Green Asia Report Series

No.8

Baseline Estimation and Mitigation of GHG Emission from SE Asia Livestock System

Koki Maeda

Green Asia

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Koki Maeda[1]

1 Japan International Research Center for Agricultural Sciences (JIRCAS)

March 2026

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Abstract

Livestock is one of the major sources of non-CO_2 greenhouse gas (GHG). Methane (CH_4) is emitted through enteric fermentation or both CH_4 and nitrous oxide (N_2O) is emitted from manure management, thus they need to be mitigated to tackle the climate change issue. This report summarizes the research effort on mitigation of GHG emissions from livestock sector in SE Asian countries, including improvement of feed efficiency to reduce the emission intensity, utilization of several promising feed additives and others. For the manure management, GHG emission factor (EFs) database has been built for precise estimation by international cooperation framework and dataset from Japan also included. The database highlights the significant geographical unevenness of the available dataset. The EFs for SE Asian countries are extremely limited while majority of dataset comes from western countries, the effort for data generation in this region is also ongoing. Here we show the examples in Vietnam and Thailand for potential EFs measured under local conditions. In addition, we detected the significant manure flow into central highland in Vietnam, where active coffee/pepper intercropping system occurs. In this region, dried cattle manure is composted with coffee husk, so here we provide another example on GHG EFs from this specific composting system in Vietnam.

I. Livestock industry and greenhouse gas (GHG) emission

1. Contribution of agriculture and livestock system on anthropogenic GHG emission

Agriculture is one of the major sources of greenhouse gas (GHG) emission, such as methane (CH_4) and nitrous oxide (N_2O). Methane is the second important GHG after CO_2 with short perturbation lifetime in the atmosphere of approximately 12 years. Current atmospheric CH_4 concentration is >160% higher than pre-industrial level, which is driven by human activity (Skeie et al., 2023). N_2O is another important GHG with its longer lifetime in the atmosphere (120 years) and higher contribution of greenhouse effect (300 times as much as CO_2). Atmospheric concentration of N_2O has also increased (>20%) compared to the pre-industrial level, mainly due to nitrogen addition to the croplands (Tian et al., 2020).

Among the agricultural system, ruminants and rice paddy systems are one of the most important contributors, especially to anthropogenic CH_4 emissions. While flooded rice paddy production system emits significant amounts of CH_4 because of the anaerobic degradation of the crop residue or other organic matter in the soil, the degradation of the feed in the rumen also occurs under strictly anoxic process, and part of the hydrogen produced during organic matter degradation is to be used for methanogenesis. Approximately 5-10 % of the energy contained in the feed stuff can be converted into CH_4 and lost into the atmosphere (Eduardo et al., 2019). Methane emission also occurs during the manure management system, especially anaerobic manure treatment facility such as biogas digester or slurry storage, while N_2O can be also emitted because of organic N degradation and through nitrification-denitrification process. Overall, emission from livestock systems is estimated to comprise 11% of total anthropogenic GHG emission, and majority (45%) of the emissions come from CH_4 emission through enteric fermentation. To meet the 1.5 °C target, methane (CH_4) from ruminants must be reduced by 11 to 30% by 2030 and 24 to 47% by 2050 compared to 2010 levels (Arndt et al., 2022).

2. Livestock production in SE Asia

SE Asia consists with many developing countries (Brunei, Cambodia, Indonesia, Laos, Malaysia, Myanmar, Philippines, Thailand, and Vietnam), where rapid economic development ongoing, with average annual growth of GDP 4.5 to 4.8% in the region. Economic development brings an increase of the people's income in the region, and it can lead to increased livestock products such as meat or milk. The climate conditions are very hot and humid with heavy rainfall in the wet season, and most of the countries belong to the tropical regions, which can significantly affect the nature of agriculture systems. Although there is a rapid growth of dairy sector in the region due to economic growth and people's income, the major portion of the cattle population in the region is beef cattle. Most of the cattle raised in the region are Zebu cattle (*Bos indicus*), which are tolerant of heat stress and well adapted to the climate condition in the region. For example, in Vietnam, most of beef cattle were local pure

breed Vietnamese yellow until 1980s, and more recently crossbred with Red Sindhi (named Lai Sind) cattle was dominant, while the latest trend is to make the crossbreed with Western beef cattle such as Angus, Belgian Blue or others getting more popular to for bigger size of cattle to improve the farmers' profit. For dairy cattle, since the high producing Holstein-Friesian is very weak on heat stress, they are raised only mountainous are with moderate climate conditions, and crossbred with local cattle breed with lower productivity, smaller body size but adapted to the climate condition are raised in the region.

3. Importance of agriculture and livestock production on total GHG emission in SE Asia

The global annual total GHG emissions from 196 countries are 48.3 billion tons CO_2 e yr^{-1}, and the contribution of CO_2 to the total GHG emission is 74.9% while CH_4 and N_2O are 16.4% and 6.5%, respectively (Climate Watch, 2022). In SE Asian countries, total GHG emissions are 2.6 billion t CO_2 e yr^{-1}, which account for 5.5% of total global GHG emission and it has tripled within these 30 years due to significant economic growth in the region. Moreover, the relative contribution of CH_4 is much higher than this average, it ranges from 16.7% (Malaysia) to 56.3% (Cambodia) except for Singapore (only 0.2%) (Fig. 1). Thus, the relative contribution of agriculture sector is important in SE Asian region compared to other regions including developed countries. Indeed, the contribution of CH_4 is very low in Japan (2.4%) because large portion of GHG emitted as CO_2 from energy, transport or other industry sectors (FAOSTAT, 2025).
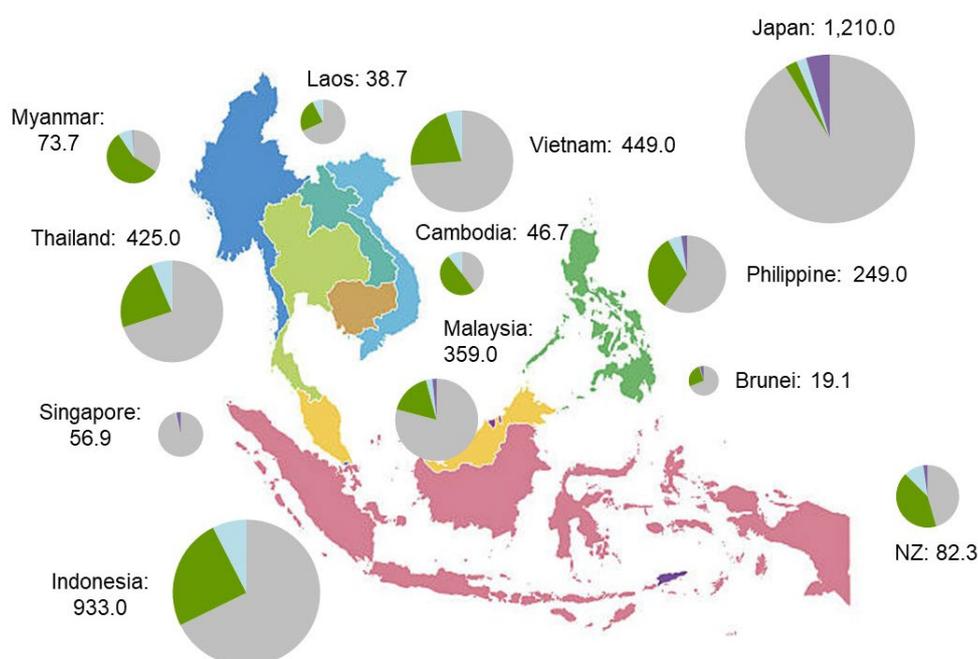
Fig. 1. GHG emissions by country (million t CO_2 e yr^{-1}) and relative contribution of CH_4 (green), N_2O (blue) and others (purple)

More focus on the agriculture sector, the majority of GHG emission comes from rice paddy systems (Fig. 2). The relative contribution of rice paddy on total agricultural emission ranges 13.6% (Brunei) to 80.7% (Thailand) while >60% of total agricultural emission comes from rice paddy in major 4 countries (Indonesia, Philippines, Thailand and Vietnam). Given typical climate conditions such as high precipitation with high temperature is favorable for rice, its production is historically and traditionally extremely important in the region. Methane emission from enteric fermentation is the second largest source of GHG in the agricultural sector in many countries the region except for Myanmar (47.4%), which comes at first place. The relative importance in Japan is quite similar (36.0%) due to the similar cultural background, while New Zealand shows extreme importance of enteric CH_4 (87.2%) due to high livestock production (FAOSTAT, 2025).
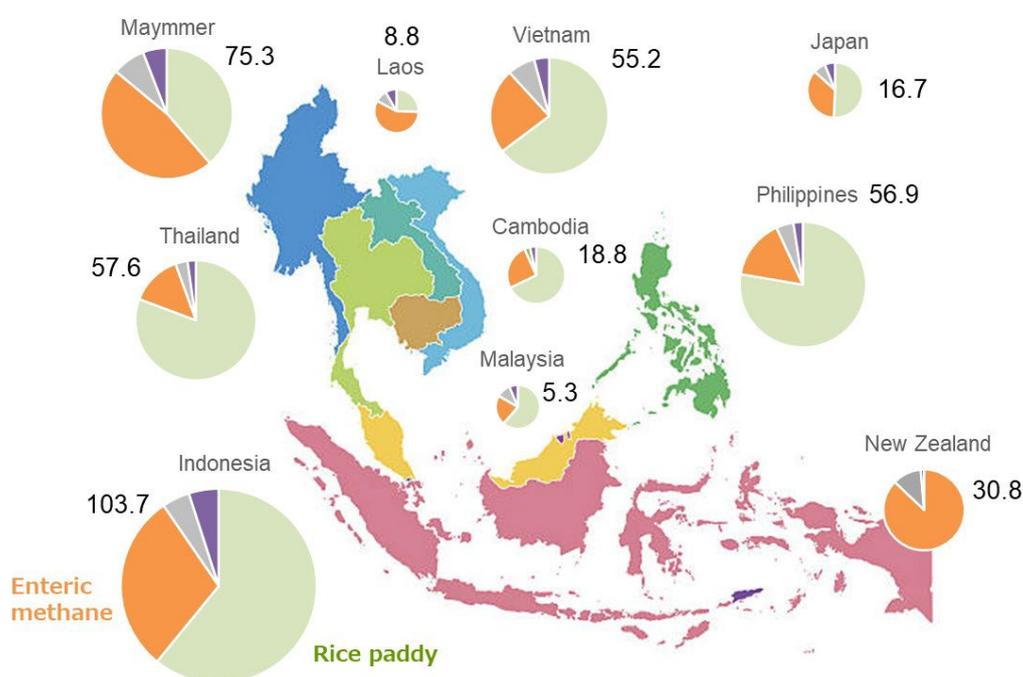
Fig. 2. GHG emissions from agricultural sector (million t CO_2 e yr^{-1}) and relative contribution of rice paddy (green), enteric fermentation (orange) and manure management (grey: methane and purple: nitrous oxide)
Note: Grey Color indicates GHG from non-agricultural Sectors

4. GHG emission intensity across regions

GHG emission intensity, expressed as GHG emissions per unit product (meat, milk and eggs), is another important indicator for assessing the efficiency of production system across regions. Fig. 3 shows the global map of the GHG emission intensity for livestock products. Faint colors indicating low emission intensity, which mainly occurs in the developed countries especially north America and Europe region, while strong colors (high emission intensity) appear in many developing countries in Africa, Latin America and SE Asia regions.

This difference comes from multiple factors; however, it can be mainly explained by difference in feeding efficiency. The quality of diet is critical factor for better feeding strategies. High-quality diet consists with high-energy grains used in the developed countries enables the animal to use more energy for production of meat or milk, while low quality diet fed in the developing countries which consists of stover or straws with low digestibility and low protein contents does not allow animals to use the energy for production but only allow them to use the energy for maintaining their body. This strongly shapes the difference in GHG emission per unit product; thus, improving the feeding efficiency in the developing countries is one of the key challenges to address the issue.

Emission intesity from all livestock per unit of protein from meat, milk, and eggs
(Kg of CO_2 eq per kg of protein)

< 50	100-150	200-250	300-350
50-100	150-200	250-300	> 350
< 1 Livestock Unit			
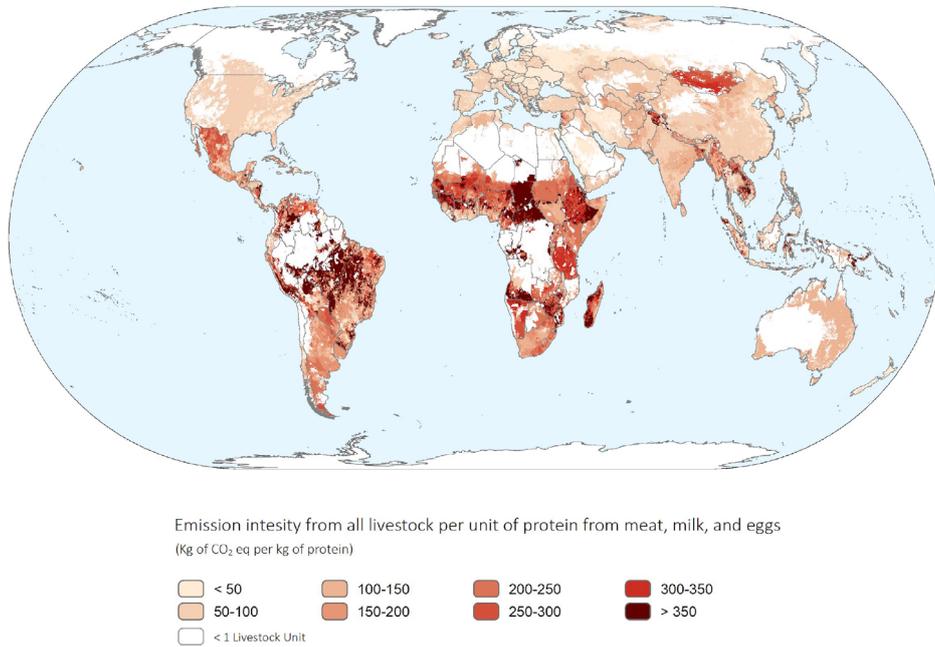
Fig. 3 from Wisser et al (2023)

Comparison of GHG emissions intensity (t CO_2 e yr^{-1}/t products) in country level shows that there is a clear difference among developing countries and developed countries. The range of European countries (Belgium, Denmark, France, Germany, Italy, Netherlands and UK), New Zealand, Japan and US is 0.76 (Japan) to 1.97 (UK and USA), while second group (Australia, Canada, China and Brazil) ranges from 2.56 to 8.04. The range of SE Asian countries is 8.45 (Thailand) from 144.16 (Lao PDR), and the average value of ten SE Asian countries is 44.6±46. This indicates that there is a plenty of room for improvement in SE Asian countries, and the main target is to introduce more high energy and high protein diet to improve the feed efficiency in the region.

II. CH₄ emission from enteric fermentation

1. Estimation of CH₄ emission from enteric fermentation in SE Asia

Estimation of CH_4 emissions from enteric fermentation requires specific technique and equipment which is not widespread in SE Asian countries. While there are several technique to measure it, it is widely accepted that the chamber-based approach is most popular and reliable one stated as 'gold standard" (Hammond et al., 2016), which also requires facility investment. Therefore, multiple CH_4 emission prediction equation models have been developed so far (Escobar-Bahamondes et al., 2017, Moraes et al., 2014, Ellis et al., 2007), which enables the estimation of CH_4 emission from enteric fermentation worldwide. More recently, there are several equations comprised by intercontinental large dataset for both dairy (Niu et al., 2018) and beef cattle (Van Lingen et al., 2019). These models consist of variables such as dry matter intake (DMI) as the most important prediction parameter for example. Indeed, the Intergovernmental Panel on Climate Change (IPCC) methodology recommends the use of the equation model with methane conversion factor (Ym) for enteric fermentation CH_4 emission prediction, but it does not take any geographical locations into account (Change, 2006). More recent updated one (Eduardo et al., 2019) define CH_4 emission as part of gross energy intake (GEI) of the cattle, and 7.0% for non-dairy cattle grazing or very poor-quality diets while lack of data. These prediction approaches strongly relied on the dataset obtained in the Western countries. The production system is quite different from that of SE Asia with different cattle breeds, different feed composition with different feed quality such as abundant high-energy and high-protein diet to maximize the cattle productivity.

Photo 1. Group photo of attendees of the experts' workshop on SE Asian enteric methane project, on 4 and 5, December 2019, Putrajaya, Malaysia.

To overcome this problem, several papers have been published which focus on SE Asian cattle dataset (Suzuki et al., 2018, Kaewpila and Sommart, 2016, Tee et al., 2022). JIRCAS has installed the head-cage respiration chamber, which is mentioned as 'gold standard' method in Thailand and Vietnam. The accumulated dataset for CH_4

emission from enteric fermentation with local cattle breed and local feed composition were used to build the prediction equation model (Suzuki et al., 2018). More recently, similar approach has done trying to cover all SE Asian countries (Tee et al., 2022). Researchers focusing on enteric CH_4 emission from 8 countries in SE Asia (Cambodia, Laos PDR, Indonesia, Malaysia, Myanmar, Philippines, Thailand and Vietnam) were gathered to obtain the dataset (Photo 1). This activity was achieved in the part of global research alliance, livestock group (GRA-LRG), feed and nutrition network (FNN).

After removing the extremely high/low and unrealistic CH_4 data, total number for CH_4 emission observations were 398 data points. Equation model only with DMI shows lower root mean square prediction effort (RMSPE) value (16.9%) compared to that of updated IPCC Tier 2 method which is using GEI as the variable (19.9%), indicating equation model with SE Asian cattle provide better prediction than proper IPCC model. Furthermore, inclusion of other variables such as neutral detergent fiber (NDF) or bodyweight into the equation model enables further lower RMSPE values (14.2-15.2%) (Fig. 4).

Total dataset can be further divided into three groups based on the roughage/ concentration ratio (all forage: 119, high: 163 and low forage: 116). In general, the typical feed composition in SE Asian countries is forage-based ration, therefore, more focused approach on all and high forage group. All-forage-group gives further significantly better predictions (RMSPE=14.7-16.5%) than that of current IPCC Tier 2 method (22.9%) or other published models which are based on datasets from Western countries (19.3%).
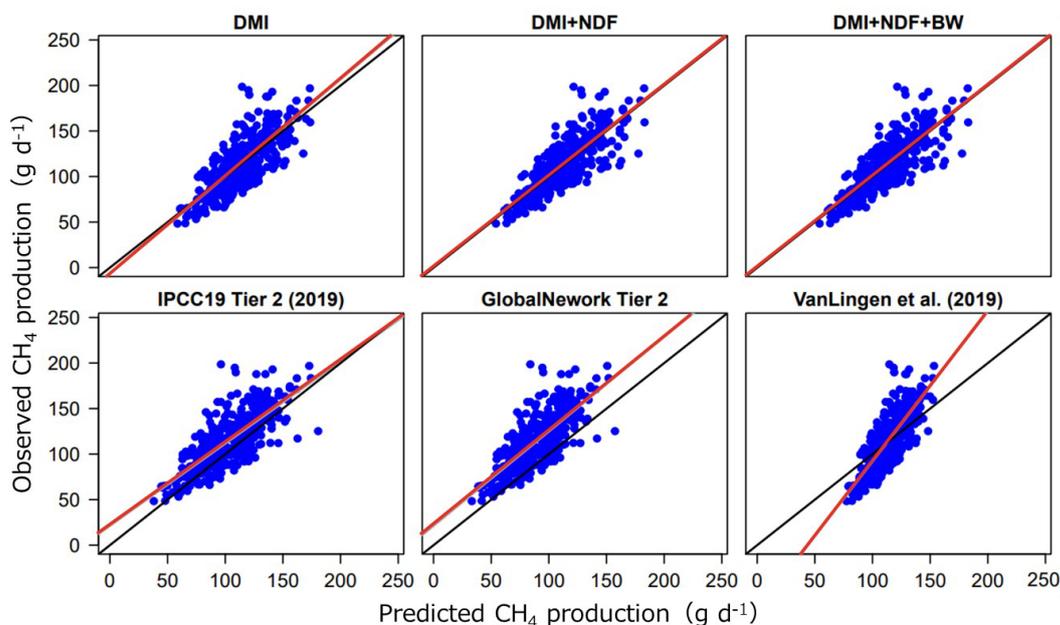

Fig. 4 Observed vs. predicted plots for CH_4 emission (g d⁻¹) for all datasets (n=398) and comparison with IPCC Tier 2 method or other prediction models. The red line represents the fitted regression line against identity line (black). (Tee et al., 2022)

This activity tried to cover all SE Asian region by gathering the representative scientists from 8 countries. However, the majority of dataset still comprised with Thailand and Vietnam, where respiration chambers located installed by JIRCAS. As a result, the accuracy of the prediction equation model obtained in the study was very similar to that of the previous one (Suzuki et al., 2018). Current efforts are ongoing to install the respiration chambers to other countries such as Cambodia or Laos PDR, which enables more robust dataset and allows better prediction equation model in the future.

2. Mitigation of enteric CH_4 emission by feed additives

Prediction equation models provide the baseline estimation of the CH_4 emission from enteric fermentation in the region, while there is a need to mitigate the CH_4 emission by direct or indirect approaches to achieve the goal. As I mentioned in the previous section, the improvement in production efficiency should be the primarily approach to mitigate enteric CH_4 emission, since there is plenty of room for improvement in the feed quality in the region. Meanwhile, alternative approaches to mitigate enteric CH_4 emissions such as the utilization of feed additives which can inhibit CH_4 emission through wide variety of modes of actions is also needed.

1) 3-nitrooxypropanol (3-NOP)

So far, several feed additives have been discovered and some of them are already at a commercial stage. One of the promising approaches is the feeding of 3-nitrooxypropanol (3-NOP), which was discovered by Dutch company. It is a synthetic chemical and was designed to bind to the active site of the methyl CoM reductase (MCR) of the methanogenic archaea, required for the last step of the methanogenesis (Duin et al., 2016). It is already shown that the feeding of 3-NOP can reduce 30% of enteric CH_4 emission from lactating dairy cattle (Hristov et al., 2015, Melgar et al., 2021). The product is already approved by U.S. Food and Drug Administration (FDA) to meet safety and efficacy standards for use in dairy cattle and is already commercially available as Bovaer.
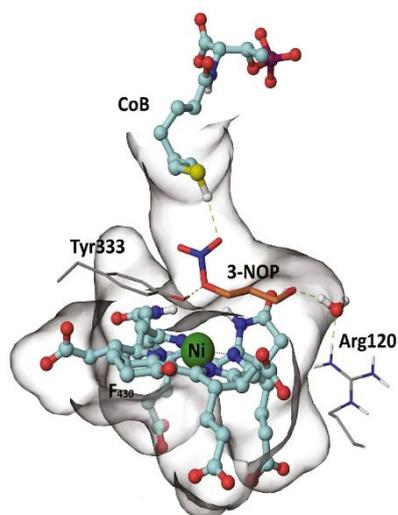
Fig. 5
3-NOP preferentially binds to the active site of methyl-coenzyme M reductase (MCR), an enzyme that catalyzes the methane-forming reaction of methanogens in the rumen (Duin et al., 2016).

2) Seaweed

Another approach is to utilize seaweed (red: Rhodophyta, brown: Phaeophyceae or green algae: Chlorophyta) that contains bromoform, one of the halogenated methane analogues (HMAs), which can inhibit coenzyme M methyltransferase (MTR). MTR is also known to be an essential part of methanogenesis, which is shared in all three known pathways (hydrogenotrophic, acetoclastic and methylotrophic methanogenesis). Dietary supplementation of *A. taxiformis* can reduce enteric CH_4 emission in both beef steers (Roque et al., 2021) and dairy cows (Stefenoni et al., 2021). Given these observations, the current challenges are ongoing especially on sustainable cultivation and processing supply chain of these seaweeds.

3) Cashew nut shell liquid (CNSL)

Besides these activities, the feeding of cashew nut shell liquid (CNSL) can be also another promising approach to mitigate enteric CH_4 emissions from ruminants. Cashew is produced widely in the developing countries including SE Asia and Africa. Especially, Vietnam is one of the world leading cashew producers and processors. Therefore, the use of CNSL as biproduct of cashew industry in SE Asia is structurally benefitable in terms of supply chain. The active compounds contained in CNSL is the anacardic acid, which inhibits the activity of gram-positive bacteria and methanogens. It has firstly discovered by Japanese domestic research project (Watanabe et al., 2010), and shown to be effective in vivo study for the dairy cattle (Shinkai et al., 2012).

Photo 2. Lai Sind – Senepol crossbred cattle used for the CNSL feeding experiment

In our previous study, we used Lai Sind cattle, most popular crossbred Zebu beef cattle (Vietnamese yellow and Red Sindhi) in Vietnam, shows that CNSL feeding can reduce enteric CH_4 emission by 20～23% under local condition (Maeda et al., 2021). There was a significant increase in propionate in the rumen fluid, indicating there was a shift of hydrogen flow from methanogenesis into propionate production. The microbiome analysis also shows the significant increase in *Prevotella* species (propionate producers), which agree well with the propionate concentration in the rumen. We also worked on the effect of CNSL on cattle productivity and long-term effect on rumen microbiomes. The result shows that there was neither any negative effect on production in Vietnamese cattle (Lai Sind – Senepol crossbred) nor blood parameters which can be used as cattle health indicator. Nevertheless, long term feeding (same dose as 20% reduction in enteric CH_4 emission) shows that there was continuous effect on increasing the proportion of propionate producers (unpublished data) (Photo 2).

Zebu cattle (*Bos indicus*) are widely raised in tropical countries since they are well adapted to hot and humid climate conditions and genetically different from *Bos taurus* cattle in terms of heat and parasite tolerance. Zebu cattle have another characteristic on roughage utilization capacities since they are well adapted to fiber-rich diet. Indeed, the typical diet condition in SE Asian countries are straw-rich due to widespread rice cultivation in the region. Our finding indicates that the CNSL feeding technology can be integrated into local beef production system without any kind of negative impact on productivity and farmers' profitability.

3. Alternative approaches for enteric CH_4 emission mitigation

Although feed additive based approach is promising, there is an alternative approach to mitigate enteric CH_4 emission through genetic improvement of cattle. Research effort ongoing how to measure the genetic variation of CH_4 emission as trait. Since there are several methods to measure enteric CH_4 emission (respiration chamber, SF6 tracer technique, greenfeed etc.) the 'gold standard' respiration chamber method has limited throughput, an alternative measurement approach such as greenfeed based method are considered to be suitable for phenotypic value measurement on large numbers of cattle herd (Garnsworthy et al., 2019). Previous

study focused on evaluating the heritability of enteric CH_4 emission in Dutch dairy cattle shows that it is 0.21 with genetic correlation of 0.4 with several production traits such as milk lactose, indicating that there is a plenty of room to improve it by classical selective breeding approach (de Haas et al., 2021). Similar results are reported in Spanish dairy cattle herd with potential genetic improvement on CH_4 emission intensity with harmonized manner on several production traits (González-Recio et al., 2020). This type of research is not ongoing in SE Asian region as far as I know, but to be done in the near future.

III. GHG emission from livestock manure management

1. Livestock manure management characteristic across regions

Livestock manure is an alternative source of GHG emission, not only for CH_4 but also for N_2O (Petersen et al., 2013). In addition, ammonia (NH_3) is also emitted from manure, and it can be significant loss of N and the source of air pollution. It also can be an additional source of N_2O after nitrification and denitrification in soil; thus, it can be defined as indirect GHG emission. Livestock manure management system is responsible for 7% of both agricultural CH_4 and N_2O emissions (USEPA 2012). Manure is excreted from cattle after digestion of the feed; it still has enough energy to produce GHGs. Especially methanogens are still abundant in the manure after passing through the digestive system, the manure can be a significant source of CH_4 emissions. Anaerobic treatment such as storage before land application can be the significant source of CH_4 emissions (Hilgert et al., 2022), while aerobic treatment such as composting or land application which allows nitrification-denitrification can be the significant source of N_2O (Maeda et al., 2011, Broucek, 2017).

Manure management systems differ across countries and regions, since land availability, climate condition or scale of the farming are the strong factors in shaping them. In the European and North American countries with cool temperature and abundant land for manure application, slurry (solid and liquid mixed) storage of dairy manure and land applications by spreader or soil injectors are widespread (Photo 3). Large scale farming systems are widely distributed with high production efficiency in these regions, forcing farmers to manage the huge amount of manure, which can lead to higher CH_4 emissions because of the large mass with highly anaerobic conditions. Slurry injection system is preferred since it can reduce the loss of NH_3 emission, but it requires the expensive machine and only used in the developed countries (Hansen et al., 2003).

Photo 3. Slurry storage (left) and soil injection system (right) in large scale dairy farming system in Europe or north America

On the other hand, given the limited land availability or high temperature conditions in the developing countries, the manure management systems are very different from those of developed countries. Since majority of the farmers are small holders (Ates et al., 2018), the amount of the manure produced per farm is much smaller, and large-scale storage facility is often not required, but the farmers keep it in their stockyards. In many cases solid and liquid fractions of manure are separated, except

for biogas digestion system, which is the mixed manure stored under anaerobic controlled conditions to harvest CH_4 for cooking or producing electricity (Photo 4). High temperature can induce more methanogen activity, but the limited amount of manure leads to less anaerobic conditions compared to large-scale storage, preventing the opportunity for CH_4 production.

Photo 4. Manure management in developing countries. Biogas digester system of livestock manure to harvest CH_4 for cooking (right).

As there is also severe limited land availability for manure application in Japan, the most popular manure management system is composting, which can reduce the mass of manure significantly. Mature compost after organic matter degradation can be used for crop production systems, which is similar to typical crop-livestock mixed production in the developing countries.

As indicated above, there is a significant diversity for livestock manure management system across regions and countries. In turn, it means that there are high variations in CH_4 or N_2O emissions per unit organic matter or organic N treated, which is expressed as the emission factors (EFs). Therefore, representative data for EF values which reflect the local manure treatment and activity data (how many % of farmers or how much manure are processed in which treatment system) in each country are necessary for precise estimation of the GHG emission.

2. Japanese inventory data on livestock manure management

Current Japanese official national GHG emission estimation is reported at Tier 2 level in most of the categories. In Japan, there is a precise enough public statistical data on manure management system for each livestock species (MAFF, 2021a,b). Liquid-solid separation system works on 30% of dairy manure and 76% of swine manure while only on 2.5% of beef cattle manure. As already mentioned above, the most popular manure management is composting, after liquid-solid separation, 87% of dairy manure, 92% of beef cattle manure and 98% of swine manure are composted, while majority of cattle manure are passive system, but half of swine manure are composted with active aeration system. In the liquid-solid mixed treatment system, composting is still the majority treatment, 56% of dairy, 91% of beef cattle, 75% of swine manure is treated by passive or active composting, while 25% of dairy manure is storage and 6% goes to anaerobic digestion system, and 11.7 of swine manure is treated in purification system. Other manure management systems such as sun-

drying, incineration or grazing exist, but they are all less than 3% for each of all livestock species. EF values for these popular manure management systems are already available, according to the published data of the measurement in local conditions (GIO, 2025).

These EF values are not available in most of SE Asian countries; therefore, they calculate their national GHG emissions by using default values provided IPCC, which is called Tier 1 approach. We have worked in Thailand and Vietnam, through these activities, some data is available for sun-drying system of beef cattle manure in south Vietnam (Nguyen et al., 2022) and composting of beef cattle manure with rice straw as bulking agent in north-east region of Thailand (Angthong et al., 2022).

3. DATAMAN: A global database of GHG emission factors for livestock manure

Again, the emissions are estimated by multiplying activity data and EFs. There are three categories for inventory reporting, Tiers 1 to 3. IPCC provides the default values for EFs for each animal subcategory (Tier 1), still many developing countries are using this approach for livestock manure management. If country specific data is available, we can estimate with Tier 2 approach, which includes more detailed country-specific EFs. Tier 3 uses more complex models which enable the effect of mitigation measures to be taken into account.

At the early stage of arrangements of GHG EFs from manure management, the activity depends on each scientist, which could lead to un-standardized manners. Indeed, there were a range of units with different experimental manners and expression of emissions across studies in different regions. Therefore, there was a challenge on the development of a database of all relevant published EFs on manure management, which enables the improvement of the models with less uncertainty. This was supported by GRA-LRG manure management network, led by New Zealand.

So far, two database papers has been published, one for field (land application) (Beltran et al., 2021) and the other for housing and storage (Hassouna et al., 2023). The field database, which mainly focuses on N_2O and NH_3 emissions from land applications of the manure, contains 5,632 observations from 184 studies (Beltran et al., 2021). However, there was a significant imbalance on geographical distribution of the data source, 90% of total dataset comprise with European temperate climate, from UK, Denmark, Netherlands or also temperate to cool climate conditions New Zealand and Canada. Since there is a strong need for quality control, the published dataset with robust methodology and enough data reliability is required. Therefore, there is a significant missing of dataset from Asia, middle east, Latin America or African countries, where many developing countries exist.

The other database paper, which focuses on housing and storage, the total number of EFs collected for housing was 2024, while 19.5% and 17.5% of these were CH_4 and N_2O, respectively (Hassouna et al., 2023). Majority of these EFs for CH_4 or N_2O for animal housing still come from Europe and North America, which comprise 97-

98% of the database, while none come from Asia. There was only small contribution from Asia, 24 datapoints from China and 5 from South Korea, out of 1,281 datapoints in total for NH_3 emissions. For the outdoor manure storage database, the EFs from European and North American countries are still majority, there was a significant contribution from Asia, 87 out of 243 (35.8%) for CH_4 and 91 out of 654 (13.9%) for N_2O, respectively (Fig. 6).

a)
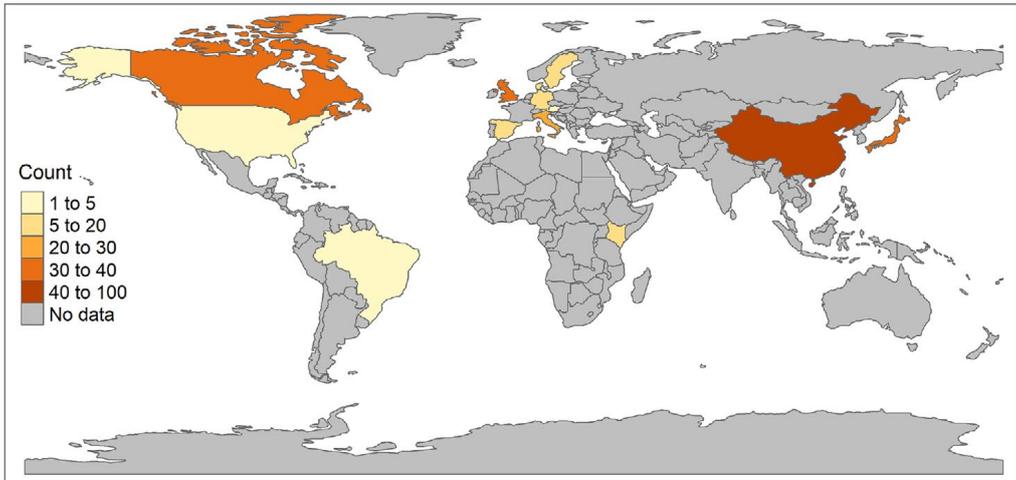
b)
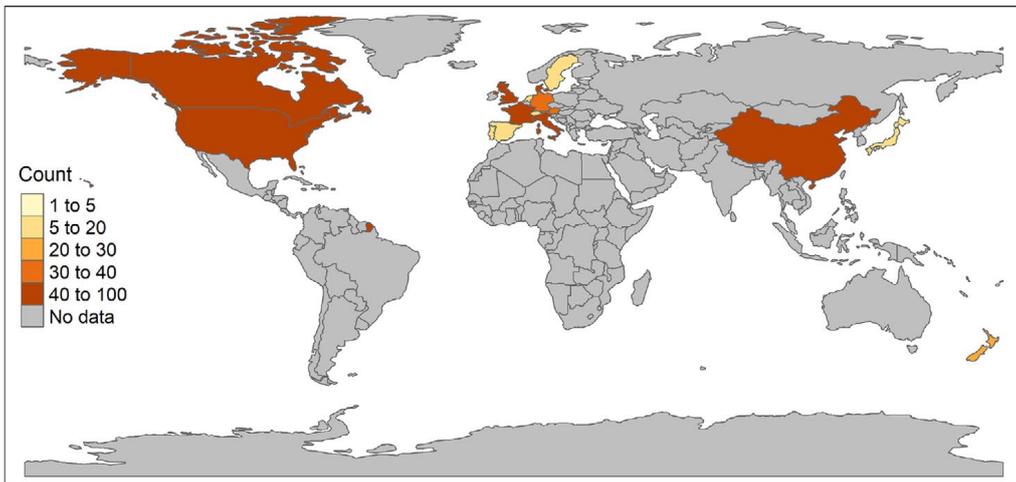
c)

Fig. 6. Distribution per country for (a) CH_4 emission factors (EFs), (b) NH_3 EFs, and (c) N_2O EFs, associated with outdoor storage of manure (Hassouna et al., 2023)

The largest data provider was China, while Japan came to the second position. The data deposited to DATAMAN coming from the EFs reported in GIO paper, as described in section III-2 (GIO, 2025). In addition, there was a small contribution from Vietnam (8 dataset for N_2O EFs) but no data was available for CH_4 from SE Asian countries, indicating that there is a significant ro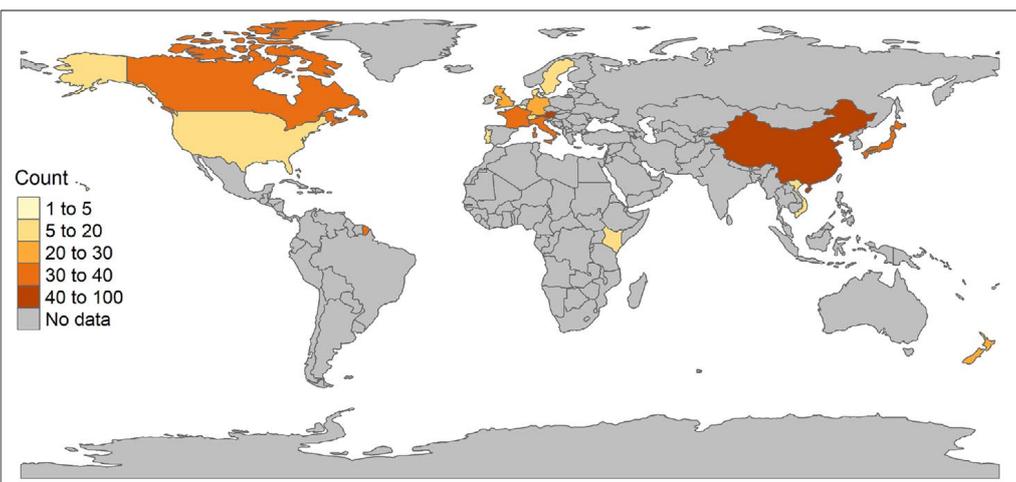om for improvement. There was a significant limitation of availability on variables, no paper contains all variables listed in the database, and is strongly recommended to work with the standardized manner as indicated in Webb et al. (Webb et al., 2021). Altogether, there is a strong need to establish EFs (and activity data) from livestock manure management in SE Asian countries in standardized manner for better and more precise basement GHG emission estimation.

4. JIRCAS contribution on EFs estimation from manure management

As stated in the previous section, the GHG EFs for manure management is very limited in SE Asian countries. One of the JIRCAS activity has targeted on this issue, we have obtained the potential EF value for cattle manure composting in Northeast Thailand. We obtained the dataset for both enteric CH_4 emission and manure management at the same time from Thai native cattle at local conditions (Angthong et al., 2022), which is also novel approach to take care both sides of the emission sources. The observed CH_4 conversion factor (*Ym*: 6.87±0.11% GEI) was slightly higher than IPCC default value, and CH_4 emission from manure obtained by dynamic chamber technique (Photo 5) accounted for 0.69% GEI. The addition of rice straw, which is abundant in the local condition as the bulking agent of composting, had significant impact on relative abundance of methanogens in the manure, indicating the rice straw addition has the potential to mitigate the CH_4 emission from manure management.

Photo 5. Dynamic chamber system for quantifying the gaseous emission from cattle manure composting in Northeast Thailand

In addition, we performed the livestock farmer survey in Southern Vietnam to identify the dominant manure management system in the region and found that sun-drying system of beef cattle manure is widespread around Mekong delta region (Ben Tre and Tra Vinh provinces) where majority of the cattle farmers located in the region (Photo 6). The GHG emission through this sun-drying treatment in the local condition was measured, it was 0.295±0.078 g kg^{-1} volatile solid for CH_4 and

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0.132 ± 0.136 g N_2O-N kg^{-1} $N_{initial}$ for N_2O, respectively (Nguyen et al., 2022). These values can be used for EFs on this manure management system in Vietnam. Significant CH_4 emission only occurred at the beginning of the drying process, while N_2O emission was negligible, agree with the abundance of methanogens detected by culture-independent method. Moreover, we detected the significant flow of manure from Mekong delta region into the central highland, where massive coffee-pepper production occurs.

Photo 6. Manure sun-drying by beef cattle farmers in Ben Tre province, Vietnam

IV. Livestock industry and greenhouse gas (GHG) emissions

1. Transport of dried cattle manure to the central highlands

As described in the previous chapter, sun-drying is the most dominant management for beef cattle manure in Southern Vietnam (Nguyen et al., 2022). The farmers dry the manure in their backyard and sell it to the middleman, who brings the manure to the central highland, where massive coffee-pepper intercropping system occurs. Vietnam is the second largest coffee producer in the world, 17% of global coffee production occurs in there, after Brazil (37%) (USDA, 2025). Coffee production in Vietnam is very concentrated in only four provinces (Dak Lak, Gia Lai, Dak Nong and Lam Dong) in the highland out of 58 provinces (recently they were combined into 28 provinces in total in June 2025), where more than 90% of the domestic production occurs. In the region, coffee production strongly relied on the chemical fertilizer application in past decades, but more recently they face soil health problems. Therefore, local government recommends the application of organic fertilizer such as animal manure to the farmers.

Due to this situational background, there is a high demand for manure as organic fertilizer and soil texture improvement. The cattle farmers in the surrounding region can make their business by selling the dried manure, and the middlemen also make their business by bring the manure to the highland and sell to the coffee-pepper farmers. It takes up to 12 hours or more to get the dried manure transported from Mekong delta region to the highland, which never occurs in Japan due to the high transport cost and labor. However, the sun-drying can make this happen, since moisture content significantly drops and it reaches around 10 to 20%, which also significantly reduces the manure weight.

Photo 7. Bags of dried cattle manure and its transportation to the central highland.

Our finding is underpinned by the previous research, which reports the transport of manure and chain of the price from coastal side to central highland (McRoberts et al., 2017). Manure trade is an important source of supplementary income for the cattle farmers, while it can be primary source of income for some of middlemen. The

estimated income for cattle farmers is 100 USD yr^{-1} for the manure sellers, while 13,000 USD yr^{-1} for the middlemen. Since this previous research only focus on the coastal side provinces (Phu Yen and Binh Dinh) into north part of central highland (mainly Gia Lai, and some for Dak Lak or Dak Nong or Binh Thuan), and it strongly focus on the value chain and the economical side of the manure flow, we tried to figure the environmental issue of this flow and see the other side from Mekong delta to central highland.

2. Farm survey on coffee-pepper farmers and manure transporters

In order to make a big picture of manure transport from surrounding area into central highland, we had an interview-based farm survey in four main provinces (Dak Lak, Gia Lai, Dak Nong and Lam Dong). Cultivation area, livestock number (heads), manure management, manure/chemical fertilizer application to the coffee/pepper land, amount of manure purchased from outside the region, and so on.

Ninety % of coffee/pepper farmers utilize manure as organic fertilizer and apply it to their land. The average manure application rate was 13 kg/tree, majority of farmers apply it once per year, from April to August. The farmers who do not have cattle purchase the manure from middleman. Among them, 51% of farmers apply manure after composting, while 22% apply raw manure and only 7% apply chemical fertilizers (no organic fertilizers). From our obtained data and official statistical data, the estimated amount of the manure applied to the coffee/pepper land in four provinces was 3,121 Gg DM yr^{-1}, while pasture and other fields receive 311 Gg DM yr^{-1}.
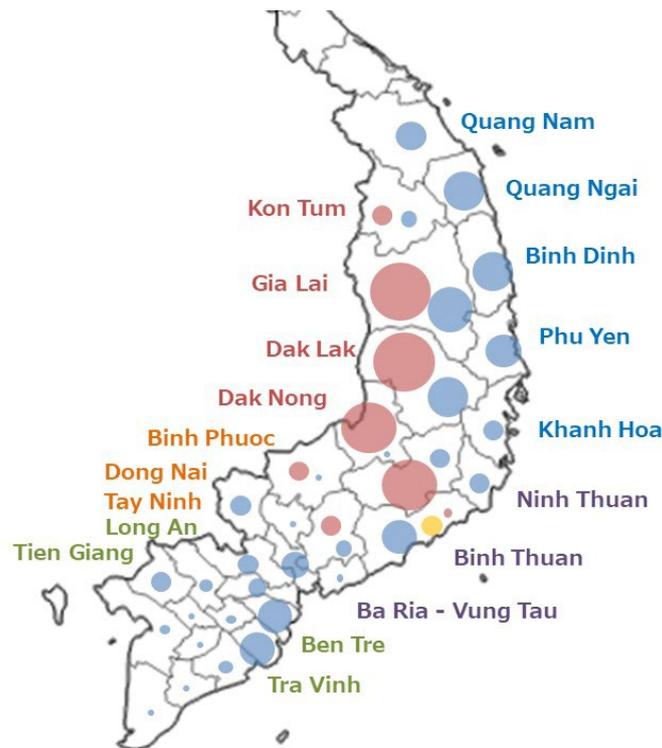
Fig. 7. Coffee cultivation area (red), dragon fruit cultivation area (yellow) and cattle head (blue) in central and southern Vietnam. This figure illustrates the provinces prior to the provincial restructure in 2025.

The estimation of manure produced inside highland region was 357 Gg DM yr^{-1}, which can be only 10.4% of total manure demand in the region, strongly indicating that there is a significant shortage of manure in the region. This situation creates a business chance for the manure transporter (middleman), who transport the manure from outside (Mekong delta or coastal region) into the central highland. The estimated amount of manure purchased from outside regions was 2,273 Gg DM yr^{-1}, which accounted for 66.2% of total demand in the region. The total manure from outside and inside the region was 2,630 Gg DM yr^{-1}, and 46% (1,201 Gg DM) of these manures were estimated to be applied into coffee/pepper land, while 54% went to composting, mixed with bulking agent (estimated to be 1,270 Gg DM).

Based on the statistical data, we further split these four provinces into two groups, one with cattle rich group (Gia Lai and Dak Lak), the other is group without enough amount of cattle (Dak Nong, Lam Dong) (Fig. 7). The estimation of latter group shows extreme imbalance of the manure produced in the region and manure amount from outside the region, they were 22 Gg DM yr^{-1} and 1,593 Gg DM yr^{-1}, respectively. This means self-sufficiency of the manure was only 1.36% in these two provinces. This explains that the coffee/pepper farmers need the cattle manure from outside the region, and why there is a massive flow of the dried manure from Mekong delta (especially Ben Tre and Tra Vinh provinces) to the central highlands.

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3. Composting cattle manure with coffee husk and its GHG emissions

Our survey also focused on the manure management of these coffee/pepper farmers after purchasing from middleman. As mentioned above, the majority of farmers (51%) make the compost by the manure purchased, while other options were raw manure application or only chemical fertilizer application. The sun-drying treatment only reduces the moisture content of manure, and organic matter degradation does not occur since activity of microbes in the manure is significantly reduced in the dry condition. We have also identified that the major bulking agent for composting is the coffee husk, which is abundant as the by-product of coffee production in the region. Therefore, we had an experiment of composting cattle manure mixed with different levels of coffee husk mixing under local conditions to obtain the potential EF value from this category.

Photo 8. Composting experiment of dried cattle manure mixed with coffee husk

Composting experiment of cattle manure was mixed with 2 levels of coffee husk, which was performed in institute of animal science for southern Vietnam (IASVN) experimental station. About 600 kg of dried manure was mixed with coffee husk; high ratio (manure: coffee husk as 1:1, v/v) and low ratio (2:1) and no-addition control was placed on the concrete floor and turned every two weeks. Gas emission was measured by chamber-based technique which is described in the previous section (Nguyen et al., 2022). Methane and N_2O concentrations in the vials were determined by standard gas chromatography equipped with FID/ECD, respectively.

Adding coffee husk as bulking agent had significant impact on the manure heap temperature due to the promotion of organic matter degradation, as expected. The maximum temperature with high mixing ratio was 56-59℃, while it was only 38.4℃ in no addition control manure heap (Fig. 8). The mixing of coffee husk as bulking agents also promotes both CH_4 and N_2O emissions, which was not expected. The beef cattle manure has less moisture content compared to dairy manure, and the initial amount of manure was relatively small (600 kg), which lead to less anaerobic condition in the manure preventing significant CH_4 emission from raw material. The manure used for the experiment was dried manure purchased from the middleman. The experiment was performed after water addition to mimic the farmer's behavior, but less moisture can lead to the oxic condition which also inhibit methanogen

activity. The total gas emission will be converted into GHG emissions per unit organic matter or organic N treated, which can be used for the potential EF value for this specific category. The published data can be used for the Vietnamese national country specific data to be registered in the EF database.
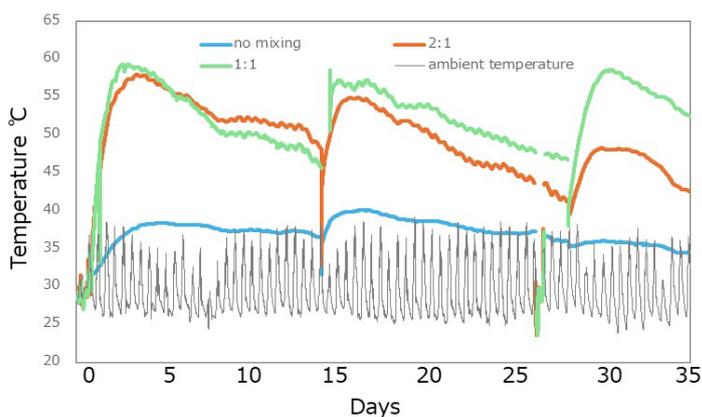
Fig. 8.
Temperature profile of the dried beef cattle manure mixed with coffee husk

Since both CH_4 and N_2O emission depend on the activity of the microbiome in the manure, the explanation of these emissions based on the microbiome information is needed. For example, the coffee husk mixing did affect relative activity of the methanogens in the whole microbiome or nitrifiers/denitrifiers abundance can be the key factors for better understanding of the gaseous emissions. Further dataset will be obtained and to be coupled with these gaseous emission data to estimate the reasons for increase in GHG emission by coffee husk mixing.

Conclusions

GHG emission mitigation from livestock production system in SE Asian countries is an urgent issue. Current GHG emission intensity is very high in the region, thus there is plenty of room for improvement on emission intensity through optimized feeding management and increasing production efficiency. Some promising feed additives are already available in the market, especially CNSL is one of the most promising approaches since cashew production occurs inside the region, while its CH_4 mitigation effect already proved in Zebu cattle. It is also shown that these feed additives do not harm cattle productivity, so there is a need to make these feeding technologies integrated into the production system in the region through appropriate strategies, especially from the economic and governmental regulation/ registration points of view.

Manure management is an alternative source of GHG emissions, while still baseline estimation is not precise enough in the region. The EFs database for manure management across regions, which was recently established under international cooperation paved the way for better estimation under standardized manners. In SE Asian countries, still data is extremely lacking and need investment for higher Tier estimation. JIRCAS activity contributed to some limited countries and limited specific manure management systems in the region so far. More robust and feasible activity to help the local government and scientists are needed in the future.

Authors contribution statement

Acknowledgement

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