Animal (2015), **9:3**, pp 526–533 © The Animal Consortium and Her Majesty the Queen in Right of Canada, as represented by the Minister of Agriculture and Agri-Food in Canada. [2014]
doi:10.1017/S1751731114002626

animal

Development of methane emission factors for enteric fermentation in cattle from Benin using IPCC Tier 2 methodology

J. B. Kouazounde[1], J. D. Gbenou[1], S. Babatounde[2], N. Srivastava[3], S. H. Eggleston[3], C. Antwi[4], J. Baah[5] and T. A. McAllister[5†]

[1]*Department of Chemistry, Faculty of Science and Technique, University of Abomey-Calavi, P.O. Box 526, Cotonou, Republic of Benin;* [2]*Department of Animal Production, Faculty of the Agronomic Science, University of Abomey-Calavi, P.O. Box 526, Cotonou, Japan;* [3]*Technical Support Unit, IPCC National Greenhouse Gas Inventory Program, C/0 I.G.E.S., 2108-11, Kamiyamaguchi, Hayama, Kanagawa 240-0115, Republic of Benin;* [4]*Department of Animal Science, College of Agriculture and Natural Resources Kwame Nkrumah, University of Science and Technology Kumasi, Ghana;* [5]*Agriculture and Agri-Food Canada, Lethbridge Research Centre P.O. Box 3000, Lethbridge, AB, Canada T1J 4B1*

(Received 7 November 2013; Accepted 21 July 2014; First published online 11 November 2014)

The objective of this study was to develop emission factors (EF) for methane (CH_4) emissions from enteric fermentation in cattle native to Benin. Information on livestock characteristics and diet practices specific to the Benin cattle population were gathered from a variety of sources and used to estimate EF according to Tier 2 methodology of the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories. Most cattle from Benin are Bos taurus *represented by* Borgou, Somba *and* Lagune *breeds. They are mainly multi-purpose, being used for production of meat, milk, hides and draft power and grazed in open pastures and crop lands comprising tropical forages and crops. Estimated enteric CH_4 EFs varied among cattle breeds and subcategory owing to differences in proportions of gross energy intake expended to meet maintenance, production and activity. EFs ranged from 15.0 to 43.6, 16.9 to 46.3 and 24.7 to 64.9 kg CH_4/head per year for subcategories of* Lagune, Somba *and* Borgou *cattle, respectively. Average EFs for cattle breeds were 24.8, 29.5 and 40.2 kg CH_4/head per year for* Lagune, Somba *and* Borgou *cattle, respectively. The national EF for cattle from Benin was 39.5 kg CH_4/head per year. This estimated EF was 27.4% higher than the default EF suggested by IPCC for African cattle with the exception of dairy cattle. The outcome of the study underscores the importance of obtaining country-specific EF to estimate global enteric CH_4 emissions.*

Keywords: methane, enteric fermentation, emission factor, cattle, Benin, Africa

Implications

Methane (CH_4) is second to carbon dioxide in terms of its contribution to climate change (Lassey, 2007). More than 70% of CH_4 is generated by anthropogenic activities including animal husbandry (27%; enteric fermentation in livestock, manure management), paddy rice cultivation (26%), petroleum sources (26%), waste management (13%) and 9% from biomass burning (Kvenvolden and Rogers, 2005; Sejian *et al*., 2012). Enteric fermentation is the largest source of CH_4 from ruminant livestock with cattle being the major contributor. Cattle emit CH_4 as a result of intestinal fermentation and identification of those geographical regions where this source is significant is required for targeted mitigation. There is a paucity of information on enteric CH_4 emissions in regions of Africa. Use of Tier 2 methodology of the Intergovernmental Panel on Climate Change (IPCC) (2006) improves estimates and reduces uncertainties around enteric CH_4 emissions from cattle. The present paper compiled country-specific data to develop emission factors to more accurately estimate enteric CH_4 emissions from cattle in Benin, Africa.

Introduction

Scientific evidence established by the Intergovernmental Panel on Climate Change (IPCC) reveals that increasing greenhouse gas (GHG) concentrations in the atmosphere attributable to human activities are responsible for global climate change (IPCC, 2007). The contribution of GHGs namely, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and halocarbons to global anthropogenic emissions in 2010 expressed as CO_2 equivalents (CO_2eq) were estimated at 76%, 16%, 6% and 2%, respectively (Olivier and Janssens-Maenhout, 2012). In 2000, the main GHG in Benin

† E-mail: tim.mcAllister@agr.gc.ca

https://doi.org/10.1017/S1751731114002626 Published online by Cambridge University Press

was N_2O, accounting for 40% of CO_2eq emissions, followed by CH_4 (37%) and CO_2 (23%) (Ministry of Environment, Urban Settlement and Town Planning (MEHU), 2011). Agriculture was the main source of GHG in Benin, accounting for ~68% of total CO_2eq emissions in 2000 with enteric CH_4 mainly from cattle (84%), accounting for 29% of emissions from this sector (MEHU, 2011).

The effectiveness of any global measure to combat the threat of climate change will depend significantly on the accuracy of country-specific national GHG inventories. These inventories support the prediction of GHG emission trends and in assessing the potential value of mitigation options. However, a previous review of national GHG inventories from West African countries including Benin revealed high uncertainties largely caused by gaps in activity data and the use of IPCC default emission factors (EFs) that did not reflect West African conditions (United Nations Development Programme (UNDP), 2002). Indeed, national GHG inventories are performed in West Africa mainly using Tier 1 methodology as outlined in IPCC guidelines. The GHG inventory methods given in the IPCC guidelines estimate emissions based on the extent to which a human activity takes place (activity data) along with an EF which quantify emissions or removals per unit of activity using the following equation:

$$\text{Emissions} = \text{AD} \times \text{EF} \quad (1)$$

For estimating CH_4 from enteric fermentation, methodologies in IPCC guidelines vary from the simpler Tier 1 approach towards the increasingly more complex Tier 2 and Tier 3 methods (IPCC (2006)). Tier 1 methods involve using the default enteric CH_4 EFs, which provide fixed values for each species of animal in different regions of the World, irrespective of variations in animal physiological state or production level. Tier 2 methods substitute default EFs with those that are country specific, to more accurately reflect country-specific information on livestock populations and feed and feed intake characteristics. Tier 3 methods are also country specific and involve modeling and or detailed measurements that are expected to provide the most accurate estimate of emissions (IPCC (2006)), requirements that are difficult in nations where financial and specialized human resources are limited and novel types of equipment whose cost and maintenance may not be within the scope of many laboratories. At present, national inventories of enteric CH_4 emissions are estimated in Benin using IPCC Tier 1 methods. Among EFs contributing to uncertainty in the estimation of West African GHG emissions, enteric fermentation from domestic livestock was second only to forest and grassland conversion (UNDP, 2002). The lack of a country-specific enteric CH_4 EF that reflect Benin production practices impedes accurate estimation of agricultural emissions (MEHU, 2011). One of the main future improvements identified in Benin national GHG inventory system is the need of enteric CH_4 from cattle to be estimated using IPCC Tier 2 methodology.

This study aimed to develop enteric CH_4 EFs for cattle native to Benin using Tier 2 methodology following the *2006 IPCC Guidelines for National GHG Inventories*.

Material and methods

Enteric CH_4 EFs (annual CH_4 emissions per animal) for cattle that are used for multi-purpose within Benin were estimated using the Tier 2 method of IPCC (2006) which is based on National Research Council (NRC) (1996) energy model. The steps as outlined in Figure 1 were used to estimate EFs.

Collection of input data

Data related to the characterization of cattle populations and the description of performance and diet by cattle subcategory were collected from sources of country-specific data as suggested by IPCC protocols through a literature search of national libraries (University of Abomey-Calavi of Benin, Livestock Department of Benin, Ministry in charge of Environment in Benin), publications in scientific journals and data compiled by the IPCC (2006), the Food and Agriculture Organization (FAO), the International Livestock Research Institute (ILRI) and the International Livestock Centre for Africa (ILCA). Thus, scientific and technical articles (17), dissertations (7), project reports (2), national inventory reports of agriculture sector from Benin (1), consultative groups on international agricultural research (ILRI, ILCA) or international organizations (FAO, IPCC) were consulted. Collected data included that generated by studies carried out on cattle bred in traditional production systems (see 'Feeding situation' section) and studies designed to improve cattle productivity.

Data related to some of the Benin cattle breeds were sparse (reproduction trait for all cattle, live BW for *Borgou* cattle) or not available (average weight gain per day for *Borgou* and *Lagune* cattle, live BW for *Lagune* cattle) as censuses on livestock population and characteristics are not carried out on a regular basis. Under these conditions, additional data were derived from expert opinion and compiled from Togo (West African country) as suggested by IPCC protocols (IPCC, 2006). Traditional cattle production systems (see 'Feeding situation' section) are the dominant production systems in Benin (Ministère de l'Agriculture et de l'Elevage (MAEP), 2003) and consequently this production system constituted the majority of the data in deriving EF estimates. In the absence of such data, estimated average weight gain per day for *Borgou* and *Lagune* cattle, live BW data of *Lagune* cattle bred under similar production and climate conditions in Togo (tropical soudanian climate in the North and subequatorial climate in the South) and average weight gain of *Borgou* cattle of 6 to 12 months from improved systems in Benin were used.

Characterization of cattle population and performance data of cattle subcategories.

Compiled data were summarized by the three principal Benin breeds, *Somba* (Supplementary Tables S1 and S4), *Borgou* (Supplementary Tables S2 and S4) and *Lagune* (Supplementary Tables S3 and S4). Where available and appropriate, recorded variables included live BW, average daily gain, % of

https://doi.org/10.1017/S1751731114002626 Published online by Cambridge University Press

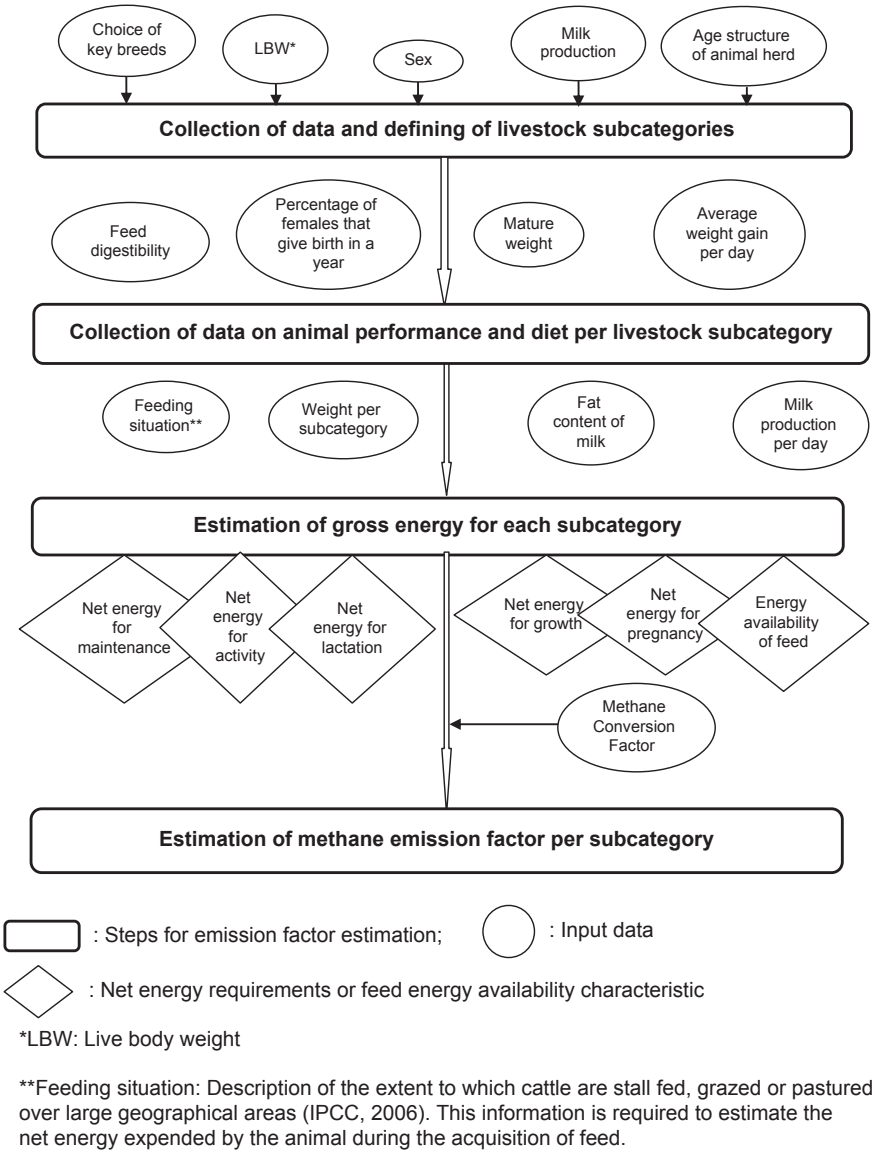


Figure 1 Flow chart of methodology used for enteric methane EF estimate: IPCC (2006).

population, mature weight, daily milk production, milk fat content, calving rate and the % of castrated males.

Breed description

Cattle bred in Benin are composed of *Bos taurus* and *Bos indicus* subgroups. *Bos taurus* are often referred to as 'European' or 'taurine' cattle including similar types from Africa and Asia whereas *B. indicus* have a prominent hump forward of the shoulder and are known as zebu cattle and are of south Asian origin. Locally adapted, *B. taurus* breeds include *Lagune* (Dwarf West African Shorthorn), *Somba* (Savanna Shorthorn), *Borgou* and *N'Dama* cattle. According to Dehoux and Hounsou-Ve (1993), *Borgou* cattle arose from a cross between West African Shorthorn (*Lagune* and *Somba* cattle in particular) and West African *B. indicus* (mainly *White Fulani*). With the exception of *N'Dama* cattle which were imported from the Republic of Guinea, *B. taurus* breeds are native to Benin. Outside of Benin, *Borgou* cattle also exist in the neighboring countries of Togo, Burkina Faso (*Méré*) and Nigeria (*Kétéku*), while *Somba* cattle are mainly resident to Togo. In West Africa, *Lagune* cattle are principally located in Togo, Ghana and Nigeria. The *B. indicus*' subgroup is exotic from West Africa and includes *N'Bororo*, *White Fulani*, *Gudali* and *Djilli* (MAEP, 2003). The distribution by breed type of cattle reared in Benin is as follows: *Borgou* (88%), *Lagune* (3.7%), *Somba* (0.3%) and *B. indicus* cattle (7.7%) (Senou *et al.*, 2008; Gbangboche *et al.*, 2011). This distribution illustrates that *Borgou* cattle are the dominant breed and *B. taurus* are the dominant subgroup accounting for 92% of cattle in Benin.

Main categories of cattle

In Benin, cattle are primarily low productivity multi-purpose being used for production of meat; milk and hides as well as for draft power (MAEP, 2003). Meat is by far the most important product derived from cattle, whereas relatively

https://doi.org/10.1017/S1751731114002626 Published online by Cambridge University Press

few cattle (4%) are used for draft power with only 80 000 head used for this activity (MAEP, 2003). Milking cows represent 15% of the cattle population with an average milk production of 0.5 to 2 l/lactating cow per day (Faculté des Sciences Agronomiques (FSA), 2006). Around 60% of the milk produced by milking cows is consumed by the calf, 20% to 25% is consumed by the farm family in the home and the remaining is sold for human consumption and processing (cheese) (Dehoux and Hounsou-Ve, 1993; FSA, 2006). According to FSA (2006), farm family consumption can reach 75% to 80% during the dry season and during transhumance when the milk production is extremely low. Following IPCC (2006) and taking into account that cows from Benin are multi-purpose and of low productivity, the category 'Dairy Cow' as defined in the 2006 IPCC guidelines is not applicable to Benin. Therefore, Benin cattle are categorized as 'other cattle' according to IPCC protocols (IPCC, 2006). Each cattle breed was divided into two broad sub-categories namely 'Growing livestock' for that part of the population that had yet to reach mature BW and 'Other Mature livestock' for those that have achieved mature BW (Supplementary Tables S1 to S3). This approach accounted for the mature age and weight and the reproductive traits of the animal (Supplementary Tables S4 and S5).

Identification of livestock population subcategories. On the whole, subcategories defined were based on estimation of live BW. They included sex, live BW and age structure of the herds (Supplementary Tables S1 to S3).The subcategories of *Borgou* cattle were obtained by combining the age groups identified by Dehoux and Hounsou-Ve (1993) and Chabi Macco (1992) that categorized the age of different breeds of cattle on the basis of available records and dentition. Data on suckling calves are not presented in Supplementary Tables S1, S2 and S3 as it was assumed that CH_4 emissions were negligible up to weaning, as calves were mainly fed milk until at least 4 months of age (Dehoux and Verhulst, 1994). Indeed, rumen function in calves <3 months and Y_m for young cattle consuming only milk are minimal with negligible emission of enteric CH_4 (IPCC, 2006).

Live BW and average weight gain per day. Information on the live BW of *Lagune* cattle in Benin was not available and as result values were adapted from weights recorded for this breed raised in Togo under similar conditions. The live BW and weight gain of 6 to 12-month-old *Somba* cattle were used as a default for 6 to 12-month-old *Lagune* cattle as the breeds are very similar. The live BW of 2 to 4-year-old *Borgou* cattle was obtained from Symoens and Hounsou-Ve (1991) and Chabi Macco (1992). This subcategory corresponds to the subgroup of *Borgou* cattle aged on the basis of having two to six teeth (Symoens and Hounsou-Ve, 1991). Average live BWs were estimated for all Benin cattle and subcategories of yearlings, mature cows and mature bulls as weighted means of live BWs over *Borgou*, *Somba* and *Lagune* subcategories at 156, 115, 240 and 275 kg, respectively, and compared with the data of the IPCC (2006) and FAO (2000). Data on growth rates for *Somba* cattle were obtained from Adanléhoussi *et al*. (2003). However, growth rates of other cattle subcategories (Bull *Somba* 5 to 6 years, *Borgou* cattle over 1 year, *Lagune* cattle) were estimated on the basis of live BW and predicted age as reported in Supplementary Tables S1 to S3. Consecutive subcategories in Supplementary Tables S1, S2 and S3, were used to estimate average daily gain as the difference between their weights divided by the difference in ages.

Milk production and fat content. The average daily production of milk for lactating cows (Supplementary Table S4) was calculated by dividing their total annual production by 365 days. The annual milk production in a year was assumed to be equal to the quantity of milk produced per lactation. The milk production from Togo was used as a default data for *Lagune* cattle. Fat content of milk was estimated as a percentage of milk weight for lactating *Borgou* and *Lagune* cows using data from Kora (2005), who estimated the quantity of lipids in milk relative to milk dry matter.

Percentage of females that give birth in a year. Cow fertility or calving rate was estimated as the ratio of calves born during the year to the number of females of breeding age (Supplementary Table S4).

Average amount of work performed per day. Among the breeds raised in Benin, *Borgou* cattle are most commonly used for draft power. However, this activity is marginal in Benin and little information is available about it. Therefore, draft power was not taken into account in EF estimates.

Feeding situation. An animal's feeding situation is required to estimate the net energy expended by the animal during the acquisition of feed (IPCC, 2006). It describes the extent to which cattle are stall fed, grazed or pastured over large geographical areas. In the present study, the feeding situations of other cattle were defined by analyzing farming methods and feeding practices. In Benin, the farming method is generally traditional, which corresponds to minimal-input, low-production extensive systems using natural pastures in open rangeland or crop residues within fields (Goutondji, 2007; Babatounde *et al*., 2009; Youssao *et al*., 2013). Approximately 99% of cattle are produced using a traditional farm management system with <1% being produced on ranches or research stations (Hoste *et al*., 1992). The traditional method is dominated by two village-based systems of utilizing natural pastures namely transhumance and sedentary systems. The transhumance system predominates (80%) and is characterized by continuously herding cattle across pasture land (Dehoux and Hounsou-Ve, 1993; MAEP, 2003). Under the sedentary system, livestock are raised in areas of crop cultivation and subsist on crop residues near villages (Dehoux and Verhulst, 1994). The average grazing time of cattle on pasture is estimated at about 8 h per day and distributed as follows: 75% for grazing, 20% for walking, 5%

https://doi.org/10.1017/S1751731114002626 Published online by Cambridge University Press

for rest/rumination and water consumption (Dehoux and Hounsou-Ve, 1993). During the dry season, the grazing time averages 10 h, but can range from 8 to 19 h depending on the availability of forage. During the rainy season, it averages 6 h, but ranges from 10 to 17 h depending on terrain and sward density. Cattle on ranches or research stations are raised on small grazing areas using improved management practices. Improved management systems in Benin include supplementation of cattle on natural pastures or those receiving crop residues as well as health and disease management. When not on pasture, herds may be tied in barns or fenced night parks, with shelter for calves. *Borgou* and *Somba* cattle are mainly located in the northern part of Benin and are bred under transhumance and sedentary systems while grazing large land areas. Following Aho (Faculty of Agronomic Science of the University Abomey-Calavi (Benin), personal communication) and IPCC guidelines (IPCC, 2006, table 10.5), *Borgou* and *Somba* cattle were assumed to be raised on large grazing areas that required considerable energy expenditure for feed acquisition. *Lagune* cattle are abundant in the southern part of Benin, bred under sedentary conditions and maintained under grazing systems on small natural pastures or fed crop residues, under palm and coconut trees or on fallow land. Following IPCC (2006), *Lagune* cattle were considered to be maintained mainly in small paddocks and thus only expended modest amounts of energy to acquire feed.

Forages and their digestibility

In Benin, forages mainly include natural pastures and crop residues. Natural pastures include tropical grasses and legumes (Supplementary Table S6) with a dominance of the former and a scarcity of non-woody legumes (Achard *et al*., 2001). The main crop residues are maize, sorghum, millet, rice, cotton, cowpea and groundnut. During the rainy season, grasses are the principal forages utilized by grazing cattle (Babatounde *et al*., 2009), but during the dry season fodder, multi-purpose trees and crop residues are the main feeds. Crop residues account for 70% of the feed available to cattle in the African Sudano-Sahel region (Djenontin *et al*., 2004). An average value of 54% was used for forage digestibility based on Benin-specific data on grasses and crop residues digestibility from 2013 version of FAO's Global Livestock Environmental Accounting Model (Gerber *et al*., 2013).This digestibility value is consistent with that of 55% and 45% to 55% suggested by IPCC (2006) for mature females and bulls grazing African forages and ruminants fed low-quality forage (crop by-products and range lands).

Estimation of feed intake per animal subcategory

After assessment, performance and diet data were used to calculate the feed intake for each animal subcategory in terms of gross energy using the equations from IPCC (2006) as presented in Supplementary Table S7. The metabolic function relevant for each livestock category was identified (Figure 1) and the net energy requirements associated with these functions were estimated using relevant performance data. The net energy requirements were summed and combined with the energy availability in feed to estimate the gross energy requirements for each subcategory. The energy availability of the feed was estimated from the feed digestibility and the energy required for growth and maintenance. The reproductive traits of cattle in Supplementary Table S5 were taken into account in the estimation of net energy requirements for metabolic function (maintenance, growth, pregnancy, lactation). The net energy for pregnancy was estimated for heifers that had reached puberty and for cows whereas the net energy for lactation was estimated only for cows with consideration for the yearly calving rate. Data on the gestation length and age at first calving were used to identify cattle age groups from which net energy for pregnancy and lactation were estimated. Mature cattle were considered to be at maintenance and as a consequence the net energy for growth was considered to be zero.

Estimation of enteric CH_4 EFs

The enteric CH_4 EF was estimated for each subcategory of cattle, and for each breed within *B. taurus* and all Benin cattle. Considering cattle subcategories, EFs were calculated using the IPCC (2006) equation:

$$EF = (GE \times (Y_m/100) \times 365\ \text{days})/55.65 \qquad (2)$$

In this equation, EF is the emission factor (kg CH_4/head per year), GE the gross energy intake (MJ/head per day), Y_m the methane conversion factor (%), with 55.65 (MJ/kg CH_4) being the energy content of CH_4, it was assumed that the EF was developed for each category of cattle over a year (365 days). The emission of CH_4 was quantified by its conversion rate which was the percentage gross energy in feed converted to CH_4. A Y_m of 7% was selected for grazing cattle in tropical Africa where forages are of poor quality as previously reported by Sejian *et al*. (2012). This Y_m value is within the range 6.5% ± 1.0% suggested by IPCC (2006) for other cattle grazing or primarily fed low-quality crop residues and by-products.

For each breed, an average EF was estimated as a weighted mean of EFs of its subcategories across its demographic profile. The individual EF estimated for each subcategory of cattle was then multiplied by the associated demographic profiles and summed. The national average EF for *B. taurus* was calculated by weighting average EFs for breeds on the basis of their national demographic distribution and was assumed representative for all Benin cattle owing to their predominance. EFs were not included for *B. indicus* cattle types as similar information was not available and they accounted for <8% of the total cattle population. Cattle demographic profiles are presented in Supplementary Tables S1, S2 and S3 and were derived mainly from Dehoux and Hounsou-Ve (1993) and Akadiri (1979). The day weighted population mix for cattle aged 0 to 8 months (11.9% for male and 11.9% for female) from Akadiri (1979) was used as default value for cattle aged 0 to 6 months. The day weighted population mix of *Borgou* cattle estimated by Dehoux and Hounsou-Ve (1993) was used as default value for *Somba* and *Lagune* cattle 0 to 12 months.

https://doi.org/10.1017/S1751731114002626 Published online by Cambridge University Press

Results and discussion

Enteric CH_4 EFs estimated for cattle from Benin are presented in Table 1. They varied with breed and subcategory ranging from 15.0 to 43.6, 16.9 to 46.3 and 24.7 to 64.9 kg CH_4/head per year for subcategories of *Lagune*, *Somba* and *Borgou* cattle, respectively. National average EFs of 24.8, 29.5 and 40.2 kg CH_4/head per year were estimated for *Lagune*, *Somba and Borgou* cattle, respectively.

The IPCC (2006) Tier 2 methodology is a function of a number of attributes including live BW, growth rate, feeding practices, gender and productivity (e.g. pregnancy, milk production, work). These parameters are known to influence cattle energy demand and hence enteric CH_4 production, with the level of animal productivity being the most important factor (Yan *et al.*, 2009). Differences in live BW and grazing systems among breeds of cattle contributed to the variation in estimated EFs among cattle breeds and subcategories. This was expected since the productivity of cattle from Benin is low and a large proportion of gross energy intake is used for maintenance which is related to metabolic $BW^{0.75}$ (FAO (2000)). The highest EF was observed for *Borgou* cattle owing to their greater live BW relative to both *Somba* and *Lagune* cattle and the fact that they are primarily raised in extensive pasture systems unlike *Lagune* cattle which are raised under more intensive conditions. The EF for *Lagune* cattle was lower than that of *Somba* cattle, which is a reflection of the need for *Somba* cattle to expend more energy to acquire feed. The national average EF of all Benin cattle was estimated to be 39.5 kg CH_4/head per year, slightly lower (2.0%) than national average EF for *Borgou* cattle. This observation reflects the fact that *Borgou* are the prominent cattle breed in Benin and thus are more heavily weighted in the estimation of the average EF for Benin cattle.

The present study reveals the national average EF for cattle from Benin was 27.4% higher than the default EF suggested by IPCC (2006) for other African cattle (Table 2).

The default EFs suggested by IPCC (2006) for other cattle (other cattle default EF) from Africa were estimated using Tier 2 methodology and average performance data and feed characteristics reflecting African regional-specific circumstances (IPCC, 2006; annex 10A.1, table 10A.2; Lassey, 2007). Therefore, discrepancies between results from this study and other cattle default EF for Africa may reflect deviations in cattle management practices within Benin as compared with other African regional-specific circumstances. Among subcategories provided by IPCC (2006) for Africa, only young cattle, mature cows and mature bulls were defined for Benin. On the whole, EFs generated by this study for these subcategories were higher than those from IPCC (2006) except for subcategories of young cattle, mature *Lagune* and mature *Somba* bulls. National average EFs estimated for *Lagune* and *Somba* cattle were 19.9% and 4.8% lower, respectively than for the EF for other cattle from Africa. In contrast, the national average EF for *Borgou* cattle was 29.6% higher than the African EF default for other cattle. In general, the differences observed between EFs generated by the present study and default EFs may be attributed to discrepancies in Y_m, demographic profile and growth performance data, in particular live BW and feeding practices (IPCC, 2006, annex 10A.1, table 10A.2). Indeed, the Y_m value of 7.0% for grazing cattle from tropical Africa (Sejian *et al.*, 2012) used in the present study was higher than the default Y_m of 6.5% provided by IPCC (2006) for Africa. It is well known that Y_m is inversely related to forage quality (IPCC, 2006). Lower Y_m value suggested by IPCC (2006) for Africa may reflect the assumptions associated with temperate forages which are of higher quality and of lower Y_m. Apart from mature *Lagune* and mature *Somba* cattle, the live BWs of cattle

Table 1 *Estimated gross energy intake (mj/head per day) and enteric CH_4 EF (kg/head per year) for cattle breeds and subcategories*

Somba cattle			*Borgou* cattle			*Lagune* cattle			All cattle
Subcategory	GE	CH_4 EF	Subcategory	GE	CH_4 EF	Subcategory	GE	CH_4 EF	CH_4 EF
Female 0 to 6 m	NE	0.0	Female 0 to 6 m	NE	0.0	Female 0 to 6 m	NE	0.0	
Male 0 to 6 m	NE	0.0	Male 0 to 6 m	NE	0.0	Male 0 to 6 m	NE	0.0	
Female 6 to 12 m	36.8	16.9	Female 6 to 12 m	53.7	24.7	Female 6 to 12 m	32.8	15.0	
Male 6 to 12 m	39.9	18.3	Male 6 to 12 m	58.8	27.0	Male 6 to 12 m	35.1	16.1	39.5
Heifer 1 to 2 y	56.6	26.0	Heifer 1 to 2 y	82.7	38.0	Heifer 1 to 2 y	64.5	29.6	
YB 1 to 2 y	61.2	28.1	Heifer 2 < 4 y	120.9	55.5	YB 1 to 2 y	66.5	30.5	
Heifer 2 to 3 y	76.4	35.1	YB 1 to 2 y	88.2	40.5	Heifer 2 to 3 y	56.2	25.8	
YB 2 to 3 y	82.3	37.8	YB 2 to < 4 y	125.9	57.8	YB 2 to 3 y	62.6	28.7	
Heifer 3 to 4 y	90.3	41.5	MC ⩾ 4 y	141.5	64.9	YB 3 to 4 y	92.4	42.4	
YB 3 to 4 y	94.8	43.5	Bull ⩾ 4 y	135.5	62.2	Heifer 3 to 4 y	69.2	31.8	
Cow 4 to 5 y	100.8	46.3	Average		40.2	MC ⩾ 4 y	80.9	37.1	
YB 4 to 5 y	92.2	42.3	–		–	Bull > 4 y	94.9	43.6	
YB 5 to 6 y	94.5	43.4	–		–	Average		24.8	
MC ⩾ 5 y	100.9	46.3	–		–	–		–	
Bull ⩾ 6 y	95.7	43.9	–		–	–		–	
Average		29.5	–		–	–		–	

y = year; m = month; NE = not estimated; GE = gross energy; EF = emission factor; YB = young bull; MC = mature cow.

https://doi.org/10.1017/S1751731114002626 Published online by Cambridge University Press

Table 2 *Comparison between estimated enteric CH_4 EFs and those from other sources (kg/head per year)*

Estimated CH_4 EF (Average values)	IPCC (2006)	FAO (2000)
Somba cattle: 29.5	MFG cattle: 41	
Borgou cattle: 40.2	Bulls-grazing: 49	
Lagune cattle: 24.8	Young cattle: 16	SSA cattle: 40.1
All MFG: 63.3		
All cattle from Benin: 39.5	Other cattle from Africa: 31	

EF = emission factor; IPCC = Intergovernmental Panel on Climate Change; FAO = Food and Agriculture Organization; MFG = mature females grazing; SSA = Sub-Saharan Africa.

subcategories from Benin were higher than the default data reported for cattle from Africa by IPCC (2006). The levels of production of cattle subcategories from Benin were also slightly higher than those suggested by IPCC (2006) for cattle subcategories in Africa. The national average live BWs of young cattle and grazing mature cows from Benin were 1.6 and 1.2 times higher, respectively than those reported for these cattle subcategories in greater Africa (IPCC, 2006). National average EF estimated for mature females grazing in this study was 54.3% higher than that suggested by IPCC (2006) for this cattle category in Africa, mainly due to differences in estimated live BW, milk production and Y_m values. The study reveals the national average EF for cattle from Benin was consistent with EF reported by FAO (2000) for other cattle from Sub-Saharan Africa, being 1.5% lower than this author finding. This observation may be due to differences in the data rather than the approach used in the two studies as the FAO (2000) used Tier 1 methodology based on an emissions algorithm derived in IPCC/Organization for Economic Cooperation and Development (1994) and United States Environmental Protection Agency (1994). This method is similar to the methodology of 2006 IPCC guidelines where energy calculations are based on NRC (1996). The average live BW for cattle and energy digestibility used in the present study were 6.9% and 11.2% higher, respectively, than those reported by FAO (2000) for Sub-Saharan Africa. In contrast, the value reported by FAO (2000) for Y_m in Sub-Saharan Africa circumstances was 1.1 times higher than Y_m used in our study.

The application of IPCC Tier 2 methodology may be limited by the availability and quality of data in a given country (Storm *et al.*, 2012). The present study was subject to limitations such as gaps in data on live BW and average weight gain per day per subcategory of *Borgou* and *Lagune* cattle. These gaps undoubtedly contribute to uncertainty in estimated EF. Execution of an uncertainty assessment was beyond the scope of the present project owing to a lack of information of the variability around select parameters. As IPCC (2006) proposes that the uncertainty of the Tier 2 method may be similar to that of Tier 1 method (±30% to 50%), uncertainty associated with EFs in the present study could be as high as ±40%. It would be useful to undertake a detailed uncertainty assessment to know which parameters contribute most significantly to variability in EFs.

Conclusion

This study has revealed that enteric CH_4 EF estimated for cattle from Benin using the Tier 2 method of IPCC (2006) offer additional insight into emissions over the IPCC (2006) default EF suggested for cattle categorized as 'other' in Africa. The national average EF calculated for *Borgou* cattle is representative of the EF for bovine species in Benin. The application of the Tier 2 method contained in IPCC (2006) to Benin conditions also illustrates the challenges in developing Benin country-specific EFs stemming from lack of data within defined subcategories of cattle for animal live BW and growth rate. Further research should also focus on the estimation of uncertainties in Tier 2 inputs. The compiled country-specific data and the estimated EF should be beneficial to Benin in the estimation of national GHG inventories and provide FAO with additional information to improve estimates of enteric CH_4 emissions from African cattle.

Acknowledgments

This research work was carried out at IPCC-TFI Technical Support Unit (TSU). The 'TSU Inventory Internship' programme has been launched by the Institute for Global Environmental Strategies and funded by the Japanese Government. The authors have benefited from the support of all kind from Mr Taka Hiraishi (TFI Co-chair) and all TSU staff. They have also benefited from the advice from or collaboration with Dr Keith R. Lassey (NIWA, New Zealand), Mr Epiphane D. Ahlonsou (ASECNA, Benin), Prof. Nestor Aho (UAC, Benin), Dr Sabin Guendehou (CBRST, Benin), and Ms Eunice DOSSA (Benin).

Supplementary material

To view supplementary material for this article, please visit http://dx.doi.org/10.1017/S1751731114002626

References

Achard F, Hiernaux P and Banoin M 2001. Les jachères fourragères naturelles et améliorées en Afrique de l'Ouest. In La jachère en Afrique tropicale vol 2, De la jachère naturelle à la jachère améliorée (ed. Ch Floret and R Pontanier), pp. 201–239. John Libbey Eurotext, Paris, France.

Adanléhoussi A, Bassowa H, Défly A, Djabakou K, Adoméfa K and Kouagou NT 2003. Les performances de la race taurine Somba en milieu paysan. Tropicultura 21, 135–141.

Akadiri FA 1979. Contribution à l'étude de la place de l'Elevage dans l'économie de la République Populaire du Bénin. Thèse de docteur en médecine vétérinaire, Inter-State College of Veterinary Sciences and Medicine of Dakar, Dakar, Sénégal. Retrieved October 19, 2013, from www.sist.sn/gsdl/collect/eismv/inHASH0107dex/assoc/.dir/TD79-1.pdf

Babatounde S, Sidi H, Houinato MRB and Mensah GA 2009. Comportement alimentaire des taurins de race Borgou sur des jachères de la zone nord-soudanienne du Benin. Rencontres autour des Recherches sur les Ruminants 16, 29–32.

https://doi.org/10.1017/S1751731114002626 Published online by Cambridge University Press

Chabi Macco Y 1992. Etude de quelques paramètres de productivité de la race bovine Borgou. Thèse d'Ingénieur agronome. National University of Benin, Abomey-Calavi, Bénin.

Dehoux JP and Verhulst A 1994. Une race trypanotolerante méconnue: la *Borgou*. Animal Genetic Resources Information Bulletin. 13, 39–45. Retrieved October 12, 2013, from ftp://ftp.fao.org/docrep/fao/012/t1820t/t1820t03.pdf

Dehoux JP and Hounsou-Ve G 1993. Productivité de la race bovine Borgou selon les systèmes d'élevage traditionnels au nord-est du Bénin. Revue Mondiale de Zootechnique 74/75, 36–48. Retrieved October 12, 2013, from www.fao.org/DOCREP/U9550T/u9550T0g.htm

Djenontin AJ, Amidou M and Baco NM 2004. Diagnostic gestion du troupeau: gestion des ressources pastoralles départements de l'Alibori et du Borgou au nord Bénin. Bulletin de la Recherche Agronomique du Bénin 43, 30–45.

Faculté des Sciences Agronomiques (FSA) 2006. Production et transformation du lait frais en fromage Peulh au Bénin, Guide de Bonnes pratiques. Retrieved September 15, 2013, from www.repol.info/IMG/pdf/Fiche_wagashi_VF.pdf

Food and Agriculture Organization (FAO) 2000. Global impact domain: methane emissions. Retrieved September 18, 2013, from http://www.fao.org/wairdocs/lead/x6116e/x6116e00.htm

Food and Agriculture Organization (FAO). Domestic Animal Diversity Information System (DAD-IS). 2009. Retrieved on 11 September 2013, from http://dad.fao.org/

Gbangboche AB, Alkoiret TI, Toukourou Y, Kagbo A and Mensah GA 2011. Growth curves of different body traits of *Lagune* cattle. Research Journal of Animal Sciences 5, 17–24.

Gerber PJ, Steinfeld H, Henderson B, Mottet A, Opio C, Dijkman J, Falcucci A and Tempio G 2013. Tackling climate change through livestock – A global assessment of emissions and mitigation opportunities. Food and Agriculture Organization of the United Nations (FAO), Rome.

Goutondji LESA 2007. Preventing water pollution by dairy by-products: risk assessment and comparison of legislation in Benin and South Africa.Dissertation of Magister Scientiae (Veterinary Science). University of Pretoria, Pretoria, South Africa.

Hoste CH, Chalon E, d'Ieteren G and Trail JCM 1992. Trypanotolerant livestock in West and Central Africa. Vol. 3: A decade's results (Monograph No. 2. ILCA, Addis Ababa, Ethiopia.

Intergovernmental Panel on Climate Change (IPCC) 2006. Chapter 10: Emissions from Livestock and Manure Management. In 2006 IPCC guidelines for national greenhouse gas inventories (ed. Eggleston HS, Buendia L, Miwa K, Ngara T and Tanabe K), pp. 10.1–10.87. Institute for Global Environmental Strategies (IGES), Hayama, Kanagawa, Japan.

Intergovernmental Panel on Climate Change (IPCC) 2007. Chapter 2: Causes of Change. In Climate change 2007: synthesis report. Contribution of working groups I, II and III to the fourth assessment report of the Intergovernmental Panel on Climate Change (ed. Core Writing Team, Pachauri RK and Reisinger A), pp. 35–41. IPCC, Geneva, Switzerland.

Kora S 2005. Contribution à l'amélioration de la technologie de production du fromage peulh au Bénin. Thèse d'Ingénieur agronome, National University of Benin, Abomey-Calavi, Bénin.

Kvenvolden KA and Rogers BW 2005. Gaia's breath-global methane exhalations. Marine and Petroleum Geology 22, 579–590.

Lassey KR 2007. Livestock methane emission: from the individual grazing animal through national inventories to the global methane cycle. Agricultural and Forest Meteorology 142, 120–132.

Ministère de l'Agriculture et de l'Elevage (MAEP) 2003. Etat des ressources zoogenetiques, rapport national. Cotonou, Benin. Retrieved September 18, 2013, from ftp://ftp.fao.org/docrep/fao/010/a1250e/annexes/CountryReports/

Ministry of Environment, Urban Settlement and Town Planning (MEHU) 2011. Deuxième communication nationale de la République du Benin sur les changements climatiques. MEHU, Cotonou, Benin.

National Research Council (NRC) 1996. Nutrient requirements of beef cattle. National Academy Press, Washington, DC, USA.

Olivier J and Janssens-Maenhout G 2012. Part III: Greenhouse-gas emissions. In CO_2 emissions from fuel combustion (pp. III.1–III.57) (ed. Van der Hoeven M). International Energy Agency, Paris, France. Retrieved November 5, 2013, from http://www.pbl.nl/en/publications/2012/co2-emissions-from-fuel-combustion-2012-edition

Sejian V, Shekhawat I, Ujor V, Ezeji T, Lakritz J and Lal R 2012. Chapter 16: Global climate change: enteric methane reduction strategies in livestock. In Environmental stress and amelioration in livestock production (ed. V Sejian, SMK Naqvi, T Ezeji, J Lakritz and R Lal), pp. 469–499. doi:10.1007/978-3-642-29205-7_16. Springer-Verlag, Berlin Heidelberg, Germany.

Senou M, Toléba SS, Adandédjan C, Poivey J-P, Ahissou A, Touré FZ and Monsia C 2008. Increased milk yield in *Borgou* cows in alternative feeding systems. Revue d'Élevage et de Médecine Vétérinaire des Pays Tropicaux 61, 109–114.

Storm IMLD, Hellwing ALF, Nielsen NI and Madsen J 2012. Methods for measuring and estimating methane emission from ruminants. Animal 2, 160–183.

Symoens C, Hounsou-Ve G 1991. Mesures barymétriques chez le bétail *Borgou* dans le nord-est du Bénin. Revue d'Élevage et de Médecine Vétérinaire des Pays Tropicaux 44, 487–490.

United Nations Development Programme (UNDP) 2002. Capacity building for improving the quality of GHG inventory in West and Francophone Central Africa. Retrieved September 12, 2013, from www.thegef.org/gef/sites/thegef.org/files/repository/Regional_-_Capacity_Building_for_Improving_Greenhouse_Gas_Inventories.pdf

Yan T, Porter MG and Mayne CS 2009. Prediction of methane emission from beef cattle using data measured in indirect open-circuit respiration calorimeters. Animal 3, 1455–1462.

Youssao AKI, Dahouda M, Attakpa EY, Koutinhouin GB, Ahounou GS, Toleba SS and Balogoun BS 2013. Diversité des systèmes d'élevages de bovins de race bovine *Borgou* dans la zone soudanienne du Bénin. International Journal of Biological Chemical Science 7, 125–146.

https://doi.org/10.1017/S1751731114002626 Published online by Cambridge University Press