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Overcoming Major Environmental and Production Challenges in Cattle Owned by Smallholder Farmers in the Tropics

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Abstract

The world's population is expected to increase significantly by 2050, leading to significantly increased demands for meat and dairy products. However, cattle are major emitters of greenhouse gases that speed up climate change. To achieve food security by 2050, livestock enterprises need to double their outputs from constant resources, in the face of increased competition for inputs such as land, water, grain and labour. To cope with climate change, the livestock need to be productive under hotter and drier climates and be able to tolerate increased challenges from parasites and vector-borne diseases. The best way for smallholder cattle farmers in tropical low-medium income countries to overcome these multiple challenges is to focus on improving the productivity of their herds. This paper discusses a range of simple and cost-effective options already available to smallholder farmers to significantly improve the productivity and profitability of their herds and by doing so, they will indirectly reduce greenhouse gas emissions from their cattle and improve the natural resource base on which their cattle graze. Improved herd productivity will in turn deliver significant social, environmental, economic and livelihood benefits to the smallholder farmers themselves and the communities and value chains in which they operate.

Keywords: beef and dairy cattle; improved productivity; methane emissions; tropical environments

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INTRODUCTION

The world's population is expected to increase from 7 billion people in 2011 to 9 or 10 billion by 2050, with most of that growth occurring in Africa and Asia (Gerland et al., 2014). The increasing population is leading to an increased demand for meat and dairy products (Delgado et al., 2001). Livestock industries contribute 40% of the world's agricultural output and the livestock sector employs around 1.1 billion people globally (Hurst et al., 2015). However, the livestock sector is also the largest source of anthropogenic methane emissions and this is expected to increase in future to meet the increased demand for livestock products (Chang et al., 2021). To achieve food security by 2050, livestock enterprises need to double their outputs from constant resources (Mullen and Keogh, 2013), but due to pressures on agriculture in developed countries, much of that increased production must occur in Africa and Asia, where tropical production climates impose even greater challenges.

Climate change is adding to this challenge (Hughes, 2003), requiring livestock that are productive under hotter and drier climates and, in the tropics, requiring cattle that can tolerate significant increases and broader areas of infestation of ecto- and endo-parasitic burdens

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and vector-borne diseases. Achieving cattle that are well adapted to their production environments also contributes to more sustainable agricultural systems through reduced use of chemicals to control parasites.

There is therefore an urgent need to greatly increase the productivity of cattle herds but using less resources, whilst the cattle simultaneously tolerate more extreme climates and disease stressors and reduce their methane emissions. As suggested by Pulina et al. (2017), solutions to these major challenges need to consider the following factors: a) the effects of consumption of livestock projects on human health; b) the importance of sustainable intensification of ruminant production systems such as better feed conversion and increased production output per unit of input; c) the environmental impacts of ruminant production; d) the improvement of animal performance through improved animal welfare; e) the adaptation of ruminants to climate change; f) sustainable nutrition for ruminants; g) the challenges posed by ruminant production intensification and conservation of animal biodiversity; and h) strategies to increase ruminant production and achieve human food security in developing countries.

This paper examines cost-effective options currently available to smallholder cattle farmers in low-middle income countries (LMICs) to improve both the productivity and profitability of their herds, whilst simultaneously reducing methane emissions to sustainably develop the cattle industries in tropical climates impacted by climate change.

As suggested by Burrow (2019), the best way for smallholder farmers to simultaneously improve the sustainability, productivity and profitability of their cattle farming enterprises is to focus on the key drivers of business profitability. Smallholder farmers in LMICs are encouraged to use a simple profit-focusing tool (Figure 1) to identify the income and costs associated with their cattle herds and other aspects of their farming businesses (Burrow, 2019). The aim of this type of tool is to identify ways of either increasing the price received or the volume sold or by reducing the costs of undertaking the business. The volume or throughput of product can be increased by increasing animal growth rates, milk production or breeder herd reproductive performance or by reducing cattle deaths. Those aspects are strongly influenced by genetics, animal nutrition, animal health and herd and rangeland management. Price received per kg of product and costs are influenced by marketing. Improving the productivity of cattle from smallholder herds will also indirectly improve the natural resource base on which those cattle are grazed. These options are examined briefly in the following sections of this paper.

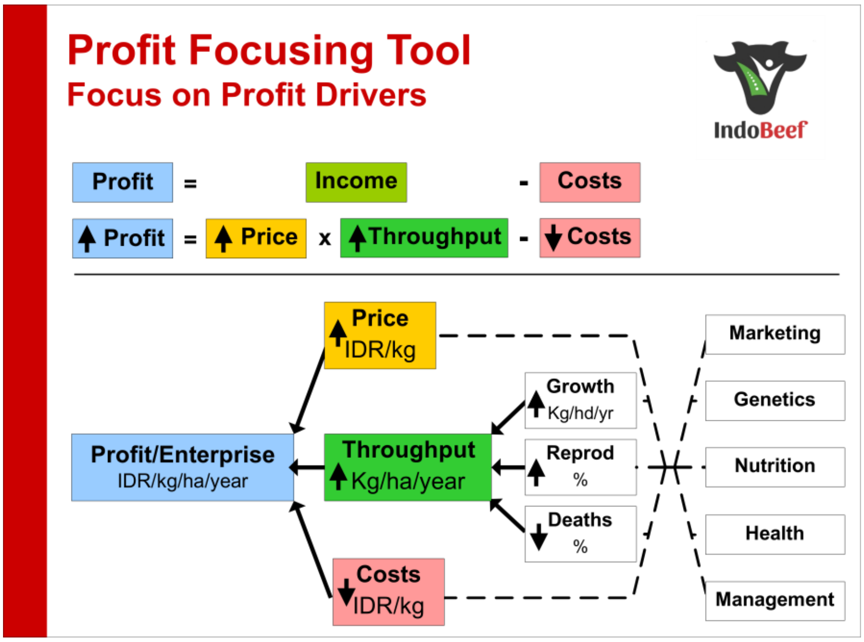

Figure 1. Profit focusing tool used to focus cattle farming decision-making on aspects of the business that generate profit as well as improving productivity (Burrow, 2019)

MATERIALS AND METHOD

This paper was prepared as the basis of a presentation to the first International Conference on Livestock in Tropical Environment in 2021. It is based on the author's extensive experience in undertaking research to investigate factors that impact on the ability of ruminant livestock to tolerate or resist the very wide range of environmental stressors encountered by those livestock in tropical and sub-tropical environments. The paper is enhanced by reference to scientific publications derived as a result of a review of the literature, particularly as it relates to impacts of those livestock on the environment and natural resource base and the opportunities that are now available to mitigate those impacts to reduce the impacts of climate change.

RESULTS AND DISCUSSION

The need for adapted cattle breeds

Maximizing beef and dairy productivity and profitability requires cattle are matched to their production environments. Indigenous livestock that evolved in stressful tropical environments have a range of unique adaptive traits enabling them to survive and be productive in those environments (Devendra, 1987). A detailed summary of a wide range of environmental stressors experienced by cattle grazed at pasture in tropical environments, the impacts of those stressors and the methods used to measure an animal's resistance to them is provided by Burrow (2015). In this paper, only cattle grazed at pasture in low-input production systems are considered.

In tropical environments, the differences that exist between cattle breeds in temperate environments for traits such as growth, milking ability, reproduction and product quality are masked by the effects of the environmental stressors (Burrow et al., 2001; Burrow, 2006). Hence in the tropics, breeds are best categorized into breed types to compare their performance across environments. Those broad breed groupings (Hodges and Payne, 1997) include:

1. *Bos taurus* (British and Continental e.g. Angus, Simmental, Holstein-Friesian, Jersey), which have good growth and reproductive rates and high quality products when reared in the absence of environmental stressors but which are poorly adapted to tropical environments;
2. *Bos indicus* breeds (e.g. Brahman, Nellore, Ongole, Sahiwal, Sindhi) are the best adapted to tropical environments, but this is at the expense of productive traits;
3. Tropically adapted taurine breeds (e.g. southern African Sanga, West African humpless and the Criollo breeds of Latin America and the Caribbean) retain the productive attributes of *B. taurus* and are also relatively well adapted to tropical environments though less than that of pure *B. indicus*;
4. Synthetic tropical breeds based on *B. indicus* and/or tropically adapted taurine breeds that have been inter-bred for several generations. They perform similarly to tropically adapted taurine; and
5. Of direct relevance to Indonesia, *Bos javanicus* (Bali and Banteng) evolved independently of these other breed types (Copland, 1996). They have a different number of chromosomes than *B. taurus* and *B. indicus*. They can be crossed with *B. taurus* and *B. indicus*, though male offspring may be infertile (Jellinek et al., 1980). There are no known direct breed comparisons between *B. javanicus* and other breeds but their performance can be inferred from Copland (1996) to be similar to the tropically adapted taurine breeds.
6. Farmers aiming to maximize the productivity of cattle grazed at pastures in tropical environments should use breeds that are well adapted to their production environment. For most tropical environments, optimal levels of productivity, adaptation and cattle welfare will be achieved using a combination of multiple breed types (Prayaga et al., 2003) i.e. *B. indicus*, tropically adapted taurine, British and/or Continental. In Indonesia, this could include Bali cattle and their crosses, particularly if crossbreeding amongst crosses proves feasible (i.e. that the crosses are fertile).

Improving animal nutrition and health

As shown in Figure 1 and described by Burrow (2019), improving animal nutrition and health is one of the best ways to increase farm business throughput (i.e. number of cattle, weight of carcasses or volume of milk sold) as good animal nutrition and health increases cattle growth, milk production and reproduction rates and also reduces cattle deaths. The simplest option to achieve all of these goals is to ensure animals have adequate (quantity and quality) nutrition. Metabolizable energy requirements for cattle across different life stages are readily available for animals grazed at pasture in tropical and subtropical areas i.e. FutureBeef (2019) and Nutrition EDGE (2019). Those online resources are based on *B. taurus* and *B. indicus* breeds and crossbreeds, but information is also available specifically for Bali cattle (Quigley et al., 2014).

In smallholder farming systems in Indonesia, cattle are fed with crop residues and by-products such as rice straw and maize stover. Additionally, there is strong evidence of the value of feeding cattle with forage tree legumes, in both intensive and extensive production systems (Dahlanuddin, Ningsih, et al., 2014; Dahlanuddin, Yanuarianto, et al., 2014; Dahlanuddin, Yuliana, et al., 2014).

It is important for smallholder farmers to routinely monitor animal liveweight and/or body condition score, as well as the condition of the grazing lands, to ensure stocking rates are appropriate for maintaining good animal performance. Use of vaccinations for endemic diseases where vaccines are available is also a cost-effective way of maintaining general herd health.

Improving reproductive performance

As detailed in Burrow (2019) cattle performance, and particularly cow reproductive performance, can be improved using both management (improvement of the current herd) and genetic approaches (improving the future herd using sires and/or breeding females that are known to be genetically superior for economically important traits). Best practice management of the breeding herd is the simplest way to improve most economically important traits and hence, to improve calf weaning rates. Cattle businesses should aim to achieve weaning rates (number of calves weaned within 1 calendar year, relative to the number of cows joined with a bull over the previous joining period) of at least 70%. Achieving weaning rates of at least 70% provides farmers with the opportunity to sell non-productive older cows and replace them with heifers born into the herd. If bulls/semen used for breeding have above average genetic breeding values, then their calves will contribute to overall genetic improvement of the future herd. There are a number of key management practices that can be cost-effectively implemented to improve calf weaning rates in Indonesia. These are described in Burrow (2019) and include: testing and eliminating reproductive diseases from the herd; introducing new bulls where possible to avoid inbred calves; breeding the cows at the start of the wet season each year to ensure calves are born (and cows are lactating) towards the beginning of the following wet season to achieve peak nutrition for both cows and calves; weaning all calves at times that best suit seasonal conditions (including early weaning and supplementary feeding of the calves to reduce lactation stress on cows during dry seasons where required); pregnancy testing cows and where possible, culling non-pregnant cows to conserve pasture for pregnant cows; selling all cows that have failed to rear a calf two years in succession because they should be regarded as infertile; and maintaining good records of the weights, body condition scores and calving dates of all breeding cattle to enable effective decision making.

Opportunities for genetic improvement

Genetic improvement is a very important method already used by the cattle industries in developed countries to achieve productivity gains and directly address the challenges that need to be overcome to ensure global food security by 2050. However, traditional genetic improvement programs based on measuring large numbers of pedigreed animals in well-defined cohort groups for the full range of economically important productive and adaptive traits are generally impossible for smallholder farmers in LMICs. Over recent years though, new genomic (DNA-based) technologies, together with new information and communication technologies, is providing significant new opportunities to achieve genetic improvement of cattle herds in LMICs. These opportunities are described in more detail in Burrow (2021), Burrow et al. (2021) and Mrode et al. (2021). Similar approaches can also be used to develop new plant varieties that tolerate environmental stressors to improve crop and pasture quantity and quality in tropical environments, thereby improving animal nutrition.

In addition, the use of genomic information is providing new opportunities to optimize management of individual animals or groups of cattle to best meet market specifications and to create value-based marketing systems that reward all sectors of the value chain.

The opportunities described in greater detail in Burrow (2021) include improved crossbreeding systems designed on accurate information about the breed composition of animals used in breeding programs, accurate characterization of indigenous cattle breeds and also genomic selection, which provides new opportunities to combine animal measurements (phenotypes) with genomic data not only within and across herds, but also across breeds, regions and countries as demonstrated by Cardoso et al. (2021).

In Indonesia and most other LMICs, the opportunities to achieve genetic improvement by smallholder farmers has in the past been too difficult primarily because of the difficulty and cost of effective recording of phenotypes, the complex funding arrangements often needed to achieve effective phenotype recording, the lack of on-farm, laboratory and computing infrastructure and lack of human capacity. All of these challenges are examined in detail by Burrow et al. (2021), who identify new opportunities that could be captured by smallholder farmers in Indonesia through the use of national and international partnerships to establish animal resource populations, provide data analytical platforms, possibly overcome the lack of laboratory infrastructure and also strengthen the power of the datasets by pooling data across countries. The use of portable devices that do not require on-site internet connection (e.g. mobile phones, tablets) is now overcoming problems associated with data capture and storage. And in future, there is very strong potential that genomic data will be able to replace an animal's phenotype, not only by identifying causal mutations and regions of the genome impacting on particular traits, but also through the use of new '-omics' technologies such as functional genomics, gene expression, transcriptomics, proteomics and metabolomics that have the potential to deliver simpler and more cost-effective diagnostic tests. A potential operational framework to enable smallholder farmers to cost-effectively capture the benefits of genomic selection is provided by those authors, with evidence of the feasibility of the approach now becoming available amongst smallholder dairy and small ruminant farmers in Africa and Asia (see examples presented by Mueller et al. (2015); Bhuiyan et al. (2017); Karnauh et al. (2018); Haile et al. (2019); Marshall et al. (2019); Mrode et al. (2019); Ojango et al. (2019); Haile et al. (2020); Al Kalaldeh et al. (2021)).

Reducing methane emissions from cattle by improving production efficiency

As indicated by Chang et al. (2021), the livestock sector is the largest source of anthropogenic methane emissions, with many recommendations now being made globally that livestock products be significantly reduced or eliminated from human diets to overcome issues around greenhouse gas emissions and climate change. However, those recommendations ignore the very significant benefits of livestock, which contribute to food supply by converting low-value feeds that are inedible or unpalatable for people into milk, meat and eggs to directly contribute to nutrition security through high quality protein and micronutrients essential for normal human development and good health (Smith et al., 2013; UN Nutrition, 2021). Particularly in LMICs, livestock have a unique potential to enhance food and nutrition security and provide income to pay for education, health and other important household needs (Capper et al., 2009; UN Nutrition, 2021). As indicated by Smith et al. (2013), "the challenge is how to manage complex trade-offs to enable livestock's positive impacts to be realized while minimizing and mitigating negative ones". This section explores opportunities to minimize and mitigate the impacts of greenhouse gas emissions and particularly methane emissions by cattle.

As a consequence of their ruminant digestive systems, cattle convert poor quality pastures and feeds with few other uses into high quality protein for human consumption. However, methane and nitrous oxide are end-products of ruminant digestive systems and their emissions speed up climate change. Methane is of particular concern because it has a longer half-life than other greenhouse gases and thus takes longer to dissipate. Methane emissions from cattle also represent a 10% to 15% loss of production efficiency, so reducing methane emissions is warranted for both environmental and productivity reasons.

The most practical existing abatement strategy, particularly for LMICs, is to maximize the productivity of cattle herds by improving calving and growth rates, milk production, animal health and feed efficiency using management and genetic options to reduce methane emissions per unit of livestock product. A study of the US dairy industry showed that by 2007, US dairy farmers required 21% fewer cows, 23% less feed, 65% less water and 90% less land to produce 1 billion kg of milk with large reductions in manure (76%), methane (57%) and nitrous oxide (44%) wastes cf. 1944 through improved productivity of US dairy herds (Capper et al., 2009).

Evidence that improving productivity of cattle herds in LMICs will also significantly reduce greenhouse gas emissions in tropical environments in LMICs is shown in Figure 2 (Gerber et al., 2013; Herrero et al., 2013) and Figure 3 (Howden and Reyenga, 1999) for dairy and beef cattle respectively. In addition to reducing greenhouse gas emissions through improved production efficiency in cattle herds, other technologies such as supplementary feeds that reduce methane outputs and genetic improvement of methane emissions are now being implemented. These will offer new opportunities to LMICs in future, but for now, it is clear the best way to reduce methane emissions in cattle in LMICs is to focus on improved productivity of those herds.

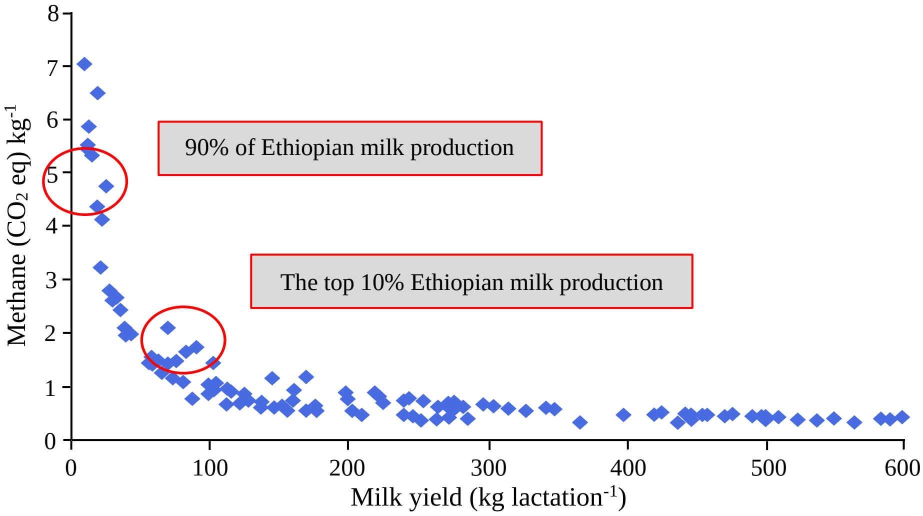

Figure 2. Relationship between methane emissions and milk yield in dairy cattle and highlighting the significant potential for reducing methane emissions by improving productivity in Ethiopian dairy herds (Gerber et al., 2013; Herrero et al., 2013)

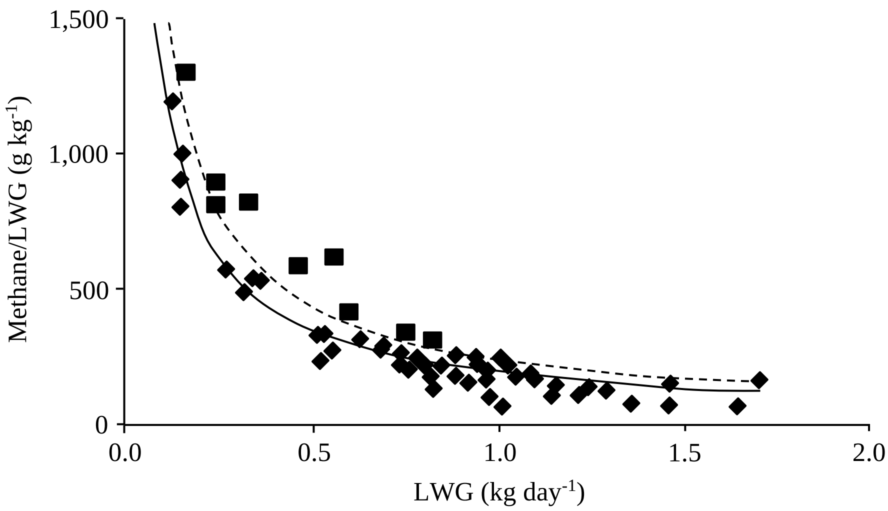

Figure 3. Change in efficiency of liveweight gain (LWG) in beef cattle in terms of methane emissions with increasing rate of LWG for *Bos indicus* eating a tropical forage diet (square) and *B. taurus* and *B. indicus* on a high grain diet (triangle) (Howden and Reyenga, 1999)

Average annual liveweight gains for beef cattle in smallholder herds in LMICS are generally around 0.2 to 0.3 kg head per day, indicating significant potential to reduce methane emissions by improving liveweight gain. Greater reductions in methane emissions would accrue in these herds if all traits contributing to herd productivity were included in the modelling as suggested by Capper et al. (2009) in the US.

CONCLUSIONS

Encouraging smallholder farmers to improve productivity of their herds will deliver cattle that are more resilient to increased environmental stressors, produce higher volumes and better-quality beef and milk and with reduced greenhouse gas emissions per kilogram of product. The cattle grazing land will also be improved as an indirect consequence of improved productivity. Additionally, the farmers' profitability will improve, thereby benefiting the communities and value chains where they operate. Ultimately, the changes will deliver significant social, environmental, economic and livelihood benefits, enhance job creation, skills and economic opportunities, enhance and protect the integrity and resilience of biodiversity and ecosystems, and enhance social inclusion, equity and resilience of social systems and governance.

REFERENCES

Al Kalaldeh, M., Swaminathan, M., Gaudare, Y., Joshi, S., Aliloo, H., Strucken, E. M., Ducrocq, V., & Gibson, J. P. (2021). Genomic evaluation of milk yield in a smallholder crossbred dairy production system in India. *Genetics, Selection, Evolution*, *53*, 73. https://doi.org/10.1186/s12711-021-00667-6

Bhuiyan, M. S. A., Bhuiyan, A. K. F. H., Lee, J. H., & Lee, S. H. (2017). Community based livestock breeding programs in Bangladesh: Present status and challenges. *Journal of Animal Breeding and Genomics*, *1*(2), 77–84. https://doi.org/10.12972/jabng.20170009

Burrow, H. (2019). Strategies for increasing beef cattle production under dryland farming systems. *WARTAZOA: Indonesian Bulletin of Animal and Veterinary Sciences*, *29*(4), 161–170. https://doi.org/10.14334/wartazoa.v29i4.2452

Burrow, H. M. (2006). Utilization of diverse breed resources for tropical beef production. *Proceedings of the 8th World Congress on Genetics Applied to Livestock Production, Belo Horizonte, Brasil*. Retrieved from https://scholar.google.co.id/scholar?cluster=17900599203617553000&hl=id&as_sdt=2005&sciodt=0,5

Burrow, H. M. (2015). Genetic aspects of cattle adaptation in the tropics. In D. J. Garrick & A. Ruvinsky (Eds.), *The Genetics of cattle*. CAB International. Retrieved from https://rune.une.edu.au/web/handle/1959.11/17403

Burrow, H. M. (2021). Opportunities and challenges to increasing productivity in cattle farmed by smallholders in Asia and Africa. *Proceeding of International Seminar on Livestock Production and Veterinary Technology¸ 2021*, 3–20. https://dx.doi.org/10.14334/Proc.Intsem.LPVT-2021-p.1

Burrow, H. M., Moore, S. S., Johnston, D. J., Barendse, W., & Bindon, B. M. (2001). Quantitative and molecular genetic influences on properties of beef: A review. *Australian Journal of Experimental Agriculture*, *41*(7), 893–919. https://doi.org/10.1071/EA00015

Burrow, H. M., Mrode, R., Mwai, A. O., Coffey, M. P., & Hayes, B. J. (2021). Challenges and opportunities in applying genomic selection to ruminants owned by smallholder farmers. *Agriculture*, *11*(11), 1172. https://doi.org/10.3390/agriculture11111172

Capper, J. L., Cady, R. A., & Bauman, D. E. (2009). The environmental impact of dairy production: 1944 compared with 2007. *Journal of Animal Science*, *87*(6), 2160–2167. https://doi.org/10.2527/jas.2009-1781

Cardoso, F. F., Matika, O., Djikeng, A., Mapholi, N., Burrow, H. M., Yokoo, M. J. I., Campos, G. S., Gulias-Gomes, C. C., Riggio, V., Pong-Wong, R., Engle, B., Porto-Neto, L., Maiwashe, A., & Hayes, B. J. (2021). Multiple country and breed genomic prediction of tick resistance in beef cattle. *Frontiers in Immunology*, *12*, 2189. https://doi.org/10.3389/fimmu.2021.620847

Chang, J., Peng, S., Yin, Y., Ciais, P., Havlik, P., & Herrero, M. (2021). The key role of production efficiency changes in livestock methane emission mitigation. *AGU Advances*, *2*(2), e2021AV000391. https://doi.org/10.1029/2021av000391

Copland, J. (1996). Bali cattle: Origins in Indonesia. In G. E. Wilcox, S. S, D. M. N. Dharma, & J. W. Copland (Eds.), *Proceedings Jembrana disease and the Bovine Lentiviruses, Proceedings of a workshop* pp. 29–33. Retrieved from https://www.aciar.gov.au/publication/technical-publications/jembrana-disease-and-bovine-lentiviruses

Dahlanuddin, Ningsih, B. S., Poppi, D. P., Anderson, S. T., & Quigley, S. P. (2014). Long-term growth of male and female Bali cattle fed *Sesbania grandiflora*. *Animal Production Science*, *54*(10), 1615–1619. https://doi.org/10.1071/AN14357

Dahlanuddin, Yanuarianto, O., Poppi, D. P., McLennan, S. R., & Quigley, S. P. (2014). Liveweight gain and feed intake of weaned Bali cattle fed grass and tree legumes in West Nusa Tenggara, Indonesia. *Animal Production Science*, *54*(7), 915–921. https://doi.org/10.1071/AN13276

Dahlanuddin, Yuliana, B. T., Panjaitan, T., Halliday, M. J., Van De Fliert, E., & Shelton, H. M. (2014). Survey of Bali bull fattening practices in Central Lombok, Eastern Indonesia, based on feeding of *Sesbania grandiflora*. *Animal Production Science*, *54*(9), 1273–1277. https://doi.org/10.1071/AN14325

Delgado, C., Rosegrant, M., Steinfeld, H., Ehui, S., & Courbois, C. (2001). Livestock to 2020: The next food revolution. *Outlook on Agriculture*, *30*(1), 27–29. https://doi.org/10.5367/000000001101293427

Devendra, C. (1987). Goats. In H. D. Johnson (Ed.), *World animal science B5. Disciplinary approach, bioclimatology and adaptation of livestock* pp. 157–168. Elsevier. Retrieved from https://scholar.google.co.id/scholar?cluster=8488194368331368768&hl=id&as_sdt=2005&sciodt=0,5

FutureBeef. (2019). *Nutrient requirements of beef cattle*. Retrieved from https://futurebeef.com.au/knowledge-centre/nutrient-requirements/

Gerber, P. J., Steinfeld, H., Henderson, B., Mottet, A., Opio, C., Dijkman, J., Falcucci, A., & Tempio, G. (2013). *Tackling climate change through livestock: A global assessment of emissions and mitigation opportunities.* Rome: Food and Agriculture Organization of the United Nations (FAO). Retrieved from https://www.fao.org/3/i3437e/i3437e.pdf

Gerland, P., Raftery, A. E., Ševčíková, H., Li, N., Gu, D., Spoorenberg, T., Alkema, L., Fosdick, B. K., Chunn, J., Lalic, N., Bay, G., Buettner, T., Heilig, G. K., & Wilmoth, J. (2014). World population stabilization unlikely this century. *Science*, *346*(6206), 234–237. https://doi.org/10.1126/science.1257469

Haile, A., Gizaw, S., Getachew, T., Mueller, J. P., Amer, P., Rekik, M., & Rischkowsky, B. (2019). Community-based breeding programmes are a viable solution for Ethiopian small ruminant genetic improvement but require public and private investments. *Journal of Animal Breeding and Genetics*, *136*(5), 319–328. https://doi.org/10.1111/jbg.12401

Haile, A., Getachew, T., Mirkena, T., Duguma, G., Gizaw, S., Wurzinger, M., Sölkner, J., Mwai, O., Dessie, T., Abebe, A., Abate, Z., Jembere, T., Rekik, M., Lobo, R. N. B., Mwacharo, J. M., Terfa, Z. G., Kassie, G. T., Mueller, J. P., & Rischkowsky, B. (2020). Community-based sheep breeding programs generated substantial genetic gains and socioeconomic benefits. *Animal*, *14*(7), 1362–1370. https://doi.org/10.1017/S1751731120000269

Herrero, M., Havlík, P., Valin, H., Notenbaert, A., Rufino, M. C., Thornton, P. K., Blümmel, M., Weiss, F., Grace, D., & Obersteiner, M. (2013). Biomass use, production, feed efficiencies, and greenhouse gas emissions from global livestock systems. *Proceedings of the National Academy of Sciences of the United States of America*, *110*(52), 20888–20893. https://doi.org/10.1073/pnas.1308149110

Hodges, J., & Payne, W. J. A. (1997). *Tropical cattle: Origin, breeding and breeding policies*. Blackwell Science. Retrieved from https://scholar.google.co.id/scholar?cluster=4721960224218261537&hl=id&as_sdt=2005&sciodt=0,5

Howden, S. M., & Reyenga, P. J. (1999). Methane emissions from Australian livestock: implications of the Kyoto Protocol. *Australian Journal of Agricultural Research*, *50*(8), 1285–1292. https://doi.org/10.1071/AR99002

Hughes, L. (2003). Climate change and Australia: Trends, projections and impacts. *Austral Ecology*, *28*(4), 423–443. https://doi.org/10.1046/j.1442-9993.2003.01300.x

Hurst, P., Termine, P., & Karl, M. (2015). *Agricultural workers and their contribution to sustainable agriculture*. FAO-ILO-IUF Report, FAO. Retrieved from https://scholar.google.co.id/scholar?cluster=2040448697390871804&hl=id&as_sdt=2005&sciodt=0,5

Jellinek, P., Avenell, K., Thahar, A., & Sitorus, P. (1980). Infertility associated with cross breeding of Bali cattle. In *Laporan Seminar Ruminansia II*. Bogor (Indonesia): Balai Penelitian Ternak. Retrieved from https://scholar.google.co.id/scholar?cluster=7791755549263853626&hl=id&as_sdt=2005&sciodt=0,5

Karnauh, A. B., Dunga, G., & Rewe, T. (2018). Community based breeding program for improve goat production in Liberia. *MOJ Current Research and Reviews*, *1*(5), 216–221. https://doi.org/10.15406/mojcrr.2018.01.00036

Marshall, K., Gibson, J. P., Mwai, O., Mwacharo, J. M., Hailem, A., Getachew, T., Mrode, R., & Kemp, S. J. (2019). Livestock genomics for developing countries – African examples in practice. *Frontiers in Genetics*, *10*, 297. https://doi.org/10.3389/fgene.2019.00297

Mrode, R., Ojango, J. M. K., Okeyo, A. M., & Mwacharo, J. M. (2019). Genomic selection and use of molecular tools in breeding programs for indigenous and crossbred cattle in developing countries: Current status and future prospects. *Frontiers in Genetics*, *9*, 694. https://doi.org/10.3389/fgene.2018.00694

Mrode, R., Ojango, J., Ekine-Dzivenu, C., Aliloo, H., Gibson, J., & Okeyo, M. A. (2021). Genomic prediction of crossbred dairy cattle in Tanzania: a route to productivity gains in smallholder dairy systems. *Journal of Dairy Science*, *104*(11), 11779-11789. https://doi.org/10.3168/jds.2020-20052

Mueller, J. P., Rischkowsky, B., Haile, A., Philipsson, J., Mwai, O., Besbes, B., Valle Zárate, A., Tibbo, M., Mirkena, T., Duguma, G., Sölkner, J., & Wurzinger, M. (2015). Community-based livestock breeding programmes: essentials and examples. *Journal of Animal Breeding and Genetics*, *132*(2), 155–168. https://doi.org/10.1111/jbg.12136

Mullen, J., & Keogh, M. (2013). The future productivity and competitiveness challenge for Australian agriculture. *Australian Agricultural and Resource Economics Society (AARES)*, 5–24. http://dx.doi.org/10.22004/ag.econ.152170

Nutrition EDGE. (2019). *Nutrient requirement tables for nutrition EDGE Manual*. Retrieved from https://www.mla.com.au/research-and-development/reports/2015/nutrient-requirements-tables-for-nutrition-edge-manuals/

Ojango, J. M. K., Mrode, R., Rege, J. E. O., Mujibi, D., Strucken, E. M., Gibson, J., & Mwai, A. (2019). Genetic evaluation of test-day milk yields from smallholder dairy production systems in Kenya using genomic relationships. *Journal of Dairy Science*, *102*(6), 5266–5278. https://doi.org/10.3168/jds.2018-15807

Prayaga, K. C., Henshall, J. M., & Burrow, H. M. (2003). Optimisation of breed proportions in tropically adapted beef composites based on growth and resistance traits. *Proceedings of the Association for the Advancement of Animal Breeding and Genetics*, *15*, 302–305. Retrieved from https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.1060.4612&rep=rep1&type=pdf

Pulina, G., Francesconi, A. H. D., Stefanon, B., Sevi, A., Calamari, L., Lacetera, N., Dell'Orto, V., Pilla, F., Marsan, P. A., Mele, M., Rossi, F., Bertoni, G., Crovetto, G. M., & Ronchi, B. (2017). Sustainable ruminant production to help feed the planet. *Italian Journal of Animal Science*, *16*(1), 140–171. https://doi.org/10.1080/1828051X.2016.1260500

Quigley, S. P., Dahlanuddin, Marsetyo, Pamungkas, D., Priyanti, A., Saili, T., Mclennan, S. R., & Poppi, D. P. (2014). Metabolisable energy requirements for maintenance and gain of liveweight of Bali cattle (*Bos javanicus*). *Animal Production Science*, *54*(9), 1311–1316. https://doi.org/10.1071/AN14355

Smith, J., Sones, K., Grace, D., MacMillan, S., Tarawali, S., & Herrero, M. (2013). Beyond milk, meat, and eggs: Role of livestock in food and nutrition security. *Animal Frontiers*, *3*(1), 6–13. https://doi.org/10.2527/af.2013-0002

UN Nutrition. (2021). *Livestock-derived foods and sustainable healthy diets - Discussion paper*. Retrieved from https://www.tabledebates.org/research-library/livestock-derived-foods-and-sustainable-healthy-diet