Chapter 9
Soil Quality and Agricultural Sustainability in Semi-arid Areas

Msafiri Yusuph Mkonda and Xinhua He

Abstract Soil quality and agricultural sustainability are required to feed about nine billion people by the year 2050. To feed such a population, the planet ought to increase food production by 60%. To attain agricultural sustainability, there should be a balance among biophysical, economic and social dimensions under which soil quality is a core aspect. It is worthwhile to explore soil quality versus agricultural sustainability in sub-Saharan countries because the population is expected to increase by 80%. This chapter reviews the current agronomic practices in countries characterized by semiarid agro-ecological zones and their implications to soil quality and agricultural sustainability, using Tanzania as a case study.
We found that agro-pastoralism based on maize, sorghum, millet, sheep, cattle and cow is a current dominant agricultural system but with low yields. Monoculture has contributed to the degradation of soil quality. Drought has raised issues to already stressed ecosystems and made rain-fed agriculture a vulnerable and unsustainable livelihood for smallholder farmers. This situation has reduced the per capita grain harvested area from 0.6 to less than 0.4 ha and thus, affected for more than 70% the smallholder farmers' livelihoods. Fortunately, areas using fertilizations of animal manure and other organic soil management practices have increased soil fertility and crop yields from 0.82 tn ha^{-1} under no-fertilization to 1.8 tn ha^{-1} under organic fertilization.

Keywords Agricultural sustainability · Climate change · Ecology · Food security · Nutrient use efficiency · Organic fertilizations · Semiarid · Smallholder farmers · Soils quality · Tanzania

---

M. Y. Mkonda (✉)
Centre of Excellence for Soil Biology, College of Resources and Environment, Southwest University, Chongqing, China

Department of Geography and Environmental Studies, Solomon Mahlangu College of Science and Education, Sokoine University of Agriculture, Morogoro, Tanzania

X. He
Centre of Excellence for Soil Biology, College of Resources and Environment, Southwest University, Chongqing, China

School of Biological Sciences, University of Western Australia, Crawley, Australia
e-mail: xinhua.he@uwa.edu.au

E. Lichtfouse (ed.), *Sustainable Agriculture Reviews 32*, Sustainable Agriculture Reviews 32, https://doi.org/10.1007/978-3-319-98914-3_9

9.1 Introduction

Increasing needs for food due to global population has forced agricultural systems to be the main concern to addressing the problem (Vermeulen et al. 2012; and IPCC 2014). Global food demand has increased rapidly due to the fact that, the growth of cereal grain is 1% while that of population is 3% (FAO 2006, 2008; and 2012). This demands has been more rampant from the last two decade of twentieth century and the first decade of twenty-first century (Monfreda et al. 2008; and Branca et al. 2013). During this time, the per capita cereal produced has decreased from 150 to 130 kg per person in Africa while increasing in Asia and South America from 200 to 250 kg per person (FAO 2008, 2012; and Sieber et al. 2015). This has led to the growing demand of sustainable agriculture to attain optimal food security (Monfreda et al. 2008; and FAO 2012).

The pressure from increasing population, limited arable land and increasing scenarios of climate change have compelled experts to assess agricultural sustainability (Branca et al. 2013; Ahmed et al. 2011; and Rowhani et al. 2011a). The decline of agricultural productivity is evidenced by a number of scenarios such as frequent food insecurity, hunger and malnutrition cases (URT 2007, 2012; and FAO 2012). While the decline of per capita grain harvested areas at global level is the most alarming indicator of agricultural unsustainability in sub-Saharan Africa (UNEP 2011; and Poppy et al. 2014). The per capita harvested area declined from 0.23 ha in 1980s to 0.12 ha in early 2000s in the region (FAO 2006; UNEP 2012; and Branca et al. 2013). In addition, irrigated land has declined from 0.047 ha in 1980s to 0.044 in 2000s (URT 2007; FAO 2013; and Duru et al. 2015). Unfortunately, the Sub-Saharan Africa and more especially in the arid, semiarid tropical climates experience the most consequences of climate stress (Giller et al. 2009; Branca et al. 2013; Chai et al. 2015; and Pauline et al. 2016).

In Tanzanian semiarid tropics, long-term monoculture practices have significantly decreased total carbon, nitrogen contents and other important minerals (Bockstaller et al. 1997; Hartemink 1997; Medeiros et al. 1997; Sosovele et al. 1999; Monfreda et al. 2008; and Msongaleli et al. 2015). This situation had later declined the level of soil quality and crops production and therefore affecting the livelihoods of over 70% of the smallholders in the area (Duru et al. 2015; and URT 2014; 2012). The continued stresses from climate change have exacerbated the vulnerability of these farmers and later on elevated food insecurity and abject poverty (Paavola 2008; Lema and Majule 2009; Yanda 2015; Kangalawe 2016; and Kangalawe et al. 2016).

The annual food deficit was approximated to 50% in the area because the little obtained yields were consumed within 3–6 months leaving the people under severe starvation for the rest of the year (URT 2007, 2012 and 2014). More bad years still happen in the area and has skyrocketed food insecurity and abject poverty among the smallholder farmers (Ahmed et al. 2011; Rowhani et al. 2011b; Kangalawe and

Lyimo 2013; and URT 2014). From that point, improvement of soil quality is very important. According to the context, good agronomic practices is an immediate resolution (Andrews 1998; Lal 1998; Andrews and Carroll 2001).

The improvement of soil ecology is a primary factor to elevate crop yields and food security (Doran and Zeiss 2000; Lichtfouse et al. 2009; and FAO 2013). Organic fertilizations increases the accumulation of soil organic matter that raise cations ions in the soil and facilitate the uptake of important nutrients especially nitrogen, phosphorus and potassium for crops growth. A number of studies have recommended soils organic management as good proposition to achieving agricultural sustainability (Lal 1998; Bationo et al. 2006; and Kimaro et al. 2015). Organic manure has increased soil organic matter replenishment where applied. Practically, soils replenishments has been significantly higher in the homestead areas than far farmland. This is because most farmers have no reliable means of transporting these manure to far distance (McDonagh et al. 2001; Thierfelder and Wall 2009; Partey and Thevathasan 2013; and Msongaleli et al. 2015). Therefore, crops yields were significantly higher in the homestead than distant farms.

Organic soil managements have significantly increased crops yields by more than 40% and they act as climate smart practices in the midst of changing climate (Vanlauwe 2004; and Giller et al. 2009). Similarly, they serve as a sustainable measure for environmental services (URT 2007). Among other things, they create favorable condition that catalyzes biological functions of mycorrhizas and other soil microorganisms (McDonagh et al. 2001). In this environment, the influence of mycorrhiza fungi on plant nutrient uptake and growth, resistances to pathogens is significantly higher than in no-fertilization (Birch-Thomsen et al. 2007; and Wall et al. 2013). Therefore, agricultural sustainability will be attainable only when soil quality is optimal. Under such a situation, conservation of environment is particular important to yield optimal agricultural outputs. The mutual environment and agricultural synergies can ensure increased crops yield, food security, and ecological conservation (UNEP 2011, 2012; and Poppy et al. 2014).

However, in semiarid areas of Tanzania, food production is among the main driver of environmental degradation, and if not well addressed, it may completely destroy the ecosystems. Therefore, food policies should be respectful to environment and more especially on the fragile ecosystems in order to achieve the win-win situation between the two aspects. This study explored the role of good agronomic practices (e.g. organic fertilization and other soil organic management) in soil quality improvement and agricultural sustainability in the semiarid tropics agro-ecological zone of Tanzania, and other countries where these organic managements are practiced.

9.2 Tanzania

The present study focuses on Tanzania, an Eastern African country with rich biodiversity. Based on altitude, precipitation pattern, dependable growing seasons and average water holding capacity of the soils and physiographic features, Tanzania has seven agro-ecological zones although there are numerous micro ones. Agro-ecological zones refers to the geographical areas exhibiting similar climatic conditions that determine their ability to support rain-fed agriculture (Bockstaller et al. 1997; and URT 2007). Therefore, climate varies over different agro-ecological zones while agricultural systems and crops produced depend on agricultural knowledge of the farmers.

Tanzania semiarid zones covers a number of regions and it has been grouped into two major parts. These are central and southern. The central region includes Dodoma, Singida, Northern Iringa, some parts of Arusha, Shinyanga (URT 2007). These regions are located at 1000–1500 m altitudes and receive unreliable unimodal rainfall ranging from 500 to 800 mm per annum. In general, the topography of the area is characterized by undulating plains with rocky hills and low scarps with a well-drained low fertile soils. It has an alluvial hardpan and saline soils in Eastern Rift Valley and Lake Eyasi and black cracking soils in Shinyanga (URT 2007).

The southern parts involves the regions of Morogoro (except Kiliombero and Wami Basins, and Uluguru Mountains), Lindi and Southwest of Mtwara. These regions are located at 200–600 m altitudes and receive unreliable unimodal rainfall ranging from 600 to 800 mm per annum. Overall, the topography of the area is characterized flat or undulating plains with rocky hills, moderate fertile loams and clays in South Morogoro, infertile sand soils in center (URT 2007). The growing season in both parts starts from December to March however, it has been changing due change of onset and cessation of rainfall caused by global climate change.

To write this paper, we reviewed more than 50 journal papers conducted within the topic, area or/and nearby area with similar climates. We selected the scientific papers published in authentic journals mostly from the web of science. Mainly from journals with high impact factors and number of citation of a particular paper. The most recent publications were given priority in the selection. Analyses and modification of some data were done to suit the study objectives. We considered all publication ethics including the seeking of permission to journal authors where necessary. The review was done to meet the standards of Sustainable Agricultural Reviews.

9.3 Dominant Agricultural Systems and Crops Produced

Small scale agro-pastoralism is a dominant livelihoods in the area (Sosovele et al. 1999; and Lema and Majule 2009). It produces maize, leguminous, millet and sorghum, sheep, goat, cattle and donkey for both food and sale. The Maasai tribe forms the core of this semi-nomadic system in the area. Agro-pastoralism prevails in Arusha, Singida, Shinyanga and Morogoro regions just to mention some (URT 2007). Extensive semi-nomadic grazing and small scale cultivation of drought tolerant roots and cereals are practiced to cope with climatic conditions (URT 2007; Lema and Majule 2009; and Kangalawe and Lyimo 2013).). However, the level of adoption is based on the biophysical characteristics of the place (see Table 9.1), but mixed farming is not yet effectively adopted to harvest full potentials.

Table 9.1 Farming systems in the study area

Farming systems types	Rank of Farming Systems
Maize/legume system	1
Livestock/Sorghum-millet system	2
Pastoralist system	3
Agro pastoralist system	4
Cassava/cashew/coconut system	5
Agroforestry (the enclosed systems *"ngitiri"* in Shinyanga)	6
Wetland paddy/sugarcane system in water sources	7

Livestock/sorghum-millet system is prevalent in Shinyanga. Sorghum, millet and maize are dominant. Sugarcane are the least adopted farming system due to nature of climate. It can only be adopted in fewer areas with swamps and wetlands. (Source: Modified from Sosovele et al. (1999))

In few areas where manure fertilizations is practiced, the yields from maize, millet and sorghum have increase from 0.82 to 1.8 tn ha^{-1} under no-fertilization and organic fertilization respectively. The same has applied on ecology by increasing the influence of mycorrhiza fungi and other microorganism to perform biological functions (Hartemink 1997; Partey and Thevathasan 2013; and Kimaro et al. 2015). These are benefits that outsmart the areas under no-fertilizations. In this aspects, organic manure raise cation ions that increase the uptake of important soil nutrients by the plants. As well, this acts as a buffer to avoid nutrients loss through leaching.

9.4 Soil Quality Status at Agroecosystem level and Farm Level

Soil quality can be defined in a number of ways depending on the community context and understanding (Doran and Zeiss 2000). It is regarded as a capacity of the soils to perform specific function (Lal 1998). Similarly, Doran and Parkin (1994) asserted that soil quality is a capacity of the soils to functions with the surrounding ecosystem to sustain biological productivity, conserve the quality of the environment as well as safeguarding the health of animals and plants. They also pointed that it can be a measure of the soil condition in relation to the requirements of one or more species and/or to any human needs. Generally, soil quality can be understood differently from various discipline (Karlen et al. 2003). This study assessed the influence of soil quality on agricultural sustainability to estimate the impacts of diverse agricultural systems to peoples' livelihoods in semi-arid and tropical climates. These practices either increase or/and decrease soil fertility and thus, the whole process has implications to the sustainability of agriculture and food security in various countries.

According to Lal (1998) soil degradation often prevails due to monoculture and land-use conversion and thus, reducing soils quality and fertility. This degradation may vary over soils types such as Chromic Luvisols, Cambisols, Histosols etc. (Hartemink 1997; and Glaser et al. 2001). In Tanzania (i.e. with diverse agro-ecological zones) and other tropical countries, this soil quality decline has been affecting crop yields and thus, putting food security in risk. Various soil models predict that this decline may be more pronounced in future if substantial interventions are not taken (Hartemink 1997; and Bationo et al. 2006). Under such a situation, food security and malnutrition will continue affecting the vulnerable societies especially in sub-Saharan Africa.

To improve the agro-ecosystems, good agricultural practices (i.e. organic soil management) seem to increase soil fertility/quality at farm level and entire ecosystems (Andrews and Carroll 2001). Manure fertilizations and other forms of organic soils management serve as adaptation measures and optional livelihoods to the vulnerable communities in most semi-arid areas of Tanzania and Africa in general. Manure offers optimal ingredients of nitrogen, carbon, phosphorus and potassium for plant growth. These nutrients also create favorable condition for mycorrhiza fungi to function well especially in helping the plants to optimize nutrient uptake, growth and resistances to pathogens (Glaser et al. 2001; Vanlauwe et al. 2014; and Kimaro et al. 2015). In Shinyanga, Dodoma and parts of Morogoro regions organic fertilization has significantly increased crops yields under smallholders farming. And animal manure has been a major source of organic fertilizations (see Fig. 9.1).

Various studies show that under organic fertilizations; organic soil nutrients i.e. carbon, nitrogen and phosphorus were significantly higher than under no-fertilizations (Hartemink 1997). It was further realized that these nutrients are always abundant on top soil 0–20 cm than below 30 cm due to continued fertilizations (Thierfelder and Wall 2009; Partey and Thevathasan 2013; and Msongaleli et al. 2015). Ecologically, this implies that crops with shallow roots can trap sufficient nutrients because their roots excel within the nutrient abundant and thus, giving more yields probably than the one with deep roots that seem to trap nutrient beyond the nutrient storage zone. That situation was contrary to areas under no-fertilizations where a bit deep soils had numerous nutrient than top soils (Hartemink 1997). The major reason for this difference is that under no-fertilization the top soil is under severe utilization while the beneath layer is a bit of resting or with little disturbances from anthropogenic activities. To alleviate this, the soils under no-fertilizations need to undergo organic fertilizations to restore its fertility and ecological functions.

Fig. 9.1 The animal manure deposited at farm level before fertilizations. The fertilization can be done through even spreading in the whole farm, i.e. when manure are plenty, or applying in the seeding holes only, i.e. when manure are scarce

9.5 Agricultural Sustainability

Agricultural sustainability is among the most concern in the era of global climate change (Paavola 2008; Yanda 2015; Kangalawe 2016; and Kangalawe et al. 2016). It is approximated that by 2050 there will be an increase in population for two billion and making over 8 billion people all dwelling on the Planet Earth. To feed all these population, we need to increase food production for 60% (UNEP 2012; Poppy et al. 2014). And about 80% of these two billion people will be residing in developing countries especially Sub-Saharan region. Despite of that fact, the region is expected to produce the least of the required food. Overall, the region among the most vulnerable regions to environmental stress especially climate change impacts (Lema and Majule 2009; Ahmed et al. 2011; and Rowhani et al. 2011a) thus, immediate interventions are needed to curb both short and long-term challenges.

Precisely, agricultural industry can be beneficial and sustainable if it operates to meet the food requirements of the present population without compromising the needs of the future generation (Lichtfouse et al. 2009; UNEP 2011, 2012). Since agriculture involves people and environment synergies, there should be a balance among the involved dimensions (see Fig. 9.2). These dimension include biophysical, economic and social (Lal 1998). Biophysical involves the quantity of output (Mg of yield/ha) while economic and social dimensions refers to the value of gross or net, and the capacity of the system to support farming respectively (see Fig. 9.2).

9.6 Integrative Effects of Soil Quality on Agricultural Sustainability and Environment

There is a close link between soil quality, economic progress and environmental quality (Andrews and Carroll 2001). Under such a situation, a decline in soil quality always lead to degradation of environmental and reduction of agricultural productivity (FAO 2006; Monfreda et al. 2008; and UNEP 2012) and thus increasing food insecurity. In Tanzania and other developing countries, the degradation of environmental quality has brought serious problems of hunger, food insecurity and poverty at large. The semiarid tropic regions such as Shinyanga, Singida and Dodoma, monoculture has degraded soils nutrient to the extent that replenishment has been a difficult alternative (Herdt and Steiner 1995; URT 2007; Monfreda et al. 2008; Kimaro et al. 2015).

In the labile of degraded soils, the available nutrients are likely to be found at deep soils than top ones due to permanent cropping (Hartemink 1997). However, our review indicated that organic soil management and some intensification agriculture can improve soil quality and crops yield in the area. Thus, it should be understandable that, to achieve agriculture sustainability with socio-economic and socio-ecological potentials, depend on the conservation of soils quality (see Fig. 9.3).

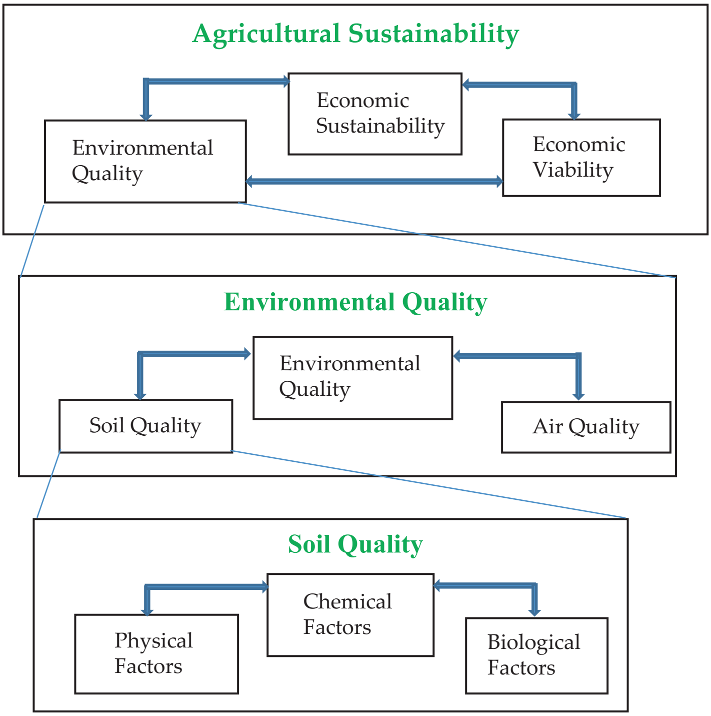

Fig. 9.2 Soil quality, environmental quality, and agriculture sustainability synergies. Soil fertility improvement creates favorable environmental condition for crop production and environmental conservation. Source: Modified from Andrews (1998)

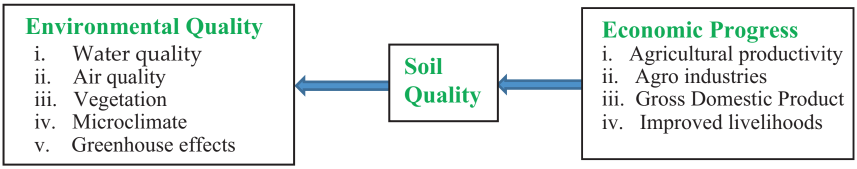

Fig. 9.3 Relationship among soil, environment and economic progress. Economic development is a good tool in ensuring agricultural production through the use of advanced farm instruments. This in turn raise the gross domestic product of the country and its people. Consequently, this ensures the maintenance of soil and environmental management. The whole process enables the provision and sustainability of environmental services. (Source: Modified from Lal (1998))

9.7 Climate Change and Soil Quality

Climate has a significant influence to soil quality (Doran and Parkin 1994; and Doran and Zeiss 2000). By nature, semiarid zone has high climate variability with some extreme stresses to agriculture and biodiversity (Yanda 2015; Mkonda and He 2017c). Rainfall and temperature either increase or decrease soil quality through the processes of degradations or formation and accumulation of important soil minerals.

Table 9.2 Percentage of annual increase of yield due to good agronomic practices in the semiarid areas of Tanzania

Crops	Area %/year	Production % /year	Production%
Maize	9.4	0.8	3.9
Sorghum	0.7	0.1	1.1
Millet	2.8	0.4	3.8
Groundnuts	8.3	0.6	7.4
Sunflower	0.1	2.4	4.2

Source: Extracted from Lema and Majule (2009), and Msongaleli et al. (2015)

The accumulation of soil carbon, total nitrogen, phosphorus and potassium just to mention a few is highly attributed by climate (IPCC 2000; Mkonda and He 2017d).

The temperature influences the decomposition of organic matter, mineralization and immobilization of soil nutrients (Doran and Parkin 1994; Lal 1998; and IPCC 2000).Similarly, high temperature increase the level of carbon offset through decomposition. Therefore, reducing carbon content in the soil, an important nutrient for crop production. On other hand, rainfall can have two side effects as it either increase or decrease soils nutrients. High rainfall facilitate the production of a wide range of plant biomass while downscaling the dominance of minerals which readily dissolve in water and therefore increasing the rate of mineral mobilization while low rainfall can reduce the production of important nutrients such as phosphorus that need abundant water.

Therefore, it is healthy for both temperature and rainfall to be kept at average. Otherwise, their extremes can have ecological repercussions. As intervention to the problem, Kalhapure et al. (2013) suggested that under drought condition, effective soil organic management can increase optimal amount of minerals in soil. Under such a condition, carbon (C) which is potential for C sequestration, seem to be abundant than other soils nutrients.

In general, the abundance of carbon and other important minerals in the soils depend on depth, types of agronomic practices and level of organic fertilization. Similarly, the abundance the soils nutrients the higher the yields. Table 9.2 show how good agronomic practices (e.g. organic fertilization and conservative tillage) has increased crops yields from maize, millet, sorghums, groundnuts and sunflower in the study area.

The statistics in Table 9.2 are based on the average of 10 years i.e. 2000–2010. Therefore, it can be recommended that smallholder farmers should apply good agronomic practices to attain socio-ecological achievements.

9.8 Integrative Adaptation and Mitigation Strategies for Agricultural Sustainability

There is a close link between the adaptation and mitigation practices, and sustainable agriculture (Andrews 1998; and Birch-Thomsen et al. 2007). These practices promotes soil quality and increase carbon sequestration for the betterment of both the

Table 9.3 Adaptation and mitigation practices in semiarid areas of Tanzania

Adaptation	Mitigation
Adoption of drought-tolerant crops and animal breeds	Reduced or more efficient use of chemical fertilizers
Adjustments in irrigation practices and systems	Management of water sources especially wetlands
Changes in timing of planting	Reduced tillage
Conservation of crop and livestock genetic	Planting of biofuels and trees for fuel wood
Crops rotation or production systems	Use of improved feeding practices for livestock
Conservation of agrobiodiversity	Planting of fast-growing tree plantations

Source: Extracted from Lema and Majule (2009), and Kangalawe and Lyimo (2013)

present and future generations (Lichtfouse et al. 2009; and Duru 2015). Farmers in the area have been doing such a combined activities by knowingly or unknowingly.

Adaptation options may include a wide range of approaches designed to reduce the vulnerability and enhance the adaptive capacity of agricultural systems to climate change impacts (Yanda 2015; and Mkonda and He 2017c) while mitigation options involve activities that increase carbon stocks above and below ground, that reduce direct agricultural emissions (carbon dioxide, methane, nitrous oxides) anywhere in the lifecycle of agricultural production; and actions that prevent the deforestation and degradation (Kangalawe and Lyimo 2013) as seen in Table 9.3.

9.9 Experience from Other Countries

Although ecological management for agriculture is important for every parts of the world, the Sub-Saharan African and other tropical parts of the world need it the most (Pretty et al. 2006). Most of these areas are facing food shortage due to the existence of production-limiting constraints faced by resource-poor farmers that include: shrinking farm sizes and inequitable land-distribution patterns, depleted soils and limited use of fertilizer and soil amendments (either organic and inorganic), unreliable rainfall and lack of irrigation capacity, and limited access to improved varieties and seed distribution systems (Hartemink et al. 2008; and Okeyo et al. 2014). Food and Agriculture Organization (2013) pointed that most small-scale farms both in in Africa are less than 2 hectares and they are dependent on household members as a sole source of labor force. To underpin this discussion, we earmark the agricultural systems that are practiced in East, West and Southern Africa.

In East Africa, climate smart agriculture has been under implementation for some couple years aiming at conserving the environment and improving crop yields (Osman-Elasha et al. 2006; and Mkonda and He 2017a). The implementation of climate smart agriculture has been done through projects and programs. These programs (i.e. funded by both local and international organs meant to improve food security and climate resilience among farmers in the region. Food and Agricultural

Organization of the United Nation is a lead institution in this aspect. In this aspect, some areas/zones have benefited from these programs (Solomon et al. 2007). However, high diversity in agro-ecological zone impedes the implementation of these projects. This is amplified by climate change impacts. In Kenya, Rusinamhodzi et al. (2011) pointed out that the adoption of conservation agriculture especially under rain-fed maize production, would improve the yields. This idea was supported by Kimaro et al. (2015) who asserted the same when proposing the optimization of yields along the Uluguru Mountain in Tanzania. In addition, agroforestry systems i.e. woodlots has significant contribution to ecological improvements tenable for agricultural production (Christensen 1988; and Nyadzi et al. 2006). The findings of these studies underpinned that the potential and actual optimization of yields had its base from adequate soil quality improvement in the area. They concluded by endorsing organic soil management against long-term chemical fertilization which appeared to affects the ecosystems (Mkonda and He 2017b).

According to various reports by IPPC (2014), FAO (2013) and other findings from various studies, East Africa is among the worst vulnerable region in Africa. This vulnerability is intensified by climate change impacts which have been hitting the region for couple of years. In addition, poverty, market value of resources, rapid population growth and technology are among the underlying factors affecting agricultural development in the region. In fact the poor performance of Agriculture sector has significant impacts to gross domestic product of Tanzania, Kenya, Uganda, Rwanda, Burundi and Sudan depends on agriculture for about 50–70%). The adoption of various agricultural systems has also been impeded by land conflict especial in countries where land and its implementation is somewhat loose. This conflict has been rising even where formal governance of access to land is in place, government land regulations often conflict with customary laws of land tenure in Africa. In addition, competitive prices have only led to more land acquisition by both domestic and foreign investors with many local farmers being left out because of their weak financial muscles to compete. Therefore, it is essential to improve the ecological condition by undertaking all possible necessary steps ranging from crops genetics, intensive irrigation, fertilization and institutional framework to optimize crop yields.

In the Southern African countries such as Zimbabwe, Zambia, Malawi, Botswana, Mozambique and Angola; agricultural intensification is given high attention to alleviate the predominant food shortage in the region. Here, intensive agriculture ranges from crop production, livestock rearing, forestry and fish farming (Nyong et al. 2007; and Duru 2015). For example, Malawi attempts to improve fishing industry by applying different techniques like animal manure to feed the fish in the ponds (Blythe 2013). This program has significantly increased yields especially "tilapia" that eventually has raised income through selling. In this aspect, sustainability is measured in terms of environmental, economic, social and cultural aspects. Attaining many of these aspect during the production process is regarded as agricultural sustainability. On the other hand, the growing demand of organic products in the world market has risen the desire to adopt organic farming. Principally, this system gives little yields but of high value. Now that, it is worthwhile to ensure food security than safety in order to solve the immediate challenges of food shortage.

West Africa is another important region where agricultural systems need restoration to improve soil quality (Nezomba et al. 2010). Despite the agricultural diversity, the region practices both traditional and modern agricultural systems (Bationo et al. 2006). The majority of the farming systems are traditionally practiced and they range from the extensive (i.e. shifting cultivation and nomadic herding) to more intensive and specialized types of farming (such as compound farms and terrace farming). Shifting cultivation is an extensive agricultural system which mainly involve 'slash-and-burn' cleared land alternates with a fallow period. The system degrades the environment as it involves serious deforestation. The cut materials are burned to allow the plantation of crops like yams, sorghum, millet, maize and cassava depending on the ecological zone (Nyong et al. 2007). On other hand fallowing involve the resting of the cultivated areas for regrowth of natural vegetation and rejuvenation of soil fertility (quality) through nutrient cycling, addition of litter and suppression of weeds. In most cases, the resting period can be 4–5 years however, ideally the longest period can range between 10 and 20 years.

In Liberia, the traditional agriculture of the Loma people involves farmers planting crops in fertile man-made soil known as *'anthropogenic dark earth'*. This man-made highly fertile soil, which is used for growing crops, forms in the same localized areas, building up over generations (Kareemulla et al. 2017). The soil is created inevitably by everyday domestic life, from deposits of charred and fresh organic matter, including manure, bones, ash, charcoal and ceramics. It is evident that this traditional agriculture has twice the energy efficiency of either 'slash and burn' rice production and hunting and gathering. However, the sustainability is this farming systems is at "cross road" because it is limited by 'sacred' forests, which form around current settlements and cover areas of fertile man-made soil which used to be towns in the past. On top of that, customary laws prohibit these forests being cleared for farming, as some trees are believed to have mystical 'medicinal' power, and also because of the presence of graves.

On the other hand, Mali is highly vulnerable to the threat of soil fertility decline and food deficit (Kalra et al. 2013). A series of development organizations have promoted inappropriate "new green revolution" technologies that depend on external inputs rather than local abilities and resources, and food aid has become a fallback resolution to alleviate food shortages. Women are particularly vulnerable, and face particular challenges in accessing productive resources (land, water, credit) and receiving technical advisory services. Therefore, Mali is in need of long-term solutions for small-scale farmers to optimize crop production and ecosystems services.

Further, a wide range of crop cultivars and species have been introduced to cope with the global and local environmental change. This has been done through different programs funded by both local and international organs e.g. FAO. For example, in Senegal about 14 high-yielding, early maturing and drought resistant dry cereal varieties have been developed thus, have succeeded to optimize productivity by at least 30% (Duru 2015). Alongside, this program has benefitted more than 423,000 farmers in the country whose yields have boomed after adopting the new varieties and thus, they have become more resilient to climate shocks. Likewise, in other countries such as Guinea, Sierra Leone, Liberia and Côte d'Ivoire, the new saline-tolerant rice varieties, climate-smart irrigation techniques and better soil fertility management increased rice yields of more than 100,000 farmers (Nyong et al. 2007).

This change (i.e. adoption of new agricultural technology and crop cultivars) in region have been influenced by a number of reasons such as introduction of Asian and New World Crops, population expansion, the need for spices and agricultural raw materials for industry; expansion of cassava production into marginal areas where other crops often fail, and introduction of mechanization into farming and adoption of new techniques just to mention a few.

India, the second most populous country in the world, its priority has been to elevate agricultural yields, maintain food security and ensure the availability of industrial raw materials (Kalra et al. 2013). However, the country has great diversity in agro-climatic zones with as many as 127 zones under five agro-ecosystems such as rain-fed, arid, irrigated, coastal and hilly systems (Kareemulla et al. 2017). In that respect, there are spatial and temporal differences in agricultural systems tenable to meet the local challenges. However, for agriculture to be sustainable, it needs to walk along with of ecological, economic, cultural and social sustainability. Another aspect that prompts agricultural differences is population density. In India, West Bengal, Bihar, Himachal Pradesh, Punjab, Bihar, Uttar Pradesh, Jharkhand and Kerala are among the major states with high population density of over 800 persons per square kilometer (Kareemulla et al. 2017). Thus far, population necessitates the intensive agriculture rather that organic and extensive farming. Intensive agriculture can give more yields even in a small geographical area. Therefore, intensive agriculture forms the major agricultural system in India.

China, the most populous country in the Planet has significant contribution to global agricultural sustainability (Tilman et al. 2002). With diverse climatic region, China applies different farming systems to meet this spatial biophysical characteristics. Most dry areas such as Northwest and Central China apply intensive irrigation in agriculture while other parts that still receive reliable rainfall depend on rain-fed (Sharma and Minhas 2005). On other hand, the intensive high-yield agriculture is dependent on addition of fertilizers, especially industrially produced NH_4 and NO_3. This is done to accrue high yields for food and industrial raw materials. Unfortunately, only 30–50% of applied nitrogen fertilizer 40, 41 and ~45% of phosphorus fertilizer 42 is taken up by crops. This means, a significant amount of the applied nitrogen and a smaller portion of the applied phosphorus is lost from agricultural fields and thus, polluting the environment.

While fertilization is highly emphasized, the agricultural systems in most dry areas is limited of irrigation. In this respect, the availability of water is essential for agricultural production in these dry areas (Sharma and Minhas 2005). Nevertheless, despite of strongly influencing local agricultural development; excessive utilization of water resources plays a vital role in accelerating environmental degradation (Li et al. 2009). In arid land of northwest China, the water consumption for agriculture accounts for approximately 90% of the total water uses (Li et al. 2010) but the average available water is less than 1635×108 m^3 per year, only 5.8% of the China average level. Now that, this tells that agricultural sustainability is promising where there is no shocks or immediate demand of environmental services that can exert more pressure on resources utilization (Huang et al. 2012). Otherwise it is difficult to maintain environmental conservation while optimizing crop yields.

On the other hand, according to European Union (2012) Europe plays great roles in both practicing and funding agricultural sustainability around the globe. Europe strongly believes that agriculture that is environmentally, economically and socially sustainable and can make a vital contribution in our response to the most urgent challenges especially reducing poverty and ensuring food security. The report further elaborates that increasing demand of organic products at global level has raised organic agriculture in Europe. It is envisaged apart from giving quality yields, this farming system ensures constant provision of environmental services. For example, the southwest regions of Spain and southern Portugal the "*Dehesa" is* a very specific Mediterranean system of extensively grazed, wooded pasture that shows the multifunctional role of forests. Their intrinsic characteristics and management practices ensure the provision of a wide range of environmental services such as biodiversity, soil conservation, and carbon storage. In these areas farmers rear Iberian pig species known as 'pata negra', which feed on acorns of oak trees.

Besides, Europe has been a main partner and donor of the Global Rinderpest Eradication Campaign in collaboration with the World Organization for Animal Health (OIE) and FAO, contributing 390 million € over the last 50 years (www.oie.int/en/for-the-media/rinderpest/). The European Union is also supporting local communities in building capacities to restore and sustainably manage their dryland ecosystems, improve their marketing "activities" as well as support dialogues among stakeholders to share knowledge, ideas and priorities. A good example of the supported countries includes: Jordan, Mali, Botswana and Sudan which most of their areas are dryland.

9.10 Conclusion

This study assessed the influence of soil quality on agricultural sustainability. We found that, monoculture is the dominant degradation activity in semiarid tropics of Tanzania. Through that, optimal amount of soils nutrients get lost. Unfortunately, climate change impacts have stressed the already affected environment and sterilized all biological functions of the soil especially mycorrhiza fungi (especially primary and ecto-mycorrhizas). Under such a situation, soil quality decreases, crops yields are lowered and the risk of food insecurity increases. However, in few areas good agronomic practices have significantly elevated soil quality through organic fertilizations and other organic soil managements. Animal manure appeared to have significant contribution to organic fertilizations. It provides substantial nutrients such as nitrogen, phosphorus, potassium and carbon to the soils. In those areas, yields of food crops have increased to 1.8 tn ha^{-1} compared to 0.82 tn ha^{-1} under soils with no-fertilizations. This is implies that if serious organic fertilization is done, we can attain agricultural.

Acknowledgement The authors are thankful to the Editor-in-Chief of Sustainable Agricultural Reviews, Professor Eric Lichtfouse for inviting them to write a chapter in "Ecology for agriculture". They are also appreciative to the reviewers for the constructive comments and insights.

References

Ahmed S, Deffenbaugh N, Hertel T, Lobell D, Ramankutty N, Rios A, Rowhani P (2011) Climate volatility and poverty vulnerability in Tanzania. Glob Environ Chang 21(2011):46–55

Andrews SS (1998) Sustainable agriculture alternatives: ecological and managerial implications of poultry litter management alternatives applied to agronomic soils. PhD dissertation. University of Georgia, Athens, GA, USA

Andrews SS, Carroll CR (2001) Designing a soil quality assessment tool for sustainable agroecosystem management. Ecol Appl 11(6):1573–1585

Bationo A, Kihara J, Vanlauwe B, Waswa B, Kimetu J (2006) Soil organic carbon dynamics, functions and management in West African agro-ecosystems. Agric Syst 94(1):13–25. https://doi.org/10.1016/j.agsy.2005.08.011

Birch-Thomsen T, Elberling B, Bjarne F, Magid J (2007) Temporal and spatial trends in soil organic carbon stocks following maize cultivation in semi-arid Tanzania. Springer, East Africa.

Blythe JL (2013) Social-ecological analysis of integrated agriculture aquaculture systems in Dedza, Malawi. Environ Dev Sustain 15:1143–1155. https://doi.org/10.1007/s10668-012-9429-6

Bockstaller C, Girardin P, van der Werf HMG (1997) Use of agro-ecological indicators for the evaluation of farming systems. Eur J Agron 7:261–270

Branca G, Lipper L, McCarthy N, Jolejole M (2013) Food security, climate change, and sustainable land management. Agron Sustain Dev 33:635–650. https://doi.org/10.1007/s13593-013-0133-1

Chai Q, Gan Y, Zhao C, Xu H, Waskom R, Niu Y, Siddique K (2015) Regulated deficit irrigation for crop production under drought stress, Agron Sustain Dev. Diplomacy of a New State. NOK Publishers, New York

Christensen B (1988) Effects of animal manure and mineral fertilizer on the total carbon and nitrogen contents of soil size fractions. Biol Fertil Soils 5:304–307

Doran JW, Parkin TB (1994) Defining and assessing soil quality. In: Doran JW, Coleman DC, Bezdicek DF, Stewart BA (eds) Defining soil quality for a sustainable environment. SSSA, Inc., Madison

Doran J., Zeiss M. (2000). Soil health and sustainability: managing the biotic component of soil quality. Appl Soil Ecol. 15, 1, pg 3–11 https://doi.org/10.1016/S0929-1393(00)00067-6

Duru M (2015) How to implement biodiversity-based agriculture to enhance ecosystem services. Agron Sustain Dev 35:1259–1281. https://doi.org/10.1007/s13593-015-0306-1

Duru M, Therond O, Fares M (2015) Designing agroecological transitions. Agron Sustain Devaluation of farming systems. Eur J Agron 7:261–270

European Union (2012) Agriculture and Rural Development http://ec.europa.eu/agriculture

FAO (2006) Conservation agriculture for SARD and food security in Southern and Eastern Africa. Terminal report, Kenya and Tanzania

FAO (2008) Investing in sustainable agricultural intensification: the role of conservation agriculture. A Framework for Action, Rome

FAO (2012) Conservation agriculture and sustainable crop intensification in Karatu District, Tanzania, Integrated crop management, vol 15. Food and agriculture organization of the United nations (FAO), Rome

FAO (2013) Climate-smart agriculture sourcebook. FAO, Rome

Giller K, Witter E, Corbeels M, Tittonell P (2009) Conservation agriculture and smallholder farming in Africa: The heretics' view. Field Crops Res 114:23–34

Glaser B, Lehmann J, Führböter M, Solomon D, Zech W (2001) Carbon and nitrogen mineralization in cultivated and natural savanna soils of Northern Tanzania. Biol Fertil Soils 33:301–309. https://doi.org/10.1007/s003740000324
Hartemink AE (1997) Soil fertility decline in some Major Soil Groupings under permanent cropping in Tanga Region, Tanzania. Geoderma 75:245–229
Hartemink AE, Veldkamp T, Bai Z (2008) Land cover change and soil fertility decline in tropical regions. Turk J Agric For 32:195–213
Herdt RW, Steiner RA (1995) Agricultural sustainability: concepts and conundrums. In: Barnett in East Africa: the impacts of resource variability on human security Clim Change. https://doi.org/10.1007/s10584-010-9884-8
Huang Y, Li YP, Chen X, Ma YG (2012) Optimization of the irrigation water resources for agricultural sustainability in Tarim River Basin, China. Agric Water Manag 107:74–85. https://doi.org/10.1016/j.agwat.2012.01.012
IPCC (2000) Land use, land use change and forestry, a special report of the IPCC (Watson RT, Noble IR, Bolin B, Ravondranath NH, Verardo DJ, Dokken DJ, eds). Cambridge University Press, Cambridge
IPCC (2014) Climate Change 2014 impacts, adaptation, and vulnerability. Part A: global and sectoral aspects. Contribution of Working Group II to the fifth assessment report of the Intergovernmental Panel on Climate Change (Field CB, Barros VR, Estrada, Genova RC, Girma B, Kissel ES, Levy AN, MacCracken S, Mastrandrea PR, White LL, eds). Cambridge University Press, Cambridge/New York
Kalhapure A, Shete B, Dhonde M (2013) Integrated nutrient management in maize (Zea Mays L.) for increasing production with sustainability. Int J Agric Food Sci Technol 4(3):195–206 ISSN 2249-3050, http://www.ripublication.com/ ijafst.htm
Kalra RKB, Tonts AM, Siddique KHM (2013) Self-help groups in Indian agriculture: a case study of farmer groups in Punjab, Northern India. Agroecol Sustain Food Syst 37:509–530
Kangalawe R (2016) Climate change impacts on water resource management and community livelihoods in the southern highlands of Tanzania. Clim Dev. https://doi.org/10.1080/17565529.2016.1139487
Kangalawe R, Lyimo G (2013) Climate Change, Adaptive Strategies and Rural Livelihoods in Semiarid Tanzania. Nat Res 2013(4):266–278. https://doi.org/10.4236/nr.2013.43034
Kangalawe R, Mung'ong'o C, Mwakaje A, Kalumanga E, Yanda P (2016) Climate change and variability impacts on agricultural production and livelihood systems in Western Tanzania. Clim Dev. https://doi.org/10.1080/17565529.2016.1146119
Kareemulla K, Venkattakumar R, Samuel M (2017) An analysis on agricultural sustainability in India. Curr Sci 112(258):2
Karlen D, Ditzlerb C, Andrewsa S (2003) Soil quality: why and how? Geoderma 114:145–156. https://doi.org/10.1016/S0016-7061(03)00039-9
Kimaro A, Mpanda M, Rioux J, Aynekulu E, Shaba S, Thiong'o M, Mutuo P, Abwanda S, Shepherd K, Neufeldt H, Rosenstock TS (2015) Is conservation agriculture 'climate-smart' for maize farmers in the highlands of Tanzania? Springer-Verlag, Berlin/Heidelberg. Nutr Cycl Agroecosyst. https://doi.org/10.1007/s10705-015-9711-8
Lal R (1998) Basic concepts and global issues: soil quality and agricultural sustainability. In: Lal R (ed) Soil quality and agricultural sustainability. Ann Arbor Science, Chelsea, pp 3–12
Lema MA, Majule AE (2009) Impacts of climate change, variability and adaptation strategies on agriculture in semi-arid areas of Tanzania: the case of Manyoni District in Singida Region. Tanzan J Environ Sci Technol 3:206–218
Li YP, Huang GH, Wang GQ, Huang YF (2009) FSWM: a hybrid fuzzy-stochastic water management model for agricultural sustainability under uncertainty. Agric Water Manag 96:1807–1818. https://doi.org/10.1016/j.agwat.2009.07.019
Li W, Li YP, Li CH, Huang GH (2010) An inexact two-stage water management model for planning cultural irrigation under uncertainty. Agric Water Manag 97:1905–1914. https://doi.org/10.1016/j.agwat.2010.07.005

Lichtfouse E, Navarrete M, Debaeke P et al (2009). Agron Sustain Dev 29:1. https://doi.org/10.1051/agro:2008054
McDonagh JF, Birch-Thomsen T, Magic J (2001) Soil organic matter decline and compositional change associated with cereal cropping in Southern Tanzania. Land Degrad Dev:13–26. https://doi.org/10.1002/ldr.419
Medeiros C, Serrano R, Martos J, Girón V (1997) Effect of various soil tillage systems on structure development in a Haploxeralf of central Spain. Soil Technol 11(2):197–204. https://doi.org/10.1016/S0933-3630(96)00131-6
Mkonda MY, He XH (2017a) Conservation agriculture in Tanzania. In: Lichtfouse (ed) Sustainable agriculture reviews 22. Springer, Switzerland, pp 309–324. https://doi.org/10.1007/978-3-319-48006-0_10
Mkonda MY, He XH (2017b) Long-term chemical fertilization in Tanzania. In: Lichtfouse (ed) Sustainable agriculture reviews 25. Springer, Switzerland, pp 261–276. https://doi.org/10.1007/978-3-319-58679-3_9
Mkonda MY, He XH (2017c) Yields of the major food crops: implications to food security and policy in Tanzania's semi-arid agro-ecological zone. Sustainability 9:1490. https://doi.org/10.3390/su9081490
Mkonda MY, He XH (2017d) Sustainable environmental conservation in East Africa through agroforestry systems: a case of the eastern arc mountains of Tanzania. Int J Sustain Green Energy 6(4):49–56. https://doi.org/10.11648/j.ijrse.20170604.11
Monfreda C, Ramankutty N, Foley JA (2008) Farming the planet. 2. Geographic distribution of crop areas, yields, physiological types, and net primary production in the year 2000. Glob Biogeochem Cycles 22:GB1022. https://doi.org/10.1029/2007GB002947
Msongaleli B, Rwehumbiza F, Tumbo S, Kihupi N (2015) Impacts of climate variability and change on rain-fed sorghum and maize: implications for food security policy in Tanzania. J Agric Sci 7(5). https://doi.org/10.5539/jas.v7n5p124
Nezomba H, Tauro TP, Mtambanengwe F, Mapfumo P (2010) Indigenous legume fallows (indifallows) as an alternative soil fertility resource in smallholder maize cropping systems. Field Crop Res 115:149–157
Nyadzi G, Janssen B, Oenema O (2006) Analysis of the effects of rotational woodlots on the nutrition and yield of maize following trees in western Tanzania. Agric Ecosyst Environ 116:93–103
Nyong A, Francis A, Osman-Elasha B (2007) The value of indigenous knowledge in climate change mitigation and adaptation strategies in the African Sahel. Mitig Adapt Strat Glob Chang 12:787–797
Okeyo A, Muchera-Muna M, Mugwe J, Ngetich K, Mugendi D, Diels J, Shisanya C (2014) Effects of selected soil and water conservation technologies on nutrient losses and maize yields in the central highlands of Kenya. Agric Water Manag 137:52–58
Osman-Elasha B, Goutbi N, Spanger-Siegfried E, Dougherty B, Hanafi H, Zakieldeen S, Sanjak A, Atti H, Elhassan, H (2006) Adaptation strategies to increase human resilience against climate variability and change: lessons from the arid regions of Sudan. AIACC Working Paper No. 42
Paavola J (2008) Livelihoods, vulnerability and adaptation to climate change in Morogoro. Tanzan Environ Sci Policy 11:642–654. https://doi.org/10.1016/j.envsci
Partey ST, Thevathasan NV (2013) Agronomic potentials of rarely-used agroforestry species for smallholder agriculture in Sub-Saharan Africa: an exploratory study. Commun Soil Sci Plant Anal 44(11):1733–1748
Pauline N, Vogel C, Grab S, Liwenga E (2016) Smallholder farmers in the Great Ruaha River sub-Basin of Tanzania: coping or adapting to rainfall variability? Clim Dev:1–14. https://doi.org/10.1080/17565529.2016.1184607
Poppy GM, Chiotha S, Eigenbrod F, Harvey C, Honzák M, Hudson M, Dawson T (2014) Food security in a perfect storm: using the ecosystem services framework to increase understanding. Philos Trans R Soc Lond Ser B Biol Sci 369(1639):20120288. https://doi.org/10.1098/rstb.2012.0288
Pretty J, Noble A, Dixon J, Hine J, Penning de Vries F, Morison J (2006) Resource-conserving agriculture increases yields in developing countries. Environ Sci Technol 40:1114–1119

Rowhani P, Lobell DB, Linderman M, Ramankutty N (2011a) Climate variability and crop production in Tanzania. Agric For Meteorol Sci Direct 151(2011):449–460
Rowhani P, Degomme O, Guha-Sapir D, Lambin E (2011b) Malnutrition and conflict in East Africa: the impacts of resource variability on human security. Clim Change 105:207–222. https://doi.org/10.1007/s10584-010-9884-8
Rusinamhodzi L, Corbeels M, van Wijk MT, Rufino MC, Nyamangara J., Giller K. E. (2011). A meta-analysis of long-term effects of conservation agriculture on maize grain yield under rainfed conditions. Agron Sustain Dev 31: 657-673.
Sharma BR, Minhas PS (2005) Strategies for managing saline/alkali waters for sustainable agricultural production in South Asia. Agric Water Manag 78:136–151. https://doi.org/10.1016/j.agwat.2005.04.019
Sieber S, Tscherning K, Graef F, Sergio U, Paloma G (2015) Food security in the context of climate change and bioenergy production in Tanzania: methods, tools and applications, vol 15. Springer, Berlin/Heidelberg, pp 1163–1168. https://doi.org/10.1007/s10113-015-0834-x
Solomon T, Snyman H, Smit G (2007) Cattle-rangeland management practices and perceptions of pastoralists towards rangeland degradation in the Borana zone of southern Ethiopia. J Environ Manag 82:481–494
Sosovele H, Schechambo F, Kisanga D (1999) Rethinking natural resource degradation in semi-arid Sub-Saharan Africa: the case of semi-arid Tanzania. ODI, University of Dar Es Salaam, Tanzania
Thierfelder C, Wall PC (2009) Effects of conservation agriculture techniques on infiltration and soil water content in Zambia and Zimbabwe. Soil Tillage Res 28:209–220. https://doi.org/10.1111/j.1475-2743.2012.00406.x
Tilman D, Cassman KG, Matson PA, Naylor R, Polasky S (2002) Agricultural sustainability and intensive production practices. Nature 418:671–677
UNEP (2011) Food and ecological security: identifying synergy and trade-offs. UNEP, Nairobi http://www.unep.org/ecosystemmanagement/Portals/7/Documents/unep_policy_series/Food and Ecological solutionsJS.pdf
UNEP (2012) Avoiding future famines: Ecological foundation sustainable food systems. United Nations Environment Program (UNEP), Nairobi
URT (2007) United Republic of Tanzania, National Adaptation Program of Action (NAPA). Division of Environment, Vice President's Office, Dar es, Salaam
URT (2012) [Tanzania] National Sample Census of Agriculture 2007/2008 Small Holder Agriculture: Regional Report – Singida Region (Volume Vm). United Republic of Tanzania, Ministry of Agriculture, Food Security and Cooperatives, Ministry of Livestock Development and Fisheries, Ministry of Water and Irrigation, Ministry of Agriculture, Livestock and Environment, Zanzibar
URT (2014) Review of food and agricultural policies in the United Republic of Tanzania, MAFAP Country Report Series. FAO, Rome
Vanlauwe B (2004) Integrated soil fertility management research at TSBF: the framework, the principles, and their application. In: Bationo A (ed) Managing nutrient cycles to sustain soil fertility in Sub-Saharan Africa. Academy Science Publishers, Nairobi
Vanlauwe B., Wendt J., Giller K. et al. (2014). A fourth principle is required to define conservation agriculture in sub-Saharan Africa: the appropriate use of fertilizer to enhance crop productivity. Field Crops Res 155. pg 10–13.
Vermeulen S, Campbell B, Ingram J (2012) Climate change and food systems. Annu Rev Environ Resour 37(1):195–222. https://doi.org/10.1146/annurev-environ-020411-130608
Wall PC, Thierfelder C, Ngwira A, Govaerts B, Nyagumbo I, Baudron F (2013) Conservation agriculture in Eastern and Southern Africa. In: Jat RA, Graziano de Silva J (eds) Conservation agriculture: global prospects and challenges. CABI, Cambridge ISBN-13: 9781780642598
Yanda P (2015) Climate change implications for management and use of agricultural biodiversity resources in Africa. Environ Ecol Res 3(2):35–43 http://www.hrpub.org. https://doi.org/10.13189/eer.2015.030201