Bal Ram Singh · Andy Safalaoh
Nyambilila A. Amuri · Lars Olav Eik
Bishal K. Sitaula · Rattan Lal *Editors*

Climate Impacts on Agricultural and Natural Resource Sustainability in Africa

Springer

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ISBN 978-3-030-37536-2 ISBN 978-3-030-37537-9 (eBook)
https://doi.org/10.1007/978-3-030-37537-9

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Foreword

Climate change and sustainable management of natural resources remain the major issues for all interventions to improve agricultural production, food access, and agriculture-based livelihoods in sub-Saharan Africa (SSA). Agriculture in SSA is predominated by small farms and subsistence farming by hand tools and limited use of other inputs including fertilizers, pesticides, and irrigation. There is also an increasing concern on declining land resources due to rapid soil degradation, harsh and uncertain climate, and the rapidly increasing population. Population of 800 million in 2010 is projected to increase to 1.1 billion in 2020 and to 1.8 billion in 2050 in Africa.

Despite these limitations, signs of agronomic yield increases and noticeable promise with impressive annual growth rates have been observed. However, sustaining the growth rate will become harder in the future due to increasing population, warmer climate, limited water resources, soil erosion and contamination, and more pervasive pests and pathogens. Furthermore, the IPCC Special Report on Global Warming indicates an increase of 1.5 °C change in temperature in SSA, creating a threat to ecosystems, biodiversity, and human health. These threats are more challenging and apparent in SSA than elsewhere. These challenges create a need of generating new knowledge on natural resource management and climate change to provide an enabling environment for smallholder farmers for engaging in sustainable agricultural practices.

Recognizing the value of agricultural production, the problems of natural resource degradation, and the challenge of climate change in SSA, a project entitled "Capacity Building for Managing Climate Change in Malawi" (CABMACC) was supported by the Royal Kingdom of Norway and implemented during the period 2013–2018. The Lilongwe University of Agriculture and Natural Resources (LUANAR) and the Norwegian University of Life Sciences (NMBU) jointly implemented the program. CABMACC was aimed to strengthen the teaching, training, research, technology development, and outreach for climate change adaptation and mitigation planning. A long-term and outstanding collaboration of LUANAR, NMBU, and Sokoine University of Agriculture (SUA) is further extended in this knowledge and experience-sharing platform to enhance dissemination of research findings from CABMACC project and beyond. The research under the abovementioned project focused primarily in Malawi, and therefore, contributors beyond the project were invited to cover wider geographical regions and their physical and social heterogeneities.

This book, *Climate Impacts on Agricultural and Natural Resource Sustainability in Africa*, deals with both the natural science and social science aspects, under dwindling natural resources, changing climate, and increasing climate uncertainties in SSA.

We convey our thanks to the successful authors, editors, and reviewers of the chapters in this book. We believe that the knowledge presented here is a crucial piece in the ingredients required for sustainable resource management under changing and uncertain climate in SSA.

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Preface

Most countries in sub-Saharan Africa (SSA) are dependent primarily on agriculture for economic growth and livelihoods. Majority of the households, especially rural smallholder farmers, are perpetually food insecure due to unsustainable practices in agriculture, degrading agroecology, poor natural resource management, and political and institutional challenges. Agriculture in SSA countries is dominated by small farms, often less than 2 ha, and is primarily based on hand tools and manual operations with limited use of farm machinery and soil amendments, insufficient supplemental irrigation, and inadequate measures for soil and water conservation.

The harsh and changing climate has further aggravated the situation, adversely affected the natural resources, jeopardized agricultural production, and marginalized the livelihood opportunities. Adverse effects of climate change on agricultural production and the environment have made the SSA region as one of the hot spots leading to severe degradation of soil, drastic depletion of nutrients and soil organic matter stocks, water scarcity and contamination, and reduction of the above- and below-ground biodiversity.

The overall goal of the project "Capacity Building for Managing Climate Change in Malawi" (CABMACC) was to improve livelihoods and food security through innovative responses and enhance the capacity of adaptation to climate change. It was conducted at the Lilongwe University of Agriculture and Natural Resources (LUANAR) in Malawi in cooperation with the Norwegian University of Life Sciences (NMBU). The project was implemented in several districts of Malawi, which are considered the hot spots for climate change-related vulnerability.

To deliberate some of the challenging issues stated above, an international conference on Sustainable Agriculture and Natural Resource Management under Changing Climate in sub-Saharan Africa was organized at LUANAR, Lilongwe, Malawi, from 16 to 18 October 2018. The conference was an avenue to bring in researchers who conducted research in SSA and share findings that can be documented to provide scientific evidences to form policies to attain sustainable agriculture and natural resource management under changing climate. The major objectives of the conference were to bring new knowledge on sustainable use of natural resources to enhance agricultural productivity under changing climate and explore new avenues of policies, value added chain, and adoption of innovative technologies on smallholder's farms.

The 34-chapter book represents the oral presentations made during the conference. The book includes, in addition to introductory and concluding chapters, five thematic parts, namely, (i) Conservation Agriculture, Carbon Sequestration, and Soil and Water Management, (ii) Sustainable Crop/Livestock/Aquaculture/Fish Production, (iii) Policy and Institutions for Sustainable Agriculture and Natural Resource Management, (iv) Value Added Options for Smallholder Market Access and Integration, and (v) Upscaling Innovative Technologies on Smallholder Farms.

Nearly 150 participants attended the conference from Malawi, Rwanda, Ethiopia, Tanzania, Kenya, Norway, and the USA. The steering committee involved in the organization of the conference included representatives from LUANAR, Malawi; NMBU, Norway; Ohio State University (OSU), USA; and Sokoine University of Agriculture (SUA), Tanzania. The conference was a concluding activity of the project "CABMACC" in Malawi funded by the Royal Kingdom of Norway.

We, the editors, wish to thank all the authors for their outstanding contributions for the book. We also thank the staff at Springer for following the proposed publication schedule and bringing out the publication on time. Our special thanks are due to PCO staff at LUANAR for their help in the organization of the conference and managing the flow of manuscripts between the authors and the editors.

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Editors Biographies

Bal Ram Singh, PhD is a professor emeritus at the Norwegian University of Life Sciences. He earned his PhD degree from G.B. Pant University of Agriculture and Technology, India. His program focuses on bioavailability and mobility of heavy metals in the soil and plant system, fertility management and agricultural sustainability in soils of the tropics, and carbon sequestration in soils. He has served as chairman of the program board "Soils and Plants" of the Research Council of Norway and as deputy head of the Department, in addition to many national and international committees. He chaired the Cost Action FA0905 (EU) "Mineral Improved Crop Production for Healthy Food and Feed," in which more than 200 scientists from 31 countries participated. He has supervised 76 graduate students and 16 visiting fellows/scientists from 20 countries and published 456 articles, of which 260 are in peer-reviewed journals and books. He is a fellow of ASA (2004) and SSSA (2005) and recipient of the International Soil Science Award (SSSA) in 2011. He is currently chair of Division 3 of the International Union of Soil Science, president of the Norwegian Society of Soil Science, and member of the Geomedicine Committee – Food, Environment, and Health of the Norwegian Academy of Science and Letters.

Andy Safalaoh, PhD is an associate professor of Animal Nutrition at the Lilongwe University of Agriculture and Natural Resources (LUANAR), Lilongwe, Malawi. He earned his PhD degree in Science and Technology Studies from the University of Nottingham, UK, and his Master of Science in Animal Science from Oklahoma State University, USA. His research interests focus on nutrient evaluation of unconventional feedstuffs such as sorghum and millet and recently on the use of insects as feeds. In addition, he has developed interest in the development and exploration of climate-resilient agricultural technologies and innovations as instruments for climate change adaptation and mitigation with a focus on the food-feed nexus. He has previously served as deputy head, Animal Science Department, and postgraduate and seminar coordinator and chairperson, Research and Publications Committee, LUANAR. He is currently the university program coordinator at LUANAR and has been leading the implementation of the 5-year (2013–2018) Norwegian Government-funded Capacity Building for Managing Climate Change in Malawi (CABMACC) Program and other projects. He is also a Leadership in Environment and Development (LEAD) Cohort 12 fellow (2004), Imperial College London. At regional level, he has facilitated several training sessions on agriculture, science, technology, and innovation (ASTI) in collaboration with Technical Centre for Agricultural and Rural Cooperation (CTA), Wageningen, Netherlands, and under the RAEIN-Africa Innovation Systems Approach Competency Building Training Program in eight countries. Before joining the university, he worked with Save the Children USA-Malawi Country Office in various portfolios as training and development coordinator, food production coordinator, and program manager.

Nyambilila A. Amuri, PhD is a senior lecturer at Sokoine University of Agriculture (SUA), Morogoro, Tanzania. Currently, she serves as a coordinator for research and publication and head of Department of Soil and Geological Sciences at SUA. She earned her PhD in Soil Science from the University of Arkansas, Fayetteville, USA, and her Bachelor of Science in Horticulture and MSc in Soil Science and Land Management from SUA, Morogoro, Tanzania. Her research, university teaching, and outreach experience and interest are on C and N dynamics and residue management in agricultural soils, integrated soil fertility and agroecological management, appropriate fertilizer uses in agriculture, agronomic micronutrient fortification and mineral nutritive quality of food crops, site-specific fertilizer recommendations and innovative and cost-effective soil testing methods, and soil chemistry. Currently, she serves as a secretary general for the Soil Science Society of East Africa (SSSEA) and also chaired East Africa Fertilizers and Soil Conditioners of the Agriculture and Agrochemicals Technical Committee. She has supervised 17 graduate students and published 50 papers in peer-reviewed journals, conference proceedings, chapters in books, and extension manuals. She is a recipient of the Fulbright Scholar Award, Margaret MacNamara Memorial Fund Award, and NORAD Sponsorship Award.

Lars Olav Eik is a professor at the Norwegian University of Life Sciences (NMBU) specialized in animal nutrition and small ruminant production systems. After graduating from NMBU, he joined Sokoine University of Agriculture (SUA), Tanzania, working on dry season feeding of ruminants and introduction of dairy goat keeping in Tanzania. After this assignment, he returned to NMBU and completed his PhD based on work with dairy goats in Norway.

Since 2005, he has coordinated three major research programs in collaboration with SUA. He has also participated in research projects in Ethiopia, Malawi, and South Africa. Often working together with farmers and private sector, his main interest is developing multifunctional production systems and value chains for small ruminants, both in tropical and temperate regions. He has supervised a number of PhD students, particularly from East Africa. His teaching covers small ruminant nutrition and production systems and tropical animal husbandry and aquaculture.

Bishal K. Sitaula, PhD is a professor at the Norwegian University of Life Sciences, where he earned his PhD degree. His program focuses on various institutional collaboration programs in higher education and research in South Asia, Africa, and Western Balkan. His international collaboration experiences in diverse environmental and development issues, in inter- and multidisciplinary framework, mainly focus on ecological and socioeconomic issues influencing the environment and global changes. The specific topics covered are anthropogenic influences in soil water and air, land use and changes, agricultural intensification, GHG fluxes from land uses, carbon dynamics, land degradation, system analyses, environmental education, conflict, peace and development studies including wisdom and personal transformation relevant for ecosystem management, and global change and development. He has field research experiences from Europe, Asia, Africa, and North America through institutional collaboration, educational program, and networking projects with national and international organization. He has various program leadership experiences. He has contributed in developing various educational program and course curricula and created several educational documentary films. Despite more than 190 scientific publications, he has wider public engagements/social work with extensive delivery of public talks with media coverage.

Rattan Lal, PhD is a distinguished university professor of Soil Science and director of the Carbon Management and Sequestration Center, Ohio State University, and an adjunct professor of the University of Iceland. He was president of the World Association of Soil and Water Conservation (1987–1990), International Soil and Tillage Research Organization (1988–1991), Soil Science Society of America (2006–2008), and International Union of Soil Sciences (2017–2018). His professional research interests include soil carbon sequestration for food and climate security, conservation agriculture, principles and practices of soil erosion control, eco-intensification of agroecosystems, soil restoration, and sustainable management of soils. He authored 950 journal articles, authored/edited 100 books, mentored 350 researchers, has 144 h index and total citations of 95,000, and is editor of the *Advances in Soil Science* and *Encyclopedia of Soil Science*. He is laureate of the GCHERA World Agriculture Prize 2018, Glinka World Soil Prize 2018, and Japan Prize 2019.

Part I
Introduction

Agricultural and Natural Resource Sustainability Under Changing Climate in Africa

Bal Ram Singh, Andy Safalaoh, Nyambilila A. Amuri, Lars Olav Eik, Bishal K. Sitaula, and Rattan Lal

Abstract Sustaining soil and forest resources, ensuring food security, and reducing poverty under changing climate in Africa are major challenges. The ever-increasing population, which may reach 1.4 billion by 2030, demands that food production must increase by 20% as compared to the present production. The population growth rate of 2.7% in 2017 in SSA region is also the highest in the world. This has intensified the problem of food insecurity as nearly 34% of population in SSA appears to be food insecure. Soils of SSA are prone to a range of soil degradation processes, and this is further aggravated by the increase in frequency and intensity of extreme events. The biophysical process of soil degradation is strongly influenced by the socio-economic, political, and cultural factors including the land tenure and gender-related issues. Indeed, soil-climate-human factors are intricately interlinked, and humanity's impact on soil is increasing with the increase in population, affluence with which the population lives, and changes in technologies. Use of innovative technologies, financing value-added investments, and promotion of value addition to agricultural products are the ways of increasing and ensuring sustainable agricultural and livestock production. The adoption of new technologies, such as integrated

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B. R. Singh et al. (eds.), *Climate Impacts on Agricultural and Natural Resource Sustainability in Africa*, https://doi.org/10.1007/978-3-030-37537-9_1

dairy and cropping systems, leading to increased farm productivity and income, is spreading in central Malawi and the southern highlands of Tanzania. For example, integrated dairy and cropping systems are spreading and farmers are keeping few but more high-yielding cows in both regions. These cows produce milk and meat for household consumption and sale, but the dung provided is used for biogas production for cooking and light, as well as fertilizer for the crops. Currently, dairy goats provide milk and meat for approximately 100,000 Tanzanian smallholder farmers. The idea of personal transformation for changing our attitude for greater good and for sustainable agriculture is also a part of this process.

1 Introduction

Providing food security, reducing soil degradation, maintaining forests and improving soil and ecosystem pools, adapting climate smart agriculture, and reducing poverty are the major challenges in Africa. These challenges are further aggravated by the ever-increasing population, which is expected to rise from 0.87 billion in 2010 to 1.4 billion in 2030 and 2.1 billion in 2050 in sub-Saharan Africa (SSA) (United Nations 2015). This increased population also leads to increased food demands, and FAO (2015) has forecasted that the food demands will increase by 20% by 2030 in SSA. Nearly 95% of agriculture in Africa is rainfed, and it is highly susceptible to drought and the projected climate change; and the increasing temperature has further aggravated the situation, adversely affecting the natural resources, agricultural production, and the livelihood opportunities for small farmers. Adverse effects of climate change on agricultural production and the environment have made the SSA region one of the global hot spots, leading to severe soil degradation, depletion of nutrients and soil organic matter (SOM) stocks, scarcity and contamination of water resources, and reduction of the above- and below-ground biodiversity.

Soil resources in sub-Saharan Africa (SSA) are diverse but suitable for agricultural land use and can support the growing of a wide range of food crops, horticultural crops, plantations, and livestock-based systems. However, these resources have experienced the severity of degradation by diverse processes (i.e., erosion, salinization, soil organic carbon or SOC, and nutrient depletion); and this has resulted into stagnated crop productivity, insecurity in food supply (one in four Africans), and mal- and undernourishment. The problem of food and nutritional insecurity is further aggravated by drought and heat waves caused by changing climate.

One of the ways of increasing and ensuring sustainable agricultural production is financing value-added investments and promotion of value addition to agricultural products (World Bank 2018). For example, in Malawi, the agricultural sector is limited by market access constraints and limited integration/coordination of most agricultural value chains. Therefore, the Malawi government has identified investments in agribusiness, value addition, and investments into the domestic markets as priority intervention areas, with emphasis on crops (Malawi Government 2017). Recent developments are, however, encouraging as livestock is also gaining prominence. The adoption of new technologies, such as integrated dairy and cropping systems, leading to increased farm productivity and income, is spreading in central Malawi and the southern highlands of Tanzania. For example, farmers keep few but more high-yielding cows for producing milk and meat for household consumption and sale. These cows also provide dung which provides biogas for cooking and light, as well as fertilizer for the crops. Combined with appropriate use of compound fertilizer and lime, crop yields have doubled or even tripled.

The objective of this chapter is to introduce briefly the issues pertaining to natural resource management, crop and livestock production, value addition, and innovative technologies for small farmers as they are affected by the changing climate in Africa.

2 Agricultural Productivity and Population Growth

Agriculture is a strategic sector that provides great potential for economic transformation to achieve inclusive development through poverty reduction and ensuring food security in Africa. This is affirmed by the African Union (AU) Comprehensive Africa Agriculture Development Programme (CAARDP), which highlights the importance of agriculture as the employer of more than half of the population of Africa and hence re-emphasizes agriculture in development programs and investment choices (NEPAD 2013). The role of agriculture as an employer of the majority of population, including youths, in Africa cannot be overemphasized. A study by Kafle et al. (2019) demonstrated that farming is still the major employment opportunity for a large section of the population in Tanzania and Malawi, with 59% and 56% of youth, respectively, consistently engaging in farming. Agriculture being the main employer in SSA is rated highly as a potential contributor to poverty reduction, especially in small-scale farming, if well developed (Dorosh and Thurlow 2018). The population growth of SSA has been steadily increasing, reaching 1.061 billion people in 2017 (Fig. 1; World Bank Data 2019); this makes SSA the region with the highest average world population growth rate of 2.7% in 2017 (NEPAD 2013; 1.06). The FAO forecasted an increase in food demand by 20% in 2030 in SSA due to increase in population (FAO 2015; FinMark Trust 2016). The increase in production must go hand in hand with increase in agricultural productivity, to ensure sufficient food and fiber and improve livelihood of the majority who depend on agriculture.

The population growth in SSA can both have positive and negative impacts to agriculture. SSA is a region with a strategic potential for rapid economic growth due to its increasing population; it is endowed with natural resources, including water and land (Deininger et al. 2014), and it has a high market potential. The increased population corresponds to increased food demand (Jayne et al. 2017; NEPAD 2013), making this an opportunity for agro-food system development to drive other non-farming sectors, since agriculture would be more productive and profitable. Considering SSA land coverage and diversity in agro-ecological zone (eco-region and soil types) (Lal 2015), SSA is strategically both the supply and the market for

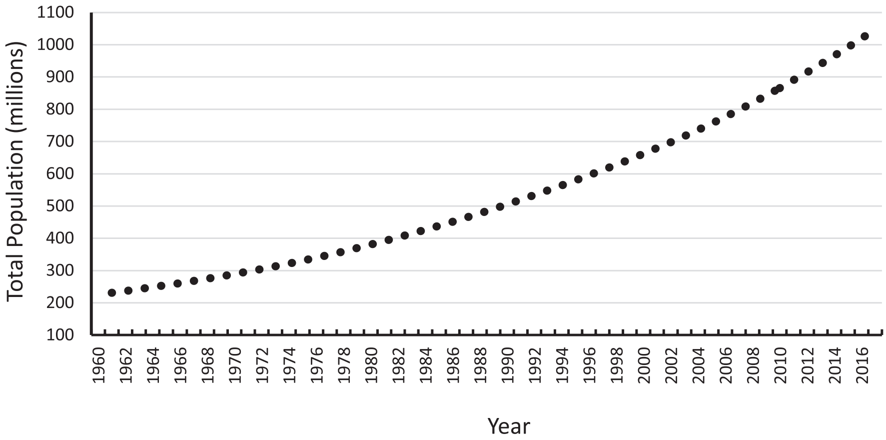

Fig. 1 Increase of total population in sub-Saharan Africa (excluding high-income countries) over 56-year period. (Data source: https://data.worldbank.org/indicator/SP.POP.TOTL?display=graph&locations=ZF)

agricultural produce, including food, fiber, and fuel. There is a great potential for SSA to trade within the region, considering the comparative advantages in natural resources and climate. Areas with high potential for crop production (humid and sub-humid areas) can trade with areas of high potential for extensive livestock keeping (semi-arid areas) of SSA. Developing agriculture begins with increasing its productivity and profitability, followed by distribution and agro-processing for value addition and preservation. This has been evidenced in a study by Dorosh and Thurlow (2018), who showed that non-agriculture sector, especially trade, transportation, and manufacturing (especially agro-processing), can effectively contribute to poverty reduction. However, Jayne et al. (2017) urge that agriculture is the major driver of development for the non-farming economy because if made profitable, it will provide higher income to a large population, resulting into high demand of goods and services. Therefore, agriculture and population growth are potentially major drivers of other sectors through provision of market, ensuring the availability of agro-produce as raw materials for agro-processing, and access and affordability of food to the growing population. Thus, the agricultural and non-agricultural sectors in SSA depend on each other for development.

The major challenge that remains in SSA is to increase agricultural productivity to meet the requirement of the growing population, in the face of climate change. Food insecurity is still prevalent in SSA with about 33.8% of population appearing to have severe prevalence of food insecurity in 2017, which represents an increase of 18% from 2016 (FAO and NECA 2018). Food supply from domestic agricultural production is not sufficient to meet the domestic demand in most of the SSA countries due to low yields and declining productivity, caused by low input use (Jayne et al. 2010). Thus, intensification of agriculture to increase yield per unit area is inevitable. Many SSA countries have attempted to increase productivity through ensuring supply/accessibility of agricultural inputs (improved seeds and fertilizers) using different approaches. Common approaches have included provision of subsidies to resource poor small-scale farmers in Tanzania, Malawi, Zambia, and Ghana (FinMark Trust 2016), with varied success, including improved productivity and ensuring the countries are food secure (FinMark Trust 2016). Further, performance of these programs is documented, discussed, and presented in this book as a way to provide evidence to improve similar future endeavors. Alternative sustainable intensification performances are also presented.

Another major threat caused by population growth is the increase in pressure on land, which may constrain farming system. One way of ensuring increased productivity is agricultural intensification, which can be done by increasing yield per unit area through increased use of agricultural inputs (improved seeds, fertilizers, pesticides), labor, and technology (irrigation, mechanization, frequency of cultivation) (Carswell 1997), as opposed to increasing production by expanding the area under cultivation or rangeland. A study in Ethiopia by Josephson et al. (2014) showed an increase in agriculture intensification and a decrease in farm size with increase in population. Similarly, a community approach to the study of increased population and climate change impact in SSA revealed that these two stresses cause shift in livestock-keeping practice from purely migratory pastoralism to agro-pastoralist coupled with adoption of conservation agriculture (CA) and have a positive impact by improving food security in SSA dryland areas (Burian et al. 2019). However, improved food security due to change of agro-pastoral system has not been universally achieved (Tache and Oba 2010; Josephson et al. 2014), especially in areas with less than 500 mm annual rainfall and without CA. Further analysis by Burian et al. (2019) cautioned that with continued increase in population, it would reach a stage when the household land area will be too small to sustain household food security, leading to food shortage, to the extent that increased productivity might not solve the food shortage problem. Another study in Kenya reported that 500 people/km^2 is the threshold for intensification in farming; beyond this population density, even agricultural intensification will also decrease (Muyanga and Jayne 2014), and the agricultural productivity may not sustain the population demand. These findings suggest that the current increase in population may cause serious problems in food supply and increase in hunger and poverty. The warning is that increase in productivity per unit area alone may not solve the problem. In such a scenario, sustainable intensification that ensures increase in productivity without compromising environmental and social benefits is needed (Dicks et al. 2019). Therefore, a more integrative approach that includes other sectors such as health and environment is necessary.

Although agricultural production increased during the 30 -year period from 1983 to 2013, the anticipated productivity is yet to be realized (NEPAD 2013). The increased production has been due to expansion of agricultural land (Amuri 2015; Charles et al. 2010), leaving less or no improvement in intensification of land and labor (NEPAD 2013). The trend of expansion of agricultural land can be exemplified by the increase in land area under cereal production (major staple food for most of SSA population) at the rate of 1 million ha (Mha) per year (Fig. 2). The trend of increase in cropland is similar to that of increase in population in SSA, indicating

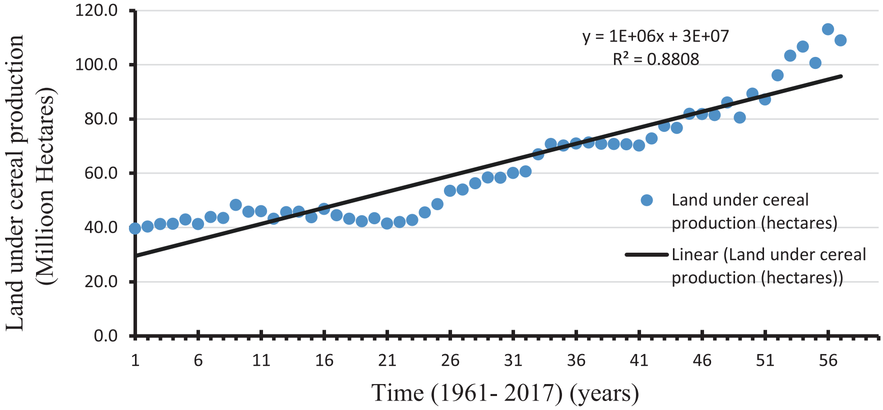

Fig. 2 Increase of land area under cereal production in sub-Saharan Africa (excluding high-income countries) over 56-year period. (Data source: https://data.worldbank.org/indicator/AG.LND.CREL.HA?view=map)

that the major coping strategy to satisfy food demand has been through expansion of agricultural land. The productivity per unit area is low, ranging from 1.1 to 1.7 Mg/ha for cereals for 2009–2017 (FAOStat 2019a, b) and 0.2–0.7 Mg/ha for cotton under rainfed conditions (Mathews and Tunstall 2006; VIB Fact Series 2017). The dominant agricultural production system in most of SSA is still subsistence, with small farm size and limited use of fertilizers and/or other agrochemicals. These farming systems are usually uncoordinated, with weak farmer's institutions and cooperatives, which render farmers less competitive in the market and usually fetch lower prices than investment in agriculture. As a result, the farming system in SSA has less promise to sustain employment, especially for youth. Therefore, a first step toward agricultural development in SSA should be increased productivity and empowerment of farmers to implement modern agricultural technology effectively to improve productivity.

The farming systems and population pressure in SSA tend to increase the extent of soil degradation, causing depletion of SOM (Lal 2016a), nutrient mining (Amuri 2015; Lal 2015), overgrazing, and accelerated erosion. Soil degradation is further exacerbated by poor land use planning, with little or no scientific evidence to back up land use and fertilizer use. It further reduces the ability to utilize adequately the land resources to support demands from the growing population. The land degradation and expansion of agricultural land has also been linked to land conflicts among multiple users. Some studies have suggested that land tenure may manage conflicts, but Kalabamu (2019) reported persistence of land conflict despite some success in land tenure system in Botswana. Thus, land tenure system may not be effective in solving land conflicts without soil conservation and restoration of degraded land.

The steady increase of population in SSA creates market for produce and commodities and increases demand for food and fiber. To sustain the steadily growing population, agricultural productivity must be increased, and the latter must take into account sustainable use of resources to ensure neither soil degradation nor expansion of agricultural land encroaches on areas such as water sources, wetlands, natural forests, and wildlife. Thus, ecological advocacies must be increased to ensure sustainable intensification. Further, a more comprehensive analysis is needed to come up with an innovative and sustainable intensification package that is sound in terms of policy, technical, and environmental considerations. The papers in this book provide some potential technologies and practices toward sustainable crop and livestock production.

Climate change has become an additional challenge to rainfed agriculture among smallholder farmers. Weather variability has been experienced, with some seasons having adequate rainfall, others having it in insufficient amounts, while in other seasons the onset of rain has been changing. Under such climate variability, efforts to increase productivity by intensifying sustainable use of input have not yielded results. In some cases, use of fertilizers and pesticides has rendered no yield due to moisture deficit. Therefore, sustaining increase in population calls for innovative intensifications that are resilient to climate change impact and weather variability. Burian et al. (2019) suggested more changes in the farming system to bring on board irrigation agriculture, mechanization, and increase in off-farm jobs. These innovative technologies must be adaptive to the farming system in SSA, if the positive effect of increased population as market for agricultural produce is to be realized.

3 Soil and Water Resources

Soil resources in general and those of SSA in particular are diverse and suitable for agricultural land use and growing a wide range of food crops, horticultural crops, and plantations and for livestock-based systems. Further, soil resources of Africa have been mapped (EC 2017). The extent and severity of degradation by diverse processes (i.e., erosion, salinization, soil organic carbon, and nutrient depletion) is assessed, and their causal factors are identified (ITPS 2018). Yet, the agronomic productivity of food staples has stagnated since the 1960s, soil degradation is rampant, food insecurity affects one in four Africans, and malnourishment and undernourishment are serious issues. Further, the problems of food and nutritional insecurity may be exacerbated by the uncertain and changing climate characterized by extreme events including the pedological drought and heat waves. Further, the risks of the already serious problem of soil erosion by water and wind may be drastically aggravated because of the change in climate and the agronomic yields of food staples adversely affected because of the increase in frequency and intensity of drought, the prevalence of heat wave, and the increase in frequency of other extreme events. Soil degradation is caused and aggravated by land misuse and soil mismanagement and perpetuated by the prevalence of extractive farming practices.

Soil and water resources in SSA, as anywhere else, are intricately interlinked through climate. Soil is the largest reservoir of fresh water. Therefore, the soil hydrological cycle and its partitioning into different components are determined by the climatic parameters at micro-, meso-, and macroscales. Retention, denaturing, filtration, and purification are done during percolation of water through the soil solum. Land use and management is a strong control of the hydrological cycle and its partitioning into different components.

The low agronomic yield and perpetual hunger have persisted in SSA despite the widespread adoption of improved varieties developed by the national and international programs including those released by the CGIAR centers (e.g., CIMMYT, ICRISAT, ICARDA, IITA, WARDA, IRRI, ILCA, ICRAF). Indeed, the Green Revolution (GR) of the 1960s by-passed SSA despite the availability of improved varieties because other components (i.e., fertilizers, irrigation, appropriate farm machinery, and energy-based inputs) were either not available to the resource-poor farmers and small landholders (<5 Ha) or farmers were not sure of their usefulness because of the fragile soils and harsh environments.

Soils of SSA are prone to a range of soil degradation processes – physical, chemical, biological, and ecological. The extent and severity of degradation (especially the physical degradation by accelerated erosion) will exacerbate due to the ever-growing pressure of the rapidly increasing population in conjunction with the increase in frequency and intensity of extreme events (e.g., drought stress, heat wave, high incidence of pests and pathogens including infestation by weeds). Further, the extent and severity of soil degradation is related to the interaction between the factors and causes of soil degradation. Among the causes, the human dimensions are the critical determinants of soil degradation. Indeed, the biophysical process of soil degradation is strongly influenced by the socio-economic, political, and cultural factors including the land tenure and the gender-related issues (Lal 2007a). A high percentage of farms in SSA are operated by women, and often the technological advances are neither available because of being prohibitively expensive nor are these often appropriate for their specific needs.

Rather than the seed-centric approach of the conventional GR package of the 1960s, the constraints to narrowing the yield gaps must be addressed through a soil-centric approach (Lal 2019). The latter must be based on restoration and sustainable management of soil health (physical, chemical, biological, and ecological). In this context, key determinants of soil health must be identified and judiciously managed (Lal 2016c). As is evident, the yield potential of elite varieties can only be realized, if grown under optimal conditions of soil environments especially those of soil physical conditions (e.g., structure, tilth, plant available water capacity, and water infiltration rate and soil temperature regime).

Most soils of agroecosystems of SSA are severely depleted of their soil organic carbon (SOC) concentration and stock. The SOC concentration in the root zone of upland soils may be as low as 1 g/kg or lower in comparison with the threshold level of >11 g/kg (Aune and Lal 1997) and preferably 20 g/kg (Loveland and Webb 2003). Severe depletion of the SOC concentration may be attributed to a widespread adoption of extractive farming practices such as residue removal for competing uses (e.g., feed, fuel, fencing and house construction, and uncontrolled grazing), in-field burning, and none or low rate of inputs of organic and inorganic amendments.

Susceptibility to a range of soil degradation processes is another cause of the depletion of SOC concentration and stock in soils of SSA. The SOC-related degradation is set in motion by decline in soil structure, reduction in proportion and strength of soil aggregates, crusting, compaction, decline in water infiltration, high runoff, erosion and non-point source pollution, and the attendant drought-flood syndrome. Indeed, drought and flood are the two sides of the same coin. Thus, restoration and judicious management of SOC concentration and stock is the most critical strategy to reverse the degradation trends.

4 Impact of Climate Change

Climate is one of the five active factors of soil formation (Jenny 1941), and "human" is now the sixth factor, hence the name "Anthrosols" (Bidwell and Hole 1965; Dudal 2004). Leopold (1949) stated that "Human beings are all interlocked with plants, animals, soils and waters in one humming community of cooperation and competition: one biota. They are related and bound into a seamless fabric." Indeed, soil-climate-human factors are intricately interlinked, and humanity's impact on soil is increasing with increase in population, affluence with which the population lives, and changes in technologies. Thus far, from the onset of agriculture about 10–12 millennia ago till now, the impact of humanity on climate and soil has been negative because both of these resources have been taken for granted. Indeed, climate and soil, considered and used as global commons, are prone to the tragedy of commons and are a phenomenon of the Anthropocene (Lal 2007b).

Global abundance of greenhouse gases (GHGs) in 2017 was 405.5 ppm for carbon dioxide (CO_2), 1859 ppb for methane (CH_4), and 329.9 ppb for nitrous oxide (N_2O) (Lal 2018a; WMO 2019).The atmospheric concentration of CO_2 attained the value of 415.6 ppm during May 2019 (NOAA-ESRL 2019). Carbon dioxide levels at present are more than those at any time during the past 800,000 years (Lindsey 2018). Three principal sources of emission of GHGs are fossil fuel combustion, tropical deforestation, and accelerated soil erosion. For the decade of 2008–2017, annual average emissions were 9.4 ± 0.5 Pg C/year from fossil fuel combustion and 1.5 ± 0.7 Pg C/year from tropical deforestation. Of this, 4.7 ± 0.02 Pg C/year was absorbed by the atmosphere, 2.4 ± 0.5 Pg C/year by the ocean, and 3.2 ± 0.8 Pg C/year by the land-based sinks with a budget imbalance of 0.5 Pg C/year (Le Quéré et al. 2018). For the year 2017, emission was 9.9 ± 0.5 Pg C/ year from fossil fuel combustion and 1.4 ± 0.7 Pg C/ year from tropical deforestation. In comparison, uptake by different sinks was 4.6 ± 0.2 Pg C/year by the atmosphere, 2.5 ± 0.5 Pg C /year by the ocean, and 3.8 ± 0.8 Pg C / year by the land-based sinks, with a *budget imbalance* of 0.3 Pg C (Le Quéré et al. 2018). Thus, the anthropogenic activities have approximately caused global warming of 1.0 °C above the pre-industrial level (with a range of 0.8–1.2 °C). Further, with the business-as-usual attitude, global warming is likely to reach 1.5 °C between 2030 and 2052 (IPCC 2018).

The importance of land-based solutions, such as sequestration of atmospheric CO_2 in the terrestrial biosphere (Lal et al. 2018a), cannot be overemphasized. The soil C sink capacity of 135 Pg (Lal 2018a), equivalent to the historic C loss from soils of the managed ecosystems, is equivalent to CO_2 drawdown of 63 ppm. Re-carbonization of the soil and the terrestrial biosphere has numerous co-benefits, especially those related to advancing specific Sustainable Development Goals (SDGs) of the United Nations (Lal 2018b; Lal et al. 2018b).

5 Value Addition for Smallholders

Malawi is a landlocked agro-based economy in sub-Saharan Africa with a per capita GNP of just US $320 in 2017 (World Bank 2017) and is vulnerable to several external and internal shocks. About 84% of the population live in rural areas, and around 70% of the population live below the international poverty line of US $1.90 per day (World Bank 2017).

Over the past decade, Malawi's development progress has been negatively affected by climate-induced shocks leaving the country in a cycle of vulnerability. Malawi has experienced extreme droughts and floods, which have negatively impacted agricultural production. This makes adaptation a priority area, as climate change impacts disproportionately affect those least able to bear them. Climate-related shocks, market failure, domestic political, and governance shocks have collectively contributed to economic stagnation and a slow pace of poverty reduction (IMF 2018). The consequences are being felt through declining crop yields, low animal productivity, increasing costs of production, and difficulties for the economy to keep pace with population growth.

A significant proportion of the Malawi population faces serious nutritional deficiencies. Only 8% of children aged between 6 and 23 months meet their minimum meal frequency, and 37% under the age of 5 are stunted due to malnutrition. Malnutrition affects children's health condition and learning possibilities and is a severe challenge for Malawi's overall development. This calls for an integrated food systems approach that would address both food and nutrition security, including dietary diversification and nutrition education.

Smallholder farmers face significant production and market constraints, poor access to information, and inadequate public services, which adversely affect their welfare and employment opportunities. Current land use practices are eroding the capacity of the natural resource base to sustain productivity for current and future generations, with extractive land use practices causing alarming rates of land degradation: loss of top soil averages 29 tons per ha per annum, and tree cover is declining at over 1% per annum.

According to Malawi's Issues Report submitted to the UNFCCC, agriculture is the key sector to achieve food security, economic growth, and wealth creation. More than 80% of the country's population is directly or indirectly employed in the sector. This also accounts for nearly 90% of foreign exchange earnings and 39% of gross domestic product (GDP). Despite its importance, the agriculture sector faces a number of challenges including (i) overdependence on rainfed farming, (ii) limited absorption of improved technologies, (iii) weak private sector engagement, (iv) limited farmer organization, and (v) lack of investment capacity in mechanization. About 99% of Malawi agricultural land is under rainfed cultivation, and smallholder farmers cultivate 69% of that land.

One way of increasing and ensuring sustainable agricultural production is financing value-added investments and promotion of value addition to agricultural products (World Bank 2018). For example, according to the Malawi National Agricultural Investment Plan (NAIP), commercialization of the agricultural sector is limited by market access constraints and limited integration/coordination of most agricultural value chains. As such, the Malawi government has identified investments in agribusiness, value addition, and investments into the domestic markets as priority intervention areas, with emphasis on crops (Malawi Government 2017). Recent developments are however encouraging as livestock is also gaining prominence.

In both Malawi and neighboring Tanzania, pioneer farmers have adopted new technologies leading to increased farm productivity and income. For example, in central Malawi and the southern highlands of Tanzania, integrated dairy and cropping systems are spreading. Farmers are keeping more high-yielding cows for producing milk and meat for household consumption and sale. Combined with appropriate use of compound fertilizer and lime, crop yields have doubled or even tripled.

Most farmers cannot afford buying a dairy cow. Therefore, in Tanzania, dairy goats are becoming increasingly popular. Since the introduction four decades ago, Norwegian dairy goats and crosses have reached a number of about half a million, which is more than 10 times the numbers of goats in Norway.

For farmers, attaining stable and fair commodity prices is a key success factor. *Njombe Milk* Factory Company Limited in Tanzania and Lilongwe Dairy in Malawi are examples of successful enterprises contributing to increased farmer's income where milk is bought at an agreed price and farmers are assured of ready market. Smallholder farmers may also increase their income through sale of meat as exemplified by the Nyama World with its newly established slaughter facilities in Mzuzu, Malawi. The company founded in 2010 is a growing agribusiness with a known national brand of high-quality meat. It has since developed into a fully integrated value chain with a feedlot, a fattening farm, a halal-certified processing plant, and a wholesale distribution system combined with six retail outlets. The company supports farmers with improved Bonsmara bulls to crossbreed with the Malawi Zebu and then buys 6- to 8-month-old bulls from farmers for fattening, thereby providing farmers with a market outlet. The strategy is to expand the domestic business and shortly to build exports into neighboring countries and the Middle East markets. Norfund has made a 23.3 million NOK loan commitment (2.75 million USD) to Afrisphere Worldwide Limited, who trades as Nyama World with a fully integrated beef production company in Malawi. All livestock are sourced, processed, and sold predominantly in Malawi. Once the business is fully developed, the aim is to engage as much as up to 30,000 smallholder farmers in an integrated value chain.

This example demonstrates that if the successful value chains are established for different commodities, farmers are capable of responding to market demand.

6 Innovative Technologies on Smallholder Farms

In countries like Malawi and Tanzania, outside the national parks and forest reserves, small-scale farmers are keepers of the land, engaged in small-scale subsistence agriculture, producing food mainly for household consumption and an increasing amount of cash crops for domestic and export markets. In most cases, low agricultural productivity remains a challenge, and it is very important that Tanzanian farmers improve productivity in order to provide adequate amounts of food for a growing population. At the same time, conservation and sustainable management of natural resources are vital in order to mitigate climate change, maintain biodiversity, and ensure sustained supply of water. There is a vast and virtually untapped potential for improved agricultural productivity and sustainable environmental management, which can be attained through improved agricultural and livestock practices, as well as commercial smallholders' tree planting (including agroforestry) and natural resource conservation activities. The fundamental rationale envisaged is that if farming communities increase productivity, household income will subsequently increase, resulting in reduced poverty and hunger. Hence, the continuation of up-scaling and developing more efficient production and natural resource management systems can enable the small-scale farmers to escape the poverty trap.

Since soils in Malawi and Tanzania are mostly depleted and crop yields are low, continued research on use of compost, manure, lime, and appropriate compound fertilizer with micronutrients needs to be emphasized. Incorrect application of fertilizers and pesticides is a major concern in the region. Therefore, we recommend the "One Health, One World Approach" with a priority on food safety throughout the food value chain. On the best farms, appropriate fertilizer and herbicide use (*best practices*) increased maize yield from 1.3 tons/ha (national average) to 5.4 tons.

Introducing new technologies takes time. In southern highlands, Njombe, Tanzania, the work started 20 years ago with a focus on dry-season feeding of cows for improved annual distribution of milk production. Today farmers from many areas in Tanzania as well as other countries are coming to our demonstration farms in order to learn about integrated dairy farming practices. The use of "farmer-to-farmer learning," by means of lead farmers educating others based on own experiences, has become an efficient tool for up-scaling new farming practices.

The Njombe Milk Factory, which is partly owned by the dairy farmers, currently distributes milk, yoghurt, and an assortment of cheese types locally as well as to food stores as far as Dar es Salaam and Zanzibar. In Malawi, pilot biogas plants were also recently introduced in Bolero under the Capacity Building for Managing Climate Change (CABMACC). However, it is manure and not milk, which is the most important product from this integrated livestock system. Manure used as biogas initially provides energy and subsequently bio-slurry, which is used as a soil