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Potential Environmental Benefits of Residual Feed Intake as Strategy to Mitigate Methane Emissions in Sheep

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Abstract: Residual feed intake was evaluated as alternative strategy to decrease methane emissions from sheep. About 24 ewes (30±2 kg of BW) and 16 rams (32±2 kg of BW) were individually fed (42 days). Residual Feed Intake (RFI) was calculated for each individual by sex as the difference between actual and expected feed intake adjusted for metabolic body weight and gain weight rate. Animals were categorized (by sex and overall) as low (more efficient), medium and high RFI (less efficient). Methane emissions were estimated using gross energy intake (EF-CH_4) and dry matter intake (EM-CH_4). No effects ($p>0.05$) were observed on initial or final body weight neither on average daily gain. Methane production (kg day^{-1}) from low RFI ewes were lower ($p<0.01$) being 0.021 and 0.025 than for high RFI averaging 0.027 and 0.032, respectively for EF-CH_4 and EM-CH_4. Positive relationships were found in rams between RFI and CH_4 predicted emissions ($r = 0.46$; $p = 0.07$) however, no effect ($p>0.05$) was observed on RFI over methane production. Overall low RFI produced 0.023 and 0.028 for EF-CH_4 and EM-CH_4, respectively in comparison with 0.028 and 0.033 observed in high RFI sheep. Results showed that low RFI sheep decreased methane emissions without affecting productive parameters.

Key words: Methane, residual feed intake, sheep, feed efficiency, parameters, rams

INTRODUCTION

Developing alternative strategies tending to reduce methane (CH_4) emissions from ruminants are of big concern even more if strategies improve feed efficiency and increase profitability. Methane is considered a potent greenhouse gas (United Nations Framework Convention on Climate Change, 1998) with capability of trapping 21 times more heat (Global Warming Potential) than carbon dioxide also its life time in the atmosphere is 9-15 years and over the last two centuries, methane atmospheric concentrations have more than doubled arising 1% yearly in comparison with 0.5% of carbon dioxide (Intergovernmental Panel on Climate Change, 2001). Worldwide, ruminant livestock produce about 80 million metric tons of methane each year (representing 11% sheep and goat), accounting for about 28% of global emissions from human related activities (US Environmental Protection Agency, 2007). Besides, the production of methane is recognized as an energetically wasteful process to the ruminant in that it allows the conversion of useful substrates into compounds no longer useable by the host. Methane formation represents a loss of 2-15% of the ruminant's gross energy intake depending high roughage or concentrate diets (Nevel and Demeyer, 1996) and strategies tending to decrease it are directly related to improvements in feed efficiency.

In the sheep industry, biotechnology, genetic selection and management are sought to reduce the economical and environmental costs associated with ruminal methane production. Providing feed to sheep is the single largest expense in most commercial sheep production enterprises and thus any effort at improving the efficiency of feed use will help reducing costs. Selection strategies tending to increase feed efficiency arise as feasible options to diminish costs associated with methane depletion.

Through the assumption that animals with same initial and final body weight and same gain have different feed consumption, emerge the concept of Residual Feed Intake (RFI) which has been defined as the amount of feed eaten by an animal less what would be expected from the

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animal's growth rate and body weight. In other words, low RFI ruminants are more efficient and high RFI less efficient animals (Koch *et al*., 1963). This alternative of feed efficient measurement unlike feed conversion ratio (Feed:Gain) or gross efficiency (Gain:Feed) is independent of growth and body size in beef cattle (Arthur *et al*., 2001). Limited RFI testing has been conducted to calculate the effect of RFI as a selection method on methane release and productive parameters from Rambouillet sheep. The objectives of this research were to compare the relationships of residual feed intake, animal performance and predicted methane production on growing ewes and rams.

MATERIALS AND METHODS

Experimental design: About 24 ewes and 16 rams of 30±2 and 32±2 kg of Body Weight (BW), respectively were acclimated for a period of 14 days, individually fed over 42 days feeding period with a diet containing 52% alfalfa hay, 23% oat hay, 20% cracked corn, 2% soybean meal, 2% molasses and 1% premix (mineral, urea and vitamin supplementation). The NRC predicted nutrient profile (at 3.0% BW dry matter intake, DMI) was: DM, 88%; TDN, 68%; ME, 2.48 Mcal day^{-1}; CP, 16; Ca, 0.7 and P, 0.30%. Sheep were provided *ad libitum* access to the study diet which was fed in two equal sized meals at 8:00 and 15:00. Feed intake was calculated as the difference between dry matter offered and refused.

Determination of RFI: RFI was calculated for each individual within sex as the difference between actual and expected feed intake. Expected feed intake was modeled:

$$Y_i = \beta_0 + \beta_1 ADG_i + \beta_2 MTBW_i^{0.75}$$

Where:
Y_i = Expected daily feed intake of animal i
β_0 = The regression intercept
β_1 = Partial regression coefficient of feed intake on ADG
β_2 = Partial regression coefficient of feed intake on mean test $BW^{0.75}$

Calculations were done using the GLM procedure of SAS (SAS Inst. Inc., Cary, NC) (Basarab *et al*., 2003). Sheep were classified into low (more efficient), medium and high RFI (less efficient) animals.

Estimated methane emissions: Model 1 (EF-CH_4). Methane Emission Factors (EF) for enteric fermentation were calculated using the following model:

$$EF = [(GE*(Ym/100)*1)/13.3]$$

Where:
EF = Emission factor, kg CH_4 head day
GE = Gross energy intake, MJ head day
Ym = Methane conversion factor, per cent of gross energy in feed converted to methane, for lambs (<1 year old) is used 4.5%

The factor 13.3 (Mcal kg^{-1} CH_4) is the energy content of methane (NGGIP, 1996). Model 2 (EM-CH_4). Methane emissions were also calculated assuming linearity between methane emissions and dry matter intake (kg day^{-1}) (Howden *et al*., 1994):

$$\text{Methane (kg day}^{-1}\text{)} = \text{Intake} * 0.0188 + 0.00158$$

Statistical analysis: Least squares means were computed using the MIXED procedure of SAS for the categorized RFI within sex and for all animals and pairwise comparisons were made by Tukey's W procedure. Phenotypic correlations among RFI, Feed:Gain, FI, EF- CH_4 and EM- CH_4 were computed by using the CORR procedure of SAS with the partial option used to adjust for the fixed effects of sex (SAS Inst. Inc., Cary, NC).

RESULTS AND DISCUSSION

Productive parameters: No effects (p>0.05) were observed on initial BW, final BW or ADG on low, medium and high-RFI ewes, rams or overall which is in agreement with principles (Koch *et al*., 1963). Statistical differences were observed on DMI showing that high RFI (less efficient), consumed 30 and 20% more feed (p<0.05) in comparison with low RFI (more efficient), respectively for ewes and overall. However, no effects (p>0.05) were found on DMI among low, medium and high RFI rams. Summarized data of performance and feed efficiency is shown in Table 1.

Metabolic body weight ($BW^{0.75}$) was correlated (r = 0.41; p = 0.04) with RFI. This correlation provided evidence that more efficient sheep had higher $BW^{0.75}$. However, previously studies did not find correlation between RFI and $BW^{0.75}$ in beef cattle (Nkrumah *et al*., 2006). Sheep RFI was also positive correlated with DMI

Table 1: Summary statistics (LSM±SD) of performance and feed efficiency for Rambouillet sheep

Traits	Ewes	Rams	Overall
No. of animals	24.000±0.000	16.000±0.000	40.000±0.000
Initial BW (kg)	30.020±2.300	32.280±2.120	30.930±2.470
Final BW (kg)	38.560±2.350	42.910±2.540	40.300±3.220
ADG (kg)	0.160±0.027	0.195±0.050	0.174±0.040
Final $BW^{0.75}$	14.170±0.690	15.180±0.620	14.570±0.830
DMI (kg)	1.418±0.202	1.659±0.181	1.514±0.226
RFI (kg)	0.023±0.243	0.019±0.125	0.021±0.202

($r = 0.58$; $p<0.001$) indicating that less efficient animals consumed more feed which also was observed on Brangus heifers ($r = 0.70$; $p<0.05$) (Lancaster *et al*., 2009).

Net returns of integrated sheep production systems are heavily dependent on the costs of feed inputs relative to the value of outputs. Given that feed inputs are the largest variable costs associated with producing meat sheep, selection programs to improve profitability of sheep production systems should focus on reducing feed inputs. Considerable genetic variation for feed efficiency exists in sheep yet limited genetic progress has been achieved due to the costs of labor and equipment to acquire feed intake data. Studies demonstrated that 42 days of measurement of growth are enough for accurate RFI calculations in beef cattle (Golden *et al*., 2008). Limited information is available about duration of growth performance tests necessary for calculating RFI in sheep; it has been reported duration time of 49 and 62 days (Knott *et al*., 2008a, b). Moreover, Archer and Bergh (2000) concluded that performance tests could be shortened between 42 and 56 days with no loss in accuracy of the test. Obtaining RFI data is laborious and expensive and this has limited its spread as a feed efficiency measurement.

Recent studies have been demonstrated that less efficient steers (high RFI) had more variability of feed intake throughout the day. More efficient animals consumed less feed and ate few times per day (Golden *et al*., 2008) also decreasing bunk attendance and feeding duration time (Nkrumah *et al*., 2006). Because in this experiment we fed twice a day to individual allocated animals we were unable to measure feeding behavior however, for improving feeding efficiency, it is important to understand feeding behavior.

Genetic improvement in feed efficiency can be achieved through selection in general correlated responses in growth and other postweaning traits will be minimal. Also, given the associated problem with selection for ratio traits and the fact that residual feed intake is strongly correlated with feed conversion ratio, residual feed intake should be the preferred trait for genetic improvement of postweaning feed efficiency (Arthur *et al*., 2001). Residual feed intake is an alternative measure of efficiency that facilitates selection for improved feed efficiency without compromising growth performance and independent of growth traits and mature size. Residual feed intake has shown to be moderately heritable from 0.21-0.39 for British and Continental European beef cattle (Arthur *et al*., 2001; Herd and Bishop, 2000). Despite the relatively low number of animals and the high forage diet that were used in this study, we were able to categorize sheep by feed efficiency in three groups (high, medium and low RFI). With that in mind, emerge the possibility that either small or large sheep producers could categorize and select low RFI sheep, decreasing feed costs and methane release without diminish animal performance.

Because RFI is by definition phenotypically independent of the production traits used to calculate expected feed intake, it allows comparison between individuals differing in level of production during the measurement period. This independence of RFI from production has led some scientists to suggest that RFI may represent inherent variation in basic metabolic processes. Genetic variation in maintenance energy requirement per kilogram of metabolic BW was closely associated with genetic variation in RFI in young Hereford bulls (Herd and Bishop, 2000). In growing beef cattle, variation in RFI has been linked to differences in heat production, methane production, composition of gain and digestibility demonstrating that numerous biological processes are responsible for genetic variation in RFI (Carstens and Kerley, 2009; Nkrumah *et al*., 2006). Moreover, Richardson and Herd (2004) quantified biological basis for variation in residual feed intake following a single generation of divergent selection, the researchers concluded that protein turnover, tissue metabolism and stress contributed to at least 37% of the variation in RFI; differences in energy retained in protein and fat accounted for only 5% of the difference in RFI, differences in digestion contributed to at least 10%, feeding patterns 2%, the heat increment of feeding contributed 9% and activity contributed 10%. About 27% of the difference in RFI was due to variation in other processes such as ion transport.

Selection for RFI should be accompanied by monitoring for any correlated response in meat quality and palatability. Studies have been provided evidence that selection against RFI is preferred over selection against FCR in sire population for getting better correlated responses in carcass traits of their progeny (Hoque *et al*., 2006). Moreover, meat quality and palatability results observed that steaks from high RFI steers had lower off flavor scores than those from low RFI steers. Also, cook loss percentages were greater for steaks from low RFI steers (Baker *et al*., 2006).

Residual feed intake has become increasingly important and has been considered as a more effectiveness approach to evaluate feed efficiency. However, as mentioned before the cost and technical difficulties in measuring this trait restrict its adoption and necessity of markers which help to identify more efficient ruminants arise. It has been reported that high RFI sheep have greater increase in cortisol concentration in comparison to more efficient animals, demonstrated that efficiency of energy use when measure as RFI is significantly related to an animal's stress response (Knott *et al*., 2008b). Furthermore, Kolath *et al*. (2006) demonstrated that mitochondrial function is not different between the high and low RFI groups but rather the rate of mitochondrial respiration is increased in low RFI steers compared with high RFI steers. Moreover, researchers have been concluded that measurement of IGF concentration and RFI in the selection of young beef cattle during performance testing to identify animals to be progeny tested could be profitable (Wood *et al*., 2004; Kahi and Hirooka, 2007). These findings have important implications for understanding the physiological mechanisms underpinning efficiency of energy use and may be useful in successfully identified animals which are superior in terms of feed efficiency. Recently, it has been identified genetic markers suitable for RFI characterization in pig and shortly, it is believed more markers has to be identify for other species.

Methane release: The results demonstrate that high RFI produce 12 and 19% more EF-CH_4 and EM-CH_4 than low RFI sheep. In addition, positive correlations were found between RFI and predicted methane emissions ($r = 0.58$, $p = 0.001$); evidence of high RFI sheep (less efficient animals) had higher methane emissions. Also, high RFI ewes produce 29 and 28% less EF-CH_4 and EM-CH_4, respectively than low RFI ewes, furthermore strong RFI and methane correlations ($r = 0.79$; $p<0.001$) were found. However, no statistical differences ($p>0.05$) were observe among RFI categorized rams on EF-CH_4 neither EM-CH_4 values although weakly correlation between RFI and methane were found ($r = 0.46$; $p = 0.07$). The trial showed that 16 ram data were not enough to adequately find differences in methane emissions, probably because low differences were observed on DMI. However, 24 ewe data and 40 overall data were sufficient to strongly differentiate from low and high RFI ruminants by methane emissions (Table 2).

Table 2: Effects of RFI categorization on performance and methane production of Rambouillet sheep

Parameters	Low RFI	Medium RFI	High RFI	EEM	p-value
Ewes					
Initial BW (kg)	29.600	30.300	30.300	0.800	0.800
Final BW (kg)	37.200	39.200	39.300	1.100	0.130
ADG (kg)	0.160	0.160	0.160	0.010	0.970
DMI (kg)	1.240	1.400	1.610	0.070	<0.010
EF-CH_4/kg/day	0.021^a	0.023^a	0.027^b	0.001	<0.001
EM-CH_4/kg/day	0.025^a	0.028^a	0.032^b	0.001	<0.001
Rams					
Initial BW (kg)	32.700	32.300	31.900	1.000	0.860
Final BW (kg)	44.000	42.000	42.900	1.600	0.460
ADG (kg)	0.220	0.170	0.200	0.030	0.360
DMI (kg)	1.630	1.590	1.780	0.110	0.200
EF-CH_4/kg/day	0.027	0.026	0.029	0.002	0.200
EM-CH_4/kg/day	0.032	0.031	0.035	0.002	0.200
Overall					
Initial BW (kg)	30.800	31.100	30.900	1.000	0.930
Final BW (kg)	39.800	40.400	40.700	1.300	0.790
ADG (kg)	0.180	0.170	0.180	0.020	0.630
DMI (kg)	1.390	1.480	1.670	0.080	<0.010
EF-CH_4/kg/day	0.023^a	0.024^a	0.028^b	0.001	<0.010
EM-CH_4/kg/day	0.028^a	0.029^a	0.033^b	0.001	<0.010

$^{a, b}$Values within row with unlike letters differ ($p<0.05$) using Tukey as a power test

The literature reports evidence that enteric fermentation can vary widely depending on factors such as type of the animal, the amount and type of feed supplied, environment, addition of dietary fat, feed additives and body weight of the animal (Mathison *et al*., 1998; Moss *et al*., 2000). Methane is produced predominantly in the rumen (87%) and to small extent (13%) in the large intestine and principally emitted by animal eructation (Torrent and Johnson, 1994). Methane is a reduced end product of ruminal fermentation processes and contributes to the rumen microbial ecology by maintaining a low partial pressure of hydrogen helping produced energy end products of fermentation (Russell and Wallace, 1988). However, as mentioned before, there is the increasing concern that global climate is being changed due to the accumulation of greenhouse gases to which methane is considered one (Intergovernmental Panel on Climate Change, 2001). Improving animal productivity, nutritional strategies tending to increase grain consumption, manipulation of rumen fermentation, chemical direct inhibition of methane-microbial producers and immunization have been reviewed to reduce methane emissions from ruminants (Boadi *et al*., 2004; Waghorn and Clark, 2006).

Howden *et al*. (1994) reported a close relationship between dry matter intake and methane production based on analysis of Australian respiration chamber experiments with sheep fed diets typical of the range found in Australia. Those researchers found that feed intake alone explain 87% of the variation in methane production.

Some researchers have been reported by calorimetric chambers and the SF6 tracer gas technique that low RFI beef cattle had lower daily methane production rate (Nkrumah *et al*., 2006; Hegarty *et al*., 2007). The opportunity to abate livestock methane production rate by selection against RFI seems great moreover diminishing amounts of feed fermented. The mechanisms behind the observed differences among animals in methane emissions, independent of intake are unknown but they may be related to differences in metabolizability as well as possible individual animal differences in both methane production and methanogenic microbial populations.

In a long term, low RFI selected sheep will produce 8.35 kg/animal in comparison with 10.06 kg/animal of high RFI sheep. However, in order to obtain RFI values, it is necessary to measure and record the daily feed intake for each animal which can be accomplished by housing them in individual pens or by automatic bunks.

Further research is required to better understand the biological mechanisms responsible for the variation in RFI in sheep and to associate the physiological information with physiological and molecular genetic information that will become the basis for commercial tests for genetically superior animals. Animals with low residual feed intake can be used to mitigate CH_4 emissions with no changes on animal production, reducing feed fermented per unit of gained kilogram.

CONCLUSION

Results showed that low RFI sheep decreased methane emissions without affecting productive parameters.

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