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REGULAR ARTICLES

Estimation of enteric methane emission factors for Ndama cattle in the Sudanian zone of Senegal

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Abstract
Methane (CH_4) emission estimations for cattle in Sub-Saharan Africa (SSA) reflect limited production levels and diets that are high in cellulose forage. However, data on these livestock systems is lacking for their accurate evaluation. To provide guidance for climate change mitigation strategies in Senegal, it is necessary to obtain reliable estimates of CH_4 emissions from Ndama cattle reared in grazing systems, which is the predominant cattle system in the country. The objective of this study was to determine the annual methane emission factor (MEF) for enteric fermentation of Ndama cattle following the IPCC Tier 2 procedure. Our estimated annual MEF at the herd scale was 30.8 kg CH_4/TLU (30.7 kg CH_4/head/yr for lactating cows and 15.1 kg CH_4/head/yr for other cattle). These values are well below the default IPCC emission factor (46 and 31 kg CH_4/head/yr for dairy and other cattle, respectively) proposed in the Tier 1 method for Africa. Our study showed that feed digestibility values differ with season (from 46 to 64%). We also showed that cattle lose weight and adapt to lower feed requirements during the long dry season, with a resulting major reduction in methane emissions. The results of this work provide a new framework to re-estimate the contribution of grazing systems to methane emissions in Africa.

Keywords Enteric methane · Emission factor · Taurine cattle · Mixed system · Senegal

Introduction

In addition to providing an essential source of proteins in the human diet, accounting for up to 33% of total protein (Herrero et al. 2013), livestock production is also responsible for 12% of global anthropogenic greenhouse gas emissions (Havlík et al. 2014). Ruminants in particular produce large amounts of methane (CH_4) during their normal digestive processes. Emissions per gram of protein from cattle are 250 times higher than emissions per gram of protein from legumes (Tilman and Clark 2015). For this reason, considerable debate is ongoing about the role of livestock husbandry as a major producer of greenhouse gases (GHG) and the significance of its contribution to climate change. Among ruminants, cattle are the largest emitter of CH_4 because their rumen, a large forestomach, enables continuous fermentation due to the presence of a diverse population of microorganisms (Shibata and Terada 2010).

However, livestock are an invaluable source of food and income for millions of poor people, especially in developing countries such as Senegal. Therefore, in the Sub-Saharan Africa (SSA) region, climate change mitigation policies involving livestock should be developed with extreme caution and with consideration of the production benefits people obtain from livestock (e.g. meat and milk, transport, employment).

The Intergovernmental Panel on Climate Change (IPCC) provides procedures for compilation of national GHG inventories. The IPCC 2006 guidelines specify GHG estimation approaches at three levels (or tiers) of increasing complexity

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(Tier 1–3). The purpose of the tiers is to provide reliable estimates of national GHG emissions that take the characteristics and agricultural practices specific to each country into consideration.

To estimate methane emissions from ruminants, the default value of the Tier 1 approach has often been used in both extensive (e.g. grassland) and intensive (forage and concentrate) livestock production systems in SSA, even though the quantities of enteric CH_4 emitted by cattle can vary widely with diet composition and grazing season (Archimède et al. 2011). The widespread use of the Tier 1 method, which is associated with high uncertainty, is due to the shortage of measurements from indigenous cattle breeds in the SSA region (Tallec et al. 2012; Hristov et al. 2018). Improved estimates of methane emission factors from cattle reared in extensive livestock systems is a pre-condition for establishing and assessing CH_4 mitigation strategies in the SSA region.

Livestock productions systems in SSA depend on natural grasslands, the major source of feedstuff for ruminants (Opio et al. 2013). It is well established that CH_4 production from enteric fermentation varies with diet, grazing period (Eugène et al. 2011) and daily dry matter intake (Hristov et al. 2018). Studies conducted in the SSA region (e.g. Ouédraogo-Koné et al. 2008; Gaidet and Lecomte 2013) report high variation in intake and forage quality throughout the year.

In Senegal, previous experiments on feeding behaviour have described the impact of daily management of pastoral herds on the diet profiles and digestibility of forage (see Ickowicz and Mbaye 2001; Chirat et al. 2014; Assouma et al. 2018). Generally, these studies conclude that forage species in rangelands change in terms of composition and nutritive value, and that these changes are associated with fluctuation in feed intake. Guérin and Roose (2017) report additional detailed description of livestock production systems in Senegal. Based on these studies, we assume that parameters such as digestible organic matter, digestibility and intake and hence the value of the methane emission factor will vary between seasons.

The objective of this study is to evaluate enteric methane emission factors (MEF) for Ndama cattle reared in the Sudanian zone of Senegal, using the IPCC 2006 Tier 2 model and more precise estimates of model parameters that better reflect the indigenous livestock production systems.

Material and methods

Site description

The study was conducted in the Kolda region (12°49' N, 14°53' W). The local climate is tropical Sudanian with 1065 mm average annual rainfall. The average annual temperature for the period 1980–2018 was 28.6 °C, with a maximum around April–May (*Service de Météorologie Nationale, Station de Kolda*). Based on rainfall distribution patterns observed over three decades, for our study, we divided the year into three 4-month seasons as follows: a wet season (WS) from June to September, an early dry season (EDS) from October to January and a late dry season (LDS) from February to May. The rainy season usually lasts from the end of May to October. Further details on seasonal climate conditions, observed dry matter intake and digestible organic matter in the study area are provided in the Supplementary Fig. S1-a and Fig. S1-b.

Production system characteristics

Based on the classification proposed by Seré and Steinfeld (1996), the common livestock system in the study site can be defined as a rainfed mixed farming system. The main cattle breed in Kolda is the Ndama breed (*Bos taurus*). In its last activity report of 2016, the Senegalese Livestock Ministry (http://www.elevage.gouv.sn) estimated a cattle population reared in extensive systems of 3.4 million, of which the Ndama cattle represent about 30%. The calving period in the extensive livestock system is not grouped but occurs randomly, as bulls run with the herd all year round. According to Sissokho (1998), 64% of calving occurs in the WS (i.e. rainy season), 22% in the EDS and 14% in the LDS. In the Sudanian area of Senegal, the use of forages resources is organized by farmers according to the seasons (Chirat et al. 2014). For example, during the WS, ruminants are herded away from the crop fields and only browse on fallow and forest zones where grass (e.g. *Cynodon* sp., *Brachiaria* sp.), legumes (e.g. *Stylosanthes* sp., *Alysicarpus* sp.) and standing hay (e.g. *Andropogon* sp., *Pennisetum* sp.) are available. In the rainy season, forests and fallows account for around 90% of total time on pasture for cattle (Sissokho 1998). After harvest (around December), the cattle herds return from the forest areas and freely graze crop residues (i.e. maize, millet, sorghum and rice straw). At dusk, herds are assembled and tethered close to the homesteads to spend the night. Throughout the free grazing period (i.e. after harvest), cattle continue to feed on fallows, savannah and forest lands. From April–May until the first rains, the lack of natural forage resources and the infrequency of supplemented fodder (e.g. concentrate feed), cattle tend to be underfed and lose weight as their stores of body fat are mobilized from their body reserves (Grimaud et al. 1998; Ezanno et al. 2005).

Predicted methane emission factor

To date in Senegal, no models are available to specifically assess the enteric methane emission factor (MEF) for domestic cattle reared in extensive livestock systems. For this purpose, the IPCC Tier 2 model (Supplementary Fig. S2) was applied considering the particularities of Ndama cattle and their performances (e.g. live weight, average daily gain) using data from in situ studies. The IPCC Tier 2 approach for enteric fermentation is mainly based on ruminant net energy models from the National Research Council (see NRC 1996).

To use the Tier 2 model, input parameters including average live weight (LW, kg), average daily gain (ADG, kg/d), milk yield (MY, kg/d), feed situation and digestible energy (DE, % of gross energy content, GE, MJ/d) of grazed feed were estimated for each season. The formulas proposed by IPCC (2006) were used to calculate net energy (NE, MJ/d) and its components (i.e. maintenance, growth, pregnancy and lactation, locomotion) as well as corresponding average daily feed intake (in terms of GE) for each category of animal in the herd. The seasonal MEF (SMEF) was then estimated from gross energy (GE, MJ/d) and further multiplied by the predicted methane conversion factor (Ym, %). In order to achieve the weighted annual MEF (AMEF), SMEF was summed within each category and then multiplied by the percentage of each animal category in the herd. Finally, with data on the average LW of each animal category, a conversion was made to tropical livestock units (TLU, animal of 250 kg LW).

Livestock parameters

Herd composition

We used a typical herd structure reported from the Sustainable Management of Globally Significant Endemic Ruminant Livestock in West Africa, PROGEBE Senegal. The proportions of animals in each category were 15%, 38%, 37% and 10% for calves (≤ 1-year-old), sub-adults (> 1 to ≤ 4 years old), adult females (> 4 years old) and adult males (> 4 years old), respectively (Ejlertsen et al. 2012). This estimate was further refined using statistics sourced from the database of the Livestock Research Centre of Kolda (called ISRA/CRZ Kolda), which allowed us to estimate the proportion of lactating cows (i.e. annual percentage of females that give birth), and the sex ratio of growing animals.

Live weight, mature weight and average daily weight gain

Owing to the lack of published data on cattle production in the study area, we gathered data from various grey literature sources (e.g. theses, research activity reports). The average values of LW and mature weight (i.e. mature Ndama cattle in moderate body condition) were computed from the ISRA/CRZ-K database. The average daily gain (ADG) used in this study was calculated based on a dataset recorded through monitoring of 23 cattle herds from 10 villages around the Kolda region (Sissokho 1998). The values adopted for male and female calves, respectively, were + 0.176 ± 0.044 kg/d and + 0.170 ± 0.056 kg/d. For sub-adults (i.e. heifers and young bulls) and adults (i.e. cows and bulls), seasonal ADG was + 0.12 ± 0.04, − 0.04 ± 0.01 kg/d and − 0.16 ± 0.01 kg/d for the WS, EDS and LDS, respectively.

Milk yield and fat content

Because of the type of cattle reproduction system, calving rates vary by season and cows are not in the same lactation stage at a given date. A dataset on milk production collected through on-farm research surveys in the Kolda region (Sissokho 1998; ISRA/CRZ Kolda 2017, unpublished data) was used to evaluate the seasonal weighted value of milk yield (i.e. 0.834 ± 0.270, 0.594 ± 0.198 and 0.373 ± 0.044 kg/d for WS, EDS and LDS, resepctively) taking into account the proportion of lactating cows during each season. The values adopted for fat content were obtained from monitoring conducted by the ISRA/CRZ Kolda between August 2015 and May 2016.

Animal work rates and locomotion

The average daily number of hours worked by draft oxen is reported in surveys by ISRA-ITA and CIRAD (2005). Using the model proposed by Konandreas and Anderson (1982), the daily distance walked by cattle herds during grazing time is accounted for in the calculation of energy requirements for maintenance. Expert opinion provided estimates of 2, 5 and 8 km for average daily distance walked by Ndama cattle herds during WS, EDS and LDS, respectively. Tables 1 and 2 inventory the parameters and their sources used to estimate the MEF with the IPCC Tier 2 method.

Prediction of seasonal values of digestible energy and the methane conversion rate

Recent country case study (Ndao et al. 2018) demonstrates that the IPCC Tier 2 method is sensitive to variation in input parameters such as the methane conversion factor (Ym) and digestibility of the diet (DE).

In order to reduce the uncertainty in the assessment of the MEF and to consider the seasonal fluctuations in the diets, our approach computes seasonal values of DE and Ym. We first identified at the study site the forage plants (FP) most commonly encountered and consumed by cattle herds in natural grasslands. Secondly, the chemical composition of these FP from *Feedipedia* (www.feedipedia.org/) was used, considering variations in the nutritive value of each FP throughout the year (see Table 3a, 3b, 3c). Thirdly, the FP were used to mimic changes in seasonal diets and matched with experimental values of digestible organic matter (OMd, %) per TLU previously determined in the same study site by a tropical livestock feeding program, *Alimentation du Bétail Tropical* (ABT, scientific collaboration ISRA/CIRAD-IEMVT 1993–1998).

Table 1 Input parameters used to estimate emission factors for enteric methane from Ndama cattle based on the ruminant nutrition approach and referenced sources

Name of parameters	Symbol	Unit	Note of reference
Herd structure		%	Ejlertsen et al. 2012; ISRA-PROGEBE data 2009–2015
Coefficient for calculating net energy for maintenance	Cfi	MJ day/kg	IPCC 2006 (Table 10.4)
Activity coefficient corresponding to animal's feeding situation	Ca	MJ day/kg	IPCC 2006 (Table 10.5)
Coefficient	C		IPCC 2006 (Eq. 10.6)
Pregnancy coefficient	Cp		IPCC 2006 (Table 10.7)
Methane conversion rate	Ym	%	This present study
Feed digestibility	DE	%	This present study
Average live body weight	LW	kg	ISRA-PROGEBE data 2009–2015; CRZK Research reports
Mature live body weight	MW	kg	From expert opinion
Average daily weight gain	ADG	kg/day	Sissokho 1998; ISRA-PROGEBE data 2009–2015; CRZK Research reports
Average daily milk yield	MY	kg/day	Sissokho 1998; This present study
Fat content of milk	MCF	%	CRZK Research reports
Number of hours of work	Hour	h	ISRA-ITA and CIRAD 2005

The seasonal duration of cattle herds grazing in rangelands and the main FP in the pastures were considered in our analysis. For example, in the post-harvest period, cattle herds spend most of their time grazing croplands. Thus, the composition of the diet during the EDS is formulated with a higher proportion of crop residues compared to the other types of forage resources.

Finally, the percentage of each type of feedstuff and their nutritional values was used to simulate the seasonal composition of the diets and average apparent values in terms of digestible energy (DE, %), neutral detergent fibre (NDF, g/kg DM), acid detergent fibre (ADF, g/kg DM). The values of seasonal Ym were estimated following the formula developed by FAO (see Opio et al. 2013). The calculated values of DE and Ym for each season were applied to estimate the SMEF for each category, except for calves. Since the digestive system of ruminants develops progressively, reaching adult capacity at about 1.5 years (Konandreas and Anderson 1982), in addition to which experiments in the Kolda region to estimate intake by calves are absent, for calves we adopted fixed values of 65% and 4.5% for DE and Ym, respectively.

Assessment of dry matter intake

To determine daily dry matter intake (DMI, expressed in kg DM), the calculated gross energy intake for each animal category in each season was divided by the predicted seasonal energy density of the diets. These estimates of DMI were compared with the observed DMI previously reported through research in the study site.

Results

Seasonal OMd, DE, Ym

Our calculated values of digestible organic matter (OMd), feed digestibility (DE), methane conversion rate (Ym) and the nutritive values of seasonal diets are presented in Table 4.

Using data from the ABT program database for each season, the estimated apparent OMd of the intakes are 67%, 61% and 48% for the WS, EDS and LDS, respectively. Based on these values for OMd, our results show that DE varies by season. The value of DE is highest in the rainy season (64%) and declines over the early dry season (57%) and the late dry season (46%), with an average annual value of 55 ± 9.2%. With an opposite trend to DE, the seasonal values of the methane conversion rate (Ym) increase from WS (6.6%) to LDS (7.5%) with an average value of 6.9 ± 0.5%.

Predicted diet composition

Considering the chemical composition of seasonal diets consumed by cattle herds in the study, crude protein (CP) concentration is lower during the LDS, while the values of crude fibre (CF), neutral detergent fibre (NDF) and acid detergent fibre (ADF) are increased from the WS to the EDS. In other words, the highest CF, NDF and ADF contents were recorded in the LDS, which is logically linked to changes in the digestibility of feed. In contrast to others components, the values of gross energy content of the seasonal diets are very similar, i.e. 17.8, 17.7 and 17.9 MJ/kg DM for the WS, EDS and LDS, respectively.

Gross energy and dry matter intake

The values of daily gross energy intake and the associated daily dry matter intake (DMI) of the diet consumed by each animal category during the WS, EDS and LDS are shown in Table 5.

Given our estimate based on the Tier 2 method, Table 5 shows that the expected intakes in terms of energy and dry

Table 2 Average values of input parameters used to determine gross energy intake (GE, MJ/kg DM) of each class of Ndama cattle reared in southern Senegal

Category	Class	Season	Inputs parameters [1]									
			Cfi MJ/d/kg	Ca	LW kg	C	MW kg	ADG kg/d	MCF %	MY kg/d	Hr h	Cp %
F Calves	0–1 yr	WS	0.322	0.17	42	0.2	180	0.170	0	0	0	0
		EDS	0.322	0.17	42	0.2	180	0.170	0	0	0	0
		LDS	0.322	0.17	42	0.2	180	0.170	0	0	0	0
M Calves	0–1 yr	WS	0.322	0.17	49	0.2	180	0.176	0	0	0	0
		EDS	0.322	0.17	49	0.2	180	0.176	0	0	0	0
		LDS	0.322	0.17	49	0.2	180	0.176	0	0	0	0
Y Heifers	1–2 yr	WS	0.322	0.17	65	0.8	180	0.120	0	0	0	0
		EDS	0.322	0.17	65	0.8	180	0	0	0	0	0
		LDS	0.322	0.17	65	0.8	180	0	0	0	0	0
Y Bulls	1–2 yr	WS	0.322	0.17	74	1.0	180	0.120	0	0	0	0
		EDS	0.322	0.17	74	1.0	180	0	0	0	0	0
		LDS	0.322	0.17	74	1.0	180	0	0	0	0	0
B Heifers	2–4 yr	WS	0.322	0.36	118	0.8	180	0.120	0	0	0	0
		EDS	0.322	0.36	118	0.8	180	0	0	0	0	0
		LDS	0.322	0.36	118	0.8	180	0	0	0	0	0
R Bulls	2–4 yr	WS	0.322	0.36	133	1.0	180	0.120	0	0	0	0
		EDS	0.322	0.36	133	1.0	180	0	0	0	0	0
		LDS	0.322	0.36	133	1.0	180	0	0	0	0	0
Draft oxen	> 4 yr	WS	0.37	0.36	250	1.0	180	0.120	0	0	0.8	0
		EDS	0.37	0.36	250	1.0	180	0	0	0	0	0
		LDS	0.37	0.36	250	1.0	180	0	0	0	0	0
A Bulls	> 4 yr	WS	0.37	0.36	250	1.2	180	0.120	0	0	0	0
		EDS	0.37	0.36	250	1.2	180	0	0	0	0	0
		LDS	0.37	0.36	250	1.2	180	0	0	0	0	0
D Cows	> 4 yr	WS	0.37	0.36	180	0.8	180	0.120	0	0	0	0
		EDS	0.37	0.36	180	0.8	180	0	0	0	0	0
		LDS	0.37	0.36	180	0.8	180	0	0	0	0	0
L Cows	> 4 yr	WS	0.37	0.36	223	0.8	180	0.120	3.61	0.83	0	0.1
		EDS	0.37	0.36	223	0.8	180	0	3.59	0.59	0	0.1
		LDS	0.37	0.36	223	0.8	180	0	5.35	0.37	0	0.1

[1] Feed digestibility (DE, %) and methane conversion rates (Ym, %) are computed

F female, *M* male, *Y* young, *L* lactating, *D* dry, *A* adult, *R* replacement, *B* bull, *EDS* early dry season, *LDS* late dry season, *WS* wet season

matter are greater in the dry season (EDS and LDS) than in the rainy season (WS) for all categories of animal. Expressed in TLU, the average daily DMI was 3.9 ± 0.4 kg, when averaged through the year and across all animal categories, representing average daily intake at the herd scale.

Expected methane emission factors

Enteric CH_4 emission factors of Ndama cattle were evaluated using the Tier 2 approach. The expected seasonal enteric emission factors (SMEF) and annual methane enteric emission factors (AMEF) per animal category are reported in Table 6.

The AMEF ranged from 4.13 to 30.7 kg CH_4 per head of cattle. In view of the average LW and the proportion of each category of animals in the herd, the weighted annual methane emission factors due to enteric fermentation of Ndama cattle were 30.7 kg CH_4/hd for lactating cows (L Cow) and 15.1 kg CH_4/hd for other categories of cattle. Considering the herd structure, the annual weighted EF is 27.2 kg CH_4/hd. When expressed in TLU, the value is 30.8 kg CH_4/TLU/yr.

Table 3a Forages plants used to predict diet in the wet season

Species	DM	CP	CF	NDF	ADF	ADL	EE	Ash	OMd	GE	DE	References
Elephant grass (*Pennisetum purpureum*)	18	17	65	128	76	10	4	25	61	17	59	www.feedipedia.org/node/12365. Accessed 12 February 2019
Rhodes grass (*Chloris gayana*)	25	22	92	187	107	15	5	22	60	18	58	www.feedipedia.org/node/12518. Accessed 12 February 2019
Desert date (*Balanites aegyptiacus*)	94	134	165	303	199	101	48	144	61	17	51	www.feedipedia.org/node/11591. Accessed 14 February 2019
Umbrella thorn (*Acacia tortilis*)	91	131	86	501	292	125	76	106	73	18	71	www.feedipedia.org/node/12810. Accessed 12 February 2019
Guinea grass (*Megathyrsus maximus*)	23	25	85	164	99	14	4	24	59	18	55	www.feedipedia.org/node/416. Accessed 15 February 2019
Sweet potato (*Ipomaea batatas*)	89	117	176	355	285	100	25	104	66	18	62	www.feedipedia.org/node/12808. Accessed 12 February 2019
Alyce clover (*Alysicarpus ovalifolius*)	29	46	88	0	94	0	6	32	65	18	62	www.feedipedia.org/node/12821. Accessed 14 February 2019
Indian sandbur (*Cenchrus biflorus*)	29	26	107	207	124	17	5	33	71	18	68	www.feedipedia.org/node/12201. Accessed 16 February 2019
Gamba grass (*Andropogon gayanus*)	28	11	83	181	98	12	2	23	65	18	62	www.feedipedia.org/node/12115. Accessed 14 February 2019
Spear grass (*Heteropogon contortus*)	39	20	145	291	164	20	5	34	59	18	56	www.feedipedia.org/node/12630. Accessed 14 February 2019
Egyptian crowfoot grass (*Dactyloctenium aegyptium*)	30	25	101	208	118	16	5	28	63	18	61	www.feedipedia.org/node/12067. Accessed 14 February 2019
False brandy bush (*Grewia bicolor*)	44	67	99	198	127	47	22	45	63	19	71	www.feedipedia.org/node/12146. Accessed 14 February 2019

The list of forages is bases on previous works in the study site, while the average nutritional composition in terms of apparent dry matter (DM, %), crude protein (CP, g/kg DM), crude fibre (CF, g/kg DM), neutral detergent fibre (NDF, g/kg DM), acid detergent fibre (ADF, g/kg DM), acid detergent lignin (ADL, g/kg DM), ether extract (EE, g/kg DM), digestible organic matter (OMd, %), gross energy (GE, MJ/kg DM) and feed digestibility (DE, %) is sourced from Feedipedia

Discussion

Seasonal feed digestibility

The fluctuation in the estimated value of DE with the seasons is explained by the change in digestible organic matter (OMd), which results from plants ageing and dietary changes due to feed selection by cattle. This was recently confirmed by in vivo measured values of dietary OMd after F-NIRS analysis of 708 samples of faeces collected in the vicinity of our study area (Lecomte et al. 2016). Their results confirmed that OMd is higher in the rainy season and declines during the dry season, with a total decrease from 70% to 46% over the course of the year. These values reflect the same tendencies as our estimated DE values. A similar profile was reported in the sylvopastoral region of Senegal, where Doreau et al. (2016) and Assouma et al. (2018) reviewed the variability of digestibility of forage available in tropical rangelands. Their conclusions confirm an overall range of OMd from 40% to 70%.

In other regions of tropical Africa, Elliott et al. (1961) recorded OMd over a continuous period of 2 years under natural pasture grazing with no supplemental feed. Using the faecal N and Cr_2O_3 method, Elliott et al. (1961) reported that OMd declined progressively from 60 to 44% between November and June. Furthermore, in Western Kenya, research from Goopy et al. (2018) revealed that depending on season, the digestibility of intake varies from 58% to 64%, i.e. around 10% greater than the fixed estimate of 50 ± 5% proposed in the IPCC 2006 Tier 1 method. As mentioned previous by Patra (2017), there is a need to characterize more accurately tropical feeds. Indeed, the chemical composition of diets influences significantly the intake, and hence the estimate of the enteric methane calculation.

Variation of methane conversion rate

Because of limited data on extensive livestock systems (including those in SSA), the IPCC Tier 1 model assumes that the methane conversion rate (Ym) represents 6.5 ± 1.0% of gross energy intake for cattle fed forage-based diets (IPCC 2006). This value of Ym is close to our predicted value (i.e. 7% lower). However, the methane conversion rate is still the subject of debate among scientists (see Escobar-Bahamondes et al. 2017). In view of the different diet composition

Table 3b Forages plants used to predict diet in the early dry season

Species	DM	CP	CF	NDF	ADF	ADL	EE	Ash	OMd	GE	DE	References
Pearl millet straw (*Pennisetum glaucum* L.)	93	48	389	745	493	100	7	80	47	18	44	www.feedipedia.org/node/399. Accessed 12 February 2019
Maize straw (*Zea mays* L.)	93	34	394	766	494	78	6	61	55	18	53	www.feedipedia.org/node/12874. Accessed 12 February 2019
Sorghum straw (*Sorghum bicolor* L. *Moench*)	93	34	363	712	448	68	11	70	54	18	49	www.feedipedia.org/node/379. Accessed 12 February 2019
Elephant grass (*Pennisetum purpureum*)	89	92	318	635	374	52	17	97	59	18	55	www.feedipedia.org/node/12366. Accessed 12 February 2019
Rhodes grass (*Chloris gayana*)	86	87	305	654	356	48	15	84	60	18	56	www.feedipedia.org/node/12519. Accessed 12 February 2019
Desert date (*Balanites aegyptiacus*)	94	134	165	303	199	101	48	144	61	17	51	www.feedipedia.org/node/11591. Accessed 14 February 2019
Umbrella thorn (*Acacia tortilis*)	91	131	86	501	292	125	76	106	73	18	71	www.feedipedia.org/node/12810. Accessed 12 February 2019
Pangola grass (*Digitaria eriantha*)	81	64	289	575	337	46	15	61	58	18	55	www.feedipedia.org/node/11654. Accessed 15 February 2019
Guinea grass (*Megathyrsus maximus*)	90	82	330	644	383	54	14	103	57	18	54	www.feedipedia.org/node/11522. Accessed 15 February 2019
Bermuda grass (*Cynodon dactylon*)	92	93	270	674	325	54	25	76	54	18	50	www.feedipedia.org/node/11850. Accessed 15 February 2019
Molasses grass (*Melinis minutiflora*)	90	70	312	630	365	50	20	81	59	18	56	www.feedipedia.org/node/12339. Accessed 15 February 2019
Sweet potato (*Ipomaea batatas*)	89	117	176	355	285	100	25	104	66	18	62	www.feedipedia.org/node/12808. Accessed 12 February 2019
Alyce clover (*Alysicarpus ovalifolius*)	95	105	304	0	0	0	20	86	60	18	57	www.feedipedia.org/node/12822. Accessed 14 February 2019
Indian sandbur (*Cenchrus biflorus*)	95	75	355	413	59	59	13	121	56	17	53	www.feedipedia.org/node/12202. Accessed 16 February 2019
Gamba grass (*Andropogon gayanus*)	90	34	374	687	432	64	10	57	51	18	48	www.feedipedia.org/node/12116. Accessed 14 February 2019
Spear grass (*Heteropogon contortus*)	93	30	358	738	429	75	12	68	54	18	50	www.feedipedia.org/node/12631. Accessed 14 February 2019
Egyptian crowfoot grass (*Dactyloctenium aegyptium*)	93	56	390	712	450	68	7	66	51	18	48	www.feedipedia.org/node/12068. Accessed 14 February 2019
False brandy bush (*Grewia bicolor*)	90	99	166	374	252	82	52	121	72	18	69	www.feedipedia.org/node/15706. Accessed 14 February 2019
Rice straw (*Oryza sativa* L.)	93	39	326	641	393	45	13	168	50	16	47	www.feedipedia.org/node/557. Accessed 12 February 2019

The list of forages is bases on previous works in the study site, while the average nutritional composition in terms of apparent dry matter (DM, %), crude protein (CP, g/kg DM), crude fibre (CF, g/kg DM), neutral detergent fibre (NDF, g/kg DM), acid detergent fibre (ADF, g/kg DM), acid detergent lignin (ADL, g/kg DM), ether extract (EE, g/kg DM), digestible organic matter (OMd, %), gross energy (GE, MJ/kg DM) and feed digestibility (DE, %) is sourced from Feedipedia

consumed by cattle over the seasons, the use of a generic Ym value clearly impacts the predicted MEF (Patra 2017). For example, using a meta-analysis approach, Kaewpila and Sommart (2016) propose using 8.4 ± 0.4% (range 4.8 to 13.7%) for Ym. This seems to be overestimated with respect to the default IPCC 2006 methane conversion factor commonly used for low quality forage. Besides, Kennedy and Charmley (2012) examined tropical grasses and legume species in conditions similar to those in our study area in Sengal. These authors reported for Ym an average value of 6.1% (range 5.0–7.2%), i.e. 6% and 13% lower than the default Ym recommended by IPCC (2006) and the computed value of this present study, respectively. Thus, because of the negative relationship between the two parameters, Ym and DMI, for accurate estimation of AMEF for cattle reared under common feeding systems in West Africa, it is necessary to define a specific Ym value to account for variation in DMI over the seasons (Jaurena et al. 2015).

Table 3c Forages plants used to predict diet in the late dry season

Species	DM	CP	CF	NDF	ADF	ADL	EE	Ash	OMd	GE	DE	References
Pearl millet straw (*Pennisetum glaucum* L.)	93	48	389	745	493	100	7	80	47	18	44	www.feedipedia.org/node/399. Accessed 12 February 2019
Nigeria grass (*Pennisetum pedicellatum*)	93	37	411	733	473	73	10	80	48	18	45	www.feedipedia.org/node/12865>. Accessed 14 February 2019
Bread grass (*Brachiaria brizantha*)	84	44	323	589	378	59	13	69	47	18	45	www.feedipedia.org/node/11885. Accessed 15 February 2019
Bermuda grass (*Cynodon dactylon*)	92	93	270	674	325	54	25	76	54	18	50	www.feedipedia.org/node/11850. Accessed 15 February 2019
Indian sandbur (*Cenchrus biflorus*)	95	75	355	413	59	59	13	121	56	17	53	www.feedipedia.org/node/12202. Accessed 16 February 2019
Gamba grass (*Andropogon gayanus*)	90	34	374	687	432	64	10	57	51	18	48	www.feedipedia.org/node/12116. Accessed 14 February 2019
Rice straw (*Oryza sativa* L.)	93	39	326	641	393	45	13	168	50	16	47	www.feedipedia.org/node/557. Accessed 12 February 2019

The list of forages is bases on previous works in the study site, while the average nutritional composition in terms of apparent dry matter (DM, %), crude protein (CP, g/kg DM), crude fibre (CF, g/kg DM), neutral detergent fibre (NDF, g/kg DM), acid detergent fibre (ADF, g/kg DM), acid detergent lignin (ADL, g/kg DM), ether extract (EE, g/kg DM), digestible organic matter (OMd, %), gross energy (GE, MJ/kg DM) and feed digestibility (DE, %) is sourced from Feedipedia

Trends in expected dry matter intake

Table 7 shows the observed daily dry matter intake per TLU sourced from various research studies conducted in the Sudanian zone of Senegal. Using all references listed, the prediction for all categories were calculated assuming a linear relationship between metabolic weight ($LW^{0.75}$) and intake. Expressed per TLU, the average daily DMI (i.e. 4.2 ± 0.5 kg) reported in these earlier researches is 7% higher than our predicted value of intake. This difference can be explained by the fact that the cattle used in these previous studies received supplemental feed (e.g. cottonseed, cowpea forage) in order to adjust milk production in the dry season.

Table 4 Expected feed digestibility values obtained from organic matter digestibility sourced from various studies conducted in the study area, Kolda region

Parameters	Unit	WS	EDS	LDS
OMd	%	67.0	61.0	48.0
DE	%	64.0	57.0	46.0
Ym	%	6.6	6.9	7.5
DM	% as fed	45.5	91.1	88.8
CP	g/kg DM	55.1	81.2	41.3
CF	g/kg DM	106.0	272.3	360.7
NDF	g/kg DM	211.6	540.2	657.4
ADF	g/kg DM	154.0	319.9	418.3
ADL	g/kg DM	38.8	73.2	64.9
EE	g/kg DM	16.2	26.4	11.4
Ash	g/kg DM	51.0	99.0	79.3
GE	MJ/kg DM	17.8	17.7	17.9

OMd organic matter digestibility, *GE* gross energy density, *DE* feed digestibility, *DM* dry matter, *CP* crude protein, *CF* crude fibre, *NDF* neutral detergent fibre, *ADF* acid detergent fibre, *ADL* acid detergent lignin, *EE* ether extract, *GE* gross energy, *EDS* early dry season, *LDS* late dry season, *WS* wet season

Table 5 Predicted dry matter intake of Ndama cattle as a function of each category of animal

Category	Class	LW (kg)	GE (MJ/hd/d)			DMI (kg DM/hd/d)		
			WS	EDS	LDS	WS	EDS	LDS
F Calves	0–1 yr	42	14	14	14	0.79	0.79	0.78
M Calves	0–1 yr	49	16	16	16	0.90	0.90	0.89
Y Heifer	1–2 yr	65	16	15	19	0.90	0.85	1.06
Y Bulls	1–2 yr	74	16	17	21	0.90	0.96	1.17
B Heifers	2–4 yr	118	28	29	37	1.57	1.64	2.06
R Bulls	2–4 yr	133	31	31	41	1.74	1.75	2.29
Draft oxen	> 4 yr	250	58	59	76	3.25	3.33	4.24
A Bulls	> 4 yr	250	54	59	76	3.03	3.33	4.24
D Cows	> 4 yr	180	43	45	59	2.41	2.54	3.29
L Cows	> 4 yr	223	60	61	79	3.36	3.45	4.41

EDS early dry season, *LDS* late dry season, *WS* wet season, *LW* live weight, *GE* gross energy intake, *DMI* dry matter intake, *hd* head, *d* day, *F* female, *M* male, *Y* young, *L* lactating, *D* dry, *A* adult, *R* replacement, *B* bull, *yr* year

Average values are based on estimations of seasonal gross energy intake (GE, MJ/d) divided by the associated energy density of the feed in each season

Table 6 Summary of estimated average methane emission factors for Ndama cattle reared in the Sudanian zone of Senegal, as a function of the considered categories of cattle in each season and over the year

Category	Proportion (%)	Cattle class	LW (kg)	SMEF ($kg\ CH_4$/hd/d)			AMEF ($kg\ CH_4$/hd/yr)
				WS	EDS	LDS	
F Calves	6	0–1 yr	42	1.4	1.4	1.4	4.1
M Calves	6	0–1 yr	49	1.6	1.6	1.6	4.7
Y Heifer	11	1–2 yr	65	2.3	2.3	3.1	7.7
Y Bulls	8	1–2 yr	74	2.3	2.6	3.4	8.3
B Heifers	17	2–4 yr	118	4.0	4.4	6.0	14.4
R Bulls	5	2–4 yr	133	4.5	4.7	6.7	15.8
Draft oxen	5	> 4 yr	250	8.3	8.9	12.3	29.6
A Bulls	5	> 4 yr	250	7.8	8.9	12.3	29.0
D Cows	15	> 4 yr	180	6.2	6.8	9.6	22.6
L Cows	22	> 4 yr	223	8.6	9.2	12.8	30.7

EDS early dry season, *LDS* late dry season, *WS* wet season, *LW* live weight, *GE* gross energy, *F* female, *M* male, *Y* young, *L* lactating, *D* dry, *A* adult, *R* replacement, *hd* head, *B* bull, *SMEF* seasonal methane emission factor, *AMEF* annual methane emission factor, *yr* year, *d* day

Considering the estimate of DMI by season, it is noted that our assessment of intake showed a higher value in the dry season (LDS and EDS) compared with the rainy season. This profile conflicts with the trends reported in earlier research in Senegal. For example, Lecomte et al. (2016) demonstrated that, because of the availability and the nutritive quality of forage in the rainy season, ruminants tended to consume more feed than in the dry season. To confirm the effect of intake when the growth rate varies, we include our predicted seasonal average daily gain (kg/d) into an equation validated with data obtained from cattle fed tropical forages (Minson and McDonald 1987), considering the average live weight of each animal category, except calves (Table 8). This analysis confirms that when cattle are not gaining weight (i.e. in underfed conditions), DMI decreases. Overall, the tendency corroborates the conclusions of Lecomte et al. (2016). In an addition, others previous research (e.g. Ayantunde 1998; Schlecht et al. 1999; Ayantunde et al. 2014) in SSA are in accord with this profile of daily DMI sourced from the main research studies carried out in Senegal. The seasonality of

Table 7 Observed dry matter intake (DMI, kg DM/d) sourced from research conducted in the studied site, Saré Yoro Bana

Category	Class	LW (kg)	Ickowicz and Mbaye 2001	Chirat 2009	EFEFAECES Project 2013–2015	Lecomte et al. 2016
F Calves	0–1 yr	42	1.16	1.27	1.05	0.95
M Calves	0–1 yr	49	1.31	1.43	1.19	1.07
Y Heifer	1–2 yr	65	1.60	1.75	1.45	1.31
Y Bulls	1–2 yr	74	1.76	1.93	1.60	1.44
B Heifers	2–4 yr	118	2.50	2.74	2.27	2.05
R Bulls	2–4 yr	133	2.75	3.01	2.50	2.25
Draft oxen	> 4 yr	250	4.39	4.81	3.99	3.59
A Bulls	> 4 yr	250	4.40	4.82	4.00	3.60
D Cows	> 4 yr	180	3.44	3.77	3.13	2.82
L Cows	> 4 yr	223	4.04	4.42	3.67	3.31

LW live weight, *F* female, *M* male, *Y* young, *L* lactating, *D* dry, *A* adult, *R* replacement, *B* bull

The prediction of dry matter intake from all categories are based on daily DMI values of 4.4, 4.81, 4.0 and 3.6 kg DM/TLU (animal of 250 kg of live weight), from Ickowicz and Mbaye (2001), Chirat (2009), EFEFAECES Project 2013–2015 (https://www.ppzs.org/projets/termine/waapp-efefaeces) and Lecomte et al. (2016), respectively, assuming a linear relationship between metabolic weight ($LW^{0.75}$) and DMI

Table 8 Predicted daily dry matter intake (DMI, kg DM/d) in each season considering average daily gain (ADG, kg/d) sourced from Sissokho (1998), ISRA-PROGEBE dataset 2009–2015 and using the model from Minson and McDonald (1987) for each animal category

Category	LW (kg)	Season (ADG, kg/d)		
		WS (+0.12)	EDS (− 0.04)	LDS (− 0.16)
Y Heifer	65	2.52	2.04	1.71
Y Bulls	74	2.65	2.15	1.81
B Heifers	118	3.25	2.70	2.32
R Bulls	133	3.47	2.90	2.51
Draft oxen	250	5.18	4.48	3.98
A Bulls	250	5.19	4.48	3.99
D Cows	180	4.16	3.53	3.09
L Cows	223	4.79	4.12	3.64

forage resource availability in terms of amount (accessibility of feedstuff) and quality (digestibility) causes the movements of herds from close to the settlements to more distant transhumance (Chirat et al. 2014; Assouma et al. 2018). This seasonality, which is typical of extensive livestock systems in SSA, should be reflected in the IPCC Tier 2 model. In its current stage, the IPCC Tier 2 model assumes that feeding allowances always fulfil animals' nutritional requirements for growth, maintenance, production and locomotion. When this optimistic assumption of the Tier 2 model is verified, the estimated intake during the late dry season can be overestimated. In practice, due to the scarcity of feed resources in the late dry season, the animals' nutrient intake is limited, and they lose weight (Ezanno et al. 2005), which reduces their maintenance requirements (Kurihara et al. 1999). Also, to survive, the cattle draw on their body reserves (Ezanno et al. 2003).

Under tropical conditions, livestock performance (e.g. average daily gain) is strongly influenced by forage availability. The instantaneous intake rates of Ndama cattle grazing freely in the dry season have been reported to be the lowest and feed digestibility to decline throughout the early, middle and late dry season (i.e. the period lasting from February to May, see Chirat et al. 2014). In Senegal, voluntary intake varies with the seasons because a highly significant relationship exists between OMd and DMI (see Konandreas and Anderson 1982; Reid et al. 2005). Clearly, DMI decreases from the WS to the LDS because of the negative effect of NDF content (Salah et al. 2015), which is further reinforced by the scarcity of feed resources. In view of the production performances observed, such as average daily gain (Sissokho 1998) and body condition score (Ezanno et al. 2005) in the study area, the level of daily DMI is expected to be lower in the dry season. Hence, to obtain valuable prediction of enteric methane emission factor, it is necessary to well-describe the DMI. Indeed, operating statistical analysis, Patra (2017) demonstrates the relationship (with $R^2 = 0.69$) between intakes and methane production.

Annual methane emission factor

Considering the estimates of MEF per head, our weighted value is 33 and 51% lower than the default annual values of 46.0 and 31 kg CH_4 for dairy and other cattle in Sub-Saharan Africa (see IPCC 2006, Table 10 A.1 and 10 A.2), respectively. In addition, our proposed value of MEF (27.3 kg CH_4) is 30% lower compared with the 39.5 kg CH_4/hd suggested by Kouazounde et al. (2015) for Benin. When expressed in TLU, our estimated CH_4 MEF is 6% higher than the 29.1 kg CH_4 reported by Herrero et al. (2008) for the West Africa region, and our recommended annual methane enteric MEF is 18% below the value reported by Goopy et al. (2018) in East Africa (i.e. 37.5 kg CH_4/TLU).

These relative variances between the results of our study and some works cited in the literature may in part be due to the procedure used. For example, in comparison with the yearly value proposed by Goopy et al. (2018), our method is different from the calculation method used to propose the MEF value in that study. To take into account the herd structure, our assessment proposes a weighted MEF, while the EFs from Goopy et al. (2018) are estimated through a representative individual animal. In addition, the forage species encountered in rangelands in West Africa can change in both composition and nutritive value (Reid et al. 2005) with associated fluctuations in intake, and hence in variation in the MEF.

With regard to previous works in the study area, our estimate is 14% above the 26.6 kg CH_4/TLU suggested by Lecomte et al. (2016), who used the Faecal Near Infrared Spectroscopy approach. In the northern Senegalese sylvopastoral area, recent research by Assouma (2016) recommends a yearly value of 27.07 kg CH_4/TLU for the indigenous Gobra cattle (*Bos indicus*).

The variation between our estimated AMEF and MEF sourced from some international references (e.g. IPCC 2006) for Sub-Saharan Africa resulted directly from values in input parameters (e.g. Ym, DE) used in the predictive algorithms (e.g. Blaxter and Clapperton 1965; Charmley et al. 2008; Patra 2017) to calculate the MEF for cattle. For example, the Tier 1 default value is based on an assumed value of feed digestibility (e.g. 50 ± 5% for animals consuming low-quality forage), whereas in the present study, we computed the DE for each season in order to account for the actual livestock production found in the study area. The seasonal lack of pasture and access to water in a particular belt over the course of the year due to environmental and seasonal land use constraints pushes cattle herds to search elsewhere for grazing and watering opportunities (Ayantunde et al. 2014). Several studies were conducted a long time ago to determine how digestibility explains DMI in grazing situations with a highly variable supply of forage and high proportions of roughage in the diet, which recognized digestibility as the major factor limiting dry matter intake (e.g. Baile and Forbes 1974). Accordingly, the CH_4 production rate is increased by changing DE (Blaxter and Clapperton 1965).

Sensitivity of the predicted methane emission factor

In the West Africa region, adult animals are not the only category in a herd. In our case, herd structure is known and we were able to take this into account. This herd structure influenced the variations in AMEF at the herd scale. Indeed, depending on the proportion of a certain class (e.g. lactating cows, which has a higher AMEF) in the herd, the global estimated annual MEF increases or decreases as a function of intake by cattle in each category. For example, different proportions of lactating cows (from 20 to 30%) in the herd were tested to examine the effect of variation on the weighted AMEF. As expected, our simulation shows a positive relation between an increase in the percentage of lactating cows and the overall AMEF. When the proportion of L cows increases (e.g. by 10%), the AMEF at the herd scale increases by 2%. This effect is in agreement with findings of recent studies (e.g. Malik et al. 2015; Sejian et al. 2015), whose authors proposed to reduce the number of heads in low-productive livestock systems (e.g. in Sub-Saharan Africa) which include numerous young animals. Conversely, a logical mitigation pathway would be to reduce the proportion of high methane emitting animals, especially if they are non-productive (e.g. old cows). One difficulty with these proposals is that the existing herd structure has been shown to be suited to the low availability of food resources and the risks associated with the length of the dry season, whereby heifers first calve at the age of five and mature cows calve only every 2 years (Ezanno et al. 2003). Furthermore, improving the animal performance of each category through use of concentrate feeds or health control is not economically feasible at large scale in Senegal.

The main remaining uncertainty concerns the estimation of forage intakes. Although we estimated fluctuations in these intakes using observed changes in live weight, this may not account for all the sparing mechanisms that enable ruminants to reduce their nutritive requirements, thus greatly reducing methane emissions during the dry season (Kurihara et al. 1999).

Conclusion

The IPCC 2006 Tier 2 method was used to evaluate enteric methane emission factors for Ndama cattle in the Sudanian zone of Senegal. Our results reveal an overestimation of the MEF when using the default value provided in the IPCC Tier 1 approach, a parameter that is widely used in GHG inventories for livestock systems in Sub-Saharan Africa. Before recommending effective strategies to mitigate the environmental impact of livestock systems in Senegal, direct measurements in cattle production would be useful to accurately estimate enteric methane emissions.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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