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Body weight performance, estimated carcass traits and methane emissions of beef cattle categories grazing *Andropogon gayanus*, *Melinis minutiflora* and *Stylosanthes capitata* mixed swards and *Brachiaria humidicola pasture*

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Abstract. Cow-calf operations constitute the main land use system in the 18 million ha of well drained tropical savannas of Colombia located in the Orinoco basin. There, numerous sex and age animal categories are present ranging from suckling calves to old cull cows and steers, which in variable proportions are stocked at one animal unit (AU)/5-10 ha depending upon the ranch and distance from markets. In parallel, early on farm observations revealed that when sown pastures are introduced, graziers recur to opportunistic partial fattening of cull animals for a rapid economic return. The paper reports animal weight gains of cull cows, old steers, and young heifers and yearlings over seven consecutive years grazing on a low fertilizer-input well managed *Andropogon gayanus*-based pasture and four contemporary years on *Brachiaria humidicola*. The first two years involved three stocking rates (SR; 1.38, 1.85 and 2.32 AU/ha), whereas a single SR of 1.33 AU/ha was used for the remainder. A large database that included chemical, and *in vitro* and *in vivo* digestibility values for all forages involved, was used as input to a mathematical model to estimate methane (CH_4) emissions. Estimations were compared to weight-based predictions derived from chamber measurements recorded recently in tropical Australia. Fecal mineral concentration varied little (N.S.) between SR and animal categories. Weight gains of old steers were 4-24% larger than those of cull cows, which in turn were larger than those of young steers and heifers ($P < 0.01$). Excepting one year, the performance of cull cows and old steers did not differ between pastures, confirming earlier on-ranch observations of reasonable weight gains of adult cattle on both pastures. The predicted carcass composition of cull cows and old steers did not differ between pastures either. Over the length of the experiment cull cows emitted significantly less CH_4 than old steers (129 vs. 141 g/day) on *A. gayanus*, while emissions on *B. humidicola* amounted to 128 and 137 g/day, respectively. Despite between-years differences in animal performance they are indicative of well managed pasture sustainability. They also show some of the tradeoffs involved in the use of contrasting animal categories and pastures in terms of weight performance and predicted carcass composition and methane production. The authors expect that the present results will contribute to a rational, science-based discussion of the role of beef systems vis-à-vis environment in a region with limited production alternatives.

Additional keywords: Animal-pasture interaction, greenhouse gases, rangelands, sustainable grazing systems, tropical pastures.

Introduction

The well-drained tropical savannas of Colombia located in the Orinoco basin cover approximately 18 million hectares (de León and Rincón 2010), while 75% of them are highly dissected and non-tillable grassland plains (Beaulieu *et al*. 2006). Rainfall in the eco-region ranges between 2,000 and 2,400 mm, and turns the rangelands into temporal wetlands from April to October (Navas-Ríos 1999). This natural system has favored a rich biodiversity kept in national parks (Hoogesteijn and Chapman 1997; Rausch 2013), and has promoted the development of ecosystem services and primary industries such as fisheries, forestry, agriculture and beef production enterprises (Navas-Ríos 1999).

However, the resilience and adaptive capacity of indigenous Achaguas, Amoruas, Cuinabes, Curripacos, Guahibos, Piapocos, Piaroas, Sálivas, Sikuanis and Tunebos inhabitants, colonial and native (i.e. llanero) peoples to achieve those resource-dependent industries should not be underestimated (Navas-Ríos 1999). As pointed out by Navas-Ríos (1999) and Marshall (2010, 2011) primary resource-users are conventional drivers that foster cultural and regulatory opportunities for socio-educative, ecological, economic and productive systems.

In this context, extensive cow-calf herds typically include 50% of females, made up of empty dry cows (cull cows; 8-12 years of age) and heifers 1-3 years of age (Kleinheisterkamp and Habich 1985; Missio *et al*. 2015). The scale is the product of replacement rates of 15-20% per year that is augmented by heifers not needed for replacement of cull breeders. Given the difficulties of mustering cattle over large paddocks 1-2 times per year, steers of 2-4 years of age are also found. Thus, although the slaughter of female cattle represents a significant portion of the beef chain (Missio *et al*. 2015), the variable herd composition contributes to the well-known flexibility and adaptability of these natural resource-dependent systems to drought and flood conditions (Rivera 1988; Vera and Ramírez-Restrepo 2017).

Understanding the extent to which older animals contribute to farming income is important. According to Woerner (2010) between 15 and 25% of the annual income from cow-calf beef and dairy enterprises in the US may be derived from marketing cull cows. In parallel, recent studies (Missio *et al*. 2015) estimated that cull cows and excess replacement heifers contribute as much as 50% of the income in many Brazilian beef herds. This variability might be attributed at least under some conditions to thin and medium weight cows that are more profitable than cows in better conditions (Amadou *et al*. 2014).

Intensification of extensive cow-calf farming in the tropical savannas most frequently require the introduction of sown pastures, a relatively expensive forage resource (CONPES 2014; Ramírez-Restrepo and Charmley 2015). On farm observations made by the authors in the Colombian neotropical savannas showed that in the initial stages of pasture establishment farmers tend to favor grazing by older-cull cattle during the rainy season with the expectation of obtaining quick financial returns after a fattening period of 6-7 months. Within that environment, in at least one documented case in a single year (Vera and Seré 1989), cull cows were reported to gain in excess of 500 g/day on a low-fertilizer input *Andropogon gayanus*-based sward, liveweight gains (LWGs) similar to values reported from grazing steers of combined age that were sold for local markets at the end of the rainy season.

Similarly, unpublished farming observations made by the authors in the Colombian Eastern Plains showed that older cattle took priority over replacement yearling, heifers and breeding cows in terms of access to introduced *Brachiaria humidicola* pastures. Nevertheless, it should be highlighted that mixtures of cattle regarding different sex, age and body condition were also occasionally observed. This was further influenced by graziers management decisions that involved the use of steroidal implants with expectation of increasing animal LWGs. Overall, these on-farm findings are contrary to the experimental established tradition of evaluating new pasture species using exclusively young steers (Lascano and Thomas 1990).

More recently there has been greater interest on the nutritional and fermentative traits including the methanogenic ranking of tropical grasses and legumes for beef production systems in northern Australia (Durmic *et al*. 2017a; Vandermeuleen 2017). However, although complementary field methane (CH_4) emission measurement approaches have been explored (Ramírez-Restrepo *et al.* 2011), the environmental impact of beef grazing production systems in terms of enteric CH_4 emissions in the varied tropical rangelands remains largely elusive (Ramírez-Restrepo and Charmley 2015). Alternatively, McCrabb and Hunter (1999) indicated that the relationship between CH_4 emissions and LW factors is a practical and suitable option for comparing emission profiles in tropical beef production systems.

Reflecting on these relationships, an important aspect of the discussion has been whether this connection can be elucidated by further long-term skilled animal experimentation, but the funding magnitude for such research may be substantial. Therefore, it is reasonable to say that this can be done by building up much of this required environmental information using derived approaches (i.e. indexes and/or modeling) by experienced scientists upon their earlier, unpublished, accurate and reliable long-term field research and results. To the best of our knowledge, such methodology has not been examined in the neotropical savannas, but it warrants further consideration as the approach was recently demonstrated for contrasting beef production systems research (Ramírez-Restrepo *et al.* 2017; Vera and Ramírez-Restrepo 2017).

The objective of this study was to compare the growth of castrated yearlings, heifers, adult steers and cull cows grazing mixed swards of *Andropogon gayanus*, *Melinis minutiflora* and *Stylosanthes capitata*, and pure stands of *Brachiaria humidicola*. Effects of growth stimulants on LWGs were also measured. The second objective explores the use of recent measured tropical greenhouse gas investigations on the unpublished productive beef records to provide ways for predicting animal production and the environmental impact of meat production.

Materials and methods

Experimental design

The design of the experiment followed local commercial practices in that adult steers and cull cows are normally sold at the end of the rainy season, whereas young animals remain on pasture during the following, dry, season. The study was conducted from 1983 to 1989 involving two years of continuous grazing with variable seasonal stocking density (i.e. Preliminary studies), while rotational grazing was performed during the last five years using fixed seasonal stoking rates (SRs) at Carimagua Research Station (CRS; 4°36'44.6"N, 74°08'42.2"W) on the eastern plains of Colombia (i.e. Llanos). Animals had always free access to fresh water and to a complete mineral commercial supplement that was monitored on a fortnightly basis. The standard mineral formulation included per kg of commercial product 175 g Na, 269 g Cl; 80 g P, 137 g Ca, 20 g S, 1.038 g Cu, 3.5 g Zn, 10 mg Co and 76 mg I.

Mean annual rainfall and ambient temperature of 2,202 mm/m^2 and 26.5 ^{o}C were recorded at CRS from 1979 to 1991 with the December-March period (short-dry season) historically characterized by low rainfall rates (~7% of total precipitation) and warmer climate (~28 ^{o}C; Vera and Ramírez-Restrepo 2017). In all cases, care of Brahman (*Bos indicus*) and crossbred [Brahman x San Martinero (native; *B. taurus*)] cattle and experimental procedures was monitored by registered Doctors of Veterinary Medicine at CRS to fully comply with national husbandry and animal welfare regulations (Vera and Ramírez-Restrepo 2017).

Preliminary trials on Andropogon gayanus cv. Carimagua 1, Melinis minutiflora and Stylosanthes capitata cv. Capica mixed pasture

Forages and grazing management

Twenty ha of a two-years mixed sward located on a silty clay loam oxisol soil were subdivided into three equal paddocks to accommodate during the first (184 days) and second (194 days) rainy seasons, SRs of 1.38 (low), 1.85 (medium) and 2.32 (high) animal units (AU)//ha, while during the short-dry season (127 days) 0.64, 0.85

and 1.07 AU/ha were stocked. This factorial combination with different animal categories [i.e. cull cows, steers, castrated yearlings (afterwards named yearlings) and young heifers] and management system where individual animals were considered as replicates was designed to ensure that forage availability and its quality would not be a limiting factor. Experimental areas were fertilized with 20 kg/ha of phosphorus (P) every 3 years.

Plant measurements

Pre-grazing herbage mass and botanical composition were estimated every 56 days using the BOTANAL procedure (Jones and Tothill 1985). Forage intake was not measured. Hand-plucked samples were obtained simultaneously by three operators imitating forage selected by the animals (Johnson 1978). Representative subsamples (~ 120 g) were dissected into leaf, stem and dead material (Ramírez-Restrepo *et al*. 2004, 2005), while pooled observed ingested forage samples were stored at -20ºC for later nutritive value analysis.

Animal measurements

Adult cattle (316 ± 13 kg; initial LW, ILW ± standard deviation, SD), yearlings (154 ± 20 kg) and heifers (149 ± 16 kg) were used during the rainy seasons. Subsequently, the remaining yearlings (150 ± 19 kg) and heifers (200 ± 33 kg) were monitored during the dry season. The LW was measured off the paddocks at approximately 56-day intervals. Fecal grab samples were collected from all animals during the initial rainy season and from yearlings and heifers over the dry season to discard nutrient deficiencies other than energy. Samples were frozen at -20ºC and later thawed, dried and ground to determine nutrient levels (Ramírez-Restrepo *et al*. 2006).

Laboratory analyses

All forage and fecal samples were analyzed for total N, P and Ca concentrations following the micro-Kjeldhal, colorimetry and atomic absorption methodologies respectively at CIAT.

Long term trials on A. gayanus-based swards

Forage, animals and grazing management

The same mixed grassland preliminary used allowed between 1985 and 1989 to raise mixed groups composed of 10 animals of each of the following categories: cull cows (10-13 years of age), steers (3-5 years), yearlings and heifers (1-1.5 years) under continuous grazing. Every year a new group of 40 animals (i.e. 10 per category) selected from the commercial herd entered the experiment 30-45 days after the beginning of the rainy season to rest the sward and continued there until the end of the following dry season when the paddocks were vacated. During the rainy season, a single SR of 1.33 AU/ha was used, while after removal of adult cattle a SR of 0.70 AU/ha was implemented over the dry season.

Liveweight performance

Changes in LW were initially measured at days 0 and 4 attempting to equalize rumen fill of all categories, as animals were sourced from different provenance at CRS. Overall LWGs were further recorded approximately at 23, 42, 35, 30 and 24-day intervals during 1985, 1986, 1987, 1988 and 1989, respectively. During the last year, five animals of similar age in each group were implanted with commercial growth promoting implants placed in the middle third of the back side of the ear (Zobell *et al.* 2000). Averaged over the five years, the length of the period during the rainy season was 175 ± 21 days (range between 146 and 201 days).

Yearlings and heifers remained on the pasture during the dry season of two consecutive years (1986 and 1987), until they began to lose body weight. This resulted in grazing seasons of 210 and 216 days, respectively. Overall, the LW database during the five grazing seasons included 1,441 data points for a total of 200 animals.

Complementary studies on Brachiaria humidicola

In 1987, 1988 and 1989, parallel trials were conducted under continuous grazing with groups (*n* = 10) of cull cows and steers stocked at 1.5 AU/ha, during 179, 181 and 146 days, of the rainy season, respectively on a seven-year old pasture of *B.*

humidicola that received a maintenance application of 20 kg of P. Following the same experimental protocol, LW measurements were taken approximately at 36, 30 and 24-day intervals. Half of each animal group, equalized for age, was implanted during the last year. The total database contained 279 data points.

Data sets and its management

Carcass characteristics

Derived carcass proportions, primary cuts and meat composition from *Bos indicus x native Bos taurus* crossbred cattle at the farm gate were extracted from the database as outlined by Velásquez and Ríos (2010) and Ramirez-Restrepo *et al*. (2017).

Estimations of methane emissions

Daily (g) and yield (g/kg dry matter intake, DMI) CH_4 emissions were derived from the tropical structural and functional relationships (McArdle 1988) between gas emissions and LW (Eq. 1), and between feeding *ad libitum* on a DM basis (i.e. DMI; 2.1% of total LW; Fisher *et al.* 1987) per kg of LW (Eq. 2), using healthy, quiet temperament, and well trained Belmont Red Composite [Africander (African Sanga) x Brahman x Hereford-Shorthorn (3/4 *B. taurus*; Ramírez-Restrepo *et al*. 2014, 2016c)] and Brahman steers (Ramírez-Restrepo *et al.* 2016b). Hence, the emissions estimations are reasonable reliable.

Data was recorded on a non-additive dry diet from open-circuit respiration chambers with volumes of ~19.000 L and 360^o of visibility for each of the 16 rumen-cannulated and 2 non-cannulated steers. Information was taken out of 54 consecutive sampling periods of 48-hours measurements. The chamber system always operated under a negative pressure (-10.1 ± 0.14 Pa) to avoid gas losses, while outside ambient temperature was always 2^{o}C higher than in each of the transparent units to avoid animal discomfort, stress and reduced DMI. Live weight was recorded minutes before animals were placed in individual chambers and immediately after the last day of measurements (Ramírez-Restrepo *et al.* 2014, 2016ab). The resulting predictive equations are as follows:

Eq. 1.

CH_4 g/day = 16.176 (± 21.0879) + 0.324 (± 0.0577) (LW)

$r^2 = 0.663$, $P < 0.0001$; CV = 16.78; r.s.d = 30.82; r = 0.81, $P < 0.0001$;

Eq. 2.

DMI = 2.216 (± 1.3156) + 0.014 (± 0.0036) (LW)

$r^2 = 0.491$, $P < 0.01$; CV = 18.94; r.s.d = 1.34; r = 0.70, $P < 0.01$

Another derived calculation is CH_4 yield that measures the mathematical representation of CH_4 emissions (g/day) divided by DMI/day. The breakdown of CH_4 emissions in terms of equivalent carbon dioxide (CO_2eq) unit of gas is obtained by multiplying the fermented gas by its global warming potential (GWP_{100} 34; Myhre *et al.* 2013). To assess the accuracy of our daily CH_4 emissions (g), we have compared our derived values firstly with predicted output using the IPCC tier 3 Ruminant model (Herrero *et al.* 2013) as described by Ramírez-Restrepo *et al*. (2017). The required feed-data base was developed by the present authors considering reported quality and composition of 43 forage diets (i.e. grasses, legumes and mixed pastures), most of them grazed experimentally at CRS contemporarily with the present results. Secondly, we also compared our estimations with derived values from Kennedy and Charmley (2012) by the application of the third equation relating LWs and respiratory chamber measurements. The later research fed Brahman steers (i.e. 242 kg to 372 kg) once daily with long-chopped diets composed by hay mixed grasses plus hay legumes and fresh *Leucaena leucocephala* to mimic further grazing conditions and diet selection.

Eq. 3.

CH_4 g/day = - 56.650 (± 15.4778) + 0.502 (± 0.0496) (LW)

$r^2 = 0.695$, $P < 0.0001$; CV = 16.08; r.s.d = 23.92; $r = 0.83$, $P < 0.0001$

2.1.5 Statistical analyses

Data was analyzed using the Statistical Analysis System (SAS, University Studio 3.5, Cary, NC, USA) and results are presented as least squares means and their standard errors unless otherwise stated.

In the preliminary studies, mean values of LW, pre-grazing herbage mass, plant composition and sward botanical composition were monitored. Measurements of mineral content in fecal DM and LWGs during the wet and dry seasons were analyzed using the MIXED procedure with a linear fitted model that included the fixed effects of animal category and SRs.

Over the long-term trials, differences in initial and final LWs LWGs and derived values of carcass traits, meat composition, DMI, CH_4 emissions and CH_4 intensity and efficiency productive indices between cull cows and steers were assessed using the MIXED procedure. The linear model included the fixed effects of the interaction amongst year, pasture and animal category. Data for LWGs and estimated values of CH_4 emissions, DMI for yearlings and heifers were performed using the MIXED procedure. The fixed linear model considered the effects of year and animal category and the year by animal category interaction. Analyses of variance for repeated measures of LW on the same animal in each year were analyzed using the linear GLM procedure with the fitted variable being animal category (i.e. cull cows, steers, yearlings and heifers). An additional analysis was made for the last year using a model that included the fixed effects of the implanting strategy. Regressions equations and correlations between CH_4 emissions, LW and DMI on the Ramírez-Restrepo *et al.* (2014, 2016ab) and Kennedy and Charmley (2012) datasets were obtained using the CORR and REG procedures. Comparison of intercepts and slopes was obtained using the option contrast in the linear GLM procedure. Correlations between our derived CH_4 emissions and measured LWGs, and those values predicted by the Ruminant model were performed using the CORR procedure. Significant differences were considered at $P < 0.05$ and tendency to significance accepted at $P < 0.10$.

Results

Preliminary trials

Forages and botanical composition

Over the rainy seasons, averaged pre-grazing herbage mass increased from 6,000 kg DM/ha in the high SR to 7,500 kg DM/ha in the low SR, while pre-grazing green leaf content in the same SR levels ranged from 1,800 to 5,000 kg DM/ha, respectively. During the dry season, green leaf averaged 700 kg DM/ha with no difference between SRs. Botanical composition throughout the experiment was *A. gayanus* (70-75%) followed by *M. minutiflora* (15-25%) and *S. capitata.* (10%). This was associated with neutral detergent fiber (NDF) and crude protein (CP) sward mean concentration values of 727 g and 87 g/kg DM during the rainy season and 737 g and 89 g over the dry season.

Mineral supplement intake and fecal mineral profile

Across the seasons, averaged daily intake of mineral supplement was 56, 65, and 68 g/AU for the low, medium and high SRs, respectively. Fecal concentrations of N, P and Ca during the first rainy season and dry season are presented in Table 1. During the wet season, N and P concentration were similar among all animal categories, but Ca values of yearlings were higher than those of heifers and steers ($P < 0.05$), and cull cows ($P < 0.01$). There were no SR effects on P concentrations however, while low and high SRs had similar N concentration, the opposite was true for calcium values ($P < 0.05$).

Liveweight change

Averaged across animal categories, daily mean LWGs were larger ($P < 0.05$) for the low SR than in the medium and high SRs in both the rainy (577 g, 468 g and 496 g) and the dry seasons (269 g, 186 g and 137 g). Cull cows gained less daily weight

($P < 0.01$) than the average of the other three categories during the rainy season (422 g vs 544 g), while no differences between yearling and heifers were recorded during the dry season (mean 197 g).

Long term trials

Sward composition, plant measurements and pattern of seasonal grazing

Over the last four years the contribution of *S. capitata* to the *A. gayanus* based pasture was marginal (5%). During the wet season, pre-grazing herbage mass ranged from 5,000 to 6,000 kg DM/ha, while sward height was between 0.8 and 1 meter. In the wet and dry seasons NDF and CP concentrations reached 752 g vs 754 g/kg DM and 83 g vs 91 g/kg DM, respectively.

Brachiaria humidicola on offer was consistently lower and ranged between 2,000 and 3,500 kg DM/ha. However, the quality of the pasture did not differ from other contemporary experiments in the same area (Cajas *et al*. 1985; Vera *et al*.1993) as values of NDF and CP ranged between the wet and dry seasons from 730 g and 731 g/kg DM and between 71 g and 74 g/kg DM. Consequently, the length of the rainy season grazing period varied very little over three consecutive years (166 ± 9.5 days, mean ± SD).

Live weight performance and calculated intake and methane emissions of young cattle

Initial LW (kg) was similar between heifers and yearlings on the *A. gayanus* based pasture in 1985 (158 ± 5.40 vs 161 ± 5.70), 1986 (146 ± 4.50 vs 147 ± 4.50), 1987 (160 ± 7.32 vs 159 ± 8.19) and 1988 (173 ± 7.81 vs 171 ± 7.81). However, in 1989 heifers tended ($P = 0.08$) to be heavier (199 ± 7.06) than yearlings (181 ± 6.56). All groups reached similar final LW (FLW) in the first (198 ± 7.97 vs 212 ± 8.41), second (241 ± 8.65 vs 248 ± 8.65), fourth (230 ± 7.62 vs 238 ± 7.62) and fifth (260 ± 10.78 vs 245 ± 10.16) years, but in the third-year heifers (207 ± 9.45) were lighter than steers (248 ± 10.57; $P < 0.01$). Overall, daily gains (g) were lower in heifers (330 ± 9.92) than in yearlings (397 ± 9.92; $P < 0.0001$), while implanting practices did not improve LWGs ($P > 0.05$). Heifers and yearlings had similar averaged DMI (4.95 ± 0.02 kg). However, the calculated intake was approximately 4% higher ($P < 0.05$) in yearlings than in heifers in 1987 and 1989, respectively.

Methane estimations throughout the experimental years are shown in Fig. 1a and 1b. Although overall daily emissions (g) were similar between heifer and yearlings (78.8 ± 0.68 vs 79.0 ± 0.68), a year x category interaction ($P < 0.05$) was detected for daily emissions in two (i.e. 1986 and 1987) out of the five years. As expected, compared to yearlings, heifers tended to have lower yield emissions in the third year ($P = 0.07$), while the opposite occurred in the last year ($P < 0.05$). Averaged yield emissions were similar between both animal categories (15.8 ± 0.04).

Live weight profiles and derived values of carcass productivity, intake and environmental footprint of adult cattle

The effects of grasslands on LW performance and associated productive and environmental adult cattle footprints are presented in Tables 2 and 3. Steers gained 24% ($P = 0.07$), 5%, 12%, 35% ($P = 0.06$) and 4% more weight than cull cows in each of the consecutive years grazing the *A. gayanus* mixed pasture. Compared to steers, the later increase in percentage was also true for cull cows in the first year of comparisons on *B. humidicola*. However, although there was not an implant effect on LWGs in any forage treatment of 1989, daily LWGs in steers grazing *B. humidicola* were 25% and 67% greater than their counterparts in 1988 and 1989, respectively ($P < 0.001$).

Essentially with similar FLW between cull cows and steers, there was no difference among predicted carcass characteristics and meat composition on *B. humidicola* (1987) and the *A. gayanus* predominant pasture (1989, Tables 2 and 3). Equal effect was observed between adult animal categories in both swards on estimated DMI (Table 4 and 5). Thus, the estimates of CH_4 emissions in those years did not differ from most of those obtained for other sward-year experimental interactions (Table 4 and 5).

Discussion

In the context of the beef industry of the neotropical savannas in Colombia, the first objective of this study highlights the relation between the use of introduced pastures under different SRs and the body growth of four animal categories. The second contribution of this paper presents an approach to explore the impact of such management and cattle productivity on derived carcass indicators in adult cattle and estimations of methane emissions in all animal categories. Given current and ongoing constraints regarding the financing of long-term grazing research, the authors believe that the limited long-term data set of animal performance available should be used to apply newer knowledge and models in an endeavor to assess some of the likely results in terms of carcass quality and environmental impact. This is particularly important given current controversies on the role of ruminants, particularly in frontier regions. The authors justify this aim by the fact that keeping safe the original records, we could conceive, design and apply new knowledge on the original dataset to guarantee access to the updated information in times of lack of funding and proactive management.

From this perspective, this study adds to knowledge of cattle performance management by showing that overall LWGs (g/day) on *A. gayanus* mixed swards were significant different ($P < 0.05$) amongst steers (560 ± 0.01), cull cows (486 ± 0.01), yearlings (397 ± 0.01) and heifers (330 ± 0.01), while averaged LWGs from 1985 to 1989 were 453, 528, 355, 394 and 486 ± 0.02. In addition, this study argues that over three years, steers on *B. humidicola* swards gained 560 ± 0.02 g/day vs 464 ± 0.02 g/day ($P < 0.001$) in cull cows, whilst LWGs were similar between 1987 and 1989 (542, 513 and 513 ± 0.02 g/day). To the authors knowledge, there is no comparable experimental information about the performance of adult animals in the study region, but it supports, the limited number of available on ranch observations.

Thus, given the fact that irrespective of the year, all studied cattle were subject to a similar commercial management considerations, differences in LW performance most likely reflects a variability and/or interaction amongst environmental conditions (Domínguez *et al.* 2003; Singh *et al*. 2012); growth traits, including compensatory gains (Hernández-Hernández *et al*. 2015); genetic parameters and their interacting networks (Ceacero *et al*. 2016; Lopes *et al.* 2013; Pereira *et al*. 2016); hormones secretion (Kasuya 2016; Widmann *et al*. 2013); maternal effects (Neidhardt *et al*. 1979); grazing management (Vera and Ramírez-Restrepo 2017); diet selection (O'Neill *et al*. 2013); nutritive and metabolic trigger factors in the forage resources (Tedeschi *et al*. 2014); and the adaptive capacity of Brahman and Belmont Red Composite to respond to those triggers within a climate change environment (Ramírez-Restrepo and Charmley 2015). In parallel, a particularly relevant aspect is that putting weight on cull cows in thin to medium condition has been found to be more profitable than cows with higher body scores (Amadou *et al.* 2014).

Lascano and Euclides (1996) cite unplublished work by Lascano that shows over 16 consecutive years of grazing a *B. decumbens* cv. Basilisk pasture, a mean, year-round gain of 137 kg/steer, with extremes of approximately 50 and 175 kg/animal. An extremely heavy rainy season (i.e. 3,000 mm) compounded further by a heavy spittlebug (*Aeneolamia*, *Deois* and *Zulia* spp.) attack on the grass were the main factors suggested as causes of the lowest growth rate. This in turn was also supported by similar averaged LWGs per AU in the first year after sward establishment and during the last annual grazing 15 years later (384 g). In agreement with our *A. gayanus* based LW results, this evaluation highlighted that the careful choice of grazing intensification (i.e. seasonal SRs) and appropriate sward fertilization avoids signs of pasture degradation and influences in the long-term the potential for LWGs in beef farming system efficiency.

Alternative methods of monitoring the pastures have been also investigated. Four-year grazing experiments using *A. gayanus* in combination with one of four legumes demonstrated very large between-year differences in daily LWGs/AU ranging from 164 g to 420 g in the dry season, while between 462 g and 708 g were achieved in the rainy season (Lascano and Euclides 1996). However, part of these differences was likely due to the variable and generally decreasing, contribution of the legumes to the forage on offer over successive years. Moreover, two to three-year grazing results from *A gayanus*-legume associations summarized by Lascano and Thomas (1988) have shown equally variable between-years LWG's differences, possibly due to a variable legume density on the sward.

Nevertheless, our *A. gayanus* mixed sward results showed less variation in animal performance between years, but it still was large enough to justify caution in generalizing about potential impact on animal production and/or its cause. The reason for this within and between animal variability in grazing conditions is not known, but O'Neill *et al.* (2013) reported that diet selection of Brahman and Belmont Red Composite cattle grazing together in the tropical rangelands appears to be regulated by a dynamic interaction amongst genotype, environment and management factors. In this condition, the crossbred cattle had large CP intake and grew faster than the Brahman group. However, additional investigations and/or further dataset analysis will be required to better clarify the significant effects of physiological, breed and sire effects (Ramírez-Restrepo and Charmley 2015).

On the other hand, ignoring differences between experimental groups on *B. humidicola*, the annual LWGs presented here are in contrast with results summarized by Lascano and Euclides (1996) where over a five-year period *B. humidicola* (Syn. *B. dictyoneura*) cv Llanero showed under a similar SR a linear decrease in LWGs/AU from 384 g/day to 192 g/day, whereas LWGs on a contemporary *B. humidicola* cv. Humidicola pasture ranged between 137 g/day and 274 g/day. This implies that although none of the summarized experiments compared at the same time young and adult cattle in the same experiment, our interaction amongst adult cattle, environment and *B. humidicola* is more efficient when our pre-grazing herbage mass range is considered. However, further long-term pastoral studies would be needed to confirm such hypothesis.

Another important outcome from our trials is that the observed animal performance was similar to on-farm observations reported for by Vera and Seré (1989), which provides credibility to the naturally more variable on-farm reports. Thus, long-term grazing experiments are essential in providing a firm basis for recommendations regarding the management of properties and resources (Blench 2001; O'Reagain and Scanlan 2013; Scanlan *et al*. 2013); and for adequately matching animal genotype and its expressed phenotype to those production resources, particularly as costs of production and competition for land resources increase (Mulliniks *et al*. 2015).

As there have been very few long-term grazing experiments conducted on tropical pastures in the Neotropics, estimates of carcass merits were calculated as a baseline reference point at the farm gate assuming that the values produced by our mature cattle were processed in a commercial slaughterhouse. In practice, the similarity of the grazed cattle, animal handling, transport conditions to the slaughter house and pre-slaughter operations reported by Velásquez and Ríos (2010) indicated that our results are likely to be correct. This may be an advantage because to the knowledge of the authors, no reports have been published describing carcass and meat variables from cull cows and steers grazing all together on improved pastures in the neotropical savannas, with which to compare our derived data.

Overall, the basic premise in conducting this research was that cull cows, excess heifers and steers constitute important components of extensive beef breeding systems that can be grazed on pasture-based systems to provide a ready source of income if their LWs are raised without necessarily reaching a fat condition as suggested by Vera and Seré (1989). However, we consider pertinent to report from our observational records and in agreement with previous studies (Schmitt 1998; Durán 1998) that on the Colombian Llanos, beef systems located closer to central markets, slaughter plants and/or paved roads maintain lower proportions of these animals. The reason is because introduced pastures and farm management practices impact positively body growth and the turnover of cattle is dynamic and quick.

In contrast, young cattle (i.e. 1-3 years of age) are low priority categories in extensive systems and are relegated to low quality pastures, whereas in more intensive grazing systems young females are generally bred before reaching 3 years of age (Vera *et al.* 1993; Vera *et al.* 2002). The most prominent additional feature of this cattle productive system is that older cows are culled following weaning and/or during the dry season, when they have lost 15 to 25% of the LW recorded at conception as described by Vera *et al.* (2002). The combined inefficiency is mitigated to a large extend by placing those fragile cows on quality pasture to make compensatory gains (Lawrence and Fowler 2002). Such occurrence is later associated with meat of acceptable quality (Galli *et al.* 2008; Stelzleni *et al.* 2007), which even in low input systems, represent significant economic returns (Amadou *et al.* 2014; Vera and Seré 1989).

Sustainable intensification associated with reduced CH_4 emissions from ruminant production systems using forage-based diets is a global milestone for the scientific community (Peters *et al.* 2012; Ramírez-Restrepo and Barry 2005; Singh *et al*. 2012; Vandermeulen *et al*. 2017). In this connection, our emission results suggest that averaged daily emissions from all animal categories on *A. gayanus* mixed swards were similar in 1986 and 1989 (110.9 ± 1.18 g vs 109.6 ± 1.18 g), but different ($P < 0.05$) to the emissions profile in 1985, 1987 and 1988 (106.6 ± 1.22 g, 104.0 ± 1.18 g and 103.7 ± 1.20 g). Overall throughout the five-year period, cull cows emitted 10% less CH_4/day (128.7 ± 1.06 g) than steers (141.5 ± 1.09, $P < 0.0001$), while on *B. humidicola,* cull cows emitted 7% less CH_4 than steers (127.6 ± 2.26 g vs 136.8 ± 2.16 g, $P < 0.01$) across three years. Together, those apparent differential methanogenic values might be explained by the recent *in vitro* fermentative study of Durmic *et al.* (2017a) who shows that irrespective of seasonal variations, amongst 23 tropical screened grasses, *A. gayanus* was one with the lowest CH_4 production [millilitres/g DM incubated (DMi)] plants (28.7 mL/g DMi), while *B. humidicola* recorded higher levels (14%) of annual methanogenic potential. However, it does not rule out that some bioactive compounds in *A. gayanus* and/or the associated native and introduced plants in our experimental mixed-swards could potentially influence future CH_4 emission profiles as described by Durmic *et al.* (2017b).

Data from previous studies using Brahman steers (i.e. 311 kg to 417 kg LW) have shown that when fed *ad libitum* tropical pasture (30%) hay-mixed diet, DMI accounted for 2.1% of the total LW (Chaokaur *et al.* 2015), in agreement with our supported assumption using 15% of forage on the DM (Ramírez-Restrepo *et al*. 2014, 2016bc). In contrast, Chaokaur *et al.* (2015) reported daily and yield emissions of 163.7 ± 4.96 g and 25.1 ± 0.72 g, respectively, which does not agree with the results from adult cattle in the present study. This suggests that although cattle are physically limited in terms of the DM they can consume (Fisher *et al.* 1987), their CH_4 emissions are variable in a response to the diet composition and its feeding value that finally is likely shaped on their body weight by phenotypical expressions of their genotype code.

However, although we did not estimate emissions from bulls, our study is in better agreement with the report of Menezes *et al.* (2016) who found that Nellore young bulls fed a grain-concentrate diet with 120 g CP/kg DM emitted 150.2 ± 8.83 g CH_4/day. Do CH_4 emissions from grazing bulls differ from other cattle categories in tropical grasslands? To our knowledge, this is unknown. However, field measurements using the sulphur hexafluoride gas technique (Ramírez-Restrepo *et al*. 2010) or concomitant indoor practices with the tracer gas and open-circuit respiratory chambers (Ramírez-Restrepo *et al.* 2016a) feeding green DM diets would help elucidate potential animal, breed and physiological variabilities and/or age-related CH_4 emission factors to refine estimations on the current tier 1 and tier 2 national GHG inventory (IDEAM 2016).

It may be also inferred from our study that our mathematical approximation may reflect the mitigation effect of some plant secondary compounds such as condensed tannins as our intercept and slope are similar to those in the Kennedy and Charmley (2012)'s derived regression feeding tropical grasses plus secondary compounds-containing legumes (Jackson *et al.* 1996; Li *et al.* 1996; Castrejón *et al.* 2003). Moreover, our daily estimated emissions coincided with the stoichiometric and algorithmic estimations generated by the Ruminant model using LW and the constructed quality-feed data input (Herrero *et al.* 2013). However, the authors observed that the model underpredicted LWGs compared to our measured records.

In summary, as suggested above, cow-calf systems in the Orinoco basin are complex and multidimensional (Ezzano 2005; Vera *et al.* 1993, 2002; Vera and Ramírez Restrepo 2017). However, the present paper has only touched on a small number of their characteristics, whereas others related to additional environmental and social impacts have been addressed elsewhere (Hoogesteijn and Chapman 1997; Navas-Ríos 1999).

Conclusions

The acceptable body weight gains realized by adult animals on low quality pastures, particularly that of low external input *B. humidicola* paddocks, supports the decision by many Colombian graziers to prioritize this type of use of improved sown pastures seeking to obtain rapid returns on pasture investments in the initial stages of ranch intensification. So together there is no evidence in this study to suggest that the methodical use of improved pastures is contrary to an efficient and sustainable cattle productivity in the Colombian tropical savannas. However, the large differences in performance between animal categories and between years in contemporary swards, reinforce the need to reach a compromise between producers, the scientific community and commercial networks to use adapted plant and animal genetic resources, and support further field research.

Part of the significance of the present results derive from the duration of the experiments conducted using low external inputs and adequate, but not necessarily optimal, management resembling current ranch management practices. Thus, in the face of the growing climate variability, the authors hope that the current study may increase awareness of the environmental impact and tradeoffs of the beef industry in the Colombian Eastern Plains. However, it is postulated that to improve the livelihoods of beef farming systems and their dependent rural communities the decided support from the Colombian Government and the continued collaboration with international agencies is essential.

Conflict of Interest

The authors declare no conflicts of interest.

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Table 1. Mineral concentrations (g/kg) of fecal dry matter associated with grazing cull cows, steers, castrated yearlings and heifers stoked at 1.38, 1.85 and 2.32 animal units (UA)/ha at Carimagua Research Station, Colombia. Additional metabolic profiles of young animal categories refer to stocking rates (SR) of 0.64, 0.85 and 1.07 AU/ha

[†]Three and two fecal grab samples were collected from each animal over the rainy and dry seasons, respectively. Values between animal categories and between SRs within each season and similar column followed by the same letter are significantly different (ab.: $P < 0.05$; cd.: $P < 0.01$; ef.: $P \leq 0.10$)

	Nitrogen	**Phosphorus**	**Calcium**
First rainy season[†]			
Cull cows	1.65 ± 0.080^{a}	0.38 ± 0.029^{a}	0.33 ± 0.032^{db}
Steers	1.65 ± 0.080^{a}	0.38 ± 0.029^{a}	0.37 ± 0.032^{b}
Heifers	1.81 ± 0.080^{a}	0.39 ± 0.029^{a}	0.40 ± 0.032^{b}
Castrated yearlings	1.81 ± 0.080^{a}	0.46 ± 0.029^{a}	0.52 ± 0.032^{ac}
Low SR	$1.96 \pm 0.069_{ac}$	0.41 ± 0.025^{a}	0.35 ± 0.027^{b}
Medium SR	1.44 ± 0.069^{bd}	0.40 ± 0.025^{a}	0.41 ± 0.027^{ab}
High SR	1.80 ± 0.069^{a}	0.40 ± 0.025^{a}	0.46 ± 0.027^{a}
Short-dry season[†]			
Heifers	2.08 ± 0.099^{a}	0.38 ± 0.030^{a}	0.36 ± 0.041^{a}
Castrated yearlings	2.13 ± 0.099^{a}	0.46 ± 0.030^{a}	0.40 ± 0.041^{a}
Low SR	2.24 ± 0.122^{a}	0.34 ± 0.037^{fa}	0.29 ± 0.051^{a}
Medium SR	2.00 ± 0.122^{a}	0.54 ± 0.037^{ae}	0.38 ± 0.051^{a}
High SR	2.08 ± 0.122^{a}	0.39 ± 0.037^{a}	0.47 ± 0.051^{a}

Table 2. Effect of grazing cull cows and steers on *Andropogun gayanus*, *Mellinis minutiflora* and *Stylosanthes capitata* (AgMmSc; 70:20:10), *A. gayanus* plus *S. capitata* (AgSc; 95:5) or *Braquiaria humidicola* (Bh) swards upon body growth, and calculated carcass cuts and meat composition from 1985 to 1987 at Carimagua Research Station, Colombia

[†]Adapted from Velásquez and Ríos (2010). [‸]Calculated as the sum of forequarter, hindquarter and industrial meat mince values. [‡]Adapted from Ramirez-Restrepo *et al.* (2017) as lean meat x 0.26 factor (raw meat protein content). Values between animal category for each parameter within the same forage column followed by the same letter are not significantly different (ab.: $P < 0.05$; cd.: $P < 0.01$; ef.: $P < 0.001$; gh.: $P < 0.0001$; ij.: $P \leq 0.10$)

	Pastures							
	AgMmSc-85		AgSc-86		AgSc-87		Bh-87	
	Cow	Steer	Cow	Steer	Cow	Steer	Cow	Steer
Animals	10	8	10	10	10	10	9	9
Initial live weight (LW, kg)	312 ± 9.54^{f}	362 ± 10.66^{e}	293 ± 10.05^{d}	336 ± 9.54^{c}	309 ± 9.54^{b}	337 ± 9.54^{a}	308 ± 10.05^{a}	297 ± 10.05^{a}
Final LW (FLW, kg)	405 ± 12.15^{f}	474 ± 12.89^{e}	404 ± 11.53^{d}	447 ± 11.53^{c}	386 ± 11.53^{b}	424 ± 11.53^{a}	407 ± 12.15^{a}	392 ± 12.15^{a}
LW change (g/day)	561 ± 50.03^{j}	698 ± 53.06^{i}	573 ± 50.03^{a}	602 ± 47.46^{a}	383 ± 47.46^{a}	430 ± 47.46^{a}	550 ± 50.03^{a}	534 ± 50.03^{a}
Carcass features[†]								
Hot carcass weight (CW, kg)	202 ± 6.07^{f}	236 ± 6.44^{e}	201 ± 5.76^{d}	223 ± 5.76^{c}	193 ± 5.76^{b}	211 ± 5.76^{a}	203 ± 6.07^{a}	196 ± 6.07^{a}
Cold CW (kg)	193 ± 5.79^{f}	226 ± 6.14^{e}	192 ± 5.50^{d}	213 ± 5.50^{c}	184 ± 5.50^{b}	202 ± 5.50^{a}	194 ± 5.79^{a}	187 ± 5.79^{a}
Forequarter (kg)	49 ± 1.47^{f}	57 ± 1.56^{e}	48 ± 1.39^{d}	54 ± 1.39^{c}	46 ± 1.39^{b}	51 ± 1.39^{a}	49 ± 1.47^{a}	47 ± 1.47^{a}
Hindquarter (kg)	53 ± 1.61^{f}	62 ± 1.70^{e}	53 ± 1.52^{d}	59 ± 1.52^{c}	51 ± 1.52^{b}	56 ± 1.52^{a}	53 ± 1.61^{a}	52 ± 1.61^{a}
Industrial mince (kg)	14 ± 0.44^{f}	17 ± 0.46^{e}	14 ± 0.41^{d}	16 ± 0.41^{c}	14 ± 0.41^{b}	15 ± 0.41^{a}	14 ± 0.44^{a}	14 ± 0.44^{a}
Subproducts (kg)	59 ± 1.77^{f}	69 ± 1.87^{e}	58 ± 1.68^{d}	65 ± 1.68^{c}	56 ± 1.68^{b}	61 ± 1.68^{a}	59 ± 1.77^{a}	57 ± 1.77^{a}
Commercials (kg)	0.9 ± 0.02^{h}	1.1 ± 0.03^{g}	0.9 ± 0.02^{d}	1.0 ± 0.02^{c}	0.9 ± 0.02^{b}	1.0 ± 0.02^{a}	0.9 ± 0.02^{a}	0.9 ± 0.02^{a}
Cuts with bones (kg)	15 ± 0.47^{f}	18 ± 0.50^{e}	15 ± 0.44^{d}	17 ± 0.44^{c}	15 ± 0.44^{b}	16 ± 0.44^{a}	15 ± 0.47^{a}	15 ± 0.47^{a}
Lean meat weight (kg)[‸]	117 ± 3.52^{f}	137 ± 3.73^{e}	117 ± 3.34^{d}	129 ± 3.34^{c}	112 ± 3.34^{b}	123 ± 3.34^{a}	118 ± 3.52^{a}	113 ± 3.52^{a}
Edible protein (kg)[‡]	30 ± 0.91^{f}	35 ± 0.97^{f}	30 ± 0.86^{d}	33 ± 0.86^{c}	29 ± 0.86^{b}	31 ± 0.86^{a}	30 ± 0.91^{a}	29 ± 0.91^{a}

Table 3. Impact of *Andropogon gayanus* plus *S. capitata* (AgSc; 95:5) or *Braquiaria humidicola* (Bh) pastures on body growth, derived carcass values and edible meat protein content of Brahman (*B. indicus*) and crossbred [Brahman x San Martinero (native; *B. taurus*)] cattle during the finishing grazing periods of 1988 and 1989 on the eastern plains of Colombia

[†]Adapted from Velásquez and Ríos (2010). [*]Estimated as the sum of forequarter, hindquarter and industrial meat mince data.[‡]Derived as lean meat x 0.26 factor ([raw meat protein content; Ramirez-Restrepo *et al*. (2017)]. Values between animal category for each variable within the same pasture treatment followed by the same letter are not significantly different (ab.: $P < 0.05$; cd.: $P < 0.01$; ef.: $P < 0.001$; gh.: $P < 0.0001$; ij.: $P \leq 0.10$)

	Pastures							
	AgSc-88		Bh-88		AgSc-89		Bh-89	
	Cow	Steer	Cow	Steer	Cow	Steer	Cow	Steer
Animals	10	9	8	9	10	10	9	9
Initial live weight (LW, kg)	285 ± 9.54^{h}	340 ± 10.05^{g}	296 ± 11.40^{b}	341 ± 10.05^{a}	323 ± 9.54^{a}	343 ± 9.54^{a}	313 ± 10.05^{a}	342 ± 10.05^{a}
Final LW (FLW)	354 ± 11.53^{h}	433 ± 12.15^{g}	379 ± 13.78^{h}	444 ± 12.15^{g}	401 ± 11.53^{a}	424 ± 11.53^{a}	370 ± 12.15^{h}	433 ± 12.15^{g}
LW change (g/day)	381 ± 47.46^{j}	516 ± 50.03^{i}	457 ± 56.73^{a}	569 ± 50.03^{a}	534 ± 47.46^{a}	553 ± 47.46^{a}	384 ± 50.03^{f}	642 ± 50.03^{e}
Carcass characteristics[†]								
Hot carcass weight (CW, kg)	177 ± 5.76^{h}	216 ± 6.07^{g}	189 ± 6.89^{f}	221 ± 6.07^{e}	200 ± 5.76^{a}	211 ± 5.76^{a}	184 ± 6.07^{f}	217 ± 6.07^{e}
Cold CW (kg)	169 ± 5.50^{h}	206 ± 5.79^{g}	180 ± 6.57^{f}	211 ± 5.79^{e}	191 ± 5.50^{a}	202 ± 5.50^{a}	176 ± 5.79^{f}	208 ± 5.79^{e}
Forequarter (kg)	42 ± 1.39^{h}	52 ± 1.47^{g}	45 ± 1.67^{f}	53 ± 1.47^{e}	48 ± 1.39^{a}	51 ± 1.39^{a}	44 ± 1.47^{f}	52 ± 1.47^{e}
Hindquarter (kg)	46 ± 1.52^{h}	57 ± 1.61^{g}	50 ± 1.82^{f}	58 ± 1.61^{e}	53 ± 1.52^{a}	56 ± 1.52^{a}	49 ± 1.61^{f}	57 ± 1.61^{e}
Industrial mince (kg)	12 ± 0.41^{h}	15 ± 0.44^{g}	13 ± 0.50^{f}	16 ± 0.44^{e}	14 ± 0.41^{a}	15 ± 0.41^{a}	13 ± 0.44^{f}	15 ± 0.44^{e}
Subproducts	51 ± 1.68^{h}	63 ± 1.77^{g}	55 ± 2.00^{f}	64 ± 1.77^{e}	58 ± 1.68^{a}	61 ± 1.68^{a}	53 ± 1.77^{f}	63 ± 1.77^{e}
Commercials (kg)	0.8 ± 0.02^{h}	1.0 ± 0.02^{g}	0.9 ± 0.03^{f}	1.0 ± 0.02^{e}	0.9 ± 0.02^{a}	1.0 ± 0.02^{a}	0.8 ± 1.77^{f}	1.0 ± 0.02^{e}
Cuts with bones (kg)	13 ± 0.44^{h}	16 ± 0.47^{g}	14 ± 0.53^{f}	17 ± 0.47^{e}	15 ± 0.44^{a}	16 ± 0.44^{a}	14 ± 0.47^{f}	16 ± 0.47^{e}
Lean meat weight (kg)[*]	102 ± 3.34^{h}	125 ± 3.52^{g}	109 ± 3.99^{f}	128 ± 3.52^{e}	116 ± 3.34^{a}	122 ± 3.34^{a}	107 ± 3.52^{f}	126 ± 3.52^{e}
Edible protein (kg)[‡]	26 ± 0.86^{h}	32 ± 0.91^{g}	28 ± 1.03^{f}	33 ± 0.91^{e}	30 ± 0.86^{a}	31 ± 0.86^{a}	27 ± 0.91^{f}	32 ± 0.91^{e}

Table 4. Predicted dry matter intake (DMI) and derived methane (CH$_4$) emission indices for commercial Brahman (*B. indicus*) and Brahman crossbred cattle grazing mixed pastures of *Andropogun gayanus*, *Mellinis minutiflora* and *Stylosanthes capitata* (AgMmSc; 70:20:10) and *A. gayanus* plus *S. capitata* (AgSc; 95:5) or *Braquiaria humidicola* (Bh) monoculture

†Adapted from Ramírez-Restrepo *et al.* (2014, 2016bc). Animal category comparison within the same variable and sward treatment followed by the same letter are not significantly different (ab.: $P < 0.05$; cd.: $P < 0.01$; ef.: $P < 0.001$; gh.: $P < 0.0001$; ij.: $P \leq 0.10$)

	Swards							
	AgMmSc-85		AgSc-86		AgSc-87		Bh-87	
	Cow	Steers	Cow	Steers	Cow	Steers	Cow	Steers
Animals	10	8	10	10	10	10	9	9
DMI†	7.2 ± 0.14^{f}	8.0 ± 0.15^{e}	7.4 ± 0.14^{b}	7.9 ± 0.14^{a}	7.0 ± 0.14^{b}	7.5 ± 0.14^{a}	7.2 ± 0.14^{a}	7.0 ± 0.14^{a}
CH$_4$ emissions†								
CH$_4$ (g/day)	131 ± 3.21^{f}	148 ± 3.58^{e}	136 ± 3.21^{b}	146 ± 3.21^{a}	126 ± 3.21^{b}	137 ± 3.21^{a}	131 ± 3.38^{a}	126 ± 3.38^{a}
CH$_4$ (g/kg DMI)	18.0 ± 0.09^{d}	18.5 ± 0.10^{c}	18.2 ± 0.09^{b}	18.4 ± 0.09^{a}	17.9 ± 0.09^{b}	18.2 ± 0.09^{a}	18.0 ± 0.10^{a}	17.9 ± 0.10^{a}
Total emissions (kg/head)	21.0 ± 0.57^{d}	23.8 ± 0.63^{c}	28.5 ± 0.57^{d}	30.7 ± 0.57^{c}	25.4 ± 0.57^{b}	27.5 ± 0.57^{a}	23.5 ± 0.60^{a}	22.6 ± 0.60^{a}
CH$_4$ intensity (kg/kg CW)	0.11 ± 0.001^{a}	0.10 ± 0.001^{b}	0.14 ± 0.001^{a}	0.14 ± 0.001^{b}	0.13 ± 0.001^{a}	0.13 ± 0.001^{a}	0.12 ± 0.001^{a}	0.12 ± 0.001^{a}
CH$_4$ intensity (kg/kg edible protein, EP)	0.69 ± 0.009^{a}	0.66 ± 0.010^{b}	0.93 ± 0.008^{a}	0.91 ± 0.008^{b}	0.87 ± 0.008^{a}	0.86 ± 0.008^{a}	0.77 ± 0.009^{a}	0.76 ± 0.009^{a}
CH$_4$ efficiency (kg CO2eq/kg FLW)	1.8 ± 0.02^{a}	1.7 ± 0.02^{b}	2.4 ± 0.02^{a}	2.3 ± 0.02^{b}	2.2 ± 0.02^{a}	2.2 ± 0.02^{a}	1.9 ± 0.02^{a}	1.9 ± 0.02^{a}
CH$_4$ efficiency (kg CO$_2$eq/kg CW)	3.7 ± 0.05^{a}	3.5 ± 0.05^{b}	5.0 ± 0.04^{a}	4.9 ± 0.04^{b}	4.7 ± 0.04^{a}	4.6 ± 0.04^{a}	4.1 ± 0.05^{a}	4.1 ± 0.05^{a}
CH$_4$ efficiency (kg CO$_2$eq/kg EP)	23.7 ± 0.31^{a}	22.6 ± 0.33^{b}	31.9 ± 0.30^{a}	31.0 ± 0.30^{b}	29.7 ± 0.30^{a}	29.3 ± 0.30^{a}	26.0 ± 0.05^{a}	26.0 ± 0.05^{a}

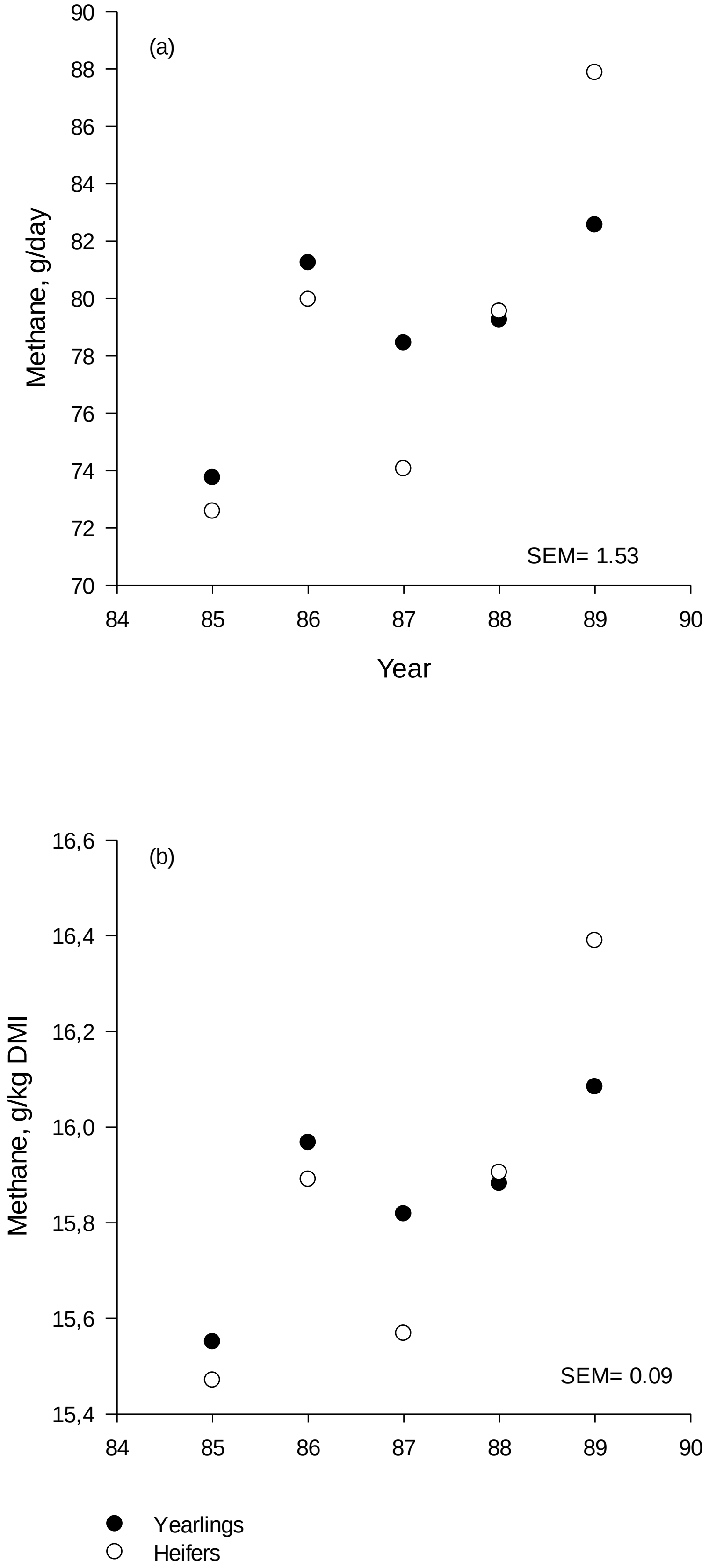
Table 5. Comparative estimations of dry matter intake (DMI) and methane (CH_4) emission factors between Brahman and/or crossbred Brahman cull cows and steers over their fattening time grazing a mixture of *Andropogon gayanus* and *Stylosanthes capitata* (AgSc; 95:5) and *Braquiaria humidicola* (Bh) over two consecutive wet seasons in the Meta Department of Colombia

†Derived from Ramírez-Restrepo *et al.* (2014, 2016bc). Values between animal category within the same parameter and forage treatment followed by the same letter are not significantly different (ab.: $P < 0.05$; cd.: $P < 0.01$; ef.: $P < 0.001$; gh.: $P < 0.0001$; ij.: $P \leq 0.10$)

	Swards							
	AgSc-88		Bh-88		AgSc-89		Bh-89	
	Cow	Steers	Cow	Steers	Cow	Steers	Cow	Steers
Animals	10	9	8	9	10	10	9	9
DMI	6.6 ± 0.14^{h}	7.5 ± 0.14^{g}	7.0 ± 0.16^{f}	7.8 ± 0.14^{e}	7.2 ± 0.14^{a}	7.5 ± 0.14^{a}	6.9 ± 0.14^{d}	7.5 ± 0.14^{c}
CH_4 emissions†								
CH_4 (g/day)	118 ± 3.21^{h}	137 ± 3.38^{g}	127 ± 3.83^{f}	145 ± 3.38^{e}	130 ± 3.21^{a}	137 ± 3.21^{a}	123 ± 3.38^{d}	138 ± 3.38^{c}
CH_4 (g/kg DMI)	17.6 ± 0.09^{h}	18.2 ± 0.10^{g}	17.9 ± 0.11^{d}	18.4 ± 0.10^{c}	18.0 ± 0.09^{a}	18.2 ± 0.09^{a}	17.8 ± 0.10^{d}	18.2 ± 0.10^{c}
Total emissions (kg/head)	21.4 ± 0.57^{h}	24.9 ± 0.60^{g}	23.1 ± 0.68^{f}	26.3 ± 0.60^{e}	19.0 ± 0.57^{a}	20.0 ± 0.57^{a}	18.0 ± 0.60^{d}	20.1 ± 0.60^{c}
CH_4 intensity (kg/kg CW)	0.12 ± 0.001^{c}	0.12 ± 0.001^{d}	0.12 ± 0.001^{i}	0.12 ± 0.001^{j}	0.10 ± 0.001^{a}	0.09 ± 0.001^{a}	0.10 ± 0.001^{c}	0.09 ± 0.001^{d}
CH_4 intensity (kg/kg edible protein, EP)	0.80 ± 0.008^{c}	0.76 ± 0.009^{d}	0.81 ± 0.010^{a}	0.78 ± 0.009^{a}	0.63 ± 0.008^{a}	0.62 ± 0.008^{a}	0.64 ± 0.009^{a}	0.61 ± 0.009^{b}
CH4 efficiency (kg CO2eq/kg FLW)	2.0 ± 0.02^{c}	1.9 ± 0.02^{d}	2.0 ± 0.02^{i}	2.0 ± 0.02^{j}	1.6 ± 0.02^{a}	1.6 ± 0.02^{a}	1.6 ± 0.02^{c}	1.5 ± 0.02^{d}
CH_4 efficiency (kg CO_2eq/kg CW)	4.3 ± 0.04^{c}	4.0 ± 0.05^{d}	4.3 ± 0.05^{i}	4.2 ± 0.05^{j}	3.4 ± 0.04^{a}	3.3 ± 0.04^{a}	3.4 ± 0.05^{c}	3.3 ± 0.05^{d}
CH_4 efficiency (kg CO_2eq/kg EP)	27.3 ± 0.30^{c}	25.9 ± 0.31^{d}	27.5 ± 0.36^{i}	26.7 ± 0.31^{j}	21.5 ± 0.30^{a}	21.4 ± 0.30^{a}	22.7 ± 0.31^{c}	20.8 ± 0.31^{d}

Legends for Figures

Fig. 1. Estimated daily (a) and yield (b) methane emissions from young cattle grazing on *Andropogon gayanus* associated with variable sward density of *Mellinis minutiflora* and *Stylosanthes capitata*.


(a)
Methane, g/day
90
88
86
84
82
80
78
76
74
72
70
84
85
86
87
88
89
90
Year
SEM= 1.53
(b)
Methane, g/kg DMI
16,6
16,4
16,2
16,0
15,8
15,6
15,4
84
85
86
87
88
89
90
SEM= 0.09
● Yearlings
○ Heifers