

## Estimation of methane emissions from local and crossbreed beef cattle in Daklak province of Vietnam

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**Objective:** This study was aimed at evaluating effects of cattle breed resources and alternative mixed-feeding practices on meat productivity and emission intensities from household farming systems (HFS) in Daklak Province, Vietnam.

**Methods:** Records from Local Yellow×Red Sindhi (*Bos indicus*; Lai Sind) and 1/2 Limousin, 1/2 Drought Master, and 1/2 Red Angus cattle during the growth (0 to 21 months) and fattening (22 to 25 months) periods were used to better understand variations on meat productivity and enteric methane emissions. Parameters were determined by the ruminant model. Four scenarios were developed: (HFS1) grazing from birth to slaughter on native grasses for approximately 10 h plus 1.5 kg dry matter/d (0.8% live weight [LW]) of a mixture of guinea grass (19%), cassava (43%) powder, cotton (23%) seed, and rice (15%) straw; (HFS2) growth period fed with elephant grass (1% of LW) plus supplementation (1.5% of LW) of rice bran (36%), maize (33%), and cassava (31%) meals; and HFS3 and HFS4 computed elephant grass, but concentrate supplementation reaching 2% and 1% of LW, respectively.

**Results:** Results show that compared to HFS1, emissions (72.3±0.96 kg CH<sub>4</sub>/animal/life; least squares means± standard error of the mean) were 15%, 6%, and 23% lower (p<0.01) for the HFS2, HFS3, and HFS4, respectively. The predicted methane efficiencies (CO<sub>2</sub>eq) per kg of LW at slaughter (4.3±0.15), carcass weight (8.8±0.25 kg) and kg of edible protein (44.1±1.29) were also lower (p<0.05) in the HFS4. In particular, irrespective of the HSE, feed supply and ratio changes had a more positive impact on emission intensities when crossbred 1/2 Red Angus cattle were fed than in their crossbred counterparts.

**Conclusion:** Modest improvements on feeding practices and integrated modelling frameworks may offer potential trade-offs to respond to climate change in Vietnam.

**Keywords:** Household Farming; Methane Emissions; Modelling; Ruminant

### INTRODUCTION

In deploying the expression “sustainable global development”, the World Bank draws the urgent attention to climate change, social relations (i.e. poverty alleviation, health protection and reduced vulnerability of disadvantaged people to climatic impacts); and the use of suitable policies and mitigation practices [1]. This is inherently linked and fluid, not individualistic and fixed [2]. Importantly, however, major advances on livestock and the environment over the past decade, may be more, or less, contextually situated for different production systems, regions and economic conditions [3-5].

Within that environment, it is widely acknowledge that sustainable livestock intensification relies to some extent on a net reduction of greenhouse gas (GHG) emissions and improved farm management practices in terms of decreased GHG emission intensities per unit of product;

and/or the use of improved forages to feed more efficient animals and breeds [6,7]. Thus, as compelling evidence indicates that developing Eastern Asia will be hit by the impacts of climate change [3], beef production and the sustainable adaptation of household farming systems (HFS) to climate-related shocks is a decision-making priority for the Vietnamese Government to improve food security and economic gains, mitigate and build resilience to climate change.

Vietnamese census data suggest that in 2014 the cattle population was approximately 5.23 million heads (mh), while ~ 2.12 mh were crossbred cattle [8]. However, to meet a growing meat demand, reduce food importation and improve public health priorities and socio-economic rural development; one of the hardest challenges ensuring climate-regulatory changes is to increase the cattle herd up to ~ 8.86 mh by 2020 [8]. These elements have been highlighted in the current planning of the DakLak Province in the central highlands of Vietnam to develop a more specialised beef HFS that will consider 60% of the a local beef herd (0.25 mh) composed by a crossbred progeny between local F<sub>1</sub> Yellow×Red Sindhi (*Bos indicus* [*B. indicus*]; Lai Sind) and Drought Master (*B. indicus*×*B. taurus*), Limousin and Red Angus (*B. taurus*) cattle [9]. In this context, more than ever, vulnerable groups and policy makers in the Province are dependent on beef homestead production strategies to improve the sustainability of critical nutrition and health interventions [10].

However, as it is expected, patterns of future interventions must rely by 2020 on the reduction of 6.30 million metric tons of equivalent carbon dioxide (CO<sub>2</sub>e) GHG emissions from the livestock sector [11]. Nevertheless, as a significant proportion of enteric methane emissions come from HFS in which beef cattle account for 55% of the national herd; a critical question arises: to what extent we can quantify and integrate in HFS the environmental impacts of alternative management options, feed and cut and carry feeding practices, and breed components.

The study provides modelled information that differentiate the effects of cattle breed resources and alternative mixed-feeding practices on meat productivity and emission intensities from HFSs in the DakLak Province. Consequently, it is argued that there is value in treating these integrated beef farming scenarios as critical for the nutritional security at the local socio-cultural articulation, land fragmentation, ecosystems, farming practices and market-mediated interactions. However, we accept that the lived reality [12] and our agreed hypothetical scenarios may be quite different from that circumstances in other rural-based mixed systems, peri-urban and/or urban areas of the country.

In parallel our approach brings attention to the fact that alternative practical future visions [13-15] may assist to optimise and articulate the use of nutrient resources, farm components, management strategies and environmental trade-offs. Thus, using the RUMINANT model [6] and local beef HFS records, the paper explores scenario simulations to identify individual or collective intervention opportunities for future planning, decisions, adap-

tation and desirable sustainable beef intensification in the DakLak Province of Vietnam.

## MATERIALS AND METHODS

### Data set and its management

Beef growth (i.e. 0 to 21 months) under grazing and indoor fattening (i.e. 22 to 25 months) data for Local Yellow×Red Sindhi (*B. indicus*; Lai Sind; LSD), and 1/2 Limousin (LS), 1/2 Drought Master (DS), and 1/2 Red Angus (RS) cattle were obtained from a household farming study [12] conducted in the EaKar District of the DakLak Province of Vietnam between September 2007 and December 2010. Animals in each breed (n = 4; [16,17]) were subject to the same measurement variables (dry matter intake [DMI], live weight [LW], and carcass characteristics). Consequently, the size of the declared differences between the treatments accounted for the variation between and within animals as well as throughout the time of the initial experimental programme [16,17]. This represented the current situation and the reference-starting point for developing simulations using the digestion and metabolism ruminant model to determine variations on growth performance, meat productivity and estimates of enteric methane emissions related to alternative feeding scenarios.

### Model set up, calibration and scenario development

Model configuration is described in detail by Herrero et al [6]. Briefly, the Intergovernmental Panel on Climate Change tier 3 model is based on stoichiometric algorithms describing for ruminants (i.e. cattle, goats, and sheep) the production of milk, meat and manure as well as nitrogen excretion and fermented emissions. Initial inputs to the model in this study were: i) numbers of animals in each breed contributing to the predicted production; ii) biomass consumption for each animal; iii) the proportion of each feed in the diet at household level [12]; and iv) data on feed availability for animal production in the EaKar district taken from a Vietnamese feed-database (i.e. crops, forages and stovers) of quality and composition developed by Le Duc et al [15], Le Dinh et al [14,18].

In the ruminant model calibration procedure, parameters were adjusted iteratively to obtain reasonable agreement between measured productivity in household systems and simulated output (data not shown). Calibration parameters were kept unchanged in the subsequent interplay connections to deal with the uncertainties in the mixed crop-beef smallholder scenarios. Independent validations have been carried out for more than 80 contrasting diets in tropical and temperate environments and the intake residuals ( $\pm 5$  g/kg, LW<sup>0.75</sup>) indicate that the model has the required accuracy not only as a research tool to evaluate alternative livestock policies, but also for providing decision support at the farm level [19]. Among its many uses, the model has been previously used for estimating methane emission factors of tropical livestock [4,20].

Consequently, the third step consisted in developing the fourth HFS using a participatory process with local household farmers and researchers for sustainable planning as follows: (HFS1) grazing from birth to slaughter on native grasses for ~10 h plus 1.5 kg DM/d (0.8% LW) of a mixture of guinea grass (*Panicum maximum*; 19%), cassava (*Manihot esculenta*; 43%) powder, cotton (*Gossypium* sp., 23%) seed, and rice (*Oryza* sp. 15%) straw; (HFS2) growth period fed with elephant grass (*Pennisetum purpureum*; 1% of LW) plus supplementation (1.5% of LW) of rice bran (36%), maize (*Zea Mays*; 33%), and cassava (31%) meals, while HFS3 and HFS4 computed elephant grass over the growth phase, but with homemade concentrate supplementation reaching 2% and 1% of LW, respectively. The fattening period for the last three scenarios considered the same supplementation offered in HFS1 as total diet fed in standard finishing cages.

### Statistical analysis

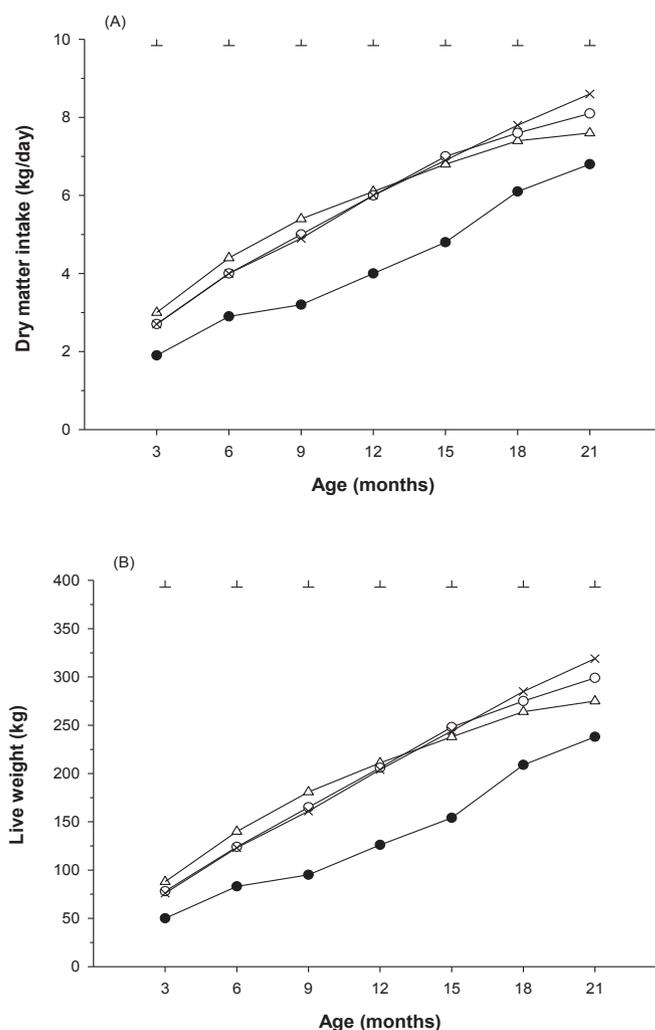
Data were analysed using SAS (Statistical Analysis System, version

9.4; SAS Institute, Cary, NC, USA). Using fitted linear models, the MIXED procedure was applied for analysis of variance. Breed (i.e. LSD, LS, DS, and RS), age (i.e. birth, 3, 6, 9, 12, 15, 18, and 21 months), sex and the interaction between breed and age were used to assess the effects on LW, DMI, methane yield (i.e. g CH<sub>4</sub>/kg DMI) and methane efficiency as kg of CO<sub>2</sub>eq/kg LW/d. Measurements over the fattening period considered the effects of breed and scenarios (i.e. HFS1, HFS2, HFS3, and HFS4), while birth LW was used as a covariate. Main effects among least squares means ( $\pm$ standard error of the mean) of variables and interactions were tested using a significance level of  $p < 0.05$ .

## RESULTS

### Experimental growing period

**Dry matter intake:** Compared to local LSD cattle, DMI was higher for LS, DS, and RS crossbred cattle throughout the growing period ( $p < 0.05$ ; Figure 1A). However, at 21 months of age, DMI



**Figure 1.** Dry matter intake (A) and body growth (B) of Local Yellow (*Bos indicus*) $\times$ Red Sindhi (*Bos indicus*; ●), and crossbred 1/2 Limousin (LS; Δ), 1/2 Drought Master (DS; ○) and Red Angus (RS; ×) cattle in smallholder farming systems of the Central Highland region in Vietnam.

was similar for DS and RS animals, but greater ( $p < 0.05$ ) than of the LSD and LS animals. Averaged from birth to 21 months of age, DMI was higher ( $p < 0.001$ ) for RS cattle ( $5.6 \pm 0.05$  kg) than that for the local LSD ( $4.1 \pm 0.05$  kg) cattle, but similar to LS and DS cattle groups ( $5.5 \pm 0.05$  kg).

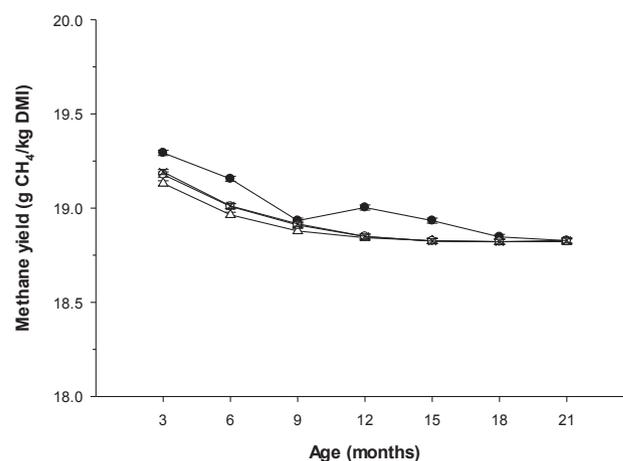
**Animal growth:** Live weight increased linearly with age for all animals, with the increase being greater for LS, DS, and RS crossbred animals than for the local LSD animals (Figure 1B). However, at the end of the growing period, the LW was higher ( $p < 0.001$ ) for the RS cattle than that of the other three cattle groups.

**Predicted methane emissions:** The model showed that relative to LS, DS, and RS cattle, methane yield (g CH<sub>4</sub>/kg DMI) was higher ( $p < 0.0001$ ) for LSD cattle ( $19.3 \pm 0.01$ ) at 3, 6, 12, and 15 months of age, but there were no differences between cattle groups at 21 months of age ( $18.8 \pm 0.01$ ; Figure 2) or averaged across the growing period ( $18.8 \pm 0.004$ ). Daily methane efficiency at 3 months of age was higher ( $p < 0.001$ ;  $0.018 \pm 0.0001$  CO<sub>2</sub>eq/kg LW) in LSD cattle than in their counterparts ( $0.016 \pm 0.0001$ ), while overall, this difference persisted through the growing period ( $p < 0.001$ ;  $0.015$  vs  $0.014 \pm 0.00003$ ).

### Fattening period

**Meat productivity:** Carcass weight (CW) proportion, CW, lean meat weight (i.e. CW × proportion raw boneless meat) and edible protein (i.e. lean meat weight × raw meat protein content, 0.26 factor, [21]) were higher ( $p < 0.05$ ) for RS cattle than for LSD, LS, and DS cattle (Table 1).

**Calculated methane emission:** The model assessment indicated that irrespective of the HFS, total emissions (CH<sub>4</sub> kg/animal/life) were lower ( $p < 0.05$ ) for local LSD cattle than for DS and RS cattle, while emission intensities (CH<sub>4</sub> kg/kg CW; CH<sub>4</sub> kg/kg edible protein) and methane efficiencies (kg CO<sub>2</sub>eq/kg CW; kg CO<sub>2</sub>eq/kg edible protein) were higher for the LS cattle than for the other



**Figure 2.** Comparative estimations of methane yield emissions between Local Yellow (*Bos indicus*) × Red Sindhi (*Bos indicus*; ●), and crossbred 1/2 Limousin (LS; Δ), 1/2 Drought Master (DS; ○) and Red Angus (RS; ×) cattle in household farming systems in Dak Lak province of Vietnam.

cattle groups (Table 1).

Methane emission indices from the four HFS are summarised in Table 2. Compared to HFS1, total emissions, emission intensities, and emission efficiencies were reduced by ~22.7%, 23.4%, and 23.6% with the use of HFS4 ( $p < 0.05$ ). Following similar indices order, there were also consistent reductions with the use of HFS2 ( $p < 0.05$ ; 14.7%, 14.5%, and 15%) and HFS3 (~6.4, 6.6, and 6.8) scenarios.

## DISCUSSION

Analysis of our data indicates that DMI and body growth of the crossbred cattle between LSD and exotic breeds were almost always higher than the LSD breed. This indicates that differences

**Table 1.** Meat productivity and methane emission (CH<sub>4</sub>) calculated indices<sup>1)</sup> from Yellow Local (*Bos indicus*) × Red Sindhi (*Bos indicus*; LSD), and crossbred 1/2 Limousin (LS), 1/2 Drought Master (DS), and 1/2 Red Angus (RS) cattle records in household farming systems during a 90-day fattening period in the Ea Kar district of the Dak Lak province of Vietnam

	Breeds			
	LSD	LS	DS	RS
Animals on feed	4	4	4	4
Initial live weight (kg)	317 ± 18.5 <sup>a</sup>	275 ± 12.5 <sup>c</sup>	313 ± 6.5 <sup>b</sup>	335 ± 4.9 <sup>a</sup>
Final live weight (kg)	348 ± 35.2 <sup>ab</sup>	302 ± 23.7 <sup>b</sup>	341 ± 12.4 <sup>ab</sup>	367 ± 9.48 <sup>a</sup>
Carcass weight proportion	0.486 ± 0.011 <sup>bc</sup>	0.484 ± 0.007 <sup>c</sup>	0.506 ± 0.004 <sup>b</sup>	0.526 ± 0.003 <sup>a</sup>
Carcass weight (CW; kg)	172 ± 18.6 <sup>abc</sup>	146 ± 12.6 <sup>c</sup>	173 ± 6.5 <sup>b</sup>	194 ± 5.0 <sup>a</sup>
Lean meat weight (kg)	134 ± 14.6 <sup>abc</sup>	112 ± 9.88 <sup>c</sup>	135 ± 5.16 <sup>b</sup>	150 ± 3.93 <sup>a</sup>
Edible protein (kg)	35 ± 3.80 <sup>abc</sup>	29 ± 2.56 <sup>c</sup>	35 ± 1.34 <sup>b</sup>	39.0 ± 1.02 <sup>a</sup>
Calculated methane emissions				
Total emissions (kg/animal/life) <sup>1)</sup>	62.6 ± 3.39 <sup>b</sup>	73.1 ± 2.29 <sup>ab</sup>	74.7 ± 1.19 <sup>a</sup>	74.6 ± 0.91 <sup>a</sup>
Emissions intensity (kg/kg CW)	0.36 ± 0.035 <sup>bc</sup>	0.51 ± 0.025 <sup>a</sup>	0.44 ± 0.013 <sup>b</sup>	0.39 ± 0.010 <sup>c</sup>
Emissions intensity (kg/kg edible protein)	1.8 ± 0.18 <sup>bc</sup>	2.5 ± 0.12 <sup>a</sup>	2.1 ± 0.06 <sup>b</sup>	1.9 ± 0.04 <sup>c</sup>
CH <sub>4</sub> efficiency (kg CO <sub>2</sub> eq/kg CW)	8.9 ± 0.90 <sup>bc</sup>	12.8 ± 0.61 <sup>a</sup>	11.1 ± 0.32 <sup>b</sup>	9.8 ± 0.24 <sup>c</sup>
CH <sub>4</sub> efficiency (kg CO <sub>2</sub> eq/kg edible protein)	44.5 ± 4.66 <sup>bc</sup>	64.2 ± 3.14 <sup>a</sup>	54.5 ± 1.64 <sup>b</sup>	49.0 ± 1.25 <sup>c</sup>

<sup>1)</sup> Adjusted to equal birth weight. Adapted from Van Tien [12].

Least squares means (± standard error of the mean) within the same row followed by the same letter are not significantly different at  $p < 0.05$ .

**Table 2.** A comparison of modelled methane emissions (CH<sub>4</sub>)<sup>1)</sup> for four household farming systems (HFS) scenarios derived from the use of Yellow Local (*Bos indicus*)×Red Sindhi (*Bos indicus*), and crossbred 1/2 Limousin, 1/2 Drought Master, and 1/2 Red Angus cattle records during a 3-month fattening period in the DakLak province of Vietnam

Variable	Household farming systems scenarios				Pooled SEM
	HFS1	HFS2	HFS3	HFS4	
Total emissions (kg/animal/life)	72.3 <sup>ab</sup>	71.3 <sup>b</sup>	75.2 <sup>a</sup>	67.6 <sup>c</sup>	0.95
Emissions intensity (kg/kg CW)	0.46 <sup>ac</sup>	0.45 <sup>ac</sup>	0.47 <sup>a</sup>	0.43 <sup>b</sup>	0.010
Emissions intensity (kg/kg edible protein)	2.2 <sup>a</sup>	2.2 <sup>ac</sup>	2.3 <sup>a</sup>	2.1 <sup>bc</sup>	0.05
CH <sub>4</sub> efficiency (kg CO <sub>2</sub> eq/kg LW at slaughter)	5.7 <sup>ac</sup>	5.6 <sup>ac</sup>	5.9 <sup>a</sup>	5.3 <sup>bc</sup>	0.15
CH <sub>4</sub> efficiency (kg CO <sub>2</sub> eq/kg CW)	11.5 <sup>ac</sup>	11.3 <sup>ac</sup>	11.9 <sup>a</sup>	10.7 <sup>bc</sup>	0.25
CH <sub>4</sub> efficiency (kg CO <sub>2</sub> eq/kg edible protein)	57.1 <sup>ac</sup>	56.4 <sup>ac</sup>	59.3 <sup>a</sup>	53.4 <sup>bc</sup>	1.31

SEM, standard error of the mean; CW, carcass weight; LW, live weight.

<sup>1)</sup> Adjusted to equal birth weight. Adapted from Van Tien [12].

Least squares means values within the same row followed by the same letter are not significantly different at  $p < 0.05$ .

of daily methane efficiency ( $p < 0.05$ ) and birth weight ( $p < 0.0001$ ) between LSD and crossbred LS, DS, and RS cattle (21.0 vs 26.0, 25.0 and 24.5±7.08 kg) persisted progressively. Therefore, those breed differences and complementary research approaches could guide the estimation of genetic parameters for specific roles and regions in order to benefit future meat portfolio projections [7,17, 22].

In this flow, as smallholder beef farming systems are not closed systems, although they are often portrayed as such; mixed-crop farming systems could be benefited from transformative technology, transferable skills and sustainable productive interactions to improve socio-economic protection and reduce people's vulnerability to climate-related events. However, it leads us to emphasize that traditional farming practices in Vietnam, could make difficult to transfer one context to another. But, at the same time, the Vietnamese socio-cultural organisation and the growing beef farming industry, its values and attitudes within the constraints of emissions-reduction policies, may provide key learning opportunities. They will help to deal with traditional ambiguities and contradictions [23], environmental goals and new climate-informed discourses [1].

Another major implication of our study is that measurements under normal household farming conditions the ruminant model can be used together to improve estimates of methane emissions and related indices from birth to mature stages as was done in this study. From the results presented in this paper, it can be also concluded that the strategic use of crossbreds between Local Yellow×Red Sindhi and imported breeds such as LS, DS, and RS will help meet the significantly increased beef meat demand in the DakLak Province. This interpretation is consistent with earlier reports on the positive effects of crossbred cattle on growth and carcass performance [24], and better meat quality [25] in South Asia. However, as noted earlier, it should not obscure the breeding value of the native cattle in Vietnam for quantitative genetic and genomic research aimed at reducing methane emissions and other desirable productive traits. Although we expect that similar crossbred differences can be found in other regions of the country,

further assessment of these effects is advisable.

On the other hand, beef productivity improvement solutions can be meaningless if they create negative environmental impacts because ability of HFS to fulfil their role as food producers under climate variability is also dependent on the efficient use of feed resources. Therefore, it is interesting to note that compared to the native grazing vision, our alternative feeding scenarios with fresh forage (~110 and 660 g/kg DM of crude protein [CP] and neutral detergent fibre [NDF]) and an improved fattening feeding practice reduced ( $p < 0.05$ ) to a great extent total methane emissions (kg/animal/life) and emission intensities (CH<sub>4</sub> kg/kg CW; CH<sub>4</sub> kg/kg edible protein). While methane efficiency indexes (kg CO<sub>2</sub>eq/kg LW at slaughter; kg CO<sub>2</sub>eq/kg CW; kg CO<sub>2</sub>eq/kg edible protein) were also improved ( $p < 0.05$ ).

This implies that any diet modification introduced to improve beef productivity in terms of improved forage and forage-to-concentrate ratio may have a positive effect of reducing methanogenesis. The main reason for this is that in cattle fed pasture dietary components (i.e. kg of CP+lipid+NDF) explain up to 51% of the daily methane (g) emissions [26], whilst the addition of grains to forage diets shifts rumen acetate to propionate formation reducing enteric emissions [27]. However, to the best of our knowledge, such complex *in vivo* interactions have not been examined in the humid tropics of Asia, but they warrant further investigation.

Similarly, future efforts and research should work towards an economic-environmental trade-off approach to capture patterns of future resource-savings, emissions, productivity gains, economic returns, food supply benefits and therefore, assess the changes between conventional practices and alternative sustainable intensification. Our results, in particular suggests that a gross margin analysis (GMA) over the fattening period may provide a basic assessment of trade-offs among breed resources, productivity growth and incomes at the local-level smallholder farming systems in current market circumstances. However, as most of the households units are family operated and members of them are the most important source of information, the GMA only

should examine three producers' measurements of financial performance. The main is the household (i.e. breed) gross income, followed by the overall gross margin and the single unit of output (i.e. head/month). Additional measure is the output: input ratio. Factors outside the control of farmers such as operating expenditure or fixed costs (i.e. acquisition value of animals sold) for each household unit should not be considered in the analysis in order to only demonstrate performance differences between cattle breeds.

## IMPLICATIONS

Given that it is not possible to control the climate pressure, but it is possible to increase our ability to pursue potential options to alleviate the stress and prevent dangerous climate change. This study has demonstrated how the combined use of cattle genetic resources and available crop-mixed feed components in HFS can achieve improved and sustainable productivity in the DakLak Province. This work also reinforces the value of the growing international network collaboration to help planners address malnutrition, minimize the vulnerability of rural livelihoods and maximize the sustainable trade-offs of the agricultural expansion and intensification in Vietnam.

## CONFLICT OF INTEREST

We certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

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## REFERENCES

- Hallegatte S, Mook B, Bonzanigo L, et al. Shock Waves: managing the impacts of climate change on poverty. Washington, DC: World Bank; 2016.
- FAO. Tackling climate change through livestock: a global assessment of emissions and mitigation opportunities. Rome, Italy: Food and Agriculture Organization of the United Nations; 2013.
- Havlik P, Valin H, Gusti M, et al. Climate change impacts and mitigation in the developing world: an integrated assessment of agriculture and forestry sectors. Policy Research Working Paper 7477 prepared for Shock Waves: managing the impacts of climate change on poverty. Climate Change and Development Series. Washington, DC: World Bank; 2015.
- Herrero M, Thornton PK. Livestock and global change: emerging issues for sustainable food systems. *Proc Natl Acad Soc* 2013;110:20878-81.
- Herrero M, Thornton PK, Notenbaert A, et al. Drivers of change in crop-livestock systems and their potential impacts on agro-ecosystems services and human wellbeing to 2030. Nairobi, Kenya: ILRI; 2012.
- Herrero M, Havlik P, Valin H, et al. Biomass use, production, feed efficiencies, and greenhouse gas emissions from global livestock systems *Proc Natl Acad Soc* 2013;110:20888-93.
- Ramírez-Restrepo CA, Charmley E. An integrated mitigation potential framework to assist sustainable extensive beef production in the tropics. In: Ghosh PK, Mahanta SK, Singh JB, Pathak PS, editors. *Grassland: a global resource perspective*. Jhansi, India: Range Management Society of India; 2015. p. 417-36.
- Ministry of Agriculture and Rural Development [Internet]. Agricultural census data 2015 [cited 2015 May 3rd]. Available from: <http://www.mard.gov.vn/en/Pages/default.aspx>
- DakLak Provincial Department of Agriculture and Rural Development. Narrative report in 2010 and development orientations in 2011. Buon Ma Thout, Vietnam; 2010.
- MDG-F. Integrated nutrition and food security strategies for children and vulnerable groups in Vietnam. Final Millennium Development Goals Achievement Fund joint programme narrative report. New York: The Millennium Development Goals Achievement Fund (MDG-F); 2013.
- Ministry of Agriculture and Rural Development. Decision 3119/QĐ-BNN-KHCN on approving the program on GHG emissions reduction in Agriculture and Rural Development sector up to 2020. Hanoi, Vietnam; 2011.
- Van Tien D. Growth performance, meat production of Lai Sind cattle and crossbred 1/2 Drought Master, 1/2 Red Angus, 1/2 Limousin kept in Ea Kar district. DakLak Province, Vietnam [Ph.D.]: Institute of Animal Science; 2011.
- Kebreab E, Johnson KA, Archibeque SL, Pape D, Wirth T. Model for estimating enteric methane emissions from United States dairy and feed lot cattle. *J Anim Sci* 2008;86:2738-48.
- Le Dinh P, Ramírez-Restrepo CA, Le Duc N, et al. Productivity and mitigation effects of alternative feeding practices in smallholder dairy farms in the north of Vietnam. In: *Proceedings of the 3rd Global Science Conference on Climate-Smart Agriculture Towards Climate-smart solutions*; 2015; Montpellier, France. p. 176.
- Le Duc N, Dinh Van D, Le Dinh P, et al. Study on enteric methane emission from smallholder semi-intensive beef cattle production system in the Red River Delta. A case study in Dong Anh District, Hanoi. *Sci Technol J Agric Rural Dev* 2015;7:70-9.
- Kittmann S, Jansen PH. Characterization of rumen ciliate community composition in domestic sheep, deer, and cattle, feeding on varying diets, by means of PCR-DGGE and clone libraries FEMS Microbiol Ecol 2011;75:468-81.
- Ramírez-Restrepo CA, O'Neill CJ, López-Villalobos N, et al. Effects of tea seed saponin supplementation on physiological changes associated with blood methane concentration in tropical Brahman

- cattle. *Anim Prod Sci* 2016;56:457-65.
18. Le Dinh P, Le Duc N, Dinh Van D, et al. Study on enteric methane emission from smallholder dairy farm in the north of Vietnam: A case study in smallholder dairy farm in Bavi, Hanoi. *Sci Technol J Agric Rural Dev* 2015;9:64-72.
  19. Herrero M, Thornton P, Kuska R, Reid RS. Systems dynamics and the spatial contribution of methane emissions from Africa domestic ruminants to 2030. *Agric Ecosyst Environ* 2008;126:122-37.
  20. Shikuku KM, Valdivia RO, Paul BK, et al. Prioritizing climate-smart livestock technologies in rural Tanzania: A minimum data approach. *Agric Syst* 2016;151:204-16.
  21. Williams PG. Nutritional composition of read meat. *Nutr Diet* 2007; 64(Suppl 4):S113-S9.
  22. Ramírez-Restrepo CA, O'Neill CJ, López-Villalobos N, Padmanabha J, McSweeney C. Tropical cattle methane emissions: the role of natural statins supplementation. *Anim Prod Sci* 2014;54:1294-9.
  23. Herrero M, Wirsenius S, Henderson B, et al. Livestock and the environment: What have we learned in the past decade *Ann Rev Environ Resour* 2015;40:177-202.
  24. Waritthitham A, Lambertz C, Langholz JH, Wicke M, Gauly M. Assessment of beef production from Brahman×Thai native and Charolais×Thai native crossbred bulls slaughtered at different weights. I: Growth performance and carcass quality. *Meat Sci* 2010;85:191-5.
  25. Waritthitham A, Lambertz C, Langholz J-H, Wicke M, Gauly M. Assessment of beef production from Brahman×Thai native and Charolais×Thai native crossbred bulls slaughtered at different weights. II: Meat quality. *Meat Sci* 2010;85:196-200.
  26. Hammond KJ, Muetzel S, Waghorn GC, et al. The variation in methane emissions from sheep and cattle is not explained by the chemical composition of ryegrass. *Proc NZ Soc Anim Prod* 2009;69:174-8.
  27. McAllister TA, Newbold CJ. Redirecting rumen fermentation to reduce methanogenesis. *Aust J Exp Agric* 2008;48:7-13.