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Maximilian Lackner
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Editors

Handbook of Climate Change Mitigation and Adaptation

Third Edition

Springer

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With 1088 Figures and 347 Tables

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To Konrad Steffen (2 January 1952–8 August 2020), a Swiss-American climate scientist who died on a research field trip to Greenland, when he fell into a crevasse. Before deglaciation, such crevasses were not known.
To the 5 million people, whose annual premature deaths are linked to climate change already now.
To those who will take action in the future to combat climate change, for all of us.

Foreword

The first two editions of this *Handbook* have already established it as an essential tool for the increasing number of theoreticians and practitioners working in the overlapping fields of the climate and life sciences, socio-economics, engineering, and even aesthetics and philosophy. The first edition had 2130 pages, 586 figures, and 205 tables; the second one 3331 pages, 1108 figures, and 352 tables.

This third edition is clearly even bigger and better. As we get ready to plunge into it, it is worth stopping for a moment and reflecting on the evolution of what has become an important field of and onto itself, namely, that of *Climate Change Mitigation and Adaptation (CCMA)*. This foreword dwells on three important topics for this field: (i) the communication problems of interdisciplinarity; (ii) the crucial role of the times in which we live for the future of humanity on this planet; and (iii) the impact of stakeholders on the science we conduct.

To start with (i), it is well known that living at or near a border is potentially very interesting but it is often also quite difficult. This statement is especially true in the sciences, where speaking a different language makes mutual understanding harder, as does having grown up with an often very different type of education. Ludwig Wittgenstein already pointed out the difficulties involved in communication among different "language communities," into which he definitely included scientific communities.

It is thus important to keep in mind, as CCMA develops its own language, that this language should be rich and creative in and of itself, but also draw on the neighboring languages of the separate communities that have contributed to its birth and are continuing to nurse it. To put this less philosophically and more concretely, Integrated Assessment Models (IAMs), as an important dialect of the new CCMA language, need to balance the requirements of both climate and economic modeling: the former deeply anchored in a physical language, in which the basic rules are natural conservation laws, the latter in a socioeconomic language, in which the rules are more empirical and consensus-driven but equally important.

There is, however, a truly striking case of a phrase jumping the language barrier; that phrase is "tipping points." Sudden jumps from one steady state of a system to another were originally studied by Leonhard Euler, three centuries ago. Euler formulated and solved a mathematical model for the buckling of a beam, i.e., for its sudden transition from a straight to a curved state, as the axial load on it is increased past a critical value. Such a transition became known as a *bifurcation.* Bifurcations were generalized in the mid-twentieth century from saddle-node bifurcations between two steady states to Poincaré-Andronov-Hopf bifurcations between a steady state and a cyclic behavior and, in the later twentieth century, to various forms of transition between periodic and chaotic types of behavior, dubbed routes to chaos.

Unaware of this rich history – which involved applications of bifurcation theory to a plethora of problems in the physical, biological, and even socio-economic sciences – a journalist, Malcolm Gladwell, had the intuition that such sudden transitions due to "little things," like a small change in a parameter value, could play a big role in sociology. His book, published in 2000, became a bestseller and the phrase took off. Tipping points are now everywhere, and they have even been given a precise mathematical definition as bifurcations in dynamical systems subject to time-dependent forcing. Relevant examples are the bimodalities in sea ice cover of the Arctic and in the vegetation cover of the Amazon basin; in both cases, the time-dependent forcing to be considered is the anthropogenic change in atmospheric composition and, hence, optical properties.

Turning now from mere linguistics issues to Earth- and humanity-shaking ones, the realization that we are at a crossroads is truly sinking in. The 2020s decade that just started has already been called the "Soaring Twenties," a wink to the post-WWI "Roaring Twenties." It is a decade that, by most accounts, will play a key role in the coevolution of humanity and its planet. While there is still no dearth of incredulous or uninformed people – in countries large and small, advanced and developing – the overwhelming consensus of informed opinion is that we have to change our spendthrift collective ways and do something to prevent the young generation and the following ones from suffering greatly.

But what exactly do we have to do about climate change? CCMA, as a field of science and engineering, has a lot to contribute to the multiple answers to this question. These answers need to also take into account that there are many other issues involved in humanity's current and future well-being than climate change: loss of biodiversity is due to human population pressure and not just to climate change; regional and social inequalities affect and are affected by climate change, and so on and so forth. One rapidly emerging fact is an increasing commitment from the giants of private business to chart a course that aligns with the approximately right direction of achieving "net-zero" carbon emissions by mid-century or earlier. Another such fact is the rapid emergence of "green finance" and, more generally, of investment that is driven by, or at least affected by, so-called *environmental, social, and governance (ESG)* criteria.

Up until recently, the efforts of climate and environmental activists and of their large crowds of followers have focused on convincing public decision-makers to deploy the means of states and international institutions in support of the requisite steps for a better future. More recently, the resources of both public and private finance, to the tune of tens of trillions of dollars, are seeking environmentally sound investments to maximize growth and mitigate risk, and the private portion is much larger than the public one. The risks incurred by such investments are transitional – i.

e., those associated with mitigation policies – as well as physical, such as asset losses due to climate change and variability. Still, the increased private-capital interest appears to be going, more and more, beyond "greenwashing" and on to real action.

And here we are getting to the third and last part of this foreword. Most private institutions, including the largest ones, do not have the same experience with fostering science in support of their goals as public ones do. Maximizing an investment bank's growth and mitigating its risks might not always harmonize with the lofty goals of saving the planet and optimizing humanity's life on it. Just to give one small example, private capital is much more in tune with the traditional measure of national and global success, namely, gross domestic product (GDP). But it has become clearer and clearer that GDP is not the unique and not even a good measure of individual or community happiness.

Over the last decade, it has been forcefully argued that the Inclusive Wealth Index (IWI) is much better at measuring welfare and not just production. It is important, therefore, to use IWI and, possibly, other multi-index measures in projecting the state of the world into the future, no matter what certain powerful stakeholders in this future might think.

A final scientific point concerns the uncertainties in such projections. It is these uncertainties that must be taken into account in deciding "what exactly do we have to do?" Beyond the well-known, and multiply attributed, saying about "the known unknowns and the unknown unknowns," there's not much one can do about the latter. But there are many ways to take into account the former. Uncertainty quantification has become a flourishing field in the sciences and engineering. The financial industry has, obviously, its own ways of quantifying uncertainty – ways which are quite sophisticated and well adapted to its purposes but are quite different from those that are used in the climate and ecological sciences. Once more, there's a language problem, and we're back to the first topic on our list.

The topics that were touched upon in this foreword are, naturally, just three out of many. I can only wish this *Handbook's* third edition all the success it deserves and hope that some heed will be paid to these topics in future editions as well.

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Preface

The third edition of the Handbook, printed 10 years after publication of the first edition, has arrived. Meanwhile, the Keeling curve has moved from 394 to 419 ppm, and evidences of the devastating climate changes have emerged, such as the complete loss of stability of the natural Atlantic Meridional Overturning Circulation (AMOC) (Boers 2021). We have also learned more about climate change and mitigation, which will be the emphasis of this edition. But what is in knowledge?

"The more I know, the more I realize I know nothing." Socrates

"The more I learn, the more I realize how much I don't know." Albert Einstein

With more knowledge also come uncertainties, and science needs to and does look at them. Climate change has been a political topic ever since. The oil lobby has been accused of denying climate change. A notorious memo from 1998 reads: "Victory will be achieved when average citizens recognize uncertainties in climate science" (https://www.govinfo.gov/content/pkg/CHRG-116hhrg38304/html/CHRG-116hhrg38304.htm, accessed August 8, 2021). It is not that simple, though, to merely demonize one industry. Climate change, this is all of us. And victory can be for no one.

Today, "sustainability" has become somewhat of a hype. Be it circular economy, meat consumption, energy use, resource consumption, carbon emissions – the feeling has emerged that both organizations and private citizens all over the planet have started to recognize that something with the current way of living is wrong. But do we see countermeasures or a changing trend? The COVID 19 pandemic was an unprecedented caesura, yet its effect on our climate is estimated on only 0.01 °C of avoided warming (https://www.bbc.com/future/article/20210312-covid-19-paused-climate-emissions-but-theyre-rising-again, accessed August 8, 2021).

This Handbook makes a contribution by offering an up-to-date, comprehensive collection of knowledge on climate change adaptation and climate change mitigation.

It is up to you, the reader, to take this knowledge and put it into action.

The editors of this Handbook want to thank all authors for sharing their research, and the publishers for enabling this format. The next decade is definitely a decisive one for our climate. Let us all act within our own sphere of influence. Like every molecule of CO_2 counts, it is every step, large or small, in the right direction that is of value, and remember that the first steps are always the most important ones.

April 2022 The editors

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Prologue

Climate change is a global issue that will affect all of us. Its negative effects have already begun and are felt on all parts of the planet, from the poles to the equator.

The concept and theory of the greenhouse effect have been described and studied for almost two hundred years, and the question of whether or not our anthropogenic activities affect the climate has been asked and answered for almost as long. Since the second half of the twentieth century, it has become apparent that we humans cause the climate to change due to modern societies' emissions of greenhouse gases, and now the science is clearer than ever. The climate is changing rapidly due to our human activities. If we do not address this issue and immediately act on mitigating it, the consequences will be potentially devastating. We can no longer ignore the facts.

Scientists studying climate change and its effects have called out for change and action for decades. They have warned the public, governments, and companies that we need to act, and that we need to act now.

However, for some reason, these warnings have seemingly passed unheard. Despite scientists urging for climate action, little has happened. Now, in the last few years, climate change has risen substantially on the international agenda. Apart from the few denying climate change, the majority agrees that something needs to be done. Still, large-scale action is yet to be seen. It seems as though society is paralyzed. Action from politicians, financial leaders, and others with the power and mandate to enact action is yet far too slow and far too little compared to what needs to be done.

The current inaction toward climate change could be described as though we are performing a collective global experiment on our earth's climate, with both nature and ourselves as the metaphorical guinea pigs. This being said, all is not yet lost. Science does not only tell us what the issue is and where it stems from, but also provides us with the tools and insights necessary to resolve the problem of anthropogenic climate change. So, to stop this enormous high-stake gamble with our planet, its ecosystems, as well as our own lives and futures, we need to collectively act and demand real, sustainable climate action from those with the economic and political mandate to enable large-scale change. With said change being rooted in science, democracy, and sustainability. It is not an impossible task, but it is a necessary one.

The climate crisis is a global crisis, and it is time to act accordingly. Listen to the science.

Alexander Ahl, Isabelle Axelsson, Alde Fermskog, Ell Jarl, Greta Thunberg
Fridays For Future Sweden

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About the Editors

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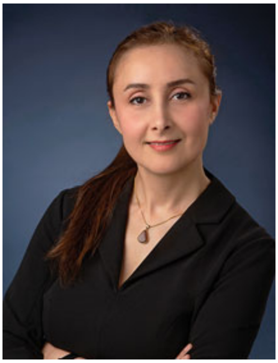

Dr. Baharak Sajjadi is an assistant professor of Petroleum and Geological Engineering in the Mewbourne College of Earth and Energy at the University of Oklahoma, USA. She has obtained her PhD in chemical engineering from the University of Malaya, Malaysia, in 2015, and has served as a research assistant professor of Chemical Engineering at the University of Mississippi, USA. She has over 10 years of research experience in advanced refinery processes and bioprocesses, carbon conversion and modification technologies, renewable energies, and computational fluid dynamics

(CFD simulation). Dr. Sajjadi has published over 50 scientific articles in peer-reviewed journals. She pioneered the use of ultrasound, non-thermal plasma, and chemical methods for carbon capture and conversion, natural gas conversion, and other environmental applications.

Dr. Wei-Yin Chen is a professor emeritus of Chemical Engineering of the University of Mississippi. He has had over 40-years of experience in developing technology-driven, knowledge-based, carbon conversion programs for in-furnace NO reduction, coal liquefaction, and low-temperature carbon modifications for sustainable food, energy, and water nexus. He founded and has been leading the Sustainable Energy and Environmental Group (SEEG) with over 250 collaborators around the globe. The SEEG pioneered the use of ultrasound, light, non-thermal plasma, biological, and chemical methods to modify the material surface for carbon gasification, carbon activation for CO_2 capture and wastewater treatment, soil amendment, electrode fabrication, desalination/deionization, biomedical material, fuel cell, etc. He has been awarded by UM and national and international organizations for his contributions to research, teaching, and services. He has served as a reviewer or panelist for institutions around the globe.

Ruminant Productivity Among Smallholders in a Changing Climate: Adaptation Strategies

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A. A. Jack, M. J. Adegbeye, P. R. K. Reddy, Mona M. M. Y. Elghandour, A. Z. M. Salem, and M. K. Adewumi

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Abstract

Smallholder farmers are the worst hit by the impact of the changing climate, especially those in developing countries. Climate change shows direct impact on the significant contribution of the production systems and related practices of smallholder farmers. Ruminant production systems emit various proportions of the primary greenhouse gases of carbon dioxide, nitrous oxide, and methane

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associated with global warming and the resultant climate change. Higher concentration of these emitted gases indicates inefficiency in production through energy, nutrient, and organic matter loss, which will negatively affect productivity of ruminants. Climate change has come to stay, and it will have some effects on agriculture through high temperature, low relative humidity, drought, erratic rainfall, and emerging pests and diseases. These will have a negative impact on feed crop and forage, water availability, animal and milk production, livestock diseases, animal reproduction, and biodiversity, thus constituting a threat to ruminant production. Livestock farmers will be most affected by the direct and indirect impact of climate change of the much more affected agriculturists. However, livestock farmers must learn how to maintain profitable production in the face of climate change. Therefore, in the face of changing climate, the purpose of this chapter is to provide insight into how smallholder farmers in developing countries can continue (adaptation) with their ruminant farming in a sustainable way.

Keywords

Climate change · Heat stress · Production system · Ruminant · Adaptation

Introduction

The livestock sector of agriculture in every developing nation is crucial for protein and micronutrient security, employment, and industrial raw materials. An attempt at meeting these needs and the improvement on these have been in progress until recently, where climate change has suddenly posed a threat to ruminant productivity. Unfortunately, it appears to be the unsustainable production system of smallholder farmers fighting back, thereby requiring modifications as adaptive strategies if ruminant productivity is to be maintained or improved.

The productivity of ruminants produced by smallholders is already faced with numerous challenges, which include, but not limited to, poor nutrition and health coupled with the use of simple and obsolete technological applications known to be part of the main characteristics of smallholder farmers. Unfortunately, these deficiencies on smallholder farmers befit them as one of the key drivers of climatic change with the effect of their operations directly or indirectly on ruminant productivity. The numerous activities associated with ruminant production have resulted in changes in climatic factors such as environmental temperature, relative humidity, precipitation, direct or indirect solar radiation, and wind speed (Joy et al. 2020). At optimal levels, these factors boost production and significantly influence the feed and water availability, fodder quality, and disease occurrence (Baumgard et al. 2012; Stocker 2014). However, when on the extreme, ruminant animals are vulnerable to their direct or indirect effects such as thermal stress, limited quantity and quality of pasture, as well as the occurrence of pests and diseases (Joy et al. 2020).

Globally, the contribution of livestock to the total yearly anthropogenic greenhouse gas emissions is about 14.5% (Gerber et al. 2013), as influenced by animal production, feed production, manure, change in land use, processing, and transportation (Rojas-Downing et al. 2017). These emit the primary greenhouse gases of carbon dioxide, nitrous oxide, and methane reported to account for 5%, 53%, and 44%, respectively, of global anthropogenic emissions (Rojas-Downing et al. 2017). With the global warming potential of methane and nitrous oxide at 34 CO_2-eq and 310 CO_2-eq, respectively (IPCC 2013), 21 and 310 CO_2-eq, respectively, were reported for a 100-year period (UNFCCC 2014) the role of ruminant animals, as well as other livestock in the changing climate, are not to be underestimated as livestock contributes more (7100 Tg CO_2-eqyr^{-1}) than the transportation sector (5656 Tg CO_2-eqyr^{-1}) globally to global warming (DSI MSU 2015; Gerber et al. 2013). Gerber et al. (2013) attributed the higher values of these gases to higher inefficiency and productivity of livestock systems as expressed in excess nutrient loss, organic matter, and energy. Of the 14.5% anthropogenic greenhouse gases emitted by livestock, enteric fermentation which is largely related to ruminant production system contributed 39.1%; 25.9% was attributed to management of manure, its application, and direct deposition; and 21.1, 9.2, 2.9, and 1.8% for production of feed, change in land use, post-farm gate, and direct and indirect energy, respectively (Gerber et al. 2013). In another study, Reddy et al. (2019a) assessed the share of individual global warming contributors and revealed higher potentiality for feed preparation (50.30%) followed by enteric fermentation (37.87%), manure CH_4 (4.20%), and manure N_2O (7.63%). The contributing percentages of individual global warming sources vary according to the methodology and region of assessment. As assessed by different authors, the relative contribution of different emission sources from global livestock supply is presented in Fig. 1.

The agricultural sector of the economy of Africa is expected to experience more of the impact of climate change globally than any other region (Sultan and Gaetani 2016; Rippke et al. 2016) with the livestock component as one of the most affected of the sector (Summer et al. 2019). The food supply and the developing countries will be the worst hit than any other by the changing climate (Conway 2012). The impact of climate change on feed crop and forage, water availability, animal and milk production, livestock diseases, animal reproduction, and biodiversity has made it a threat to ruminant animal production (Rojas-Downing et al. 2017). Two-thirds of the world's extreme poor is found in Africa (Kharas et al. 2018), with the population of the poor increasing presently by five persons per minute (Baier and Hamel 2018). A greater number of the two-third of sub-Saharan African population that live in the rural areas are smallholder farmers (Dixon et al. 2004). These farmers are part of the highly disadvantaged and susceptible in the third world in terms of the population of the undernourished people, malnourished children, and extremely poor (IFPRI 2007).

Adaptation is simply the adjustment made by smallholder farmers in the face of production challenges brought about by the changing climate and becomes the option available to smallholder farmers if the productivity of ruminant animals is

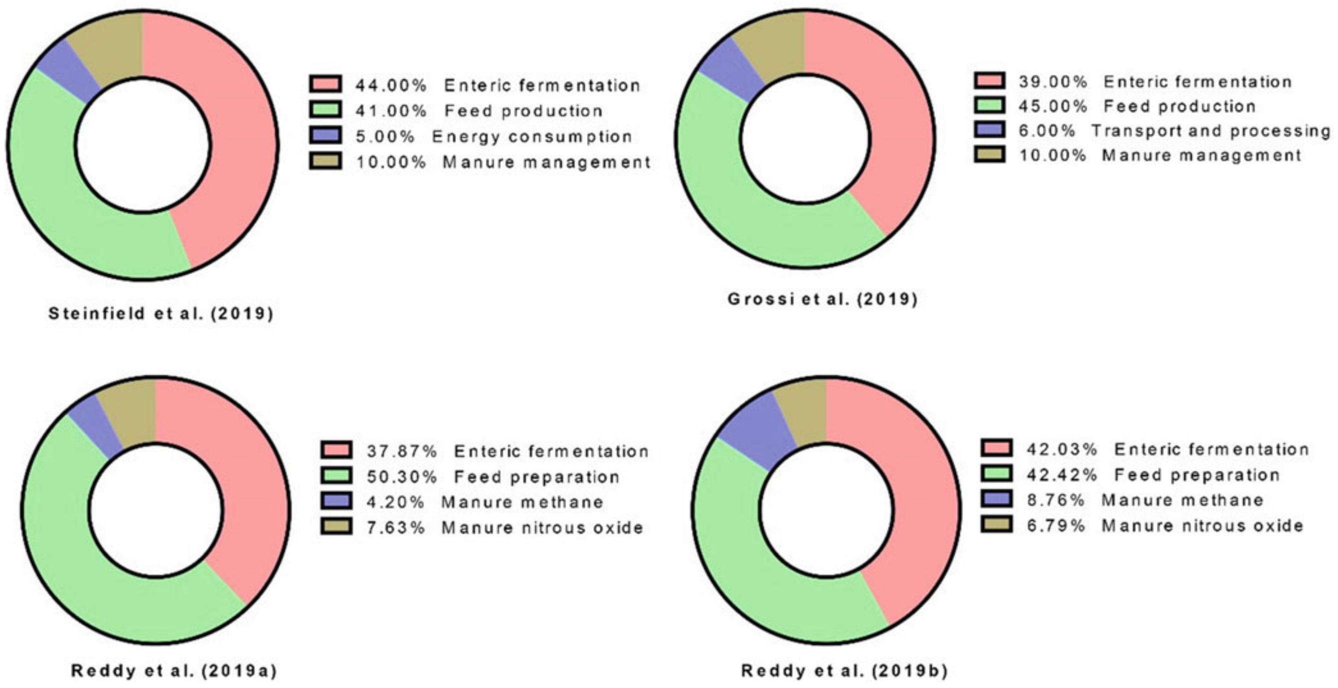

Fig. 1 Relative contribution of different emission sources from global livestock supply

to be maintained or improved. Kuwornu et al. (2013) categorized the strategies adopted by smallholder farmers into indigenous and introduced adaptation strategies. Therefore, changing climate requires that both traditional and scientific knowledge are synchronized to fine-tune knowledge that is adaptable and well-proven. Farmers need to maximize the use of available resources so that the uses of those resources do not create environmental burden but rather work in synergy with the developmental goals.

The livestock sector has varying degrees of environmental impact depending on the prevailing system practices in each country or region. However, irrespective of the production system, all the livestock will be affected by the changing climate with particular interest in ruminants. Ruminant farmers need to adapt to these inevitable circumstances if productivity is to be improved and the adaptation techniques have to be affordable and easy to use if it is to be sustainably adopted by farmers. In order to maintain and sustain animal protein from ruminant, new knowledge on adaptation, especially among smallholder farmers, is more important to them than knowledge of mitigation. Also, serious mitigation strategies that will bring efficiency will need government intervention. However, smallholder farmers from developing countries are most likely not to get such attention from their government; this can be seen in the case of the recent COVID-19 pandemic palliative measures in developing countries where many governments could not cater to their poor. Thus, farmers must be taught and given expanded knowledge on how to continue their livestock production in the face of continuous change in climate. For poor rural farmers, adaptation strategies are more important than mitigation because it relates to their source of livelihood more than mitigation.

To meet the goals and demands of livestock products in developing countries, it has always come at the cost of animal population increase rather than productivity increase per animal (Hoffmann 2013). Changing climate will not be able to accommodate this type of growth sustainably. In meeting the sustainable development goal, the means of livelihood of livestock-dependent smallholder farmers living in low- and middle-income countries must be secured (FAO 2017a). The survival of these smallholders in developing countries is essential because they supply over 60% of meat and milk produced and are projected to hold the ace in key agricultural growth in nearest future (Herrero et al. 2012). The livestock industry, especially the ruminant sector, needs to alter its operation technique or expand its production tool to improve its adaptation options. The ruminant production system will need to adapt in the future requiring changes in production and farming methods. The adaptation options must help the animal survive by enhancing its ability to adjust to the prevailing conditions in its environment (Sejian et al. 2018). Under these climate changes, challenges abound in the future for ruminant sector with the projected land unavailability and water scarcity – which are crucial resources for ruminant feeding (Weindl et al. 2015). There is a need to develop a technical way to produce optimally even when faced with drought, sand storm, disease, water scarcity, and high weather variability. In this chapter, the authors will come up with possible solutions to help smallholder farmers adapt to climate changes.

The Smallholder Farmer and the Poorest of the Poor

The term smallholder farmer differs worldwide based on location and the level of farming systems' intensification (Nyambo et al. 2019). It is most often referred to a farmer who uses a small portion of land to produce food crops and occasionally small types of cash crop (Thorpe and Muriuki 2001; Herrero et al. 2014). In addition, smallholder farmers may follow mixed crop–livestock production with small ruminants (MoFA 2010) and large ruminant at less population, usually less than five (Swai et al. 2014). The farm size of a smallholder farmer is usually less than 2 ha (Lowder et al. 2016). The production systems of smallholder farmers are known for the use of simple and obsolete technological applications, with low returns on investment, active involvement of women, and high labor differentials depending on the season (DCED 2012). Besides, farm size, resource allocation for food and/or cash crop, the utilization of hired labor and external inputs, livestock production system and off-farm operations, the expenditure patterns of household, and the share of food crop sold and consumed (DCED 2012) as well of those of livestock are common characteristics of smallholder farmers. Majority of smallholder farmers are residents in the rural areas and are faced with the challenges such as limited physical (e.g., road) and institutional infrastructure (e.g., market, communication services, etc.), limited access to endowment in production factors, such as land, water, and capital assets, lack of human capital development, lack of assets, limited information and access to services, high cost of transaction, limited reliable market and access to financial market, production of reduced quantity and quality of products as a result of low endowment in production factors, inconsistency in production, and lack of bargaining power (DCED 2012). These limit their expansion through participation in potentially lucrative markets and selling their products at the most profitable time (DCED 2012).

The smallholder farmer operates about 12% of farmland globally, with more than 475 million farms out of the about 570 million farms worldwide (Lowder et al. 2016). However, on the basis of countries' income, smallholders operate more farmland in low-income countries compared to countries of higher income with about 70–80% of smallholder farms operating about 30–40% of the farmland in low- and lower-middle-income countries and countries of East Asia and the Pacific (excluding China), South Asia, and sub-Saharan Africa (Lowder et al. 2016). In countries with higher income, farmers who use more than 20 ha operate 70% of agricultural land, while farmers using less than 5 ha operate 70% of land in the poorer countries (Adamopoulos and Restuccia 2014).

Africa has abundant land resources (Deininger et al. 2011). Despite the progress made by other ample land resource owners like Latin America, Eastern Europe and Central Asia, and Southeast Asia in large-scale agriculture, smallholder farming system has persisted in sub-Saharan Africa even in in the face of growing investment in large-scale production (Deininger and Byerlee 2012). This group of farmers in Africa constitutes a most significant part of the agricultural sector and is responsible for 75% and 50% of the agricultural production and livestock products, respectively (Nyambo et al. 2019). They are operated with family labor based on meeting the minimum requirements of the family (Nyambo et al. 2019). Thus, smallholder households harbor 60% of the 2.5 billion people in poor countries directly depending on food and agricultural sector (FAO 2012). However, with a decreasing average farm size in African region (HLPE 2013; Masters et al. 2013) with about 80% of farms being less than 2 ha and operated on about 25% of the agricultural land while only 2.4% of the agricultural land in European Union is used by 50% of farms that are less than 2 ha in size (HLPE 2013), there is need to effectively and efficiently utilize available agricultural land for improved productivity in the face of changing climate.

About two-thirds of the world's extremely poor are found in Africa, and if the current trend is unchecked, it will be responsible for nine-tenth by 2030 as 14 out of 18 countries with increased trend of poverty are in Africa (Kharas et al. 2018). This negatively impacts the climate change of Africa, with a greater proportion of its agriculture in the hands of smallholders, which is further worsened with about 40–60 million persons projected to be extremely poor in 2020 as a result of Covid-19 with the possibility of global extreme poverty rate increasing by 0.3–0.7%, further pointing to 9% (World Bank 2020). By 2030, Africa could be worse hit by poverty, with more than one person needing to escape poverty every second. Instead of a decline, Africa currently adds poorer (Kharas et al. 2018). The present trend has to be checked if African countries are not to be the top 10 poorest countries in the world by 2030 as the population of poor people in Africa is presently increasing by five persons per minute (Baier and Hamel 2018). Therefore, the rate of decreasing land for agricultural purposes available to smallholders who are synonymously getting poorer demands proactive strategies for adaptation in a changing climate, which is presently aggravated by Covid-19.

Ruminant Production by Smallholders

Livestock production offers farmers the potential for resilience in the face of climate change rather than cropping systems that mostly depend on greenwater and with both usually experiencing relatively low input in developing countries. Among livestock, most monogastric species type of livestock requires high input of feed quality offered, medication, vaccination, housing, and waste disposal while also competing with man for food such as grain and legumes. However, ruminants have the potential to produce quality animal protein under both high- and low- input systems. They digest human inedible cellulosic materials like grass, haulm stalk, agro-industrial by-product, tree seed, and leaf. Ruminants, in particular, are the most efficient organisms to convert grass into protein (Rust 2019) and can perform well even in harsh environmental conditions. In arid and semiarid regions, ruminants provide a livelihood source for farmers and pastoralists in the harsh environment and climate extremes where crops and monogastrics will find it difficult to cope. They provide a means of traction that creates a link between integration of both crop–livestock systems and serves as food and income insurance against climate- and weather-associated risks (Henry et al. 2012), and providing products such as meat,

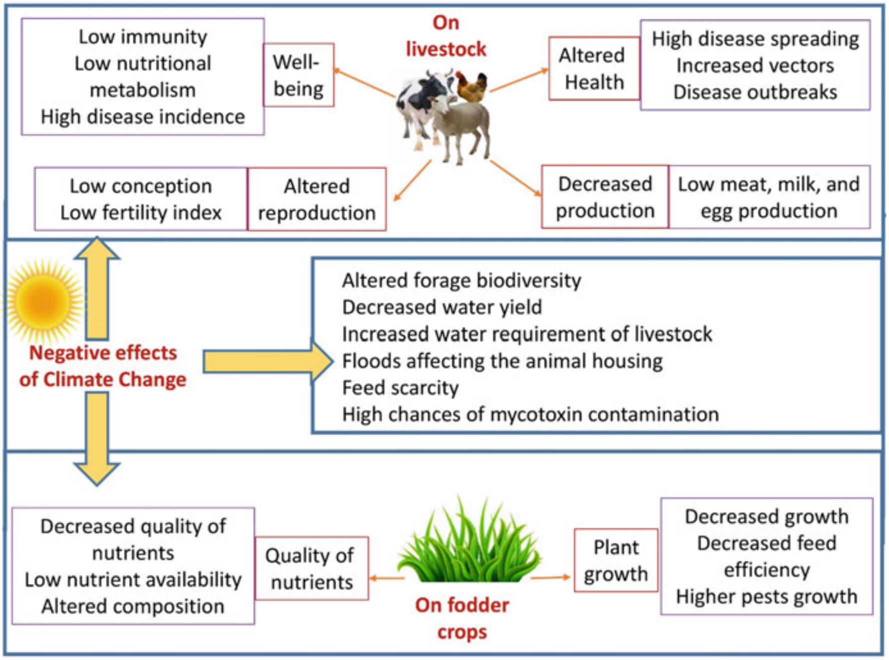

Fig. 2 Negative impacts of climate change on livestock

milk, and other industrial products. These edible products are embedded with essential micronutrients and vitamins. In addition, ruminants can be reared optimally in many different systems, including those with underinvestment across the world, such as commonly reared in mixed crop–livestock systems, grazing systems (Garnett et al. 2017), pastoralism, and agroforestry. The negative impacts of climate change on livestock are presented in Fig. 2.

The negative impact of ruminant production varies with regions and is often associated with production systems prevalent in such regions. As such, there are within and between variations and intensities of impact. Nevertheless, the common complaint against ruminant farming is related to environmental pollution (nutrient pollution and greenhouse gases), resource use inefficiency, poor waste handling, manure pollution, high emission intensity per kg productivity, land degradation through overgrazing, and arable land cultivation for feed (Reddy et al. 2019a). Overgrazing by ruminants is often caused by high stocking density, which leads to forage scarcity as a result of decreased pasture availability and increased competition for water. Due to increasing meat and milk yield, there has been resulting demand for both water and land resources, especially the high water footprint for meat production (Mekonnen and Hoekstra 2012; Bosire et al. 2019). Despite the consumption of human inedible by-products by ruminants, poor digestibility of some of these materials leads to increased concentration of the undigested nutrient in the manure as N and P concentrations (Carter and Kim 2013). They are also associated with high emission of greenhouse gas emissions and emission intensity in developing nations. However, there are reports of lower greenhouse gases emission from ruminants compared to the large number generally reported (Herrero et al. 2013). A recent study from India, the country with the largest ruminant population, showed little to no growth in CH4 emission between 2010 and 2015 (Ganesan et al. 2015). Another negative impact of ruminant farming is the constant conflict in many countries in Africa due to clashes between farmers and herders. This caused loss of lives and properties, losses in huge monetary terms, and not checkmating these activities could also cause food insecurity within countries or regions. The main cause for these problems includes limited pasture lands, low forage availability, and water scarcity, which cause migration to regions with abundant forages and water. Sometimes, the herder's trespass into farmlands leads to conflict. The ever-increasing land constraint for livestock feed necessitates decisive steps for increasing the land usage efficiency. In this view, Reddy et al. (2019b) reported that encouraging the usage of agro-industrial by-products and non-protein nitrogen compounds, as a part of ruminant's diet, is one of the potential solutions for productive land usage.

Changing Climate

Climate change is simply the resultant effect of global warming. Climate change is the result of what was contributorily caused by the production systems and operations of smallholder farmers that are hitting back. Based on this continuing occurrence, the world mean environmental temperature has been projected to increase between 1.8 and 4.0 °C by 2100 (IPCC 2007) and increase to 1.5–2.5 °C degrees only will be risking the extinction of about 20–30% of plant and animal species (FAO 2007). In Africa, this has been projected in the twentieth century to be 0.26 °C and 0.5 °C per decade (Hulme et al. 2001; Malhi and Wright 2004) and by 2080 it will increase between 3 °C and 4 °C (IPCC 2007). This indicates ill effects on the livelihoods of smallholder farmers that are dependent on farming with limited resources and technologies to adapt to the changing climate.

There have been many changes observed in many parts of the developed and developing world. In the Sahel region of Africa, temperature has increased between 0.2 °C and 2.0 °C (Reynolds et al. 2007; Epule et al. 2013) with a decrease in rainfall (Epule et al. 2017). The decrease in rainfall is both in frequency and quantity, with increased wind erosion, and frequencies of floods (Li and Zhang 2007; Garnett et al. 2017; Nori and Scoones 2019). Several researchers (Tambo and Abdoulaye 2012; Opiyo et al. 2014; Debela et al. 2015; Magita and Sangeda 2017) have reported reduced rainfall volume, increased variation, and high temperature in African countries such as Tanzania, Kenya, Ethiopia, and Nigeria. There has also been a delay in the commencement of rainfall in the season with cessation before the expected time (Kimaro et al. 2018). Water availability and land suitability for crop or forage growth, especially in low rainfall areas, have also been affected (Bosire et al. 2019). However, Pihl et al. (2019) reported higher yield of some crops in high latitudes due to warmer temperatures and lower yield in lower latitudes due to warming and dryness. Similarly, tropical forage species will be favored over the temperate species leading to pasture quality changes (Howden et al. 2008). Increased forage productivity and reduced protein concentration and digestibility, particularly in C3 plants, are also consequences of the changing climate due to increased CO_2 concentration (Stokes et al. 2010). The concentration of CO_2 alone could not have sustained plant life as there were other indices such as temperature, humidity, rainfall, etc. This could have been the reason for the increase in tree mortality, reduction in tree density, and species richness in Sahel sites such as Mauritania, Chad, Mali, Burkina Faso, Senegal, and Niger in the last half of the twentieth century (Gonzalez et al. 2012).

Indirectly, the effect of climate change on rainfall, temperature, and drought has resulted in increased frequencies of migration to chart new territories. This has caused competition for natural resources and an armed conflict between ruminant farmers and crop farmers in various countries in Africa. Droughts will cause loss and damage across all agricultural sectors including ruminant production (FAO et al. 2018). Drought could lead to losses in crop yield and vegetative covers/fodder production, which would have served as feed for nonruminant and ruminant, and with water scarcity resulting in high herd mortality (Zougmoré et al. 2016). In view of this, the low- and middle-income countries dependent on rain-fed agriculture are at the most risk (Ebi and Loladze 2019) as they are currently experiencing reduction in agricultural yield in the tropics where many developing nations reside (Pihl et al. 2019).

Ruminant Production/Productivity in a Changing Climate

The agricultural industry will feel more impact on the changing climate in Africa than in any region globally (Rippke et al. 2016; Sultan and Gaetani 2016) and the livestock sector will be one of the most affected segments of the industry (Summer et al. 2019). Across African regions, many production activities are being handled by smallholders and are long characterized by adaptation, revealed by high flexibility in reducing vulnerability to natural climate variability (Thomas et al. 2007; Eriksen et al. 2008). The impact of climate change on livestock is generally unraveling and will bring about resource distribution and utilization changes. This may bring about policies that will reorient the land utilization procedures (Tolleson and Meiman 2015) and reduce the allocated grazing land. Water and land availability in arid, semiarid, and humid regions will be limited due to restrictions on land (Elliott et al. 2014). Ruminant's production system is unique in developing countries. It is characterized by an extensive or pastoralism system, semi-intensive system, and mixed crop–livestock system. However, the most common in developing countries is the grazing system, which is practiced in various ways such as pastoralism, which is semi-intensive. These systems are vulnerable to the impact of climate change to a varying degree. In the future, climate change will bring about changes in policy as conflict may arise due to clashes between farmers and herdsmen; water becomes scarce and increasingly need for land for crop production due to increasing feed, food, and fuel demands. With the associated worsening water scarcity, ruminant farmers may need to raise animals that can thrive on less water, food, heat tolerance, etc. Producers may need to rear livestock species and breeds that can adapt to the environment or the prevailing climatic conditions (Henry et al. 2018).

The challenge of water scarcity will negatively impact the productivity of both grass-fed and grain-fed ruminants creating a need for dependence on irrigation in places with a reduction in rainfall (Henry et al. 2018). In view of this, movement of animals to drier zones should be done during rainy season and relocating the same to areas where crop production was practiced in the dry season to graze the crop field after harvest while the fields of resident farmers would be fertilized through manure deposition. However, this practice should be done among people of the common ethnicity, culture, and religion to avoid potential conflicts.

Also, increasing temperatures will create favorable conditions for mycotoxin growth in both pastures and feed ingredients, which will pose health risks to both animals and animal products' consumers in Africa, South America, and other developing regions (Gbashi et al. 2018; Adegbeye et al. 2020a). The need for farmers to know the additives to alleviate the effects of mycotoxin in ruminants and their products becomes imperative. In the face of increasing demand for meat and milk, smallholder farmers need to adapt to the climate change directly and indirectly by linking the limited land resources and water scarcity to produce food and meet their source of livelihood (Bosire et al. 2019). Notwithstanding, the decrease in arable land for grazing more land will be used for crop production and so will the by-product increase, and since these materials are not consumable by humans, there might be less potential pressure from livestock as thought previously (Mottet et al. 2017; Enahoro et al. 2020).

Impact of Climate Change on Ruminant

The direct impact of climate change on ruminants is a function of the resulting high temperature that could cause heat stress in livestock. The impact of climate change on animals' productive function depends on the animal's adaptive potential, which is a relative function of its species and breeds (Sejian et al. 2018). Africa and particularly the greater horn of Africa will be where the severe impact of climate change will be felt (Huho 2016). Reduction in pasture or forage productivity and quality, increased lignification in plant tissues and decreased digestibility, altered disease distribution patterns, and increased resilience of disease-causing organism and parasites have been attributed to climate change. Several researchers (Verschave et al. 2016; Kimaro et al. 2018; Gauly and Ammer 2020) reported the prevalence and distribution of pasture-borne parasitic helminth (nematodes and trematodes) infections as a prominent example of the effect of climate change. The reproductive efficiency of animals could be compromised by heat stress resulting from climate change due to its effect on fertilization rate, embryo development, and an increasing percentage of undetected estrus events (Hansen 2007; Hernández-Castellano et al. 2019). Every lost opportunity for reproduction by ruminant is at a cost to the farmer and worth even much more to a smallholder as such requires proactive approaches for it to be avoided. Some authors (Gaughan et al. 2010; ILRI 2018; Summer et al. 2019) have reported the negative impact of climate change on the ruminants' welfare and productivity. These include increased water intake and reduced dry matter intake, nutrient absorption efficiency, and water availability. This implies diminished growth performance by animals and extended economic losses to the farmers. Body temperature beyond 45–47 °C is lethal in most species. Such high temperature may increase the body and rectal temperature of livestock, which will induce heat stress, heat stroke, heat exhaustion, heat syncope, heat cramps, and ultimately organ dysfunction. The alteration in the animal's physiology by the indices of climatic change, such as increased temperature, could compromise its inherent potential productivity and maybe disastrous without a relevant and adequate coping strategy. This could have been responsible for the negative effect on nutrient absorption, meat quality, milk yield, and milk composition such as lipid profile due to inadequate feed and water; higher livestock death in pastoral system; reduced birthing rates; and increases in age at first calving in beef cattle (Thornton 2010; Weindl et al. 2015; Kimaro et al. 2018; Lacetera 2019; Zwane 2019; Alemneh and Akeberegn 2019).

Heat stress resulting from climate change may negatively affect livestock health by causing metabolic alterations, metabolic disorders, oxidative stress, immune suppression, and death (Lacetera 2019). This could result in changes in the feeding behavior (e.g., increase intake of concentrates and decreases in forage intake) of heat-stressed ruminants strengthening the development of acidosis, which might cause the occurrence of lameness in cattle, pathogen ecology, water resource quality and drying up, and increased mortality of individual, as well as serious conflict among the users of water and grazing land (Zwane 2019; Pasqui and Giuseppe 2019; Gauly and Ammer 2020; Ikhuoso et al. 2020).

Heat stress negatively affects the nutrient digestibility, fermentation patterns, microbial protein, and rumen microbiome (Hyder et al. 2017a). The negatively affected rumen commensals influence the feed degradation and intestinal absorption of nutrients. Rumen acidosis is directly related to high ambient temperature, i.e., beyond the thermoneutral zone of livestock. Impact of heat stress on the ruminant production parameters was elaboratively reviewed by Hyder et al. (2017b).

Climate change may mimic the effect of dry season, which could cause up to 30% body weight loss due to pasture availability and quality decrease (Hernández-Castellano et al. 2019; Pihl et al. 2019). This could be worsened in the dry season as changes in climatic indices are not limited to only the wet season. In pastoral systems, the poor performance of animals due to drought and feed scarcity could result in low selling price and death of animals. Changes in climate among pastorals may lead to animal starvation, reduced milk yield, and lowered market price among pastoralists in northern Tanzania. Besides, the climate change may also cause eruption of some diseases such as anaplasmosis, sudden death of cattle, and depletion of bone marrow in areas where they were not found in the past due to animals searching for pasture and interaction with other animals (Kaimba et al. 2011; Kimaro et al. 2018). However, in temperate regions, climate changes in grassland production may be positive due to prolonged growth with slight increases in ambient air temperature combined with elevated CO_2, provided water and nutrient supplies are not limiting (Henry et al. 2018). Furthermore, the movement of ruminants during the heat stress period could also be detrimental (Rowlinson 2008). These impacts have implications for agriculture and income of smallholder farmers and need to adapt significantly to become more productive while coping with unprecedented climate change.

Ruminant Production in the Face of Climate Change: Adaptation Strategies

Various adaptation strategies by smallholders in a changing climate are presented in Fig. 3. Preparation of resilient tools for adaptation to a greater extent is dependent on the understanding of what has changed. Adaptation is essential to reduce the damages and take advantage of new opportunities in the light of the rapid climate change already occurring and expected future impacts (Berrang-Ford et al. 2014; Lesnikowski et al. 2016). Adapting animals is a function of factors such as animal, management, and resources (Gaughan et al. 2019). Adapting to climate change is expedient for the food security and livelihood of humans and livestock farmers in many developing countries. Intensive production systems might be less affected than extensive systems, especially in least-developed countries, where no adaptation strategies are available (Rust 2019). As

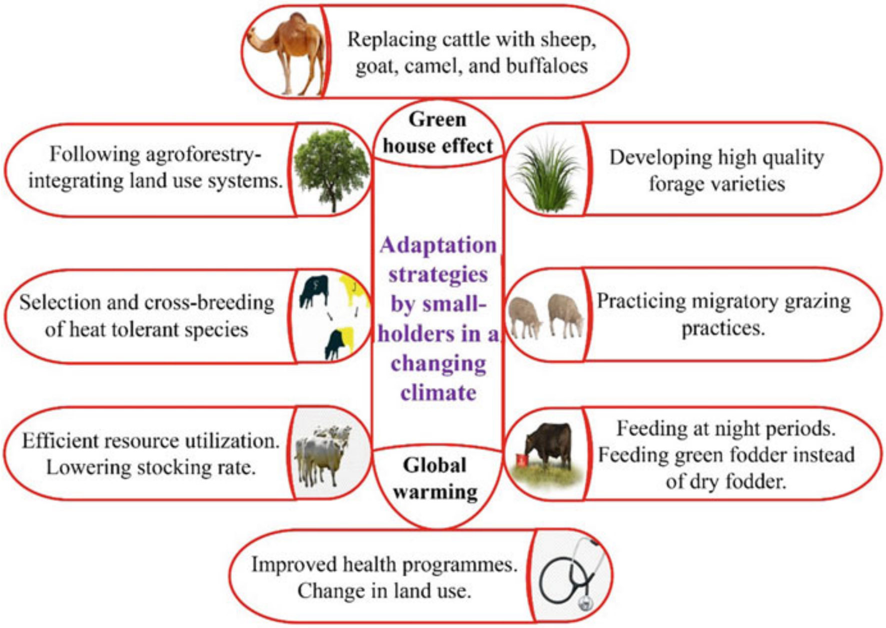

Fig. 3 Adaptation strategies by smallholders in a changing climate

such, low-income producers will be vulnerable to climate change because they lack the resources to invest in often expensive adaptive options (Vermeulen et al. 2012) that require structural changes, irrigation, ranching, etc. Pasture growth has been projected to reduce by 2100, resulting in an average decrease in meat and milk yield by up to 24.9%, depending on the region (Tapasco et al. 2015). Therefore, ruminant farmers in the tropics where we have most developing countries will have to adapt and continue to produce in the face of the inevitables like increasing human population, decreasing arable land, and worsening changes in climate conditions (Britt et al. 2018). The adaptation techniques suggested here are simple and readily adoptable by farmers. The adaptation technique will involve changes to livestock, management practice, and resource distribution (Gaughan et al. 2019) applied individually or collectively. These adaptation techniques will be decisive in offsetting the expected negative climate change impact on food security and agriculture development in Africa (Lalou et al. 2019). FAO (2006) grouped the strategies for adaptation strategies used to cope with climate change by smallholders into traditional strategies, government-supported strategies, alternative and innovative automatic adaptation strategies, and technology-driven strategies. Deressa et al. (2010) categorized the adaptation strategies as household, public, and government driven, while Kuwornu et al. (2013) grouped the strategies into indigenous and introduced adaptation strategies. However, for this chapter, the adaptation strategies will be classified into ruminant production systems, ruminant management systems, and others and modified from the groupings of IFAD (2009), Akinnagbe and Irohibe (2014), and Rojas-Downing et al. (2017) (Table 1).

Production System Strategies

Intensification

This is a production system that allows for protection of ruminants from inclement weather and predators and makes management more accessible by giving the handler the ability to exercise a measure of control over the animals (Anurudu 2011). This implies that, with intensification of ruminants, the impact of climatic extremes can be easily adapted to since the animals can be easily prevented from the direct effect of the changing climate. Ruminants under intensive system of production will be less exposed to climatic extremes as such will be less affected by the direct impact of climate change (Rotter and van de Geijn 1999; Rowlinson 2008). Nevertheless, the system may need some peripheral structural adjustments depending on the season (Rowlinson 2008). Intensification of agricultural production, such as increased livestock densities, can be useful adaptation mechanisms (Boko et al. 2007) and the livestock involved should be those resilient to the climate conditions for better productivity. With intensification, the animals will be properly provided for nutrition and health, among others. For instance, during period of climatic stress, intensively reared ruminants could be optimally fed with sufficient energy supply (Sejian et al. 2014) but extensively reared ruminants are completely dependent on pasture and

Table 1 Adaptation strategies by smallholders in a changing climate

Strategy	Summary	References
Alternative livestock production	Rearing of small stock species such as goat and sheep to dominate over large stock species like cattle and buffalos	Hernández-Castellano et al. 2019; Rust 2019; Adegbeye et al. 2020b; Gaughan et al. 2019
	Shift to rearing of dromedary camels in drought-prone areas or mixing common ruminant with camel because they are drought-tolerant species and can are best milk producer of any livestock under worst conditions	Kagunyu and Wanjohi 2014 Gebremichael et al. 2019
Chronomanagement	Feeding animal in the evening rather than in the morning improved the performance of beef cattle	Kennedy et al. 2004, Pritchard and Knutsen 1995;
	Feeding dairy cattle at 21:00 compared to 9:00 improved milk production and composition	Nikkhah et al. 2011
	Feeding or grazing animals at night showed better feed digestibility and utilization than during the day while giving better muscles and milk yield	Hongyantarachai et al. 1989; Aharoni et al. 2005
Alteration in fattening interval	Herders/pastoralist during rainy season target area with prime pasture with good species combination through strategic mobility and this gives the male animals access to forges with high nutritional value and this allows animal to produce good returns during the rainy season	Vellinga and de Vries 2018; Kratli et al. 2013; Egeru et al. 2015
	Strategic mobility	Boko et al. 2007; Deressa et al. 2010
Destocking	Having lower stocking rate on land gives possibility of good resources utilization and higher efficiency	Shang et al. 2012; Liu and Wang 2012
	Reducing herd size is a climate smart move with a potential to result in higher milk yield per animals	Gaitân et al. 2016;Enahoro et al. 2020
Breeding	Intentional breeding for adaptive traits such as lower basal metabolic traits, and morphometric features such as color, body size, disease resistance, heat tolerance, and ability to adapt to poor-quality diet	Hoffmann 2013; Berihulay et al. 2019
	Crossbreeding with zebu cattle that are well adapted to heat stress	Gaughan et al. 2010
Agroforestry	Combining forestry and cattle production in the same area and the	Ripamonti and Herder 2020; Broom et al. 2013

(continued)

Table 1 (continued)

Strategy	Summary	References
	trees provides shades from direct impact of the sun that could have induced heat stress	
	Integration of woody perennials or shrubs such as *Salix* spp, Mulberry (*Morus Alba*), Calliandra *spp,* Desmodium *spp* with animals	Dalc 2012
	Combining improved forage such as the hybrid of Napier grass with mulberry trees improved animal performance, high carbon storage capacity, and environmental accountability	Varsha et al. 2019

suffer production loses as a result of limited feed and water intake, especially in nonclimate-resilient ruminants found in dryer areas (Shilja et al. 2016).

Integration

Smallholder farmers should not only be limited to the production of ruminants but should combine two or more other components vital to the sustenance of productivity. Based on this, ruminant farmers will have to integrate crop production into livestock, pasture production and/or management, and agroforestry.

- **Ruminants and Crop Production**

  Integration of crop into ruminant production by smallholder farmers will allow for improved resource use efficiency, especially during climatic extremes where resources such as land available for production are on a declined trend and water is limited. The crops after harvesting will contribute to smallholder food supply and by-products from the processing of the crops can still be feed to ruminants. This will be in addition to the crop residue produced from the farm, fed to ruminants. The production of more food from less land and resources such as water by mixed crop–livestock production in an era of climate change indicates improved efficiency (Herrero et al. 2012), which is considered as a vital adaptation. About two-third of the world practices mixed crop–livestock farming system, which produces more than half of the meat, milk, and cereals such as rice and sorghum (Steinfeld et al. 2006; Herrero et al. 2012).
- **Pasture Management**

  A number of smallholder farmers are dependent on rain-fed pastures and the productivity of this pasture is affected by climate change. The reduction in the pasture, both in quantity and quality, will negatively relate to ruminant productivity during climate change. However, pasture management can be improved as an adaptation strategy by the fertilization, introduction of earthworms, leguminous seeds, and plant species of trees (Conant et al. 2001), especially the evergreen trees that are resilient to the local environmental conditions and/or shrubs while removing unwanted plant species. Stocking ruminants based on the carrying capacity of the available pasture could impact positively on ruminant productivity. While pasture rotation to ensure regrowth, provision of potable water, and shed to protect from extreme climatic conditions are good management practices, overstocking could kill the pasture and worm infestation (Anurudu 2011). Preventing ruminants from having access to degraded pasture is also a management practice for regrowth (IFAD 2009). This is typical on pasture that has been exposed to high grazing intensity. The practice of pasture fertilization, irrigation, and regular cutting delay the rate of pasture maturity or seeding and maintain pasture at a vegetative and nutritive stage for a longer period (Anurudu 2011). Also, reduction in grazing pressure on pasture with animal population that is more than the carrying capacity (Holland et al. 1992) is key to adapting to climate change for increased availability of forages for ruminants while avoiding worm infestation usually associated with overstocking. The strategic mobility of nomadic pastoralists lowers the pressure on the low carrying capacity of the grazing area through their seasonal migration from the drier north to wetter south representing an indigenous pasture resources system of management (Akinnagbe and Irohibe 2014). Additionally, the adaptation of rangelands during drought can be improved by building windbreaks, shelter-belts, and checking the number of trees fell and grazing animals (Osman-Elasha et al. 2006). With proper pasture management, prolonged availability of forages could be guaranteed, positively impacting ruminant productivity.

Agroforestry

Improving resource use efficiency or the multiple uses of limiting resources to derive maximum benefit will be an essential adaptation measure. Agroforestry can help resolve the challenges through carbon sequestration, multiple land use for tree cultivation and grazing zone, and desert reforestation. The changing climate requires that both traditional and scientific knowledge are synchronized to fine-tune knowledge that is adaptable and well-proven. There is a need to maximize the use of available resources to prevent environmental burden but rather work in synergy with the developmental goal. The system that favors the continuous production of ruminant livestock while at the same time ensuring nutrients' recycling and carbonsink, and greenhouse gases are reduced while improving the environmental stewardship of livestock is agroforestry. It involves the deliberate integration of woody perennials with crops or animals on the same land management unit (Dalc 2012). Inclusion of agroforestry in ruminant farming could improve carbon sequestration (Falk et al. 2019). Agroforestry can be combined with livestock production in different forms, such as in agrosilvopastoral and silvopastoral systems. Silvopasture is an agroforestry system that combines trees and livestock with forage to form a carefully designed system (Jose et al. 2019), focusing on improving forage quality and quantity, livestock performance, and carbon sequestration. Agrosilvopastoralism involves the cultivation of crop, forestry, and cattle production. The silvopastoral system is increasingly receiving attention because it seeks to combine forest and cattle production in the same area (Ripamonti and Herder 2020). Agroforestry can be synergized with reforestation and pasture management while improving agricultural practices. Agroforestry and silvopastoral systems are good alternatives to obtain animal products sustainably with ecosystem services such as carbon sequestration, landscape maintenance, and biodiversity enhancement (Pulina et al. 2018).

One of the challenges of changing climate is reduced forage productivity, thus depending on the system design and forage choices, the presence of trees could potentially influence the productivity and nutritional quality of the forages (Jose et al. 2019). Agroforestry can help implement silvopastoral system through restoration of degraded pasture and integrates pasture that has been genetically improved to increase productivity (Durango et al. 2017). Agroforestry can help livestock adapt to a changing climate by dealing with high temperatures. Agroforestry provides shades from direct impact of the sun that could have induced heat stress while helping grazing animals to reduce body temperature up to 4 °C compared with pasture-only-dependent systems (Broom et al. 2013). Access to shade tampered the negative effects of high heat load index on rectal temperature, hyperchloraemia, decreased alanine phosphatase levels, and alterations in general energy metabolism and prevented the reduced milk yield (Van laer et al. 2015). Generally, livestock production in the crop–livestock systems is similar to those in open pastures during the first years of tree growth (Teklehaimanot et al. 2002). However, too many trees or shade could negatively affect both the pasture and ruminant performance. Pontes et al. (2018) reported that shade provided by trees in the crop–livestock systems, which is as high as 39% in relation to the open field, affected pasture growth. Additionally, planting 159 trees per hectare reduced beef heifer gain than pasture without trees (Pontes et al. 2018). Tree shades may directly affect the pasture, decrease quantity and nutritive quality, and lower feed digestibility of the understorey vegetation (Ainsworth et al. 2012). In such a case, this system gives room for trade-offs/diversification because it is not only meat that comes from such system (Ripamonti and Herder 2020) as effort is also targeted at attaining optimal output all rounds. Other outputs include timber, hides and skin, carbon sink, etc.

In silvopastoral systems, shrubs and trees can supply energy, protein, and other nutrients to livestock (Papachristou and Papanastasis 1994; Kemp et al. 2001). Trees and shrubs such as *Salix* spp., *Morus alba*, *Calliandra* spp., *Desmodium*s pp., Leucaena spp., *Flemingia macrophylla*, and *Sesbania sesban* can be used as supplementary fodder and cultivated alongside improved fodder. These plants can be pruned during the rainy season and then ensiled or pelleted (Vandermeulen et al. 2018) and stored against the dry season when forages are scarce. Pruning these trees in rainy season gives room for plant regrowth. Pruning also prevents over shading of trees that could have negative effects on pasture growth and quality. Some of these tropical shrubs, such as *Calliandra calothyrsus* can be harvested on a cut-and-carry basis. In East Africa, usually, farmers follow agrosilvopastoral systems and the animals are often zero grazed, i.e.,they are sheltered in a stall and fed instead of grazing for free (Pye-Smith 2010). Intensive silvopasture that combines the hybrid of Napier grass and mulberry trees shows very high promises of improved fodder dry matter yield and increased carbon storage capacity, which meets farmer’s needs, and is environmentally accountable (Varsha et al. 2019).

However, antinutritional factors in tree by-products such as tannins and phenolic factors could affect intake and digestibility. Pretreatments with tannase-producing microbes (*Penicillium charlesii*) and other fungi could reduce this and improve its digestibility (Raghuwanshi et al. 2014). For instance, Kewan et al. (2019) reported that moringa stalks treated with yeast by solid-state fermentation for 21 days and fed to lamb had a very high economic feed efficiency.

Agroforestry systems can improve livestock mobility and integrate tree planting and pasture (FAO 2017). Silvopasture is an integrated land use practice that has been in existence for millennia (Jose and Dollinger 2019). There are reports (Pang et al. 2019a; Orefice et al. 2019) of similar or improved forage biomass of grasses planted in agroforestry systems compared to open pasture. With minimal root competition, grasses and legumes could perform well in agroforestry systems compared to open pasture systems. Even under moderate shading to dense shading, forage yield was higher than under full sun and C3 grasses performed well than C4 and with equivalent or improved nutritive quality such as the acid detergent fiber, neutral detergent fiber, and crude protein, respectively (Pang et al. 2019a, b; Orefice et al. 2019). The resistance of the silvopastoral system in forage productivity showed that in drought conditions, forage productivity outperforms open-pasture systems and woodlands (Ford et al. 2019). The trees offer additional animal feed resources in the form of tree leaves and seed pods in arid, semiarid, or even dry seasons (Jose and Dollinger 2019). The potential for livestock intensification in the drier zone is relatively low and could call for more intensive mixed crop–livestock and tree farming in rural areas that include animal fattening strategies for market (Bayala et al. 2014).

Alternative Livestock Production

Large ruminant is very popular among ruminant farmers and these include cattle, buffalo, camel, etc. Among the large ruminants, cattle production has been improved with specializations in milk and meat industry. However, these require a lot of resources for use, such as land, water, and grains. All of these resources are currently affected by climate change. This makes it difficult for smallholders to be able to maintain production with limited available resources. Because of this, pastoralists and agropastoralists changed from cattle to sheep and goat production during drought due to increase feed requirements of former compared to the latter (Oba 1997).

Small stock species such as goat and sheep are key species in the tropics and the subtropics because they are well adapted and could begin to dominate over large stock species owing to their grazing or browsing capabilities (Hernández-Castellano et al. 2019; Rust 2019). They are common in less productive areas and areas with low input availability. Small ruminants are important means of livelihood among livestock farmers in Oceania, Asia, and Africa (Adegbeye et al. 2020b) and represent over half of the global ruminant population (FAO 2016), with more than 50% of the total sheep and goat residing in arid regions (Monteiro et al. 2018). This suggests that these ruminant species will have the ability to cope with climate change, especially goats, because they are tolerable to heat stress, and hence desirable species to rear at high-temperature zones (Reddy et al. 2019c). The ability of goats to cope with stress due to their ability to produce higher plasma flow of cortisol when exposed to multiple stressors (Sejian et al. 2017) is an important species difference that should be considered when selecting/breeding for production in regions with extreme climatic conditions. Farmers and pastoralists need to switch to ruminant species and breeds that can cope with the prevailing weather conditions, producing meat and milk in poor conditions requiring less input and low environmental impact. Goats can tolerate the changing climate because they are efficient desert dwellers, and they have high digestive efficiency for survival in harsh climatic conditions (Gaughan et al. 2019; Reddy et al. 2019c). In arid zones, small body–sized and dwarf goats can survive better than other breeds (Gaughan et al. 2019). Recently, there has been an increased goat population in Africa and Asia (FAOSTAT 2017), with the total world number of small ruminants growing at a faster rate (Cannas et al. 2019). In an indirect response to the growing climate change, global goat and sheep population post-millennium has increased by more than 282 million and 142 million, respectively, compared to 177 million in cattle (FAOSTAT 2017). As such, the combined small ruminant has increased by about 247 million heads more than cattle post-millennial. Therefore, switching to small ruminant may be a better alternative in coping with the changing climates coupled with lower emission of less than 7% contribution to the total greenhouse gases and each producing less than 10% of cattle greenhouse gas contribution and at lower emission intensity (Marino et al. 2016; FAO 2016). Methane is one of the biogases generated during ruminant fermentation. Methane emission intensity per kg of final product of small ruminants is lower than the emission from cattle (Adegbeye et al. 2020b). Methane has 50–55.5 MJ/Kg of energy content (Wan 2004) and constitutes a loss of energy, which would have been channeled into ruminant production.

The camel (*Camelus dromedarius*) can provide better meat and milk in desert areas than other livestock in the face of high heat and feed and water scarcity (Hernández-Castellano et al. 2019). Dromedary camels produce more milk for a more extended period than any other milk animal held under the same harsh conditions (Gebremichael et al. 2019). In arid and semiarid zones, camels are an essential source of livelihood for pastoralists living there (Hulsebusch and Kaufmann 2002). This could be responsible for the increased population of camels despite the changing climate. The animals have biological and physiological adaptations to cope with severe environmental conditions. This could be why more pastoralists are opting to adopt camels as a drought-tolerant species and for its climate extremes tolerant abilities. The difficulty in raising cattle when rainfall is scarce in arid zones has made farmers adopt camel husbandry since climate variability has become a big challenge (Kagunyu and Wanjohi 2014). In fact, some communities that previously did not keep camel are increasingly doing so, especially in dry season. Ogutu et al. (2016) reported that pastoralists in eastern Africa have even changed from cattle to camel, goat, and sheep. Camel can adapt to rainless seasons on the scantiest feed and exist in areas where other livestock species cannot survive and they produce milk and meat, producing up to 4–6 L of milk per day during drought conditions (Kagunyu and Wanjohi 2014). Besides, the camel can produce six times the milk produced by indigenous cattle that have adapted to drylands (Field 2005). Camel milk contributes significantly to the pastoral household in Isiolo county of Kenya throughout the year, especially in dry season. The milk production will be higher during wet seasons than dry seasons (Elhadi et al. 2015).

Another livestock that can be reared as an alternative to cattle is buffalo. They are efficient utilizers of poor-quality forages and agricultural crop residues (Wanapat and Rowlinson 2007; Devendra 2007) and produce almost 50% of the milk produced from a feeding system using crop residue and cut-and-carry method (FAO 2018). They have more fibrolytic bacterial population and a higher N-recycling capacity (Devendra 1985; Wanapat and Rowlinson 2007) and are for meat and milk production. Therefore, sheep and goats, camels, and buffaloes are alternative livestock that can be raised as a means of adaptation to replace cattle in a changing climate.

Nutrition and Chronomanagement

One of the major impacts of climate change on ruminants is heat stress and poor forage quality. These two key factors affect the productivity, welfare of ruminant, and the ability of an animal to adapt which depends on its potential adaptive responses. The heat stress increases respiratory rate, alternation in body and skin temperature, blood metabolites, and hormones (Alemneh and Akeberegn 2019). Naturally, ruminants chew cud overnight and eat/graze during daytime. This has led to diurnal and nocturnal rhythms of post-rumen nutrient assimilation and peripheral nutrient metabolism (Nikkhah 2011). Hormones, body functions, and nutrient absorption occur in circadian rhythms through the day with varying peaks and troughs. Both internal and external cues coordinate these rhythms. Understanding when nutrients are best absorbed could help guide farmers for appropriate feed delivery time to ensure maximum nutrient delivery/efficiency. The timing of our feed affects ingestions, rumen fermentation, portal, splanchnic, and peripheral metabolism (Nikkhah 2013). Therefore, understanding this concept will ensure that concentrate feeding, cut-and-carry method of feeding, or grazing is properly timed to period when the rumen function is optimal without affecting animal physiology and health while securing human food supply (Nikkhah 2013).

Improving production efficiency in the face of changing climate is essential. Allowing the animals to graze early in the morning, evening, and night periods is the best measure to combat the heat stress challenge. Scheduling grazing to evening till early in the morning gives the animals an ample chance to eat under a lower temperature compared to early or peak afternoon temperature in both wet and dry seasons. Renaudeau et al. (2012) reported that hanging feed delivery time and/or frequency is a feeding strategy that could reduce heat load in animals. Feeding animals at nutrients' assimilation time may increase feed efficiency with reduced energy expenditure. The heat production and heat balance due to energy expenditure are higher during the day than at night (Puchala et al. 2007). Evidence has shown that feeding animals in the evening rather morning periods improved the performance of beef cattle (Pritchard and Knutsen 1995; Kennedy et al. 2004). Similarly, in dairy cattle, a report showed that feeding dairy cattle at 21:00 improved feed intake, rumen fermentation, and milk production and composition compared to animal feed at 9:00

in the morning (Nikkhah et al. 2011). Furthermore, animals fed at night or those grazed in the night have shown better feed digestibility and utilization than feeding during the day. Following these feed schedules reduce their energy expenditure to give better product yield in muscles or milk (Hongyantarachai et al. 1989; Aharoni et al. 2005).

It was on this basis that Rust (2019) reported strategically placing solar-powered lighting to enable animals to graze at night or cooler periods of the day and to rest during hotter periods of the day (Rust 2019), which will be at a cost that may not be affordable by smallholder farmers but in established pastures. Proper timing of nutrient delivery either through concentrate, stall feeding, or grazing could lead to the development of innovative grazing techniques that enhance feed nutrient consumption per unit of eating time "Rotatinuous" (Carvalho 2013) and a good adaptation technique.

Low feed efficiency is one of the major problems affecting ruminant productivity in the tropics (Jack 2019), and the use of feeding adaptive strategies could indirectly improve livestock production through increased feed resource use efficiency during climate change (Havlìk et al. 2013). Ruminants exposed to extreme climatic conditions take more water, less feed, and reduced duration and rumination frequency to reduce heat load (Hamzaoui et al. 2013; Chedid et al. 2014). The consumption of less amount of feed required for production as an adaptive response to heat stress negatively affects ruminant productivity. However, diet reformulation and supplementary feed can be offered to ruminants during extreme climate conditions as an adaptation strategy (Gbetibouo 2009: Iannaccone et al. 2019). Renaudeau et al. (2012) reported that the diet composition could also be altered to compensate for low feed intake. Supplementation of feed offered ruminants with various additives like betaine, antioxidants, vitamins, and electrolytes which have been beneficial in reducing heat stress in ruminants and improved performance (Ghanem et al. 2008; Sivakumar et al. 2010; Chauhan et al. 2015; DiGiacomo et al. 2016; Chauhan et al. 2016). Goats offered diets supplemented with 4% fat and soybean oil during heat stress had a higher content of milk fat than the control diet with less nutrient density (Al-Dawood 2017). Heat production of lambs was also reduced with the modification of ewes' diet at late pregnancy to include high concentrations of algae-derived cervonic acid, as well as monounsaturated and saturated fatty acids (Chen et al. 2007; Keithly et al. 2011). Production and conservation of feed are based on ecological support, that is, adequate nutrition to ruminants (IFAD 2010). In addition, introduction of agroforestry species into the feeding program to make up for feed resource deficits could help in adapting to climate change (Thornton and Herrero 2010).

Changes in Operation Time

The time of carrying out different operations on the farm by smallholder farmers is key to the outcome depending on the season and as it relates to the impact of climate change. This is one of the adaptive strategies that will reduce the stress associated with climate change (IFAD 2009). Operations such as mating, delivery, and fattening and interval will have to be adjusted to better use available resources to improve ruminant productivity.

- **Mating, Delivery, and Fattening Time**

  The time for parturition of a ruminant is also a key factor in adapting to climate change. Ruminants should be mated with the expected time of delivery on focus. Delivery should be targeted at such a time where there will be abundant feed resources for the dam. During the rainy season, climatic impact on forages will be low compared to the dry season. Naturally, both the quantity and quality of pasture are always on the decline, especially in the tropics. This is also applicable to the period of fattening. During rainy season, prime pastures with good species combinations are targeted to give ruminants access to high-quality forages with high nutritional value for good returns (African Union 2010; Kratli et al. 2013).
- **Fattening Interval**

  The ultimate goal of nondairy ruminant livestock is for meat. There is a need for a pragmatic approach for all livestock farmers irrespective of the production system used. Breeds of ruminants in tropical and subtropical zones adapted to the peculiar environmental conditions of the zones generally do not perform as much as the livestock in temperate regions (Seijian et al. 2017). Therefore, strategically raising animals to reach their average adult weight and disposing them will reduce competition for resources and help farmers for strategical planning to the next season, where the efficient utilization of resources could be done for maximum profitability. In the tropics, slow growth rate of livestock is attributed to poor nutrition and other extreme conditions. This results in the tendency to raise animals for a prolonged period before the expected market weight could be reached, as such, the number of animals in the flock keeps increasing, thereby increases the competition for limited nutritional resources. For instance, the pastoral system well practiced in African countries, such as Burkina Faso, Mali, Niger, Chad, Sudan, Somalia, Kenya, and Tanzania, tends to prolong slaughtering age due to high mobility known for its high energy expenditure which could have been used for production. Early disposal of the males either live or slaughtering for veal, fattening, or once the average adult weight is reached while retaining the young growing animals and females for milk and other reproductive purposes would have reduced the competition for limited forages. Herd population reduction through reducing the fattening interval and disposing of animals at a younger age allows for proper replacement with younger animals. Moreover, since as soon as animals have reached their adult weight, there is little or no additional meat production, and further delay in keeping the animals becomes counterproductive and at a cost. The production of calves, kids, or lambs is essential to produce new growing tissue (Vellinga and de Vries 2018). If reduction of the age at slaughter is the main goal, animals meant for this can be selected ahead of the grazing season and allowed access to areas with excellent pasture and enroute market. Hence, herders or pastoralists during rainy season target areas with prime pasture with good species combination through strategic mobility and this gives the male animals access to forages with high nutritional value which allows animals to produce with good returns during the rainy season (African Union 2010; Kratli et al. 2013). In this market, there should be a ready buyer of animals that have reached certain weight rather than age, and there should be slaughter, processing, and packaging facilities provided. For the retained female animals, proper nutrition improves their growth, allowing them to reach early maturity. However, there should be a reduction of age at first calving, decreasing calving interval, and reduced weaning age, improving reproductive efficiency. Improving reproductive efficiency could improve the overall ruminant productivity.

Strategic Mobility

The movement of animals by herders or pastoralists to targeted areas with abundant forages, especially during the rainy season with an aim of accessing to high nutritive forages for better performance, could be a useful strategy to cope with climate change (African Union 2010; Kratli et al. 2013). Also, moving livestock to graze other rangeland resources is a major measure to cope with drought, including livestock sales (Hou et al. 2012). For farmers in arid and semiarid zones, pastoralism through strategic mobility is their only adaptation option. Mobile pastoralism in the eastern and western African region performed better and had higher return per hectare than sedentary systems or ranching systems in animals reared under same condition (Ocaido et al. 2009; Kratli et al. 2013). In these zones, strategic mobility as an adaptive form of pastoralism can bring about economic and product growth, despite persistent underinvestment and centuries of negligence (Kratli et al. 2013). Animals can be moved to drier zones during the rainy season and returned to the cropped areas to graze the crop field after harvest. However, this practice should be done among people of the same ethnicity, culture, and religion to avoid conflict, whereas the fields of resident farmers would be fertilized through manure deposition by ruminants. Pastoralism provides food security across drylands and allows us to turn environmental variability or uncertainty into assets in food production ability (Krätli et al. 2013). More investment should be focused on how to get the best out of pastoralism in arid and semiarid lands region rather than replacing it. Besides, in search of pasture, they exercise transhumance grazing movements between lowlands and marshes and mountains during wet and dry seasons, respectively (Oba 2012). For this to be successful, pastoralist/farmers need to be provided good access to market and government security to their grazing lands (Nkonya and Anderson 2014; Ericksen and Crane 2018). Also, the distance traveled after grazing should be reduced as much as possible to reduce energy expenditure for more efficient production.

Selection and Breeding

Sustainable livestock production in the future may be dependent on the selection of animals that are resilient to climatic extremes (Baumgard et al. 2012). An animal's genetic flexibility to adapt to extreme environment reflects in its productive and reproductive performances (Leite da Silva et al. 2020). Breeding is essential to increase livestock productivity or resilience to certain conditions by improving productive traits such as weight gain, milk yield, and fertility (FAO 2017b). Intentional or selective breeding that purposefully targets adaptive traits with lower basal metabolic traits is one of the measures to adapt to climate change. Breeding animals with particular morphometric features or traits such as color, body size, feed efficiency, disease resistance, and heat tolerance and adaptation to poor-quality diet (Hoffmann 2013) should be considered in this era of changing climate. This is achievable by locally identifying and selecting animals with the required traits and multiplying same or crossbreeding local breeds with desired traits. However, the survival and adaptation of the outcome of the selection and crossbreed are dependent on its early stability compared to the rate of climatic change and its associated impact (Hoffmann 2008). Coat and skin color are sheep and goat features that help livestock adapt to tropical and temperate climates (Berihulay et al. 2019**)**. For instance, light- or white-colored animals have an advantage in hot tropical zones because it can reflect up to 60% solar radiation compared to dark-colored animals (Berihulay et al. 2019). Also, the short hair, skin thickness, and hair follicles per unit area improve the livestock adaptability to hot conditions (McManus et al. 2009; Mahgoub et al. 2010). The fact that exotic breeds perform lower in the tropic than the temperate region indicates that breeding for adaptation is more essential now than focusing exclusively on high productivity (Shilja et al. 2016). Therefore, selectively breeding animal en mass for this particular trait in research institutes could be a way in which government can help farmers preparing for adaptation to the changing climate.

Breeding small body–sized animals, even in cattle, could help survive harsh ambient conditions, because the small body–sized animals have lower water and feed requirements. Crossbreeding of small body size cattle such as zebu that are well adapted to heat stress with exotic breeds is a viable option because the earlier cattle possesses thermal pressure adaptation-related traits at the physiological and cellular level (Hansen 2004; Gaughan et al. 2010). This procedure gives them the ability to regulate body temperatures amidst increased heat loss capacity (Henry et al. 2018).

Important cattle breeds of Africa, such as Kenana, Boran, N’dama, Akole-watusi, and Ogaden, have genes that have been linked with heat and disease tolerance or their ability to suppress the debilitating effect of heat stress (Kim et al. 2017). Falk et al. (2019) reported that improving animal breed through upgrading is attainable using animals from two different regions that are more tolerant to heat and more efficient in nutrient and water use .Other breeding options include improvement in drought-tolerant crops and animals that can adapt to the seasonal scarcity of pasture (Hernández-Castellano et al. 2019) or perhaps focused on developing dual-purpose breeds through breeding. Crossbred animals might have a relatively low water footprint. Breeding of exotic breeds with local zebu cattle increases the adaptive ability-related traits of local breeds while increasing the production (Bosire et al. 2019).

Diversification/Multispecies Composition of Herds or Flocks

Diversification of smallholder ruminant farmers into other ruminant species production instead of concentrating on a particular one is an important adaptation strategy. This is different from completely abandoning species of interest due to adaptation challenges for alternative species. Diversification is key to smallholder farmers since keeping a number of different ruminant species that are local and resilient to local environmental conditions will reduce the impact of changing climate (FAO 2012).

Deressa et al. (2010) reported that keeping different livestock species is one of the adaptive measures in climate change in the Nile basin of Ethiopia. Diversification is an essential adaptation strategy with economic value to boost smallholder adjustment during climatic stress (Boko et al. 2007). Heatwave and drought tolerance can be improved by diversification and production during climatic stress (Rojas-Downing et al. 2017). The ability of diversification to limit pests and diseases caused by climate change (IFAD 2010) will improve the productivity of ruminants.

Mixed Livestock System of Farming

Introducing a mixed livestock farming system is a strategy for adapting to climatic change (IFAD 2009; Akinnagbe and Irohibe 2014). With stall-feeding, the direct effect of climatic elements on ruminants will be reduced as well as reduced energy expenditure that could have negatively affected performance would be channeled into production. However, pasture grazing of ruminant exposes them to inclement weather with increase energy loss depending on the distance covered.

Management System Strategies

Destocking

Poor nutrition is one of the attributes of ruminant production system in the tropics. However, to meet the local demand for animal products, farmers have resorted to a continuous increase in our animal population despite increasingly limited resources that are worsened by the changing climate. If available resources are to be properly maximized, there is a need for ruminant farmers to reduce their stock. This is because the ability of a hectare to handle some animal population, whether in arid zone or other zones, increases to a certain point before the return per animal (weight gain, meat, or milk yield) from the same plot begins to decline (Egeru et al. 2015). With a lower stocking rate, there is a possibility of good resource utilization and higher efficiency, giving room for a quick ruminant turnover rate (Shang et al. 2012). Reducing herd size, such as cattle number, is a climate-smart move with the potential to result in higher milk yield per animal (Gaitân et al. 2016;Enahoro et al. 2020). Pastoralists can also destock to manage the available livestock (Mogotsi et al. 2011; Kima et al. 2015), especially younger animals through sales or butchering on hand (Liu and Wang 2012; Ducrotoy et al. 2016). However, during the season of forage abundance, there could be restocking at an optimal level. For instance, in Kenya, during drought, a destocking program was carried out by the government to avoid mass loss (Kagunyu et al. 2017). Reducing livestock size is necessary to create a balance to avoid overgrazing and grass degradation (Liu and Wang 2012). Globally, the ratio of animal population to animal products is a major focus as this indicates the efficiency of the production systems. Rowlinson (2008) reported developing countries to have twice that of the beef cattle population but yielding only half of the yearly meat output with variation in efficiency of more than fourfold. Therefore, destocking will reduce the number of less productive animals leading to more efficient production with reduced greenhouse gases from ruminants (Batima 2006; Rowlinson 2008). Destocking of ruminants can also be done in the form of culling of weaklings from the herd or flock during periods of extreme climatic conditions (Nyong et al. 2007).

Provision of Shade and Water

The direct effect of the extremes of the indices of climatic changes such as temperature, relative humidity, wind speed, etc. on ruminants requires responses as their comfort zones are affected. Increased temperature in locations experiencing low temperature and high rainfall will be beneficial in reducing mortality in young ruminants. Providing adequate shade and water are useful management strategies in curbing the effect of climatic change, resulting in heat stress in areas being experienced with high environmental temperature (Rowlinson 2008). Therefore, it becomes necessary to use cost-effective materials in regulating these environmental conditions for improved performance.

Water Resource Management

Water limitation resulting from climate change has negative impacts on ruminant productivity, both directly and indirectly. Ben Salem and Smith (2008) reported that drought is a threat to water resources both in quantity and quality, affecting rangeland and livestock performance and health. Drought can also result in the death of livestock (Deressa et al. 2010). However, indigenous techniques such as the use of tanks linked to the roofs of houses through channels, small superficial and underground dams, etc. for irrigation with associated accessories to collect and store rainwater (IFAD 2009) will be useful in conserving water for use by smallholder farmers. These water harvesting and conservation systems will strengthen smallholder farmers mainly dependent on rain-fed farming systems to adapt to stress caused by drought (Boko et al. 2007).

Alteration in Herd/Flock Composition

The use of multiple species in animals is one of the adaptive strategies during climatic extremes (Nyong et al. 2007; Thornton et al. 2008). However, the proportion of large or small ruminants in a herd/flock kept by a smallholder farmer is a management strategy based on the potential of species to adapt differently to climate change. Some species, such as goats, are more tolerant of extreme climatic conditions and easy to survive due to their requirements of less input compared to cattle. Limitations in feed and water availability commonly associated with climate change will require species that are tolerant of the conditions and more efficient in the use of the limited resources to be combined by smallholder farmers. The population of the species that are better utilizers of critically limited resources will also be more than those that could be relatively coped with. Also, the population of rustic and resilient species and efficient utilizers than the species with either limitation will be more. Therefore, having different species with different potential to adapt to the limitation faced by ruminants during the stress period will go a long way in sustaining and improving productivity.

Limiting the Climate Change Effects

Limiting the anthropogenic emissions through various managemental practices is need of the hour to minimize the climate change effects on livestock. Various measures to be followed in reducing the anthropogenic effects were well reviewed by Adegbeye et al. (2020b). Feed additives and diet manipulation have been known as important CH_4-mitigating measures. However, the effectiveness ranges from low to high, and their long-term effects are questionable. Various techniques and practices being employed and researched for CH_4 mitigation, along with their effectiveness and long-term effects, are presented in Fig. 4. More research needs to be shifted towards reduced emissions through feed preparation, manure management, and enteric fermentation.

Feeding the livestock with low carbon footprint–based feeds is another important option for mitigating or limiting CH_4 production. The carbon footprint of feeds could be decreased by using the locally available feedstuff, thereby reducing the extra emission through transport and milling procedures. Encouraging agro-industrial by-products lowers the carbon footprint of feeds, especially concentrate mixtures, at greater extents. For instance, urea holds lower requirements of diesel, agrochemicals, fertilizers, pesticides, electricity, and land for production compared to

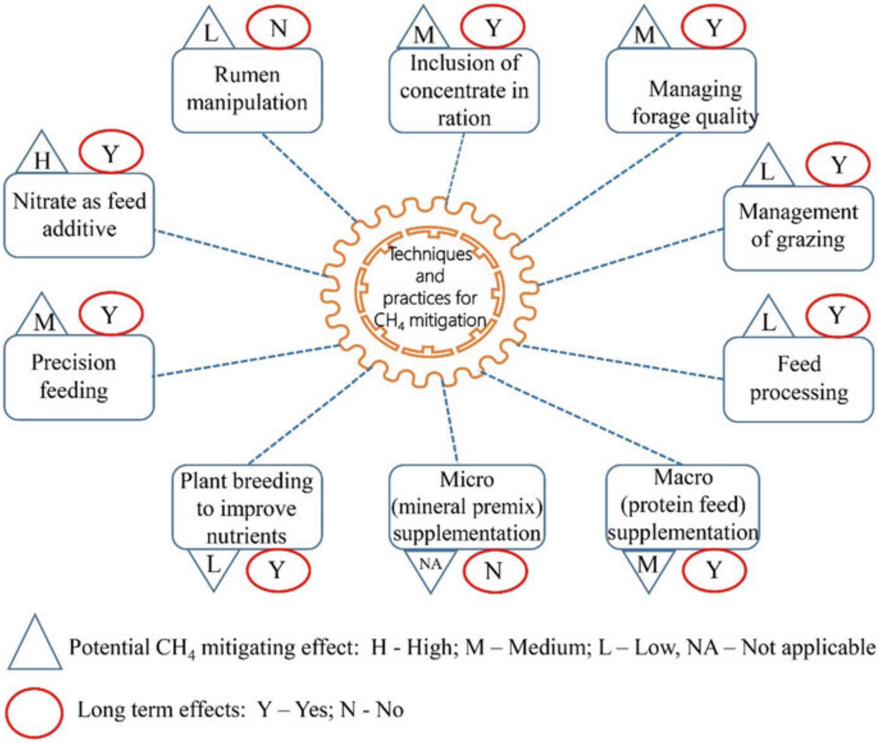

Fig. 4 Various techniques and practices for methane mitigation from livestock sector

traditional feed supplements such as soybean meal and cottonseed meal (Reddy et al. 2019a, b). The same principle applies to virtual water management, which is an essential strategy to sustain adverse environmental conditions. Virtual water is the water required to prepare a prescribed product. The virtual water of diets varies according to the type, region, and season. Moderation of animal feed may have a significant impact on virtual water use. At the policy level, the countries or regions with water scarcity should import products with high virtual water and export products with low virtual water. This phenomenon is also known as water trade. Similarly, the animal feed in these regions should contain ingredients with low virtual water. For example, the virtual water per tonne of cotton seed meal-based feed was 1062 m^3, while the same for urea-included feed was 997 m^3, prepared to feed milch animals (Reddy et al. 2019a). In another study, two sheep diets were compared, in which the virtual water per tonne of soybean meal-based feed was 38.91 and that of urea-included feed was 31.22 m^3 (Reddy et al. 2019b). In both the studies, the authors suggest encouraging urea-included diets for efficient water usage and decreasing water trade.

Others

These are nonanimal-based issues, but they can be useful to smallholder farmers in adapting to the impact of climatic change. They are caused and worsened by the limited resources faced by smallholder farmers in the cause of production. IFAD (2009), Gbetibouo(2009), Deressa et al. (2010), Akinnagbe and Irohibe (2014), and Rojas-Downing et al. (2017) have reported better market responses obtainable through improved agricultural market, inter-regional trade, and credit facilities; better institutional and policy adjustments such as subsidies, insurance, and information-sharing interventions by relevant bodies as well as diversification into nonruminant ventures; development and application of science and technological output such as improved breed of ruminants that is resilient and of better health, water, and feed use techniques; and capacity building of smallholder farmers through training for better understanding of the concept of climate change to be able to adjust their practices to suit current realities.

Conclusion

Climate change remains a serious threat to smallholder farmers, especially those in Africa where livelihood is at stake coupled with increasing population of the poor. The contribution of ruminants regarding the concentration of greenhouse gases responsible for global warming and the resultant climate change is still impactful. The global warming contribution from livestock could be atleast reduced, though not possible to eliminate completely. Livestock farmers being the most affected by the direct and indirect impact of climate change of the much more affected agriculturists must learn how to maintain profitable production in the face of changing climate.

Therefore, in the face of changing climate, smallholder farmers in developing countries can sustain ruminant productivity through adaptive strategies. The adaptation strategy or combination of strategies used by smallholder farmers is a function of their adaptive capacity. Capacity building, provision, and exposure to infrastructural and institutional facilities could be of immense importance in achieving this if ruminant productivity by smallholder farmers is to be boosted. However, there are differences in the needs and related strategies based on ecological zones.

In the arid and semiarid zone, there is a need for improved investment in pastoralism rather than methods to replace them. This is because, it is still one of the best nutrient conversion methods from forage to high-quality protein through strategic management and product-yield-oriented grazing priority. More investment should be focused on how to get the best out of pastoralism in arid and semiarid land regions rather than replacing them. For such a period, maximum nutrient delivery with an already arranged processing facility will help animals reach their average adult weight and reduce greenhouse gas intensity per kg product. Therefore, reducing the age of livestock slaughter might be an adaptation technique as animals will not stay too long on the farm premises and compete with others for space and nutrient resources.

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