ENTERIC METHANE EMISSION OF CATTLE GRAZING RANGELAND ECOSYSTEMS OF SOUTH EASTERN KENYA

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ABSTRACT

Large herds of ruminant cattle grazing degraded rangeland pastures in Kenya are associated with enteric methane (CH_4) emission, contributing to global warming potential (GWP). Yet the CH_4 emissions and associated GWP are hardly quantified to inform emerging threats to sustainable use of grassland ecosystems. This study estimated enteric CH_4 emission and the GWP from cattle grazing in Makueni County, a rangeland ecosystem in South Eastern Kenya. Estimation applied the intercontinental panel of climate change (IPCC) Tier I and Tier II approaches with Tier II incorporating seasonal differences in feed quality, dry matter intake and animal performance. Animal activity and production data for the year 2019 was obtained from the County livestock inventory reports while feed quality data was sourced from recently published literature. The resultant emission factors (EFs) (kg/year) were 47.1 for females >2 years; 27.2 for heifers 1-2 years; 46.5 for males > 2years; 32.9 for young males 1-2years; and 17.2 for calves <1year. These EFs were higher (7.7 to 14.9%) than those of Tier I for females >2years, young males 1-2years and for calves <1yr but lower (5.4 to 12.3%) for males > 2years and for heifers 1-2 years. The Tier II estimates were 4.4% higher than the estimates with Tier I approach for both total estimated enteric CH_4 emission (9,279,526.80 vs 8,889,997 kg CH_4/year) and GWP (259,826,750.4 vs. 248,919,916 kg $CO_{2\ eq}$). The results reflect uncertainty of EFs generated from Tier I approach, which necessitates development of region-specific EFs using data from local breeds of animals and feed resources. This will improve certainties of the enteric CH_4 emissions and accuracy in reporting the Nationally Determined Contributions (NDCs)

Key words: Rangelands, emission factor, dry matter intake, dry matter digestibility, feed quality

INTRODUCTION

Ruminant livestock account for most of methane (CH_4) emission that is human activity contributed. Of the global total enteric CH_4 emissions, livestock activities are estimated to account for 35% of the total emissions (Azizi *et al*., 2017). The global warming potential (GWP) due to CH_4 is 28 to 34 times per molecule greater over 100 years than carbon dioxide, and it has a lifetime of 9-15 years in the atmosphere (IPCC, 2013). The emission of CH_4 by ruminant animals comes from enteric fermentation of feeds in the rumen and from hindgut to a small extent (Haque ., 2018; Yan *et al*., 2010). This is aided by microbes in the rumen (carbohydrate fermenters) that contribute to the breakdown of fibrous feeds through anaerobic fermentation to yield energy and products for incorporation and growth of microbial cells. The by products are volatile fatty acids (VFA), free hydrogen (H_2) and carbon dioxide (CO_2) molecules. Of these products, the free hydrogen molecule is reduced using CO_2 with the help of methanogenic archaea to CH_4

$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$ (Moss *et al.,* 2000)

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The VFA constitutes the major source of energy for the ruminant. However, the enteric CH_4 production represents a loss of 5-10% of ruminant gross energy (GE) intake (Johnson and Johnson 1995; Madsen *et al*., 2010), a loss of dietary nutrients which could have been directed to production of meat and milk (Liu *et al*., 2017). The emissions of CH_4 from ruminants vary from one region to another (Goopy *et al.,* 2018; Ndung'u *et al*., 2019). Further, these emissions from livestock vary with the animal class, animal live body weight, dry matter intake, quality and quantity of feed consumed, type of volatile fatty acid produced in the rumen and animal energy expenditure (Hegarty *et al*., 2010; Johnson and Johnson, 1995; Shrestha *et al*., 2013; Steinfeld *et al*, 2006). Emission factors (EFs), the average emission rate of a given source, relative to units of activity or processes (Mareddy, 2017), are important in estimating CH_4 emission levels in any production system. The IPCC guidelines provide three-level approaches (Tier I to III) for deriving the EFs and they advance in levels of complexity. Tier I uses default values provided in the literature, Tier II accounts for animal class, diet and productivity differences and animal activity while Tier III is a country-specific methodology and parameter estimates. Tier I is the least precise but remains a predominantly used approach in African countries where a lack of technical and financial capacity is a barrier to upgrading the method.

Kenya is committed to developing and implementing strategies that improve livestock productivity while reducing greenhouse emissions. The largest proportion of greenhouse gas emissions that is of agricultural origin is by ruminant animals from both fibre digestion and from the manure they excrete to the environment (Moss *et al*., 2000). This is particularly an issue where cattle graze the rangeland pastures. This is the case in Kenya, where Tier I approach remains the method of estimating GHG from livestock, yet the method is known to yield high uncertainty levels. A move to Tier II is therefore desirable but the availability of farm-level animal and feed data on productivity and activity has limited the adoption of this approach.

For the rangelands of Makueni County in south eastern region of the country, large herds of cattle graze degraded poor pastures. The large cattle herds though support livelihoods and copping with drought risk, are likely to contribute substantial volumes of enteric CH_4 emissions and to Global Warming Potential. In Makueni County, some data on the livestock production has been collected over time and together with feed quality and animal performance that may be valuable for estimating enteric CH_4 emission for the cattle grazing the rangelands. This study used IPCC Tier I and II approaches to estimate EFs and GWP estimates for cattle grazing the rangelands of Makueni County. This approach would improve the certainties of enteric CH_4 emissions and accuracy in reporting the Nationally Determined Contribution (NDC) that each country has to report to the UN periodically.

MATERIALS AND METHODS

Study site

Makueni County, the study site, lies between Latitude 1^o 35´ and 32 00´ South and Longitude 37^o 10´ and 38^o 30´ East. It is a rangeland in the south eastern part of Kenya, with average temperature being 15^oC to 26^oC and annual rainfall of 250mm to 400mm in the lower regions and 800mm to 900mm in higher regions. The dominant vegetation are indigenous grasses (Eragrostis Superba, Cenchrus Ciliaris, Enteropogon Macrosthachyus among others) and shrubs, being the basal diet for the ruminant livestock, which includes indigenous cattle - zebu, Boran and their crosses, sheep and goats.

Estimation of enteric methane emission

The study estimated the EFs using both IPCC Tier I and II approaches in order to compare the uncertainties. Data pertaining to cattle population, animal classes and their performance and animal activity was obtained from Makueni County livestock inventory reports for the year 2019 and published information from Arid and Rangelands Research Institute (ARLRI) located in the County. Additional data on feed quality in the County was sourced from recently published literature.

Estimation of enteric CH4 applying IPCC Tier I approach was a stepwise process. Firstly, a description of cattle population of 253,175 heads (Table I) with a larger proportion (34%) being mature female>2 years, calves < 1 year (24.3%) and males > 2 years (23.8%). Secondly, the livestock numbers were multiplied by the default EFs (Table I) of the IPCC2006 guidelines to derive the net enteric CH_4 emissions. This was implemented according to the description of Gibbs *et al*. (2002):

*CH_4 Emissions= MEFt*Nt*............................... *(i)*

where,

CH_4 Emissions = Total CH_4 emission from enteric fermentation per animal class

MEFt = CH_4 emission factor per class of livestock defined in IPCC2006 guidelines

Nt = Number of head of livestock species per category or class.

The CH_4 emission levels obtained were then multiplied by CH_4 GWP of 28 (IPCC, 2013) to estimate the contribution to the greenhouse effect in CO_2 equivalent.

TABLE I-THE MAKUENI COUNTY CATTLE POPULATION BY ANIMAL CLASSES AND IPCC2006 EMISSION FACTORS (EF) USED FOR TIER I APPROACH

Animal classes	EF (IPCC2006)	Cattle Population
Females >2yrs	41	87,803
Males >2yrs	49	60,304
Heifer (1-2yrs)	31	26,617
Males (1-2yrs)	31	16,989
Calves <1yr	16	61,462
Total		253,175

Application of IPCC Tier II approach involved use of detailed data on animal classes, animal performance, feed quality, dry matter intake and animal energy expenditure. The animals were grouped into five classes based on age and sex: females (>2yrs), males (> 2years), heifer (1-2yrs), young male (1-2yrs) and calves (<1 year). Animal data on live weight and live weight gain, milk production, lactation status and estimated distance travelled by the animals from grazing fields to watering points and back to holding bomas were obtained from the County livestock inventory. The computational approach of Goopy *et al*., (2018) was followed for determining feed and animal variables needed to estimate the EF.

Determination of feed quality

Wet season mixed feed quality (total N and ADF) were those determined in wet chemistry procedure according to AOAC methods (AOAC method no.988.05 and 6.5.1, respectively). A factor of 6.25 was used to convert N to CP.

The nutritive value of average feed available for the animals in the County varied between the seasons with animals having access to better feed during the wet than during the dry season (Table II). Weight gain by the animals was season-dependent with animals gaining higher weight gains during the wet season than in the dry season.

TABLE II- FEED NUTRITIVE COMPOSITION AND DRY MATTER DIGESTIBILITY OF DIETS GRAZED BY ANIMALS IN MAKUENI COUNTY FOR BOTH THE DRY AND WET SEASONS.

Season	Feedstuff	DM	OM	%DMD	ADF	NDF	CP
Dry	Mixed range standing hay[1]	93.7	-	49.07	44.7	58.3	5.54
wet	Mixed range grasses	97.40	91.85	53.36	40.57	70.98	6.08

[1]Korir *et al.,* (2020).

The dry season feed nutritional quality was obtained from published sources (Korir *et al.,* 2020) while dry matter digestibility (DMD) was estimated using the equation of Oddy *et al*. (1983):

$$DMD(g/100gDM) = 83.58 - 0.824 * ADF(g/100gDM) + (2.626 * N(g/100gD$$
.............(ii)

where,

ADF = Acid Detergent fibre, N = Nitrogen

Estimation of cattle energy expenditure

Total energy expenditure for each class was calculated based on maintenance energy requirements, distance walked and lactation status using equations previously used in several publications: CSIRO (2007), Goopy *et al*. (2018) and Ndung'u *et al*. (2019).

The energy required for maintenance (MER) was estimated from the expression:

$$MER_M\left(MJ/day = K * S * M(0.26 * MLW^{0.75}) * exp(-0.03 * A)\right)/\left((0.02 * M/D) + 0.5\right)$$
...........(iii)

where:

K = 1.3 (the intermediate value for *Bos taurus* and *Bos indicus*), S = 1 for females and 1.15 for males, M = 1(0% milk in diet of zebu cattle), MLW = mean live weight, A = age in years and M/D = Metabolizable -energy content (ME MJ/DM kg) which was calculated as:

$$M/D = 0.172DMD - 1.707$$ ....(iv)

where:

DMD = % DM digestibility of feed.

i. Energy requirement for growth

All animal classes except for calves were found to gain an average of 200 g/day during the wet season and an averagely of 50 g/day in the dry season. For the lactating animals, an average milk yield of 2.5- 3.0 L/day was used inclusive of what the calf suckled (1 litre). Calves on milk were assumed to gain an average of 50 g /day across all the seasons.

The energy required for growth as energy consumed for weight gain /loss (MERG/L) was calculated using equations 1.29 and 1.36 in NRODR (CSIRO, 2007)

$$MER_G\ (MJ/day = (ADWG(kg) * 0.92 * EC\ (MJ/Kg))/\ (0.043 * M/D)$$
………….. (v)

$$MER_L(MJ/day) = \left(ADWL(Kg) * 0.92 * EC(MJ/Kg)\right)/0.8$$
…………………………(vi)

where:

ADWG or ADWL (kg) = average daily weight gains or loss; EC (MJ/kg) = energy content of the tissue taken as 18 MJ/kg

i. Energy requirement for lactation

The energy required for lactation, was derived from daily milk (litres) consumption by pre-ruminant calves (calves between 0-3.5 months) using calves live weight and average calves' growth rates according to Radostits and Bell (1970) equation assuming the calves' growth rate (LWG) to be 50 g/day:

$$Daily\ milk\ consumption(L/d) = (LWcalf(kg) * 0.107) + (0.143)$$
………………. (vii)

Where:

LW calf = live weight of calve in kg, 0.107 = Energy required by calves for maintenance.

Daily Milk Yield (DMY) was calculated as:

$$DMY(L/d) = (Mean\ daily\ milk\ production(L) * No\ of\ days\ in\ milk) + daily\ milk\ consumption\ of\ calves$$
……………………………………………………. (viii)

The computation assumed 70% of mature female herd to be lactating. Energy requirements for lactation were calculated using the equation given in NRODR (CSIRO, 2007) as:

$$MERL = DMY * ECM/(0.02 * M/D) + 0.04$$ .... (ix)

where:

DMY (kg) = daily milk yield, ECM (MJ/kg) = energy content of milk (taken as 3.054 MJ/kg (CSIRO, 2007) due to a lack of data regarding milk constituents), M/D = Metabolizable energy content.

The energy requirement for locomotion assumed energy expended for locomotion as an estimate of:

$$MERT(MJ/day) = DIST(km) + MLW(kg) + 0.0026(MJ)$$ …………………………(x)

Where:

DIST = average distance travelled (km) - average estimated distance from grazing field to watering point; MLW = mean LW and 0.0026 is the energy expended (MJ/(kg LW/km).

The daily total energy expenditure (MER $_{Total}$) for each animal class in each Sub County and the season was then calculated using the formulas below.

$$MER_{TOTAL}\ (MJ/day) = MERM + MERG/L + MERL + MERT$$ (Females)……………(xi)

$$MER_{TOTAL}(MJ/day) = MERM + MERG/L + MERT$$ (Males, heifers and young males) ……. (xii)

$$MER_{TOTAL}(MJ/day) = MERM + MERG/L$$ (Calves)………………………………… (xiii)

Calculation of emission factors (EF)

In estimating the emission factors (EFs), dry matter intake (DMI) was calculated as a function of MER_{TOTAL} and seasonal DMD of feed using the formulae by Goopy *et al.*, 2018 below:

$$DMI(Kg) = MER_{TOTAL}(Mj/day)/GE(Mj/day) * DMD/100))0.81$$ ……………… (xiv)

where:

MER_{TOTAL} = The sum of all animal energy requirements (maintenance, locomotion, ploughing, growth, lactation, etc.);

GE = gross energy of the diet assumed to be 18.1MJ/kg DM, mid-range value for tissue and 0.81 is the factor to convert ME to digestible energy NRODR (CSIRO, 2007)

DMD = % Dry matter digestibility of the feed

The estimated DMI was used to calculate daily CH_4 production (DMP) using the equation developed by Charmley *et al.* (2016) as follows:

*DMP(g) =20.7*DMI(kg/day)……………. (xv)*

Mean annual CH_4 production per animal (emission factor: EF) for each class of animal in the County was calculated as:

*EF(kg CH4 per head per year)=((DMP(dry season *91.25 days)+(DMP(Wet season *273.75 days))/(1000)..........(xvi)*

Statistical analysis

Data on EFs were analysed using R (R Core Team, 2021), ANOVA was run to assess the within animal class variations. A linear model was then fitted with County and animal class as fixed factors to estimate least square means. The differences between means were compared with Tukey's method at $p< 0.05$.

RESULTS

Animal energy expenditure

Maintenance energy requirements, which was mainly a function of live weight, accounted for the highest amount of energy expenditure for all animal classes and in both seasons (Table III). The lowest expenditure was on locomotion. Total energy expenditure was higher during the wet season compared to the dry season for all animal classes except for calves, corresponding to higher weight gains during the wet season when the quality of the diet was better.

TABLE III- MAINTENANCE ENERGY (MER_M), LACTATION ENERGY (MER_L), GROWTH (LOSS OR GAIN) ENERGY ($MER_{L/G}$), MOVEMENTS' ENERGY (MER_T) AND TOTAL ENERGY REQUIREMENTS (MER_{TOTAL}) FOR DIFFERENT CLASSES OF ANIMAL DURING THE WET AND DRY SEASON IN MAKUENI COUNTY

Animal class	MER_M	MER_L	$MER_{L/G}$	MER_T	MER_{TOTAL}
		Wet season			
Female >2yrs	29.30±0.994	12.42±1.000	10.31	1.29±0.319	53.32±1.774
Males >2yrs	39.46±0.994	-	10.31	1.59±0.319	51.36±1.774
Females (1-2 yrs)	21.81±0.994	-	10.31	0.84±0.319	32.96±1.774
Young males (1-2yrs)	27.29±0.994	-	10.31	0.94±0.319	38.54±1.774
Calves<1yr	14.83±0.994	-	2.58	-	17.4±1.774
		Dry season			
Female >2yrs	28.70±0.994	11.99±1.000	2.86	1.22±0.319	44.76±1.774
Males >2yrs	38.98±0.994	-	2.86	1.52±0.319	43.36±1.774
Females (1-2 yrs)	20.84±0.994	-	2.86	0.77±0.319	24.47±1.774
Young males (1-2yrs)	26.28±0.994	-	2.86	0.86±0.319	30.00±1.774
Calves<1yr	13.64±0.994	-	2.86	-	16.5±1.774

Enteric methane emission estimates

Table IV presents the enteric CH_4 EFs estimated with Tier I and Tier II for cattle population grazing the Makueni County rangelands. The EFs generated with Tier II were higher (7.7 to 14.9%) than those generated with Tier I for females>2yrs, young males 1-2yrs and for calves <1yr but lower (5.4 to 12.3%) for males>2yrs and for heifers 1-2 yrs. The EFs were closely associated with the animal body weights. The cattle in Makueni were on average heavier than the reference typical unspecified African cattle defined in the IPCC for Tier I

The Tier II estimates were 4.4% higher than the estimates with Tier I approach for both total estimated enteric CH_4 emission (9,279,526.80 vs 8,889,997 kg CH_4/year) and GWP (259,826,750.4 vs. 248,919,916 kg $CO_{2\ eq}$) for zebu cattle population grazing the rangeland ecosystem of South eastern Kenya (Table V).

TABLE IV- ENTERIC METHANE EMISSION FACTORS (KG CH_4/HEAD/YEAR) AND MEAN LIVE WEIGHT (KG) FOR DIFFERENT CLASSES OF CATTLE ESTIMATED WITH IPCC TIER I AND TIER II FOR CATTLE GRAZING MAKUENI COUNTY RANGELANDS

Cattle class	Tier I EF estimates		Tier II EF estimates	
	Live weight (kg)	Emission Factor	Live weight (kg)	Emission Factor
Females >2yrs	200	41	231.8	47.1
Males >2yrs	275	49	287.8	46.5
Heifer(1-2yrs)	-	31	148.2	27.2
Yong males(1-2yrs)	-	31	166.2	32.9
Calves <1yr	75	16	75.3	17.2

TABLE V-TOTAL ENTERIC METHANE EMISSIONS AND GWP ESTIMATES WITH TIER I AND TIER II APPROACHES FOR CATTLE GRAZING MAKUENI COUNTY RANGELANDS

Cattle class	Tier I total emissions (kg CH_4/year)	Tier II total emission (kg CH_4/year)
Females >2yrs	3,599,923	4,135,521.30
Males >2yrs	2,954,896	2,804,136.00
Heifer (1-2yrs)	825,127	723,982.40
Young males (1-2yrs)	526,659	558,741
Calves <1yr	983,392	1,057,146.40
Total (kg CH_4/year)	8,889,997	9,279,527
GWP (kg CO_2 eq/year)	248,919,916	259,826,750.4

EF for Tier 1(IPCC, 2006) EF using Tier II Current study, GWP used was 28 (IPCC 2013).

DISCUSSION

All the animal classes had higher energy expenditure and dry matter intake during the wet season compared to the dry season. This is because of the higher productivity (weight gain and milk yield) during the wet season when diets were of better quality. Maintenance energy requirements accounted for the highest energy expenditure in both wet and dry seasons. The dry matter digestibility of the diets (49.07±0.91% in dry season and 53.36% in wet season), which is indicative of diet quality, was within the range of default estimate values of (50-55%) for mixed African forages reported by Dong *et al*., (2006) and slightly lower than 55% provided in IPCC 2006 used in Tier I estimation. Ndung'u *et al.* (2019) also reported a higher range of dry matter digestibility (53.1-67.9%) from a variety of diets in the feed basket of cattle in Nandi County, which is in the highlands with high agriculture potential. Feeds harvested in a highland county differ nutritional wise from the feeds in lowland rangeland with low agriculture potential. This can be due to the fact that feeds in the rangelands deposit more structural tissue that is more fibrous hence less digestible (Wilson *et al*., 1991).

The average live weights for the different animal classes were comparable to those of the reference typical African cattle defined in IPCC2006 but slightly lower than what Ndung'u *et al*. (2019) reported. The Ndung'u study was conducted in Nandi County in the Kenyan highlands with dairy cattle breeds supported with high biomass production sustained with high bimodal distributed rainfall pattern. In contrast, the cattle population dominant in the Makueni County rangelands are the Zebu (*Bos indicus)* that have a smaller body frame compared to dairy cattle breeds with larger body frames, which dominate in the highlands (Ndung'u *et al*., 2019). The live weights in the current study however were higher than what Goopy *et al.,* (2018) reported from a study in the lowland lake basin of Nyando basin where the small East African Zebu cattle dominated.

The total enteric CH_4 emissions from cattle in Makueni County rangelands was only 4.4% higher when estimated using IPCC Tier II compared to using Tier I approach. The Kenyan inventory reporting used the IPCC Tier I approach estimates. Tier II approach uses dry matter in the computation of EF, which has a positive correlation with the amount of CH_4 emitted, from animal performance and activity data. These feed values and animal performance variables accounted for in Tier II can explain the 4.4% higher enteric CH_4 and GWP estimates made, when compared to Tier I estimates. This observation concurs with the findings of Kurihara *et al.* (1999) who concluded that the use of IPCC default EF in tropical context is likely to underestimate emissions due to the differences in animal breeds and diets between the tropics and temperate environments where Tier I estimation factors were developed.

The total enteric CH_4 emission of cattle in Makueni County using Tier I (8,916,225 kg/year) was 64% lower than the emissions estimate in Kajiado County (24,983,220 kg/year) as reported by Kimongo (2017). This can be explained by larger herds kept by the dominant pastoral community of Kajiado County. In Makueni County rangelands, animals trekked for shorter distances in search of feed and water as compared to the case of Kimongo (2017) observed in the Kajiado County study. This is a further explanation of the lower energy expenditure in the current study hence lower estimated enteric CH_4 production.

Considering the current study used EF developed in a tropical environment (northern Australia), the Tier II figures could have been higher than when Tier I approach was used because tropical diets are more methanogenic than temperate grasses (Archimède *et al.,* 2018*).* The tropical diets were what was used in the development of the Tier I EFs. The results reflect uncertainty of EFs generated from Tier I approach, therefore necessitating development of region-specific EFs using data from local breeds of animals and feed resources. This will improve certainties of the enteric CH_4 emissions and accuracy in reporting the Nationally Determined Contributions (NDCs). This would meet the requirement in reporting the NDCs, to which Kenya has declared commitment.

CONCLUSION

Enteric methane emission estimates using IPCC Tier II were higher compared to Tier I approach and marginally improved estimation of actual emissions, which is an indication that it is important to develop estimation factors under local production circumstances. This informs the need to develop locally generated estimation emission factors using local breeds and local feed resources not forgetting to factor in ecological conditions to improve inevitabilities of the enteric methane emissions. This approach would meet the requirements in reporting Nationally Determined Contribution (NDC) that each country has to report to the UN periodically.

ACKNOWLEDGEMENT

Appreciations are to Centre of Excellence in Sustainable Agriculture and Agribusiness Management (CESAAM) for funding the research, and Makueni county livestock inventory office for provision of animal data.

REFERENCES

Archimède, H., Rira, M., Eugène, M., Fleury, J., Lastel, M., Périacarpin, F., Silou-Etienne, T,. Morgavi, D. and Doreau, M. (2018) Intake, total-tract digestibility and methane emissions of Texel and Blackbelly sheep fed C4 and C3 grasses tested simultaneously in a temperate and a tropical area. *Journal of Cleaner Production* 185:455-463.

Azizi, A.A., Mardhati, M., Mohd Fairuz, M.S., Shaidatul Azdawiyah, A.T., Nurul Ain, A.B., Fauzi, J. and Reisinger, A. (2017). Local emission factors estimate for methane emission from cattle enteric fermentation using IPCC tier-2 methodology. *Mal. J. Anim. Sci*, 20(2):1-10.

Charmley, E.S.R.O., Williams, S.R.O., Moate, P.J., Hegarty, R.S., Herd, R.M., Oddy, V.H. and Hannah, M.C. (2016). A universal equation to predict methane production of forage-fed cattle in Australia. *Animal Production Science*, 56(3):169-180.

CSIRO. 2007. Nutrient Requirements for Domesticated Ruminants. 150 Oxford Street (P O Box 1139), Collingwood VIC 3066, Australia: CSIRO publishing.

Dong, H., Mangino, J., McAllister, T., Hatfield, J., Johnson D., Lassey, K., de Lima, M. and Romanovskaya, A. (2006) Chapter 10: emissions from livestock and manure management. In 'IPCC guidelines for national greenhouse gas inventories. Vol. 4: agriculture, forestry, and other land use'. pp. 10.1–10.87. (IPCC: Paris, France)

Gibbs, M. J., Conneely, D., Johnson, D., Lassey, K. R. and Ulyatt, M. J. (2000). Methane emissions from enteric fermentation. In *Background report for expert group meeting on good practice in inventory preparation for agricultural sources of methane and nitrous oxide. Wageningen, the Netherlands* (pp. 24-26).

Goopy, J.P., Onyango, A.A., Dickhoefer, U. and Butterbach-Bahl, K. (2018). A new approach for improving emission factors for enteric methane emissions of cattle in smallholder systems of East Africa–Results for Nyando, Western Kenya. *Agricultural Systems*, 161:72-80.

Haque, M. N. (2018). Dietary manipulation: a sustainable way to mitigate methane emissions from ruminants. *Journal of Animal Science and Technology*, 60(1):1-10.

Hegarty, R.S., Alcock, D., Robinson, D.L., Goopy, J.P. and Vercoe, P.E. (2010). Nutritional and flock management options to reduce methane output and methane per unit product from sheep enterprises. *Animal Production Science*, 50(12):1026-1033.

IPCC 2013. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University United Kingdom and New York, NY, USA. (Available at: http://www.climatechange 2013.org/report/) [2016-06-25].

IPCC 2006. Chapter 10: Emissions from livestock and manure management. In: Guidelines for National Greenhouse Gas Inventories. Volume 4: Agriculture, Forestry and Other Land Use. IPCC:10.1–10.87.

Johnson, K.A. and Johnson, D.E. (1995). Methane emissions from cattle. *Journal Of Animal Science*, 73(8):2483-2492.

Kimongo, A.N. (2017). Methane gas emissions by enteric fermentation from cattle production in Kenyewa location of Kajiado county in Kenya: a study on potential climate change mitigation strategies (Doctoral dissertation, University of Nairobi).

Korir, B.K., Wanyoike, M.M., Kuria, J.K., Mwangi, D.M. and Muge, E.E. (2020). Cassava leaves and azolla as crude protein supplement feed to east african short horned Zebu Heifers. *African Journal of Agricultural Research*, 16(10):1457-1462.

Kurihara, M., Magner, T., Hunter, R. and McCrabb, G. (1999) Methane production and energy partition of cattle in the tropics. *British Journal of nutrition* 81**:**227-234.

Liu, Z., Liu, Y., Murphy, J.P. and Maghirang, R. (2017). Ammonia and Methane Emission Factors from Cattle Operations Expressed as Losses of Dietary Nutrients or Energy Review. Agriculture, 7(16), 12pages. doi: 10.3390/agriculture7030016

Madsen, J., Bjerg, B.S., Hvelplund, T. and Weisbjerg, M.R. (2010). Methane and carbon dioxide Ratio in Excreted air for Quantification of Methane production from Ruminants. Livestock Science, 129, 1896-1906. doi: 10.1016/j.livsci.2010.01.001

Mareddy, A.R. (2017). 6-Impacts on water environment. *Environmental impact assessment*, , Butterworth-Heinemann, pages 217-248 ,https://doi.org/10.1016/B978-0-12-811139-0.00006-2

Moss, A.R., Jouany, J.P. and Newbold, J. (2000, May). Methane production by ruminants: its contribution to global warming. In *Annales de zootechnie* 49, No. 3:231-253). EDP Sciences.

Ndung'u, P.W., Bebe, B.O., Ondiek, J.O., Butterbach-Bahl, K., Merbold, L. and Goopy, J.P. (2019). Improved region-specific emission factors for enteric methane emissions from cattle in smallholder mixed crop: livestock systems of Nandi County, Kenya. *Animal Production Science*, 59(6):1136-1146.

Oddy, V.H., Robards, G.E. and Low, S.G. (1983). Prediction of in vivo dry matter digestibility from the fibre and nitrogen content of a feed. In *Feed information and animal production: proceedings of the second symposium of the International Network of Feed Information Centres/edited by GE Robards and RG Packham*. Farnham Royal, Slough [Buckingham]: Commonwealth Agricultural Bureaux, c1983.

Radostits, O.M. and Bell, J.M. (1970). Nutrition of the pre-ruminant dairy calf with special reference to the digestion and absorption of nutrients: A review. *Canadian Journal of Animal Science*, 50(3):405-452.

Shrestha, S., Bindari, Y. R., Shrestha, N. and Gaire, T. N. (2013). Methane Gas Emission in Relation to Livestock. Journal of Animal Production Advances, 3(5), 187-191. doi: 10.5455/japa.20130531095352

Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales M. and Haan, D.C. (2006). The Livestock Long Shadow- Environmental Issues and Options. Rome, Italy, Food and Agriculture Organization of the United States.

Wilson, J.R., Deinum, B. and Engels, F.M. (1991). Temperature effects on anatomy and digestibility of leaf and stem of tropical and temperate forage species. *NJAS Wageningen Journal of Life Sciences*, 39(1):31-48.

Yan, T., Mayne, C.S., Gordon, F.G., Porter, M.G., Agnew, R.E., Patterson, D.C., Ferris, C.P. and Kilpatrick, D.J. (2010). Mitigation of Enteric Methane Emissions through Improving Efficiency of Energy Utilization and Productivity in Lactating Dairy Cows. Journal of Dairy Science, 93, 2630-2638. doi: 10.3168/jds.2009-2929.