# 'Rotatinuous' stocking as a climate-smart grazing management strategy for sheep production

Jean Víctor Savian[a,b,*], Radael Marinho Tres Schons[a], William de Souza Filho[a], Angel Sánchez Zubieta[a], Liris Kindlein[c], Jérôme Bindelle[d], Cimélio Bayer[e], Carolina Bremm[a], Paulo César de Faccio Carvalho[a]

[a] Grazing Ecology Research Group, Federal University of Rio Grande do Sul, Porto Alegre, Brazil

[b] Instituto Nacional de Investigación Agropecuaria (INIA). Programa Pasturas y Forrajes. Estación Experimental INIA Treinta y Tres. Ruta 8 km 281, Treinta y Tres, Uruguay

[c] Department of Preventive Veterinary Medicine, Federal University of Rio Grande do Sul, Porto Alegre, Brazil

[d] Precision Livestock and Nutrition Unit, Gembloux Agro-Bio Tech, TERRA, Teaching and Research Centre, University of Liège, Gembloux, Belgium

[e] Department of Soil Science, Federal University of Rio Grande Do Sul, Porto Alegre, RS, Brazil

* Corresponding author: INIA-Treinta y Tres, Ruta 8, Km 282, CP 33000, Treinta y Tres, Uruguay.

*E-mail address*: jvsavian@gmail.com (J.V. Savian).

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**Abstract**

We aimed to evaluate the effect of different grazing management strategies on carcass characteristics traits, meat quality and $CH_4$ intensity and yield of lambs grazing Italian ryegrass pastures in Southern Brazil. A grazing trial was performed (2014 and 2015) in a randomized complete block design with two grazing management targets and four replicates. Treatments were traditional rotational stocking (RT), with pre- and post-grazing sward heights of 25 and 5 cm, respectively, and 'Rotatinuous' stocking (RN), with pre- and post-grazing sward heights of 18 and 11 cm, respectively. Castrated crossbred Texel and Polwarth lambs were used. Results indicated that diet cost per kg of dry matter ($p$ = 0.001) and per hectare ($p$ < 0.001) were lower for RN than for RT treatment. Final live weight ($p$ = 0.022) and hot and cold carcass weight ($p$ = 0.006) were greater for the RN treatment. All commercial cuts were greater for RN than for RT treatment. The RN treatment presented greater ($p$ < 0.001) production of carcass, edible food and crude protein. Feed efficiency and feed cost conversion were better for RN than for RT treatment.

$CH_4$ intensity per kg of carcass, edible food and crude protein gain were 2.6, 2.7 and 2.1 times lower ($p < 0.001$) for RN. Moreover, $CH_4$ yield was lower ($p = 0.014$) for RN than for RT treatment, with an average of 7.6 and 8.3% of the gross energy intake, respectively. We conclude that the 'Rotatinuous' stocking results in a greater carcass production, carcass quality and lower diet cost, and $CH_4$ intensity and yield of grazing lambs. Adopting this grazing management strategy could enhance both lamb production and mitigation of $CH_4$ intensity and yield in grazing ecosystems, which could be considered a good example of climate-smart livestock production.

Keywords: lamb carcass, food production, greenhouse gases, rotational stocking, methane intensity, sward management

## 1. **Introduction**

Climate change has important consequences for global agriculture production (Lipper et al., 2014). Extreme weather events, water shortages, land degradation, the disruption of ecosystems and loss of biodiversity can be expected (FAO, 2016) while agriculture systems can be significant drivers of climate change (Springmann et al., 2018).

Livestock holds the largest share in agricultural greenhouse gas (GHG) emissions, mainly because of $CH_4$ emissions from enteric fermentation of ruminants (Gerber et al., 2013; Herrero et al., 2016). At the same time, livestock products largely contribute to human feeding (Gaughan et al., 2018), which in turn is increasing (FAO, 2017) with projection around 9.8 billion people by 2050. This scenario will drive greater demand for animal protein (Eisler et al., 2014) and could increase global $CH_4$ emissions from livestock (IPCC, 2014). Considering that most ruminants in the world are raised in pasture-based or mixed systems, a strong emphasis must be oriented in understanding how grazing practices can impact GHG emissions, food production, biodiversity, carbon sequestration in the soils (Godde et al., 2018) and animal welfare (Llonch et al., 2017). Therefore, the challenge is developing strategies to reduce livestock's carbon footprint while increasing food production (Godfray et al., 2010).

Climate-smart approaches are proposed to achieve these goals under a global climate change scenario (Lipper et al., 2014).Henry et al. (2018) pointed out that some of the negative consequences of ruminant livestock production can be mitigated through adaptive management with improvements in animal nutrition. Many studies regarding grazing management strategies to mitigate GHG emission focus on the plant component and its ability to store carbon in the soil (Smith, 2014; Henderson et al., 2015; de la Motte et al., 2018). However, sustainable food production must also consider the ability of the animal to perform well in the grazed environment. Hence, climate-smart grazing practices should aim to maintain production levels with a reduced herd size (Herrero et al., 2016), which is possible with well-managed pastures under moderate grazing intensity (Souza Filho et al., 2019; Kunrath et al., 2020).

In this way, an innovative grazing management strategy would conciliate the trade-off of producing more animal products with fewer animals. One way to this appease was proposed by Carvalho (2013). The grazing management called 'Rotatinuous' stocking is based on optimum sward structure aiming to minimize the time required to achieve animals' requirements at grazing (Carvalho, 2013). It results in lower stocking rates and moderate grazing intensities, as well as greater herbage intake (i.e. animal performance) and short resting periods because of greater post-grazing sward mass. This is the opposite of the traditional rotational grazing management oriented to maximize plant growth and forage utilization efficiency by animals. In this way, Savian et al. (2018) applied ‘Rotatinuous’ stocking and reported increased in herbage intake and decreased in $CH_4$ emissions by grazing sheep by 1.6 times per area and 2.7 times per kg of live weight (LW) gain, respectively. Similarly, Souza Filho et al. (2019) working with temperate black-oat and Italian ryegrass mixed pastures in southern Brazil found greater animal LW gain with lower $CH_4$ intensity (g $CH_4$/kg LW gain).

Therefore, we hypothesized that the ‘Rotatinuous’ stocking (RN) aiming to maximize herbage intake per unit of time through offering the best sward structure results in greater carcass production, commercial cuts, meat quality and lower diet cost, carcass $CH_4$ intensity and yield of lambs grazing Italian ryegrass (*Lolium multiflorum*) pastures than the conventional rotational stocking (RT).

## 2. **Materials and methods**

### *2.1. Site, design and treatments*

The experiment was conducted in two stocking periods (2014 and 2015) at the experimental agricultural station of the UFRGS in Eldorado do Sul city, State of Rio Grande do Sul, Brazil (30°05´S, 51°39´W). The climate in the region is subtropical humid with the two-year (2014-2015) mean air temperature and total rainfall during the experimental period (May to August) of 16 °C and 1250 mm, respectively (INMET). The soil of the experimental site was classified as a Typic Paleudult with 17.5% clay, 20% silt and 62.5% sand. In the upper 20 cm, the soil presented 23 g/kg of organic matter, 23 mg/dm$^3$ of phosphorus, 105 mg/dm$^3$ of potassium, 0.60 $cmol_c/dm^3$ of exchangeable $Al^{3+}$, 3.77 $cmol_c/dm^3$ of cation exchange capacity, 39% of base saturation and a pH of 4.05.

The experiment used a randomized complete block design with two grazing management strategies as treatment with four paddocks (replicates) per treatment. Grazing treatments on Italian ryegrass (*Lolium multiflorum*) pastures were: RT, traditional rotational stocking, and RN, 'Rotatinuous' stocking (Carvalho, 2013). Under the RT treatment, the pre-grazing target of 25 cm was applied to ensure the maximum herbage accumulation in Italian ryegrass and high grazing pressure was applied to reach a post-grazing height of 5 cm, maximizing herbage harvest during the period of occupation of the strip-grazing (Mittelmann, 2017). The RN treatment was defined by an optimal sward height (pre-grazing) of 18 cm for Italian ryegrass (Amaral et al., 2013) when the herbage intake per unit of time is highest, and a post-grazing target of 11 cm, meaning an average reduction of 40% of the initial height (Fonseca et al., 2012; Mezzalira et al., 2014) aiming to maintain the highest intake rate during the entire grazing period (Carvalho, 2013).

*2.2. Herbage and animal management*

The protocol was approved by the Committee on the Ethics of Animal Experiments of the University of Rio Grande do Sul (Permit Number: 27457).

The experimental area had eight 0.22-ha experimental units (paddocks). Italian ryegrass seeds were broadcasted on April 2014 and 2015, with a density of 35 kg seed/ha. Every year, the pasture was fertilized with 155 kg N/ha, 90 kg $P_2O_5$/ha and 45 kg $K_2O$/ha. In the last two years prior to the field trial, the experimental site received the same management, that is, was cultivated with Italian ryegrass (winterspring) and pearl millet (summer-autumn), equally fertilized and grazed only by sheep.

The grazing management was based on a 1-day strip-grazing regime. Every day, the animals entered a new strip between 14:00 and 15:00 h in both treatments. The size of the strips ranged from 50 to 200 $m^2$, and the number of strips per paddock was defined by the herbage growth; the animals started a new stoking cycle when the first strip grazing reached the target height proposed for each treatment. The stocking season lasted 146 and 140 days for RN and RT, respectively, in 2014, and 155 and 146 days for RN and RT, respectively, in 2015 (Savian et al., 2018). The number of stocking cycles was 12 and 4 for RN and RT, respectively, and the rest period was 13 and 35 days for RN and RT, respectively (Savian, 2017). The sward height was monitored in all paddocks using a sward stick (Barthram, 1985) every two days with 100 measurements per strip, which included pre- and post-grazing times. A total of 166,132 sward height measurements (pre- and post-grazing) were performed during the two years.

Experimental animals were castrated crossbred Texel and Polwarth (known as Ideal in Brazil) lambs. At the beginning of the stocking season, the animals aged 10 months and weighed 26.2 ± 0.9 kg in 2014 and 22.1 ± 1.8 kg in 2015. Four test-animals per paddock and a variable number of put-and-take animals (Mott and Lucas, 1952) were used to achieve post-grazing targets in all strips.

All animals were sheared before the start of the stocking season and dosed with oral vermifuge at the beginning of the stocking season and every 30 days. The animals received water and commercial mineral block supplementation (Blokus®, SUPRA) *ad libitum* during the whole stocking season. At the beginning and the end of the stocking season, animals were submitted to a fasting period of 12 hours before weighing.

*2.3. Biometric measurements and carcass characteristics*

Only in 2015, on the last day of the stocking season, linear body conformation measurements were taken on the test animals (16 and 14 animals from RN and RT treatment, respectively), such as body length, leg length and circumference, chest width, width of croup, thoracic perimeter, rump and shoulder heights (Osório et al., 1998).

Lambs were slaughtered following humanitarian practices after fasting for 14 hours by electrical stunning followed by exsanguination. The time from mustering to stunning was on average 22.5 h. Carcasses were trimmed, and hot carcass weights recorded. Carcasses were chilled at 4-5°C for 24 hours and cold carcass weights were recorded. Carcass yield was calculated as the division of cold carcass weight by lamb LW before slaughter (kg/100 kg LW).

The internal and external length of the carcass, leg and shoulder lengths and depths were measured to assess carcass conformation according to Osório et al (1998). Subsequently, the carcasses were separated in commercial cuts that were weighed separately as such: neck, shoulder, ribs, loin and leg. According to Fisher and De Boer (1994), dissection of the shoulder was performed to measure tissue composition in terms of muscle, bone and fat.

*2.4. Carcass quality*

The carcass pH (Lutron, PH 208 model) was measured on the *Longissimus dorsi* muscle (between the eleventh and twelfth rib) twice: zero time (initial pH) and

24 hours postmortem (ultimate pH). According to Osório et al. (1998), marbling was subjectively scored by two independent assessors on slices of loin taken from the lumbar region (*Longissimus dorsi*) using a five-point visual scale ranging from 1 (little or no marbling) to 5 (high marbling). According to AMSA (1967), the area ($cm^2$), depth (mm) and width (mm) of loin and subcutaneous fat thickness (mm) were measured. The same loins were used to investigate colour stability using the CIE L* (lightness), CIE a* and (redness) CIE b* (yellowness) scale as according to Centre International de L'Eclairage (1986), using a BYK spectrophotometer (Gardner GmbH).

*2.5. Calculations*

The carcass production per hectare was based on lamb LW production (kg/ha) and stocking rate (kg LW/ha) from 2014 and 2015, and carcass yield (kg/100 kg LW) from 2015. Human-edible food and crude protein (CP) production per hectare were obtained by carcass production per hectare and the bone and CP percentage of the carcass, respectively. We considered fat and muscle as human-edible food. The carcass CP assumed was 15.3% (Silva et al., 2005).

To calculate the daily herbage intake per hectare we used individual lamb dry matter (DM) intake (Savian et al., 2018) and stocking rate (lambs/ha). Feed conversion efficiency was calculated as the division of the DM intake per hectare (individual lamb DM intake multiplied by the number of animals per hectare) and the animal carcass weight gain per hectare during the stocking season. For this, we used the estimated individual value for each animal, that is, the average of three daily DM intake measurement for each test-animal during the stocking season using the same database as Savian et al. (2018). Daily herbage intake by lamb was estimated using the faecal crude protein technique. For that, a specific equation for Italian ryegrass was used (Azevedo et al., 2014).

Sulphur hexafluoride ($SF_6$) tracer method (Johnson et al., 1994) was used to measure the daily $CH_4$ emission by lambs. For more details on the field gas sampling, the number of measurements and laboratory analysis see Savian et al. (2018).

Similarly, to calculate the lamb $CH_4$ intensity of edible food and CP production, we used the database of daily $CH_4$ emission by lamb as Savian et al. (2018) and the carcass gain. The $CH_4$ yield (% of gross energy intake) was estimated based on individual lamb $CH_4$ emission (Savian et al., 2018) and energy intake. Lamb gross energy intake was based on DM intake reported by Savian et al. (2018) and the gross energy content of Italian ryegrass pastures (17.8 MJ/kg DM) reported by Savian et al. (2014).

Lamb diet cost was based on seed, fertilizers and diesel spent to cultivate one hectare of Italian ryegrass; pasture implementation was equal for both treatments (US$239 per ha; Table 1). Then, feed cost (US$/kg DM produced) was based on herbage production per hectare (8.7 and 6.8 t DM/ha for RN and RT, respectively; Savian, 2017) and cost of pasture implementation. Diet cost per lamb and hectare were based on daily DM intake by lamb (Savian et al., 2018), the number of lambs per hectare and cost per kg of DM. Finally, feed cost conversion (US$/kg of carcass gain) was based on the amount of US$ spent on feed divided by the carcass weight gain.

### *2.6. Statistical analysis*

All data were checked for normality and homogeneity of variance using histograms and QQ plots. Data were transformed according to the Box-Cox transformation procedure if necessary. Data were subjected to analysis of variance at 5% level of significance. The analysis was performed using the R software for statistical computing version 3.5.3 (RStudio Team, 2016). For animal variables (*in vivo* and carcass measurements), treatment was considered a fixed effect, and block a random effect. For some variables (per hectare data), the year was added to the model as a random effect when the data had two years (2014 and 2015). Linear models and linear mixed models (lme) were tested and the best model was selected by likelihood ratio test and Akaike's Information Criterion (AIC).

## 3. Results

### *3.1. Herbage characteristics*

Table 1 shows the diet cots and the pre- and post-grazing sward heights according to the target proposed to this study as described by Savian et al. (2018). Diet cost per kg of DM ($p = 0.001$) and per hectare ($p < 0.001$) were lower for RN than for RT treatment. Daily diet cost per lamb was US$ 0.025 and did not differ ($p = 0.461$) between the treatments.

### *3.2. Conformation of lambs and their carcasses*

Feed intake and efficiency, and carcass characteristics of lambs are shown in Table 2. The greater ($p < 0.001$) herbage intake per hectare for RT than for RN treatment (32.2 and 22.6 kg/day, respectively) was not efficient to achieve less feed per kg of carcass gain; this means that the feed conversion was better for the RN than for RT treatment, that is, for each kg of carcass gain was necessary 18.7 and 34 kg of DM, respectively. Consequently, RN treatment presented better feed cost conversion than RT treatment, with an average of 0.51 and 1.42 (US$ spent on feed per kg of carcass weight gain), respectively. Final LW ($p$ = 0.022) and hot and cold carcass weight ($p$ = 0.006) were greater for the RN treatment. Cold carcass yield (kg carcass/100 kg LW) did not differ ($p$ = 0.399) between treatments, with an average of 45%. Carcass weight muscle was greater ($p$ = 0.041) for the RN treatment, and carcass weight fat ($p$ = 0.066) and bone ($p$ = 0.454) did to differ between treatments.

Table 3 shows the *in vivo* body and carcass conformation. The *in vivo* body conformation of lambs, such as leg length ($p$ = 0.035), width of croup ($p$ = 0.004), thoracic perimeter ($p < 0.001$) and posterior height ($p$ = 0.006) were greater for the RN treatment. Other variables such as body length ($p$ = 0.957), leg circumference ($p$ = 0.307), chest width ($p$ = 0.296) and previous height ($p$ = 0.099) did not differ between treatments. The carcass conformation of lambs, as internal ($p$ = 0.089) and external ($p$ = 0.213) length, leg length ($p$ = 0.723) and depth ($p$ = 0.079), and shoulder length ($p$ = 0.476) and depth ($p$ = 0.340) did not differ between treatments.

All commercial cuts were greater for RN than for RT treatment, with an average of 3.10 and 2.68 kg for leg ($p$ = 0.007), 2.87 and 2.35 kg for rib ($p$ = 0.001), 1.76 and 1.45 kg for shoulder ($p < 0.001$), 0.74 and 0.64 kg for neck ($p$ = 0.011), and 0.47 and 0.39 kg for loin ($p$ = 0.009), respectively (Fig. 1).

Carcass composition and quality are shown in Table 4. The percentage of muscle ($p$ = 0.993) and fat ($p$ = 0.266) in the carcass did not differ between treatments, with an average of 61 and 14%, respectively. However, carcass bone was greater ($p$ = 0.046) for RT than for RN treatment (26 and 23%, respectively). Eye muscle area ($p$ = 0.284) and width ($p$ = 0.671) did not differ between treatments; however, the eye muscle height was greater ($p < 0.009$) for the RN treatment (Table 4).

The pH in the *Longissimus dorsi* muscle was 7.0 and 5.6, for the hot ($p$ = 0.070) and cold ($p$ = 0.792) carcass, respectively, with no difference between treatments. The *Longissimus dorsi* muscle marbling fat was greater ($p$ < 0.001) for the RN treatment, while the subcutaneous fat thickness did not differ ($p$ = 0.467) between treatments (Table 4). Meat colour, $L^*$ ($p$ = 0.149), $a^*$ ($p$ = 0.807) and $b^*$ ($p$ = 0.824), with an average of 49, 15 and 8, respectively, did not differ between the treatments (Table 4).

Finally, although the stocking rate was 74% greater ($p$ < 0.001) for the RT treatment (Table 2), the RN treatment presented greater ($p$ < 0.001) carcass (184 and 122 kg/ha for RN and RT, respectively), edible food (141 and 90 kg/ha for RN and RT, respectively) and crude protein (28 and 19 kg/ha for RN and RT, respectively) production per hectare (Table 5).

### *3.5. $CH_4$ intensity and yield*

The $CH_4$ intensity and yield are shown in Table 5. $CH_4$ emission intensity per kg of carcass, edible food and crude protein gain was 2.6, 2.7 and 2.1 times lower ($p$ < 0.001) for RN than for RT treatment. Moreover, $CH_4$ yield, based on gross energy intake was lower ($p$ = 0.014) for RN than for RT treatment, with an average of 7.6 and 8.3%, respectively.

## 4. Discussion

This study shows that within rotational grazing management practices, adjusting pre- and post-grazing sward height either to maximize total forage accumulation and harvest efficiency (RT) or the herbage intake per unit of time by lambs (RN), has important consequences on carcass production and quality, diet cost,

$CH_4$ intensity and yield. In the 'Rotatinuous' stocking scheme, lambs reached greater final LW and carcass weight (Table 3), increased production of carcass and edible food and protein per hectare (Table 5), even with 74% fewer lambs per area (Table 3).

*4.1. Meat production*

The greater final LW, carcass gains and conformation of lambs grazing Italian ryegrass pastures were a consequence of the appropriate sward structure in the RN treatment, which consequently promoted greater lamb herbage intake combined with greater nutritive value of consumed herbage in each strip-grazing (Savian et al., 2018) and over the stocking season (Savian et al., 2020). The metabolizable energy intake over the whole grazing period was increased by 15% (Savian et al., 2018). Boval and Dixon's (2012) theorized that management priority in grasslands should be based on the objective to achieve the highest intakes of DM or preferably digestible nutrients, especially energy.

Accordingly, final LW and carcass weights of lambs grazing in the RN treatment were 14 and 19% greater than lambs grazing in the RT treatment (Table 3). According to Galvani et al. (2008) and Pinheiro and Jorge (2010), many other indicators of performance and quality can be improved consistently. In this sense, meat quality and final pH in the *Longissimus dorsi* (approx. 5.6) in both treatments indicates adequate feeding (Luciano et al. 2012), and that post-mortem glycolysis ensured proper meat colouring, as pH value greater than 5.7 must be avoided (Young et al., 2004). In other words, the RN management also produced meat with greater marbling which is preferred by Latin American consumers.

The consequences of such improvement in individual performances were greater efficiencies, despite lower stocking rate and herbage intake per area, which indicate that the approach of high pasture utilization per area may not be a good indicator of production and efficiency. For example, the RN grazing management increased the feed-to-food efficiency by 82% and 178%, based on feed conversion (kg forage per kg of carcass gain) and feed cost conversion (US$ per kg of carcass gain), respectively as compared to RT treatment (Table 3). This is preconized by FAO (2013) and important to highlight, as feed cost per kg of DM and hectare were respectively 1.3 and 1.8 times lower in RN than in RT (Table 1). Moreover, the consequences of improved grazing management (RN treatment) extend beyond individual performances (Savian, 2017), as they allow for a reduction in the residence time of the animals on the farm since they reach ideal slaughter weight earlier, which is evidence that the RN treatment can provide greater profitability, and which may be an attraction for farmers to adopt this innovation.

Assuming a slaughter LW of 33 kg (Da Silva et al., 2000) for the crossbreed lambs, animals in the RN treatment could have been slaughtered 42 days before RT treatment. This would possible by the greater LW gain for the RN than for the RT treatment (119 and 47 g/day, respectively; Savian, 2017). Such an increase in turn-off weights and a decrease in turn-off age on farms are key points to improve profitability (Bray et al., 2016), which are achieved in RN without any increase in production costs whatsoever. Moreover, our calculations overlook the potential positive impact on the nutritional status of reproducing females, which is key to act on profitability (Delgadillo and Martin, 2015).

In addition, it is possible to manage pastures prioritizing the individual herbage intake (‘Rotatinuous’ stocking) and consequently animal performance, and achieve good carcass conformation, such as greater weight of cuts (Fig. 1) and marbling (Table 4), and greater food production per area, such as edible food and protein (Table 5). We believe this is the right way for sustainable livestock intensification, considering the growing demand for human protein food security, which according to Broderick (2018) is the main role of ruminant livestock production.

However, greater food production is not the only global demand, as illustrated by the debate on sustainable intensification and agroecology pointed out by Dumont et al. (2018). Whatever the grazing management proposal, or whatever the chosen pathway to agricultural sustainability (Mockshell and Kamanda, 2018), it has to prove a lower environmental impact.

*4.2. Environment sustainability*

Our data indicate that $CH_4$ emission intensity was 2.6 (per kg of carcass production), 2.7 (per kg of edible food production), and 2.1 times (per kg of protein production) lower for the RN treatment (Table 5), which is a consequence of i) the greater meat production per animal (e.g. carcass weight, Table 3); ii) the greater meat production per area (Table 5) and; iii) the lower stocking rate - reduction in herd size of 74% when compared to the RT treatment (Table 3).

There are a few examples of direct interaction between intrinsic meat quality and environmental value (Hocquette et al., 2014). For this reason, we calculated the protein production in both treatments and demonstrated that RN approach is more efficient to mitigate $CH_4$ emissions per kg of protein produced. Similarly, McAuliffe et al. (2018) showed that concentrate-fed beef produced approximately half the emissions of grass-fed beef under the standard mass-based (9.8 and 18.3 kg $CO_2$-

eq/kg meat, respectively), however, when omega-3 content of meat is considered, the emissions of the grass-fed beef system was lower than the concentrate-feed system, 18.5 and 48 kg $CO_2$-eq/g omega-3, respectively. For those authors, the nutritional quality rather than quantity is likely to play a key role in sustainable livestock production systems. In this study, if we transform the $CH_4$ emission per kg of omega-3, as shown by McAuliffe et al. (2018), arguably the difference between RN and RT could be even greater, hypothetically considering that the meat content of omega-3 polyunsaturated fatty acid is greater in the RN than the RT treatment.

Another point that is pivotal for the reduction of $CH_4$ emission per kg of meat is the number of animals per hectare. We believe that if grazing management such as 'Rotatinuous' stocking is widely adopted in pasture-based systems, the number of animals can be automatically be reduced, without affecting meat production (rather an increase), and the $CH_4$ emissions would be reduced considerably. It is worth noting that, overgrazing is often the main problem of pasture-based livestock production (Soussana and Lemaire, 2014). In other words, to improve pasture and animal production with grazing management it is necessary to adjust the number of animals per area according to the pasture production, which will be the key point to reduce the stocking rate on the farm. According to Herrero et al. (2016), reduction of herd size with the maintenance of production levels is considered a climate-smart grazing practice.

In addition to the $CH_4$ emission intensity, the animals from RN treatment were more efficient in the use of the energy, considering that $CH_4$ yield (% of gross energy intake) was 9% lower (Table 5). This is explained by the greater herbage intake (Savian et al., 2018). We highlighted that the greater the energy intake (Savian et al., 2018), the lower the $CH_4$ yield. Dini et al. (2018) showed that the $CH_4$ yield by grazing beef cattle was lower when the gross energy intake was greater.

Thus, our results support the idea that the RN is climate-smart grazing management when compared to traditional rotational management, and that livestock's grazing under RN approach is productive and environmentally sustainable. This is a standpoint neglected by studies arguing about the need to reduce meat consumption (e.g. Hedenus et al., 2014; Ripple et al., 2014; Scarborough et al., 2014; Lamb et al., 2016; Parodi et al., 2018; Sandström et al., 2018; Willett et al., 2019) and to motive the consumers to a dietary change (e.g. de Boer et al., 2016). While diversifying and balancing human diet by eating more vegetal is important and reducing animal products in the human diet can be environmentally favourable, it also limits the ingestion of essential nutrients (González-García et al., 2018). Accordingly, Green et al. (2015) argue that a drastic dietary change can provoke a significant reduction in GHG emissions beyond 40% in the current consumption patterns, but also reduce the nutritional quality of diets.

GHG reduction and production of high-quality animal products are possible by adopting simple grazing management practices as described earlier. So, does grazing livestock have any good perspective? Benefits? We believe so. First, in previous research, Savian et al. (2018) showed that is possible to reduce by the $CH_4$ production by 1.6 times per area in RN well-managed grasslands. Second, we show in this study that it is possible to reduce 2.6 times of $CH_4$ per kg of carcass gain of lambs without intense use of input (e.g. supplements).

We do not show here the potential of C sequestration in this grassland system. Nonetheless, Savian (2017), in the same experimental protocol, proved that in 150 days of grazing, the herbage aboveground production was 8.7 tons per ha for the RN treatment; 28% more than the RT treatment. The net primary production is the main responsible for the C sequestration (Soussana and Lemaire, 2014). For Herrero et al. (2016), grassland can potentially reverse historical soil C losses and sequester substantial amounts of C in pasturelands. Rumpel et al. (2018) argued that sequestering more C into soils should be considered a smart strategy to meet Paris climate pledges. However, to meet this objective, smart fertilization practices (Henderson et al., 2015), moderate grazing intensity (Da Silva et al., 2014; Carvalho et al., 2018b) and legume cover crops (Veloso et al., 2018) for grazing in integrated crop-livestock systems (ICLS), for example, are indispensable actions.

A second perspective is land use. Lemaire et al. (2014) showed that ICLS offer ecosystem services such as nutrient cycling, preserving natural resources and environment, improving soil quality and enhancing biodiversity while increasing food production at the farm and regional levels. However, this is only possible with the insertion of the main agent of the ICLS, the animal component (Carvalho et al., 2018a).

The third component is related to a social approach. According to FAO (2018), globally, approximately one out of nine people is hunger or undernourished with rural people represents most of that amount (FAO, 2017) and depend directly on livestock for their livelihoods (FAO, 2018). Innovations such as 'Rotatinuous' stocking besides favouring and encouraging livestock production, can also generate more profit, mainly due to the lower feed cost per kg of DM and hectare (Table 1), and feed cost conversion (Table 3).

Fourth, improved grazing managements such as the 'Rotatinuous' stocking reduce the cost of feeding (Table 1), which could reduce livestock competition for human-edible feeds (Wilkinson and Lee, 2018). Even ruminants are less efficient in terms of overall feed conversion than monogastric (Mottet et al., 2018). They graze pastures with high-fibre content that are unsuitable for human consumption (Eisler et al., 2014). In this sense, when expressed in human-edible protein, the ruminants are very efficient to convert vegetal protein in animal protein when compared with industrial monogastric operations (Mottet et al., 2018).

According to FAO (2013), improving feed-to-food conversion efficiency is fundamental for improving environmental livestock's sustainability. Moreover, reducing food loss and waste are smart strategies for reducing food demand and the associated environmental impacts (Conrad et al., 2018; Springmann et al., 2018). In addition, improving the distribution of food in the world is a necessary action. It may be that in future, with increasing population, in some countries it will be necessary to diversify the diet of the people, which can result in a reduction of the consumption of meat per capita. However, this is not an easy activity because it involves countries economy, political economy (Godfray et al., 2018), purchasing power and culture.

Finally, to answer all these are evidence of the ecosystem services promoted by well-managed grazing systems, such as 'Rotatinuous' stocking. Livestock's good side outstands over its negative's consequences. Public policies are necessary to help farmers to improve their perception of technology adoption by changing the farm's profile and so, to see the importance of these practices to improve food production and security to reduce environmental impact. This is essential for keeping people in rural areas, reducing rural exodus and poverty in the world. According to Mlambo and Mnisi (2019), sustainable ruminant production systems would ensure food and nutrition security to humans.

## 5. Conclusions

Our study shows that grazing management termed 'Rotatinuous' stocking results in a greater carcass, edible food and crude protein production, feed efficiency, better carcass quality, and lower $CH_4$ intensity and yield of lambs grazing Italian ryegrass pastures. Therefore, this sward management strategy is a win-win solution for environmental health allowing high animal production and high mitigation of GHGs for grazing systems, that is, it is possible to reduce $CH_4$ intensity (g/kg carcass, edible food and crude protein production) and yield (% gross energy intake) at the same time. Moreover, 'Rotatinuous' stocking improves competitiveness since the feed cost efficiency is 2.8 times lower than poorly managed pastures.

Finally, we highlight that changing conventional pasture management approach to one based on optimal herbage intake is a key factor to improve food production and reduce global $CH_4$ intensity and yield on pasture-based systems. 'Rotatinuous' stocking is an example of climate-smart livestock production strategy, being technologically adaptable and conceptually applicable on any farm around of the world.

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**Table 1**

Characteristics of Italian ryegrass pastures grazed by lambs under ‘rotatinuous’ stocking (RN) and traditional rotational stocking (RT) in the subtropical region of Brazil.

| Variables | RN | RT | Mean ± SEM | *p*-value |
|---|---|---|---|---|
| Sward height (cm) | | | | |
| Pre-grazing[a] | 17.9 | 25.7 | 21.8 ± 0.03 | <0.001 |
| Post-grazing[a] | 11.4 | 8.13 | 9.76 ± 0.02 | <0.001 |
| Pasture implantation (US$/ha) | 239 | 239 | - | - |
| Diet cost (US$/kg DM) | 0.027 | 0.035 | 0.031 ± 0.00 | 0.001 |
| Diet cost per lamb (US$/day) | 0.025 | 0.026 | 0.025 ± 0.00 | 0.461 |
| Diet cost per ha (US$/day) | 0.627 | 1.148 | 0.887 ± 0.08 | <0.001 |

DM = dry matter; SEM = standard error of mean.
[a] Savian et al. (2018).

**Table 2**

Feed efficiency and carcass characteristics of lambs finished in Italian ryegrass pastures under 'rotatinuous' stocking (RN) and traditional rotational stocking (RT) in the subtropical region of Brazil.

| Variables | RN | RT | Mean ± SEM | *p*-value |
|---|---|---|---|---|
| Feed intake and efficiency | | | | |
| Herbage intake (kg/ha/day) | 22.6 | 32.2 | 27.4 ± 1.57 | <0.001 |
| Feed conversion[a] | 18.7 | 34.0 | 26.3 ± 3.30 | <0.001 |
| Feed cost conversion[b] | 0.51 | 1.42 | 0.96 ± 0.17 | <0.001 |
| Animal characteristics | | | | |
| Initial LW (kg) | 21.2 | 23.0 | 22.1 ± 0.34 | 0.007 |
| Final LW (kg) | 39.9 | 34.9 | 37.4 ± 0.84 | 0.022 |
| Stocking rate (lambs/ha) | 25.6 | 44.6 | 35.1 ± 3.04 | <0.001 |
| Carcass characteristics | | | | |
| Hot carcass weight (kg) | 18.7 | 15.7 | 17.2 ± 0.45 | 0.006 |
| Cold carcass weight (kg) | 18.2 | 15.3 | 16.7 ± 0.44 | 0.006 |
| Cold carcass yield (kg/100 kg LW) | 45.6 | 43.9 | 44.7 ± 0.78 | 0.399 |
| Carcass weight muscle (kg) | 11.1 | 9.38 | 10.2 ± 0.30 | 0.041 |
| Carcass weight fat (kg) | 2.83 | 2.10 | 2.46 ± 0.17 | 0.066 |
| Carcass weight bone (kg) | 4.22 | 3.96 | 4.09 ± 0.09 | 0.454 |

LW = live weight; DM = dry matter; SEM = standard error of mean.
[a] Amount of DM intake divided by the carcass weight gain.
[b] Amount of US$ spent on feed divided by the carcass weight gain.

**Table 3**

*In vivo* body and carcass conformation of lambs finished in Italian ryegrass pastures under ‘rotatinuous’ stocking (RN) and traditional rotational stocking (RT) in the subtropical region of Brazil.

| Variables | RN | RT | Mean ± SEM | *p*-value |
|---|---|---|---|---|
| *In vivo* body conformation (cm) | | | | |
| Body length | 68.7 | 68.6 | 68.6 ± 0.78 | 0.957 |
| Leg length | 55.1 | 53.4 | 54.2 ± 0.42 | 0.035 |
| Leg circumference | 36.9 | 35.6 | 36.2 ± 0.42 | 0.307 |
| Chest width | 13.1 | 12.5 | 12.8 ± 0.28 | 0.296 |
| Width of croup | 18.8 | 17.1 | 17.9 ± 0.32 | 0.004 |
| Thoracic perimeter | 107.1 | 97.9 | 102.5 ± 1.14 | <0.001 |
| Previous height | 63.5 | 61.8 | 62.6 ± 0.52 | 0.099 |
| Posterior height | 67.4 | 65.3 | 66.3 ± 0.40 | 0.006 |
| Carcass conformation (cm) | | | | |
| Internal length | 81.3 | 77.5 | 79.4 ± 1.12 | 0.089 |
| External length | 68.4 | 66.3 | 67.3 ± 0.57 | 0.213 |
| Leg length | 29.5 | 29.3 | 29.4 ± 0.58 | 0.723 |
| Leg depth | 34.6 | 32.1 | 33.3 ± 0.87 | 0.079 |
| Shoulder length | 26.4 | 25.3 | 25.8 ± 0.51 | 0.476 |
| Shoulder depth | 28.2 | 27.4 | 27.8 ± 0.37 | 0.340 |

SEM = standard error of mean.

**Table 4**

Carcass composition and quality of lambs finished in Italian ryegrass pastures under 'rotatinuous' stocking (RN) and traditional rotational stocking (RT) in the subtropical region of Brazil.

| Variables | RN | RT | Mean ± SEM | *p*-value |
|---|---|---|---|---|
| pH (hot carcass) | 6.97 | 7.06 | 7.01 ± 0.03 | 0.070 |
| pH (cold carcass) | 5.66 | 5.65 | 5.65 ± 0.03 | 0.792 |
| Eye muscle area ($cm^2$) | 16.4 | 15.2 | 15.8 ± 0.56 | 0.284 |
| Eye muscle height (mm) | 31.2 | 28.3 | 29.7 ± 0.58 | 0.009 |
| Eye muscle width (mm) | 60.4 | 61.5 | 60.9 ± 1.30 | 0.671 |
| Marbling | 2.5 | 1.5 | 2.0 ± 0.15 | <0.001 |
| Subcutaneous fat thickness (mm) | 3.73 | 3.15 | 3.44 ± 0.26 | 0.467 |
| Muscle (%) | 61.2 | 61.2 | 61.2 ± 0.75 | 0.993 |
| Fat (%) | 15.4 | 13.7 | 14.5 ± 0.83 | 0.266 |
| Bone (%) | 23.3 | 26.0 | 24.6 ± 0.51 | 0.046 |
| Meat colour (*L**)[a] | 47.3 | 50.0 | 48.6 ± 0.91 | 0.149 |
| Meat colour (*a**)[a] | 15.1 | 15.0 | 15.0 ± 0.30 | 0.807 |
| Meat colour (*b**)[a] | 7.99 | 8.06 | 8.02 ± 0.33 | 0.824 |

SEM = standard error of mean.
Meat colour at 24 h *post mortem* (*L** = lightness; *a** = redness; *b** = yellowness).

**Table 5**

Meat production and methane intensity and yield by lambs finished in Italian ryegrass pastures under 'rotatinuous' stocking (RN) and traditional rotational stocking (RT) in the subtropical region of Brazil.**Figure caption**

| Variables | RN | RT | Mean ± SEM | *p*-value |
|---|---|---|---|---|
| Meat production (kg/ha) | | | | |
| Carcass gain | 184 | 122 | 153 ± 12.3 | <0.001 |
| Edible food gain | 141 | 90.5 | 116 ± 9.51 | <0.001 |
| Carcass CP gain | 28.1 | 18.6 | 23.3 ± 1.88 | <0.001 |
| $CH_4$ intensity (g/kg) | | | | |
| Carcass gain | 513 | 1357 | 935 ± 206 | <0.001 |
| Edible food gain | 669 | 1813 | 1241 ± 275 | <0.001 |
| Carcass CP gain | 3356 | 7146 | 5251 ± 1026 | <0.001 |
| $CH_4$ yield (%) | | | | |
| Gross energy intake | 7.6 | 8.3 | 7.95 ± 0.30 | 0.014 |

DM = dry matter; CP = crude protein; SEM = standard error of mean.

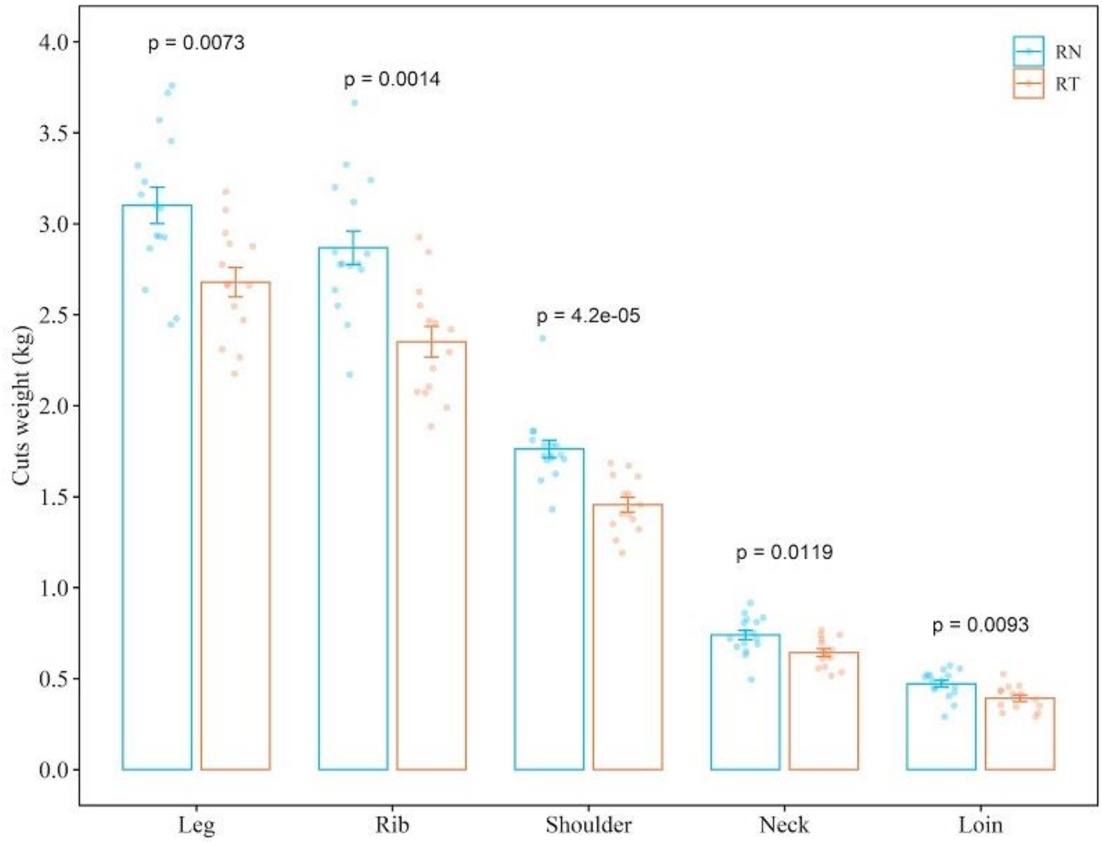


**Fig. 1.** Weight of commercial cuts of lambs finished in Italian ryegrass pastures under 'rotatinuous' stocking (RN) and traditional rotational stocking (RT) in the subtropical region of Brazil. The *p*-values are the significance level of treatment effect and when there were differences between treatments, a Tukey HSD test was performed on the averages ($p < 0.05$) for each commercial cut.