Agricultural Sciences, 2024, 15, 1497-1510
https://www.scirp.org/journal/as
ISSN Online: 2156-8561
ISSN Print: 2156-8553

Key Interventions for Sustainable Animal Agriculture in Sub-Saharan Africa: A Science-Based Approach

Michiel M. Scholtz[1,2], Motshabi C. Mokolobate-Chadyiwa[1], Cuthbert B. Banga[3,4,5]

[1]Agricultural Research Council, Animal Production, Centurion, South Africa
[2]Department of Animal Science, University of the Free State, Bloemfontein, South Africa
[3]Department of Animal Science, Botswana University of Agriculture and Natural Resources, Gaborone, Botswana
[4]Department of Animal Sciences, Tshwane University of Technology, Pretoria, South Africa
[5]Department of Agriculture and Animal Health, University of South Africa, Florida, South Africa
Email: GScholtz@arc.agric.za

How to cite this paper: Scholtz, M.M., Mokolobate-Chadyiwa, M.C. and Banga, C.B. (2024) Key Interventions for Sustainable Animal Agriculture in Sub-Saharan Africa: A Science-Based Approach. *Agricultural Sciences*, **15**, 1497-1510.
https://doi.org/10.4236/as.2024.1512083

Received: October 16, 2024
Accepted: December 21, 2024
Published: December 24, 2024

Abstract

Issues that dominate Sub-Saharan African animal agriculture are low production levels and environmental sustainability, including climate, biodiversity, and land use. There are inadequate evidence-based decisions on important issues related to sustainable animal agriculture such as greenhouse gas emissions from livestock, the water footprint, and models to estimate greenhouse gas emissions. It is therefore emphasized in this paper that decisions around strategies related to future sustainability must be evidence-based, implying that research becomes a fundamental part of ensuring the sustainability of animal agriculture, which makes collaboration between regions vitally important. Fourteen interventions that are needed for sub-Saharan Africa are mentioned and briefly discussed. These include (1) the use of indigenous/adapted genotypes, (2) the development of early warning systems and (3) alternative production systems, which can be linked to adaptation. The interventions linked to mitigation are: (4) improved cow-calf efficiency/alternative breeding objectives, (5) carbon sequestration, (6) carbon footprint within different resource environments, (7) feeding and grazing, (8) rumen manipulation (9) land use and greenhouse gas emissions and (10) management. Lastly the interventions linked to resilience are (11) resilience to variation in climate, (12) breed/genotype plasticity and (13) epigenetics. There is no simple strategy to address climate change for Sub-Saharan African animal agriculture. Furthermore, solutions for Europe and North America will be different from those for Sub-Saharan Africa. No single country, industry, or organisation within Sub-Saharan Africa can carry out such research on its own. This emphasizes the importance of focusing on Global South scientific collaborations and the establishment of virtual centres of excellence will be beneficial.

Keywords

Collaboration, Evidence-Based Decisions, Interventions, Virtual Centres

1. Introduction

Issues that dominate Sub-Saharan African animal agriculture are low production levels and environmental sustainability, including climate, biodiversity and land use. Using the 17 Sustainable Development Goals [1], the following four priority areas for animal agriculture can be identified as important, viz.: (1) food security and nutrition, (2) livelihoods and economic growth, (3) health and animal welfare and (4) climate and natural resource use. These areas are directly linked to Sustainable Development Goals (SDG) No 12 (Responsible Consumption and Production: Ensure sustainable consumption and production patterns) and 13 (Climate Action: Take urgent action to combat climate change and its impacts) of the United Nations. In addition, it can also be linked to SDG No 1 (No poverty) and 2 (Zero hunger), which are crosscutting over agriculture.

Decisions around complex issues related to climate change must be evidence-based, with relevant indicators. Therefore, science becomes a fundamental part of enhancing the resilience of human food and animal production systems. This makes research relationships and collaboration between regions important [2]. The bottom line is that information, strategies, and decisions must be based on (1) scientific evidence, (2) relevant information and (3) the results must be interpreted and applied correctly. Decisions around strategies related to future sustainability must be based on sound principles. This makes research a fundamental part of the initiative to ensure the sustainability of Sub-Saharan African animal agriculture.

This paper will present three examples of "flawed science", which tend to feature when there is (1) an information overload, (2) working with imperfect data, (3) the use of non-peer reviewed results and (4) tight timeframes to make specific recommendations rather than general statements. In most cases, more research is needed to address this issue. The three examples that will be addressed here are (1) estimates of greenhouse gas (GHG) emissions from livestock, (2) the water footprint of beef production and (3) the formula for the estimation of GHGs in ruminants. The latter is, however, somewhat controversial. Secondly, a few issues that are important for transforming and achieving the future sustainability of Sub-Saharan African animal agriculture are discussed. Lastly, a number of science-based interventions that are required to achieve this are mentioned.

2. Examples of "Flawed" Science

In the FAO book "*Livestock's long shadow*", it is claimed that livestock is responsible for 18% of the world's GHG emissions [3] and this led to the perception that livestock is a major contributor to GHG emissions and thus global warming. This value was later scaled down to 14.5% by the FAO [4]. However, numerous other estimates indicate much lower GHG emissions from livestock. For example, (1) livestock production has been reported to contribute only 3.4% of the GHG emissions in the USA [5], (2) the contribution of the total agricultural sector to GHG emissions is estimated at only 10.3% [6] and (3) the contribution of livestock and manure to the total GHG emissions was recently found to be about 5.8% [7]. Moreover, Scholtz, *et al*. [8] estimated that livestock is only responsible for 4% of the world's GHGs through methane production. They also point to the fact that if the vegetation that is high in fibre is not utilised by livestock, it will burn or rot, which will also produce GHGs, without any benefit to humans. These varying figures are very confusing and are fuelling the negative public perception towards livestock. It is important to communicate relevant and accurate values to the broader scientific community and the public.

There is also a large variation in the estimates of the water footprint of beef production. For example, Scholtz *et al*. [9] sites a study estimating that 15,500 litres of water are required to produce 1 kg of beef in Brazil. One of the assumptions made in this study was that it takes 3 years to produce 200 kg of beef. Concurrently [10], it was estimated that the water requirement for red meat production in Australia was 18 to 540 litres/kg. The reason for this difference is that a proper distinction between blue, green and grey water is not made.

If 10 mm of rain falls on one hectare, then it is 100 kilolitres. So, if 10mm of rain falls on a 3,000-hectare farm, then it is 300,000 kilolitres. If the average rainfall is 450 mm per year, then the total amount of water that falls on the farm is 135,000,000 kilolitres. If the carrying capacity is 6 hectares per large stock unit, the farm can support 500 large stock units. This means 270,000 kilolitres of water per large stock unit per year. These are the type of calculations that are made to claim that 15,500 litres of water are used to produce 1 kg of meat. The reality is, however, that ruminants only use a fraction of this water, which brings up the concepts of "green and blue" water [11]. Green water is the water absorbed by the soil and used by plants to grow. It cannot be used for anything else. On the other hand, blue water is the water in dams, rivers, underground aquafers, and ponds, and provides a source of drinking water for humans and animals as well as utilisation by households, industries, and mines. Based on studies [12] [13], the blue water footprint of beef in South Africa varies between 250 and 450 litres per kg of meat depending on the breed, production system and calving percentage.

There is growing evidence of the inadequacy of existing IPCC models in estimating GHG emissions from low input tropical systems [14]. For example, in Senegal the IPCC Tier 2 model overestimated enteric methane emissions by up to 76% in the dry season [15]. Likewise, the IPCC Tier 1 model overestimated the enteric methane emission factors in dairy systems in Western Kenya [16]. In South Africa [17], the IPCC Tier 2 model estimated that Angus x Bonsmara bulls had the highest enteric methane emission factors (EF) per unit of weight gain and the Nguni the lowest EF in the feedlot, while the opposite is expected. The reason for this discrepancy is that feed intake, and efficiency of weight gain are not considered.

3. What Is Important for Sub-Saharan African Animal Agriculture?

Decisions around complex issues related to climate change and animal production must be based on scientific excellence, with relevant indicators. Therefore, science becomes a fundamental part of enhancing the resilience of people, food and production systems. This makes research relationships and collaboration between regions important [18]. No single country, organization, or industry in Sub-Saharan Africa can undertake such research, including the requisite development and implementation, on its own. Researchers, academics, and industries from the region should combine their efforts and involve expertise from outside the region, if needed.

More emphasis should also be put on Global South scientific collaborations. Five groups exist within the Global South countries namely Asean, Asia, Africa, BRICS and Latin America [19]. The establishment of virtual centres of excellence in sustainable livestock production in Sub-Saharan Africa is essential. The objective of such an initiative will be to share research expertise and information, build capacity and conduct research and development. This will also make it possible to explore funding opportunities more successfully.

4. Interventions Needed for Sub-Saharan Africa

There is neither a simple nor uniform mitigation or adaptation strategy to address climate change for Sub-Saharan African animal agriculture. Solutions proposed for Europe and North America may be very different from those appropriate for Sub-Saharan Africa. Africa is regarded as one of the vulnerable developing regions that is already experiencing the impact of climate change, despite contributing the least to historic carbon emissions [20]-[22]. Sub-Saharan Africa therefore needs science-based interventions to address climate change. These interventions should include adaptation, mitigation, and resilience. A total of 14 different interventions have been identified that can be linked to these aspects and they are briefly discussed below.

4.1. The Use of Indigenous/Adapted Genotypes

There is a large number of different indigenous and adapted beef cattle breeds in Sub-Saharan Africa. These breeds can survive in harsh local conditions and exhibit low susceptibility to diseases and adaptation to different environmental conditions. In South Africa, the resilience that indigenous breeds such as the Afrikaner and Nguni, as well as the locally developed Bonsmara, exhibit is valuable. These indigenous breeds can be regarded as South Africa's heritage for food security. See [2] for more details.

4.2. Development of Early Warning Systems

Projections of heat stress, as well as medium-range and seasonal prediction models are important for farmers. Nutrition has an important role to play in the mitigation of heat stress. If accurate predictions for 7 to 14 days are available, licks/supplements for ruminants can be formulated to ensure a proper cation-anion balance to counteract heat stress. Nutritional strategies to maintain production in ruminants affected by environmental temperatures (heat stress) due to climate change can play an important role in addressing the effects of high temperatures [23]. Seasonal warning systems of 6 to 12 months can also be valuable since farmers can be warned to reduce animal numbers in order to manage stocking rates in periods of drought. In addition, preparations can be made to feed alternative feeds. Heat stress compromises the fertility of bulls and is a common cause of reproductive inefficiency [24]. If farmers are warned in time of seasons that may have high temperatures, they can plan to use multi-sire breeding and/or males from tropical adapted genotypes [25], to counteract possible male infertility.

4.3. Alternative Production Systems

In Sub-Saharan Africa, the type of production system to follow will primarily depend on the level of management and the environment. In the commercial farming sector, where the management skills are fair, terminal crossbreeding, with small indigenous cows, will improve the outputs. These cows are adapted to the warmer climates and will be more efficient, simply because small dams eat less than large ones. However, in less developed sectors, strait breeding or criss-cross breeding systems between indigenous or adapted breeds may be preferred. See [2] for more details. These alternative production systems will address both adaptation and mitigation.

4.4. Improved Cow-Calf Efficiency/Alternative Breeding Objectives

If the production per animal unit can be increased, the carbon footprint of ruminant production can be reduced. Such increased productivity will generate less GHG emissions per unit of product and can be regarded as a mitigation strategy. Breeding objectives that are developed to improve production efficiency in environments that are stressful, will result in the selection of animals that are adapted. The development alternative breeding objectives for both cow-calf and post weaning efficiency for beef cattle is therefore important. This should include the development of a proper cow efficiency index and alternative efficiency traits, such as residual daily gain (RDG) and residual feed intake (RFI) [26].

4.5. Carbon Sequestration

During regrowth of the vegetation utilized by ruminants, carbon dioxide is absorbed from the atmosphere as part of the annual cycle. This implies that carbon dioxide is "sucked" out of the air. Only agriculture can achieve this through soil carbon retention, soil carbon sequestration and the correct application of short rotational grazing systems [2]. The question is how this can be achieved in communal grazing areas. Regeneration through natural resource protection, restoration and proper land management is important in the Sub-Saharan African context to ensure environmentally friendly and sustainable livestock production. This process should be properly quantified through research.

4.6. Carbon Footprint within Different Resource Environments

In Sub-Saharan Africa, meat from ruminants is produced through feedlots (mostly cattle), and from grass-fed commercial and communal (small scale) production systems. There is a need to do research on and quantify the factors that influence methane emission in these different production systems. It is particularly necessary to establish whether low-input systems have high GHG emissions. There is, however, growing evidence that the existing models are inadequate to estimate GHG emissions from low input tropical systems [27] [28]. Models that are specific to low input systems should therefore be developed.

4.7. Feeding and Grazing

The formulation of rations and feeding can play a role in the release of methane emissions. Feed rations must be formulated so that animals produce more protein from less feed, which will lead to a lower carbon footprint. Research should include the use of alternative pastures (e.g. tannin-rich legumes), the use of algae and seaweed, the inclusion of feed additives and dietary fibre in the ration; as well as the use of indigenous plants to feed ruminants. The strategies mentioned here may be of value, but it is important that they are properly evaluated through research [29].

4.8. Rumen Manipulation

In general, it has been commonly accepted that diet is the main driving force shaping the gut microbial diversity. However, research is starting to indicate host genetics is also an important factor in determining the composition of gut microbiota. In ruminants it has been shown that rumen microbial diversities could be influenced by breed [30]. Based on these finding, it is becoming more evident that host genetics are influencing the rumen microbiota. However, even though much research has been done on the influence of diet on the rumen microbiome, the connection between the microbiome, production traits and genetics in beef cattle remain unclear. Certain rumen microorganisms are known to lower enteric methane emissions. Thus, a desirable rumen microbiome can be created by identifying rumen microbial markers associated with lower methane production and developing a favourable rumen environment for such microbiomes. A number of preliminary studies indicated that the cow may play a role in ensuring that favourable microbiota is transferred to the calf [31] [32].

4.9. Land Use and Greenhouse Gas Emissions

Grazing ruminants largely use grasslands, trees and shrubs that are not edible by humans. In contrast, industrial monogastric livestock (pigs, poultry) use feed produced on arable land and, therefore, can be seen as being in competition with humans for food. It is also important to note that ruminants produce methane, which has a short atmospheric lifetime of 12 years compared to the 100 - 200 years for carbon dioxide [33]. The fact that methane has an atmospheric lifetime of only 12 years, is often used as a reason to justify cutting down on ruminant production, since it will lead to a faster reduction in the concentration of GHG in the atmosphere.

4.10. Management

Better herd management will increase outputs and lead to better herd health, which will reduce the use of antibiotics. Increased production efficiency will decrease the carbon footprint per unit of product produced. Better pasture management and pasture rehabilitation (quality of pasture with better varieties of grass species and rotational grazing) will also contribute to lower methane emissions. It should also be noted that seasonal and temperature variations influence methane production in dairy cattle [34]. There are also indications that shade can reduce methane production during hot periods. The Agricultural Council of South Africa has initiated a project to look at the effect of heat stress on milk production, methane emissions, udder health, and milk composition in dairy cattle.

4.11. Resilience to Variation in Climate

Genomic signals of selection for adaptation point to environmental adaptation of the Afrikaner and Brahman breeds in South Africa [35]. **Table 1** illustrates the distribution of different genes underlying signals of selection as categorised by their major functions.

Table 1. The distribution of genes underlying signals of selection in the Afrikaner and Brahman cattle categorized by their major functions.

Breed	Function of Gene and Percentage Distribution			
	Metabolism	Production	Reproduction	Function/Adaptation
Afrikaner	17%	0%	13%	70%
Brahman	35%	11%	8%	46%

Surprisingly, there were no genes associated with production that were detected in the Afrikaner, although some breeders have selected for production, whereas it was only 11% in the Brahman. A possible explanation is that, while breeders were selecting for growth, natural selection increased the frequency of genes for function/adaptation to survive and reproduce under the harsh South African environment. It is possible that selection for growth rate in a stressful environment can be achieved through increase in resistance to environmental stress.

4.12. Breed/Genotype Plasticity

It is important to breed for less plastic or more climate resilient ruminant genotypes. Plasticity is higher when the genetic effects show greater variation between years and lower when these interaction effects are smaller. It appears that some of the indigenous beef breeds in South Africa show a lower plasticity [36] [37]. The variation in weaning weight from year to year between different crossbred genotypes are presented in Table 2. These results are from the crossbreeding project at the Vaalharts Research Station in the Northern Cape province of South Africa. In this project Afrikaner, Bonsmara and Nguni cows were mated to Afrikaner, Bonsmara, Nguni, Angus and Simmentaler bulls in all possible combinations.

Table 2. Maximum difference in weaning between years of calves sired by Afrikaner, Nguni, Bonsmara, Angus and Simmentaler calves.

Sire Breed	Afrikaner	Nguni	Bonsmara	Angus	Simmentaler
Difference in Weaning Weight (kg)	15	22	24	31	49

From the results in **Table 2**, it is clear that there are large interaction effects between breed and year for 205-day weaning weight in the exotic breeds (Angus, Simmentaler). The Afrikaner showed the least interaction, followed by the Nguni. This demonstrates low plasticity in the indigenous breeds, indicating more tolerance to variations in climate, whereas the exotic breeds demonstrate more plasticity. Adequately resourced producers can potentially provide external inputs to offset this environmental variation, for example by purchasing supplementary feed in dry years. However, it might be advisable for many commercial producers, and probably all subsistence producers, to choose less plastic breeds which can produce even under less favourable environmental conditions [36].

4.13. Epigenetics

All alterations in DNA function, without alterations in the DNA sequence, are referred to as epigenetics. It is associated with gene expression and the expression of different phenotypes (appearance). These modifications are influenced by environmental factors and can be transferred to the progeny. "Soft" or epigenetic inheritance is a more pliable system for the fine-tuning of the next generation to changing environments than the slow response to Mendelian "hard" inheritance [38]. Both genetic and epigenetic controls influence genetic expression and research on how to include this when formulating breeding programmes for changing environmental conditions is needed [39].

Epigenetic alternations have been implicated in the growth, development, health, reproduction, and environmental adaptation of livestock through links to improved immune response, feed efficiency, growth performance and livestock products. Epigenetics has gained considerable interest due to its potential to provide new insights into the mechanisms underlying complex livestock traits, diseases and environmental adaptation. This may have the potential to contribute to the improvement of current breeding programs or the development of new breeding strategies in livestock. Furthermore, knowledge of epigenome alterations is a prerequisite to the application of emerging technologies like epigenome editing, which could lead to further improvements in livestock productivity and sustainability [40].

Epigenetics has the potential to revolutionize the livestock industry by providing additional levels of information for the further enhancement of livestock production efficiency, animal health and welfare, and development of breeding and management practices to support improved and sustainable livestock production to meet the growing demand for high-quality animal products while minimizing the environmental impact of animal agriculture [40]. The bottom line may be phenotypic plasticity, which is the ability of one phenotype to produce more than another phenotype when exposed to different environments.

5. Conclusions

The 13 interventions discussed in this paper are linked to Adaptation (maintain production) + Mitigation (lower carbon footprint) + Resilience (recover quickly, toughness) as demonstrated in **Table 3**. If these interventions can be addressed in a coordinated manner, it will support Sub-Saharan Africa in its initiative to ensure sustainable livestock production in the era of climate change.

Table 3. The link of the key interventions with adaptation, mitigation and resilience.

Adaptation	Mitigation	Resilience
Maintain Production	**Lower Carbon Footprint**	**Recover Quickly, Toughness.**
• Use of Indigenous/Adapted Genotypes • Development of Early Warning Systems • *Alternative Production Systems*	• Improved cow-calf efficiency/Alternative breeding objectives • *Alternative production systems* • Carbon sequestration • Carbon footprint within different resource environments • Feeding and grazing • Rumen manipulation • Land use and greenhouse gas emissions • Management	• Resilience to variation in climate • Breed/genotype plasticity • Epigenetics

Issues that dominate Sub-Saharan African animal agriculture include low production levels and environmental sustainability issues such as climate change, biodiversity, and land use. Unfortunately, there is a lack of evidence-based decisions to address the challenges faced by the region. It is important to develop knowledge to ensure that decisions around the 14 strategies mentioned in this article are evidence-based. Thus, research has a fundamental role to play in ensuring the future sustainability of Sub-Saharan African animal agriculture.

No single country, industry, or organisation within Sub-Saharan Africa can carry out such research, development and implementation thereof on its own. Researchers need to combine their efforts and involve expertise from outside the region, if needed. More emphasis must also be put on Global South scientific collaborations. The establishment of virtual centres of excellence in sustainable Sub-Saharan African animal agriculture is needed, with the objective of sharing research expertise and information, building capacity and conducting research and development. This will also make it possible to explore funding opportunities more successfully.

There is no simple or uniform mitigation or adaptation strategy to climate change for Sub-Saharan African animal agriculture. Solutions proposed for Europe and North America will be very different from those for Sub-Saharan Africa, which is one of the vulnerable developing regions that is already experiencing the impact of climate change.

At this stage there are no clear demonstrations of virtual centres of excellence that are fully operational in Sub-Saharan Africa. The initiative of the Global Research Alliance (GRA) on Agricultural Greenhouse Gases (https://globalresearchalliance.org/), with 24 member counties may be an initiative to ensure virtual centres of excellence. In addition, it is recommended that a bibliographic mapping for climate-smart livestock agriculture in the Global South be conducted to identify the key role players to be involved in possible centres of excellence.

Author Contributions

CBB invited MMS to prepare this review. MMS prepared the first manuscript and then shared it with CBB for his inputs. After the consolidation of the inputs MMS finalized the manuscript. MCM-C assisted with the references and finalized the article for publication. All authors read and approved the final manuscript.

Ethical approval

Since this is a review article, it does not contain animal or human studies.

Acknowledgements

This review was supported by the Department of Agriculture, Land Reform and Rural Development.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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