continuous grazing treatment, the assigned cows remained in the entire area of 4200 m^2 (42 m × 100 m) without restriction during the 7 days that each phase lasted. In all three (3) grazing treatments, the first two (2) days were used as habituation period for the animals to the new paddock and grazing method. The next five (5) 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 (3) times so that all cows and paddocks could undergo all treatments.

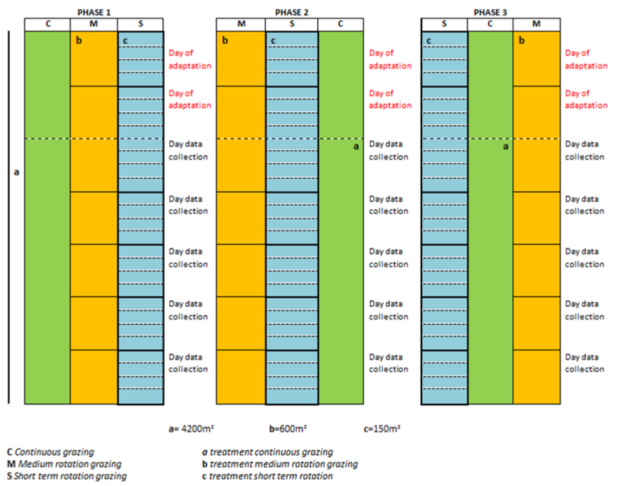

Fig. 1: *Distribution scheme of the three grazing rotation methods: (continuous) grazing with seven (7) days of grazing time; medium rotation grazing (daily) with a 24-hour grazing time; and short-term rotation grazing (hours) with a 3-h grazing time, in the three phases of the experiment.*

2.2 Animals

A total of twelve (12) Holstein Friesian cows of 3.8-year-old on average were used of which six (6) cows (two 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) 30 cm × 30 cm quadrats distributed along a fixed grid per paddock, in correspondence with the daily advance per treatment. Five (5) turf heights per quadrat were taken and averaged. In addition, to determine the availability of pasture and consumption, four (4) 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 × 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 1-s time windows. Using information on grazing, periods of meals were calculated as recommended by Gibb (1998): "periods of meals are sequences of

Table 2: *Biomass and sward heights (N = 90) and total stocking in the three stocking treatments (N = 9) (3-hourly rotation, daily rotation, continuous stocking) across the three experimental periods.*

	Treatments					Variance parameter estimates	
Item	*Hourly*	*Daily*	*Continuous*	*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.

grazing events and interruptions between two (2) consecutive grazing events as long as these interruptions do not last longer that five (5) 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, T_i 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:

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

where Y is the result, α the mean, T_i the fixed effect of the treatment (i varies from 1 to 3), P_j 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, T_i the fixed effect of the treatment (i varies from 1 to 3), P_j the random effect of the period (j varies from 1 to 3), C_k 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 2 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 continuous treatment than the two rotational treatments.

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 3).

3.3 Animal behaviour and performance

Continuous rotation expresses a higher percentage of time devoted to meals during the day, showing significant differences in relation to daily and hourly treatments (Table 4). The percentage of time devoted to grazing shows more activity per animal in the continuous treatment (+18 %) compared to the hourly treatment, and (+ 8 %) compared to the daily treatment (p = 0.027). Differences were also observed in the time devoted to rumination, where cows in the hourly 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 continuous treatment being the one that reflects the greatest distance (+ 443 m / d) as compared to the general mean. Further, animals in the hourly 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

Table 3: *Chemical composition of grass before grazing in the three stocking treatments (3-hourly rotation, daily rotation, continuous stocking) across the three experimental periods (N = 12).*

	Treatments					*Variance parameter estimates*	
Item	*Hourly*	*Daily*	*Continuous*	*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

$^{a\text{˜}b}$ 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 4: *Behaviour of dairy cows in the three stocking treatments (3-hourly rotation, daily rotation, continuous stocking) across the three experimental periods (N = 30).*

	Treatments					*Variance parameter estimates*		
Item	*Hourly*	*Daily*	*Continuous*	*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}	66^{a}	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	8.755E6
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

$^{a\text{˜}b}$ 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

hourly treatment covered the lowest distance. Interestingly, the speed of the animal was not different during the meals (P = 0.156).

The milk production shown in Table 5 does not present significant differences between the pasture rotation systems ($p > 0.05$), neither in quantity nor in quality. Nevertheless, a numerical increase of 0.5 kg of milk per cow per day was

Table 5: *Milk production of dairy cows grazing the three stocking treatments (3-hourly rotation, daily rotation, continuous stocking) across the three experimental periods (N = 18).*

	Treatments					*Variance parameter estimates*		
Item	*Hourly*	*Daily*	*Continuous*	*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

$^{a\text{˜}b}$ Means within a row with different superscripts differ ($P < 0.05$). SEM (standard error of the mean).

observed when passing from the continuous to the hourly rotation.

4 Discussion

The objective of this study has been to determine the effect of three types of pasture rotation on the productive behaviour of dairy cows in terms of pasture consumption and its impact on grazing time. 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 intersting management practice for optimal use of grasslands and efficient 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 continuous grazing 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 (3) treatments as confirmed by the similar chemical composition (Table 3). The results showed a higher percentage of meal in the time budget of the cows in the continuous and daily rotations compared to the hourly 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 treatment with hourly rotation showed the highest defoliation intensity with 39 %, the daily stoking rate showed 38 % and the continuous 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 hourly stocking, 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 daily and hourly rotation system consumed the lower layers of vegetation somewhat more, increasing the intensity of defoliation in these treatments (Gregorini *et al.*, 2009 and Benvenutti *et al.*, 2016).

The ruminating percentage showed a longer period of time for the cows that grazed in the hourly rotation, in relation to the continuous treatment. In this same order, the speed shown by the movement of dairy cows in the continuous treatment was greater than those that grazed in hourly and daily treatments. We believe that this behaviour was favoured by the freedom of movement of the cows in the continuous treatment that encouraged the exploration of the whole area, inducing higher speeds. In the hourly rotation, 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 daily rotation. 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 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 hourly 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-h 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 pasture rotation systems with milk production, we found no significant differences between the treatments. This is possibly because our cows were relatively low producing animals (12 kg of milk per day on average). However, the numerical increase we saw with the rotations with shorter occupation times are in line with the results obtained by Delaby *et al.* (2003), Flores-Lesama *et al.* (2006) and Pérez-Prieto *et al.* (2013) when they point out that the allocation of forages that coincides with the high intensity of consumption, based on a more intense rotational grazing management, could contribute to higher volumes of milk production. The same trend for the hourly rotation system is observed when it comes to milk composition although once more, those results are far from significant.

5 Conclusions

Under a moderate intensity of pasture management, intermediate forage allowance, the grazing method does not influence the productive performance of low producing dairy cows. A greater restriction of the grazing area increases the intensity of defoliation, overcoming 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 short-term occupation times.

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Conflict of interest

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

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