Chapter 9
Agricultural Sustainability and Food Security in Agroecological Zones of Tanzania

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Abstract Agricultural sustainability is crucial for developing countries, including Tanzania whose economy and food security entirely depend on agriculture. Tanzania has seven agro-ecological zones with different potentials and challenges to attain agricultural sustainability. These agro-ecological zones are coastal, arid, semi-arid, plateau, southern and western highlands, northern highlands, and alluvial. To attain agricultural sustainability and food security in the country, it is essential to explore biophysical, economic and social dimensions. This chapter reviews the climatic situation, agricultural potentials and agronomic practices. Arid and semi-arid zones are more vulnerable to environmental stress, especially climate change, than plateau, alluvial, and northern and southern highlands. Efficient agricultural sustainability has increased peoples' income and food security in resilient agroecological zones by 50%, and by 10% in vulnerable zones. This has eventually improved the livelihoods of the people in resilient agro-ecological zones, and has allowed cultivation of few crop varieties such as sorghum and millet in vulnerable zones. Areas with the best agronomic practices such as animal manure fertilization have increased crop yields from 0.75 to 1.95 tons ha^{-1}. As a result, this yield increment has improved the livelihoods of about 70% of Tanzanian farmers who entirely depend in agriculture.

Keywords Agricultural sustainability · Agro-ecological zones · Climate change · Crop yields · Food security · Nutrient use efficiency · Organic fertilizations · Smallholder farmers · Soils fertility · Tanzania

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9.1 Introduction

The essence of agricultural sustainability has increasingly attracted the attention of various stakeholders at both global and local levels (Pretty 2007). The definition of agricultural sustainability is mainly contextual in nature (Bationo et al. 2006; Solomon et al. 2007). However, the major concern for agricultural sustainability involves the need to develop technologies and practices that do not have adverse effects on environmental goods and services, are accessible to and effective for farmers, and lead to improvements in food productivity (Lal 1998; Pretty 2008; Mkonda and He 2018a). The increasing demand of food security and environmental conservation gives a prompt needs for agricultural sustainability at both global and local levels. This demand has been more extensive from the last two decades of twentieth century and the first decade of twenty-first century, and as well more pronounced in developing countries (Monfreda et al. 2008; Branca et al. 2013).

In most developing countries; food security is mainly obtained from agricultural production at local levels (Mkonda and He 2018b). This, in turn, necessitates the adoption of various technological aspects to meet the objectives of food security and environmental conservation (Lichtfouse et al. 2009). However, it has been difficult to meet these two objectives simultaneously. According to FAO (2008) and Monfreda et al. (2008) the per capita cereal production has decreased from 150 to 130 kg per person in most African countries while increasing in Asia and South America from 200 to 250 kg per person. Furthermore, FAO (2012) and Sieber et al. (2015) added that this situation has increased the demand of adopting best agriculture practices to attain food security and environmental conservation.

In this aspect, agricultural sustainability would increase agricultural yields to meet the demands of foods from global population increase (Vermeulen et al. 2012; IPCC 2014). The global food demand has significantly increased since the last decade of twentieth century and this is evidenced by the fact that, the growth of cereal grain has been at 1% while that of population is 3% (FAO 2006).

Globally, from 1980s to 2000s, the world population has grown from three billion to more than six billion, imposing an increasing impact of human footprint on the earth as consumption patterns change (Kitzes et al. 2008; Pretty 2007). The per capita agricultural production has outstripped population growth (Hazell and Wood 2008) in most countries. Specifically, for each person today, there has been an additional about 25% more food compared with that in 1960. Nevertheless, these cumulative figures, hide important regional differences especially between industrialized and developing countries. Although Europe and North American experience mega changes in this, Asia and Latin America also increased their per capita food production by 76% and 28%, respectively. However, in this aggregate figures; Africa, has managed badly, with production per person 10% lower today than in 1960.

For Africa having the poorest per capita food production and weak management systems of the environment, it is mandatory that AS should be given high attention by all stakeholders in order to simultaneously solve the problem of food shortage and environmental degradation (Mkonda and He 2018b). Now that, it is a role of scientists, climate practitioners, environmental experts and related experts to establish appropriate approaches towards succeeding this objective.

Agricultural sustainability is shown in Fig. 9.1 below. The figure stipulates the most important aspects of agricultural sustainability and its benefits to both the environment, crop production and community livelihoods. This figure applies to most countries and contexts at both global and local levels.

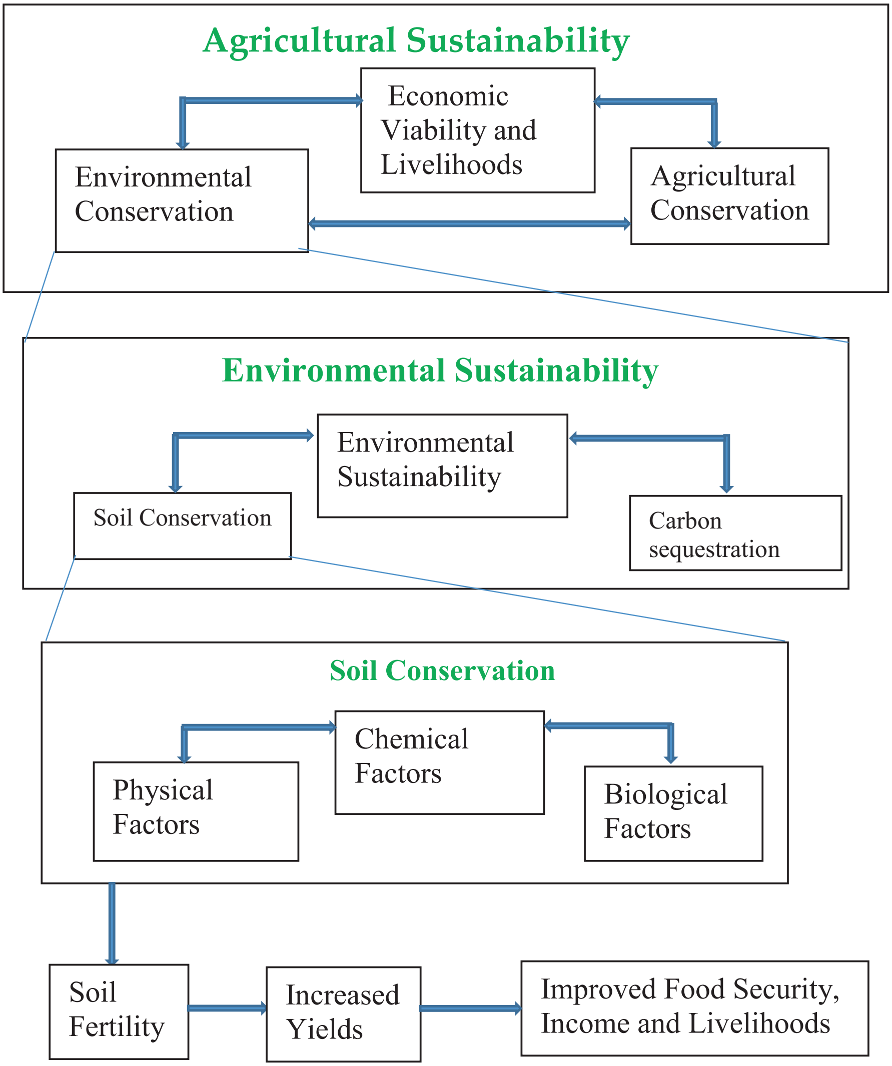

Fig. 9.1 Agricultural sustainability, environmental sustainability, and crop yields synergies. Sustainable agriculture creates favorable environmental conditions for crop production and environmental conservation. (Modified from Andrews 1998; Lal 1998; Pretty 2007)

In Tanzania agricultural sustainability is important aspect in attaining food security and environmental conservation (Andrews and Carroll 2001). It is also a tool for improving income in various communities (Ahmed et al. 2011). However, agricultural sustainability in the country is affected by the existence of diverse agroecological zones. These zones include coast, arid, semi-arid, plateau, southern and western highlands, northern highlands and alluvial (URT 2007). The alluvial zones seem to be more potential for irrigation agriculture due the influence of *Rufiji, Ruvu, Wami, Ruaha, Kilombero, Malagarasi* and *Pangani basins* that form important hydro-ecological zones (Altieri and Nicholls 2012; Lalika et al. 2017). These basins provide fruitful potentials for crop production.

For a precise view of the agroecological zones of Tanzania, Table 9.1 shows the sampled areas from region to village levels to explore the area. These regions, districts and villages are just representatives of the whole targeted area.

Although various studies have established that agricultural sustainability is important aspect to meet food security and environmental conservation, most of them have generalized it without giving a distinctive analysis of each agroecological zone. In doing so, these studies have largely conceded numerous shortcomings when a specific adaptation plan or strategy is needed within a specific agroecological zone. This has further adversely affected the implementations of programs and formulation of appropriate policies. Therefore, there is a need to establish a study that explores all agroecological zones of the country by treating each separately.

The main objective of this chapter is to assess the potentials and challenges influencing agricultural sustainability across different agroecological zones in Tanzania, and propose proper mechanism that can sustain agricultural sustainability. This, in turn, can improve environmental conservation, food security, and income. Explicitly, the results of this study can further synthesize the knowledge from diverse agroecological zones and thus, establishing the baseline for policy formulation. Finally, this can enhance agricultural sustainability in various agroecological zones of the country.

Table 9.1 Samples of the regions, districts and villages in the seven agro-ecological zones

Zone	Region	District	Village
Coast	Tanga	Pangani	Mkalamo
Arid	Mara	Serengeti	Ikoma
Semi-arid	Singida	Manyoni	Chikuyu
Plateau	Tabora	Uyui	Ufuluma
S&W Highlands	Iringa	Iringa rural	Sadani
N. Highlands	Kilimanjaro	Moshi rural	Makuyuni
Alluvial	Morogoro	Kilombero	Mang'ula

Source: Adopted from Mkonda et al. (2018) and Mkonda and He (2017d)

9.2 Study Site

The present chapter focuses on the seven agro-ecological zones of Tanzania, an Eastern African country with rich biodiversity. These zones include*; coastal, arid, semi-arid, plateau, southern and western highlands, northern highlands, plateau and alluvial plains* (Fig. 9.2). This classification bases on the altitude, precipitation pattern, dependable growing seasons and average water holding capacity of the soils and physiographic features (URT 2007). 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; URT 2007). Therefore, the important aspects of different agro-ecological zones such as rainfall, soil fertility and agricultural systems determine sustainability of the area.

Coast zone covers different regions along the Indian Ocean. To the north; it covers Tanga except Lushoto, while to the coast it covers Coastal and Dares Salaam. Lastly, to the South it covers eastern Lindi and Mtwara (except Makonde Plateau).

The *arid* and *semi-arid zones* cover a number of regions and are grouped into two major parts. These are central and southern. The central region includes Dodoma, Singida, Northern Iringa, some parts of Arusha and Shinyanga (URT 2007). These regions are located at 1000–1500 m altitudes and receive unreliable unimodal rainfall ranging from 400 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

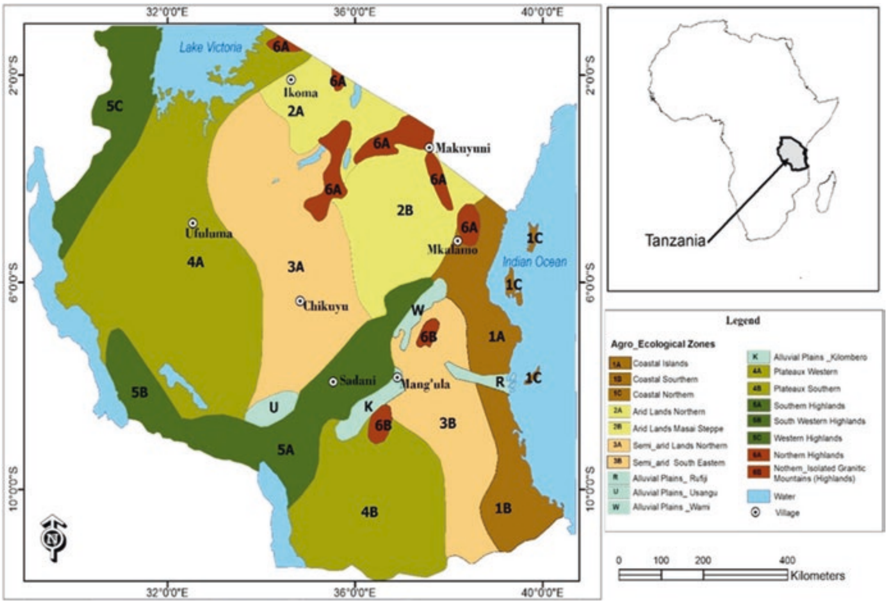

Fig. 9.2 Study area showing agro-ecological zones of Tanzania. (Adapted from Mkonda et al. 2018)

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 between 200 and 600 m altitudes and receive unreliable unimodal rainfall ranging from 500 to 800 mm per annum. Overall, the topography of the area is characterized by flat or undulating plains with rocky hills, moderate fertile loams and clays in south Morogoro, infertile sand soils in center (URT 2007; Mkonda and He 2017a). 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.

As seen in Fig. 9.2 above; *Plateau zone* covers Tabora, Rukwa and Mbeya regions to the west. It also covers Kigoma and part of Mara regions to the north. Lastly, it covers Ruvuma and southern part of Morogoro regions to the south.

Southern and western highlands. This zone covers a broad ridge from northern Morogoro to Lake Nyasa. It also covers part of Iringa, Mbeya, Ufipa plateau in Sumbawanga and along the shore of Lake Tanganyika in Kigoma and Kagera regions.

Northern Highlands. This zone covers foot of Mt. Kilimanjaro and Mt. Meru, eastern Rift Valley to Eyasi, Mt. Uluguru in Morogoro, Pare Mountains in Kilimanjaro and Usambara Mountains in Tanga, Tarime highlands in Mara.

Lastly, the *Alluvial Plain*. This covers Kilombero (Morogoro), Rufiji (Coast), Usangu (Mbeya) and Wami (Morogoro).

To write this chapter, more than 80 publications, especially journal papers, were reviewed. The scientific papers published in authentic journals and mostly indexed in the web of science were given high priority. In addition, the journals with high impact factors and number of citations were equally selected. Furthermore, the most recent publications were given priority in this selection. Analyses and modification of some data were done to suit the study objectives and the guidelines of *Sustainable Agriculture Reviews*. All publication ethics including the seeking of permission to journal authors, where necessary, were substantially considered. The review was done to meet the standards of *Sustainable Agricultural Reviews* journal.

9.3 Principles of Agricultural Sustainability in Tanzania

The pressure from increasing Tanzanian population, weak agricultural technology, and increasing scenarios of climate change have compelled experts to recommend AS as the best strategy to limit global environmental degradations and food shortage cases (Branca et al. 2013; Ahmed et al. 2011; Rowhani et al. 2011a). There has been frequent occurrences of food shortage in Tanzania due to decline of agricultural productivity. This decline is evidenced by a number of scenarios such as frequent food insecurity, hunger and malnutrition cases (URT 2007, 2012; FAO 2012). This situation is more pronounced in rural areas.

In addition, UNEP (2011) and Poppy et al. (2014) asserted that there has been an acute decline of per capita grain per harvested areas in most developing countries. In fact, this is the most alarming indicator of agricultural unsustainability. In most sub-Saharan countries, including Tanzania, the per capita grain per harvested area has experience significant decline from 0.23 ha in 1980s to 0.12 ha in 2000s (FAO 2006; UNEP 2012; Branca et al. 2013). This decline has occurred severally even in recent years.

This challenge can be limited by adopting irrigation agriculture. However, irrigated land has declined from 0.047 ha in 1980s to 0.044 in 2000s (URT 2007; FAO 2013; Duru et al. 2015). This decline reveals that agricultural is considerably unsustainable in the area. This challenge is amplified by the presence of arid, semi-arid and tropical climates in the country (Giller et al. 2009; Branca et al. 2013; Chai et al. 2015; Pauline et al. 2016). According to URT (2007), 30% of Tanzanian land is under either arid or semi-arid climate and thus, experiencing the most consequences of climate stress and unsustainable agriculture (Doran and Zeiss 2000).

Therefore, the combination of several aspects such as arid and semi-arid tropics, long-term monoculture practices, and burning of grassland have significantly reduced the total carbon, nitrogen contents and other important minerals that can support sustainable agriculture (Bockstaller et al. 1997; Hartemink 1997; Medeiros et al. 1997; Sosovele et al. 1999; Monfreda et al. 2008; Msongaleli et al. 2015; Mkonda and He 2017b). It is obvious that the decline of important minerals in the soil hampers crop production and degrade the environment. This in turn, affects the livelihoods of over 70% of the Tanzanian smallholders who entirely depend on agriculture (Duru et al. 2015; URT 2014, 2012; Kangalawe et al. 2016). Again, this has direct effects to increased food shortage and poverty in the country (Paavola 2008; Lema and Majule 2009; Yanda 2015; Kangalawe 2016).

For the past two decades, the annual food deficit was approximated to 50% in most arid and semi-arid areas because; the little obtained yields were consumed within 3–6 months, thus, leaving the people under severe starvation for the rest of the year (URT 2007, 2012, 2014; Mkonda and He 2017c). 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; URT 2014). From that point, the improvement of AS is very important to acquire both food security and income. According to the context, good agronomic practices is an immediate resolution (Andrews 1998; Lal 1998; Andrews and Carroll 2001).

9.4 Climate

The climate situation in the areas is considerably diverse almost in all agro-ecological zones of the country. Although these zones experience climate variability, some experience acute variations. As stipulated in the description of the study site section (Fig. 9.2), these zones have different climatic characteristics i.e. rains,

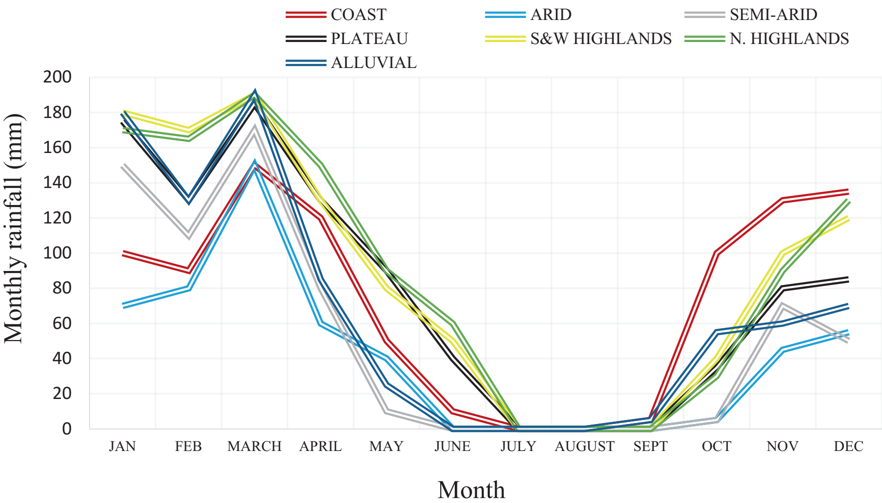

Fig. 9.3 The total monthly rainfall in different agro-ecological zones of Tanzania. (Adapted from Mkonda et al. 2018)

temperature etc. The temperature has also been varying over place and time though sometime is not so significant. Figure 9.3 above explicitly indicates the trends of the total monthly rainfall in all seven agroecological zones. Obviously, this climate variability has significantly affected the famers in their production process. So far, the vulnerability of the farmers varies from one agro-ecological zone to another.

This figure (i.e. 9.3) indicates that from May to October there is significant rain shortage in all agroecological zones. This is evidenced by the fact that about all agroecological zone experience a single rain regime in a year. Apparently, this exhibit that there is one growing season in a year (i.e. from November to April). Although there is almost 6 month of wet spells, the peak rain ranges from December to March. Actually this describes that the growing season is comprised of 4 months only (i.e. December to March). With this regards, it means that even the natural replenishment of the ecosystems is limited to those months (Bationo et al. 2006).

9.5 Biophysical Characteristics and Agricultural Situations in Agro-ecological Zones

9.5.1 Costal

This zone is mostly located to the coastal zone of Tanzania specifically along the Indian Ocean with an altitude about 3000 m above the sea level. The soil and topography in this zone is infertile sands on gently rolling uplands with alluvial soils in Rufiji (Doran and Parkin 1994). It also poses fertile clays on uplands and river flood plains (Birch-Thomsen et al. 2007). Likewise, there are infertile sand soils in some places. The northern part of the area is characterized by bimodal rainfall ranging from 750 to 1200 mm. The growing seasons in this part are October to December and March to June. The southern part experiences unimodal rainfall ranging from 800 to 1200 mm, and the growing season range from December to April.

In this zone, important crops like coconuts, cassava, rice and maize are grown under small scale farming system (Kalhapure et al. 2013). Alongside, mangoes are important fruits grown in the area. This is also accompanied by urban gardening. In addition, irrigation agriculture is predominantly done in the rea by using Pangani and Rufiji rivers.

9.5.2 Arid

This zone is mostly located in central and northern Tanzania (Fig. 9.2). It is located between the altitude 1300 and 1800 m above the see level (to the north) while the southern part is located between 500 and 1500 m above the sea level. The soil and topography in this zone is volcanic ash and sediments (Solomon et al. 2007). Soils vary in texture and are very susceptible to water erosion. In addition, the southern part is characterized by rolling plains of low fertility. The area is characterized by unimodal and unreliable rains ranging from 500 to 600 mm and 400 to 600 mm per annum in the northern and southern part, respectively. March to May form the growing season in the area.

Since annual mean rains is low; the drought resistant crops like millet, sorghum, sunflower and sesame are grown in these areas as major livelihoods of the people. Alongside, livestock keeping and organic soil management are important agricultural practices in the area. In some areas, Pangani River flood plain with saline and alkaline soil facilitates small scale irrigation in the area. However, the production per area is less than 0.5 tn/ha. This indicates that there is a need to improve agricultural system in the area in order to increase crop yields and food security.

9.5.3 Semi-arid

This zone is mostly located in central and southern Tanzania (Fig. 9.2). It is characterized by undulating plains with rocky hills and low scarps. It is located between the altitude 1000 and 1500 m above the see level (central part) while the south eastern part is located between 200 and 600 m above the sea level. The soil and topography in this zone is well drained soils with low fertility. It has alluvial hardpan and saline soils especially in the eastern Rift Valley and Lake Eyasi. In addition, it has black cracking soils in Shinyanga (URT 2007). It has a moderate fertile loams and clays in the south with infertile sand soils in the center. The area is characterized by unimodal and unreliable rains ranging from 500 to 800 mm and 600 to 800 mm per annum in the central and south eastern part, respectively. December to March form the growing season in the area.

In these areas, drought resistant crops like millet, sorghum and sesame are produced in these areas. Alongside, livestock keeping and organic soil management are important agricultural practices in the area. In some area; small scale irrigation is practiced to get vegetables and other horticultural products. However, the production per area is less than 0.8 tn/ha. This indicates that there is a need to improve agricultural system in the area to increase crop yields and food security.

9.5.4 Plateau

The area mostly located to the western part of Tanzania with an altitude between 800 and 1500 m above the sea level. In the western part; the area is characterized by wide sandy plains and Rift Valley scarps. Moreover, the flooded swamps of *Malagarasi* and *Ugalla* rivers have clay soils with high fertility upland plains with rock hills. The southern part is characterized by clay soils of low to moderate fertility. The western part of the area is characterized by unimodal rainfall ranging from 800 to 1000 mm. The growing seasons in this part are November to April.

In this zone, important crops like cashewnuts, cassava, beans and maize are mainly grown under small and medium farming system. Beside, mangoes and other citrus fruits grown in the area. In addition, irrigation agriculture is predominantly done in the rea by using *Malagarasi* and *Ugalla* rivers. Furthermore, in areas with organic fertilization, the yields have increased from 0.75 to 1.90 tn/ha (Mkonda and He 2018b).

9.5.5 Southern and Western Highlands

The area is mostly located to the western, northern and southern parts of Tanzania with an altitude ranging between 1200 and 1500 (south), 1400 and 2300 m (southwest), and 100 and 1800 m (west) above the sea level. These areas are characterized by unimodal, reliable, and local rains with 800–1400 mm (south), 800–1000 mm (southwest), and 1000–2000 mm (western). In the southern part; the area is characterized by undulating plains to dissected hills and mountains. It has moderate fertile clay soils with volcanic soils in Mbeya. In the south, the area has undulating plateau above Rift Valleys and sandy soils of low fertility. To the west, the area has north-south ridges separated by swampy valleys, loam and clay soils of low fertility in hills, with alluvium and ponded clays in the valleys. The growing seasons are this part are December–April (south), November–April (Southwest), while the western part has bimodal rains i.e. October–December and February–May.

In this area, numerous crops are produced based on the type of soils, rains and ecological gradients. In that respect, food crops such as maize, cassava, beans and maize are mainly grown under small, medium and large scale farming system. Beside, fruits like apples, mangoes, avocado, just to mention a few, are grown for household consumption and business. In addition, irrigation agriculture is predominantly done in the rea by using local swamps, seasonal rivers and wetlands.

9.5.6 Northern Highlands

The area mostly located to the northern part of Tanzania with an altitude between 1000 and 2500 m (northern) and 1000 and 2000 m (granitic) above the sea level. In the northern part; the area is characterized by volcanic uplands, volcanic soils from lavas and ash. The granite and mountainous areas are characterized by deep soils, arable and moderately fertile on upper slopes, shallow and stony on steep slopes. The northern part is characterized by bimodal rainfall ranging from 1000 to 2000 mm. The same rainfall characteristic exhibits in the granite areas. The growing seasons in the northern part are November to January and March to June, while that of granitic are October to December and March to June.

In this zone, important crops like coffee, banana, beans and maize are mainly grown under small and medium farming system. Agroforestry is also predominant agricultural system in the area where banana, beans, maize, and trees are intercropped in the areas (Kimaro et al. 2015). Kilimanjaro Region is a good example in this case.

9.5.7 Alluvial Plains

The area is mainly located in flood plains (URT 2007). It covers the regions of Morogoro (i.e. Kilombero and Wami), Coast (i.e. Rufiji) Mbeya (i.e. Usangu) Morogoro (i.e. Wami). Kilombero is characterized by clay plain with alluvial fans. It has unimodal and reliable rainfall ranging from 900 to 1300 mm per year. The growing season in the area ranges from November–April. Rufiji has mangrove swamp delta, alluvial soils, and sandy upstream, loamy down steam in floodplain. The area has unimodal, often inadequate rainfall ranging from 800 to 1200 mm. The growing season in the area ranges from December to April. Usangu has seasonally flooded clay soils in north, and alluvial fans in south. The area has unimodal rainfall ranging from 500 to 800 mm per annum. The growing season in the area ranges from December to March. Lastly, Wami has moderate alkaline black soils in the eastern part, and alluvial fans with well drained black loam in the western part. The area has unimodal rainfall ranging from 600 to 1800 mm. The growing season in the area exhibits the same characteristics with that of Usangu.

These biophysical potentials of *Alluvial plain* are very important to agricultural sector. Together, they have 44 million hectares of arable land that are potential for irrigation. If well harnessed, these hectares can significantly contribute to the development of agricultural industry in the country. Unfortunately, only 4% of these hectors have been harnessed (URT 2012, 2014).

9.6 Potentials of Agriculture Sustainability

For agricultural sustainability to be progressive and productive; there is a need to view the potentials that can facilitate its development (Pretty 2008). In developed countries, the development is viewed is more important than environmental conservation. This is a main reason for why the maximum potential photosynthetic yield in these countries is high i.e. 10^{-6} Mg/g (160 Mg/ha) compared to 3–5 Mg/ha of the developing countries. On that basis, the maximum yield potentials in developing countries, including Tanzania, is very low, and thus, becoming difficult to curb food shortage.

Agricultural sustainability is also significant at global level to accommodate the vast growing population as 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% while conserving the environment at the same time (Poppy et al. 2014). Regrettably, about 80% of these two billion people will be living in developing countries particularly the sub-Saharan region (UNEP 2012).

Besides, as much as agriculture involves people and environment, there should be a balance among these aspects. People should meet their needs through utilization of environmental resources while conserving these resources (Lal 1998). In other perspective, the dimension of the quantity of output (Mg of yield/ha) should reflect the level of temporal and spatial conservation of environmental resources.

As described in section five of this chapter, each agroecological zone has its distinctive potentials to support agricultural sustainability (URT 2007; Lema and Majule 2009). Overall, the biophysical aspects like rivers, soil fertility, sustainable agricultural systems, and the use of agricultural technology are important aspects for AS (Herdt and Steiner 1995; Ahmed et al. 2011; Rowhani et al. 2011a).

In this regard, *alluvial plains* are considerably important for the development of agricultural sustainability due to their potentials. There are sufficient water resources and fertility soil in these areas that can support conservation agriculture while optimize yields, whereas, rice production is more predominant. Likewise, the presence of mangrove swampy delta and alluvial soils gives more options to sustain agriculture. However, this does not guarantee that there will be no degradation in these areas.

Furthermore, *coastal* areas are predominantly characterized by fertile loamy sand soils that can support numerous crops especially cassava, coconuts, beans and rice without environmental degradation. In addition, these are areas with numerous deltas and flood plains. The deltas are formed when permanent rivers such as Rufiji, Ruvu and Wami enter Indian Ocean. They are also formed due to seasonal rivers along the coast. Although these potentials support agricultural sustainability, the frequent floods have posed some serious challenges to meet adequate food security in these areas.

Likewise, *plateau* areas have a considerable potentials to support agricultural sustainability. This is evidenced by the presence of fertile clay soils with high fertility upland plains with rock hills. In addition, *Malagarasi* and *Ugalla* rivers are important aspects and potential for agricultural sustainability. These biophysical characteristics support the production of numerous types of crops. Retrospectively, these potentials have increased yields are reduced environmental degradation in various areas (Lichtfouse et al. 2009; UNEP 2011, 2012).

The southern, western and northern highlands exhibit moderate potentials of agricultural sustainability. This is due to their mixed characteristics ranging from rains to soils. Some areas are fertile especially the granite and mountain feet of Kilimanjaro and Meru. The availability of rivers and wetlands in the areas add significant potentials for agricultural sustainability. Though most agricultural systems are peasantry based, there has been numerous funded projects that emphasize on agricultural sustainability. For example; Southern Agricultural Growth Corridor project which involve *planting basins*, has brought significant achievement in maize and rice production. In addition, conservation agriculture in Arusha has raised farmers' yields while conserving the environment (Mkonda and He 2017a). In a nutshell, these zones prescribe the availability of real potentials that can support sustainability in Tanzania.

On the other hand, the *arid* and *semi-arid zones* possess limited potentials for agricultural sustainability. Most of these areas are characterized by infertile soils and excessive droughts. However, there are some few areas with fertile soils due to decomposition of volcanic sediments. Droughts and poor soils are mainly caused by very low rains (˂500 mm per year) and poor soil management, respectively. Overall, these potentials can slightly support agricultural sustainability in the area. Therefore, for to support agricultural sustainability, there should be proper soil organic management to conserve the environment and optimize yields.

9.7 Dominant Agricultural Systems

There are variety of agricultural practices conducted across the agro-ecological zones (Thierfelder and Wall 2009). This study intend to give an overview of the correlation between these agricultural practices and agricultural sustainability. Since agricultural sustainability assists to optimize yields and conserve the enrolment, it is discernible that the adoption of best agricultural practices would serve the two purposes. Numerous studies have indicated that, there has been an increased efforts to adopt agricultural practices that relate to actual situation (i.e. more especially climate and soils). This scenario has influenced numerous communities to adopt varied agricultural practices as seen in Table 9.2. This variation is considerably caused by the farmers' local priorities as stated above.

Table 9.2 Ranking of the farming systems in the study area

	Agro-ecological zones						
Farming type	CS	A	SA	P	S&WH	NH	All
Maize/legume system	4	4	4	3	1	1	3
Livestock/Sorghum-millet system	5	3	1	6	2	3	4
Pastoralism system	7	2	2	5	3	4	5
Agro-pastoralism system	6	1	3	4	4	6	6
Cassava/cashew/coconut system	1	5	5	1	5	5	7
Agroforestry	3	6	6	2	6	2	2
Wetland paddy	2	7	7	7	7	7	1

Source: Extracted from Mkonda et al. (2018) and Sosovele et al. (1999)
Abbreviations: *CS* Coast, *A* Arid, *SA* Semi-arid, *P* Plateau, *S&WH* Southern and Western Highlands, *NH* Northern Highlands, *All* Alluvial

In arid and semi-arid areas, small pastoralism and agro-pastoralism are main livelihoods. Table 9.2 above indicates the mentioned agricultural systems are highly ranked in these AEZs. This is supported by the findings by other studies (Lema and Majule 2009; Kangalawe and Lyimo 2013). A good example of the communities adopting pastoralism are the Maasai of Arusha, Singida, Shinyanga and some parts of Morogoro (URT 2007). Here, extensive semi-nomadic grazing is predominantly done. Beside, these agroecological zones are dominated by the cultivation of drought tolerant though in small scale (URT 2007).

As well, organic soil managements have been adopted in semi-arid areas to rise soil fertility, crop yields under climate change scenario (Vanlauwe 2004; Giller et al. 2009). Similarly, this practice serve as a sustainable measure for environmental conservation in the area (URT 2007; Branca et al. 2013). Among other things, they create favorable conditions that catalyze biological functions of mycorrhizas and other soil microorganisms (McDonagh et al. 2001). By doing so, it helps the biological and chemical interactions of important soil ingredients (Bationo et al. 2006; Birch-Thomsen et al. 2007; Wall et al. 2013; Kimaro et al. 2015).

In addition, maize and legume systems was highly ranked in the *southern, western* and *northern highlands*. Despite of the conducive biophysical condition; maize and beans are the main food crops in these agroecological zones. Possibly this can be among the main reasons for these crops to be high ranked in the area. In these areas, agroforestry and sorghum-millet systems are moderately adopted. These serve especially under drought incidences and climate change scenarios. However, in these areas, wetland paddy are lowly ranked agricultural practice due to the facts that the areas are dry and do not support this particular agricultural system.

Likewise, cassava/cashew/coconut system was highly ranked in *coast* and *plateau* agroecological zone systems. Essentially, the mentioned crops in this particular agricultural system are dominant food and cash crops. Cassava is the dominant food crop along the shore of Lake Tanganyika (i.e. more especially Kigoma and Rukwa regions). These areas are composed of deep and right soils that support tubers expansions. Similarly; coconuts, cashewnuts and palm trees are the dominant cash crops in these areas because climate is conducive to support the production of these crops.

Lastly, wetland paddy and some agroforestry are dominant agricultural systems in *alluvial plains.* The availability of Basin Rivers such as *Rufiji, Usangu, Wami* and *Kilombero* provide conducive environment irrigation agriculture and integration of crops (agroforestry). Apparently, Kilombero and Usangu are the reputable areas for paddy plantations (rice). They are source of food in most areas of the country especially Dar es Salaam; the main business hub of the country.

Generally, the level of adoptions of these agricultural systems is influenced by the biophysical characteristics of the area (water, soil, ecological gradients etc.) and to a certain extent is determined by the nature of the society.

9.8 Challenges of Agricultural Sustainability in the Study Area

The major challenge of agricultural sustainability in Tanzania is the existence of inappropriate balance between environmental conservation and food production. In this regards, Pretty (2007) asked that if environmental goods and services are to be protected or improved, what then happens to productivity? This shows the reality that in many incidences; it is difficult to meet the two targets simultaneously. Most agroecological zones of Tanzania especially the arid and semi-arid equally face this challenge due to their biophysical vulnerability (Glaser et al. 2001; Vanlauwe et al. 2014; Kimaro et al. 2015). Although there has been numerous measures to conserve the environment (especially in Kondoa District and Shinyanga Region), environmental degradation has consequently remained a major problem.

This is also evidenced even in industrialized countries (i.e. Europe) where intensive agricultural production has yielded more products at the expense of environmental degradation (Poppy et al. 2014). In Australia, organic farming in vineyard has conserved the environment though at the expense of lower yields (Rusinamhodzi et al. 2011). Therefore, under industrialized farming systems, intensive agriculture has been adopted to optimize yields despite the environmental consequences (more particularly soil degradation) that can happen.

According to Lal (1998), soil degradation is the loss of soils quality and fertility. It often prevails due to adoption of inappropriate agricultural systems such as monoculture and shifting cultivation. Similarly, the Tanzanian agroecological zones equally face this type of degradation. This occurs mainly due to unsustainable agricultural practices. This challenge is magnified by biophysical aspects such as excessive drought and soils types (Hartemink 1997; Glaser et al. 2001).

Inadequate agricultural technology is another serious challenge in various agroecological zones of Tanzania. Mainly this involves agricultural implements (especially tractors and chemicals). In Tanzania, agriculture is mainly under small scale farming thus, it mainly uses hand hoe to cultivate. This scenario limits the attainment of agricultural sustainability in various areas of the country. Here, both agricultural sustainability and food security are not obtained easily in different agroecological zones of the country (Andrews and Carroll 2001).

Another serious challenge is land use conflicts among different land users. Although there are plans on the land use; adherence to these plans has been a difficult process. There has been increased conflict between livestock keepers and farmers. Among these land users, each group claim to have right over these land resource. Specifically, livestock keepers have been grazing their herds on the farmers' farms, while the farmers have been killing livestock of the pastoral groups. This has been more pronounced in Morogoro Region where these groups under conflicts dwell. This mostly happens in arid and semi-arid agroecological zones and definitely, this scenario subsequently affects the sustainability of various areas. Besides, this land conflict happens between local communities and large scale investors whereas the latter have been grabbing the land from the local people. As response, these local communities have been encroaching into the investors land to acquire land for agriculture and other economic activities (Benjaminsen et al. 2009). This has increased degradation and unsustainable utilization of the land, thus, impeding AS in the areas.

Poverty among the farmers is another hindrances to agricultural sustainability in various agroecological zones. Although a recent report by World Bank (July 2020) indicates that Tanzania has raised from lower income to middle lower income countries; most people are still economically weak. In the country, most farmers (>70%) entirely depend on agriculture as their main livelihoods. This situation has obviously lead to over utilization of land resources and thus, causing continuous degradation. Now that, this situation does not sustain AS in these areas.

9.9 Adaptations to Environmental Stress

As a response to environmental impacts; numerous adaptations have been in place to limit the associated impacts. However, these adaptations vary over agroecological zones. Table 9.3 below indicates those variations. These adaptations subsequently serve to optimize yields and environmental conservation in these areas.

Timing of farm operations and the adoptions of shorter cycle crops varieties are dominant adaptations across all agroecological zones. This is influenced by unreliable and erratic rains that has shortened the growing season. In addition, conservation agricultural practices such as mulching, agroforestry, crop rotation, and little tillage; are more dominant in *plateau, southern, western* and *northern* AEZs. This is influenced by the moderate rains across these agroecological zones which ranges from 800 to 1200 mm per annum. Besides, small scale irrigation are slightly practiced in *arid* and *semi-arid* agroecological zones due to prolonged drought (Osman-Elasha et al. 2006). Such environmental stress is significantly caused by unreliable rains which is less than 500 mmm per annum. These adaptations include a wide range of approaches designed to reduce the vulnerability and enhance the adaptive

Table 9.3 Comparison of farmers' adaptations to environmental stress presented in percentage

Adaptation activities	CS	A	SA	P	S&WH	NH	All
Timing of farm operations	80	75	75	50	60	50	65
Adopted shorter cycle crop varieties	50	35	45	60	50	70	60
Little tillage	40	50	55	65	50	60	40
Mulching	35	55	35	40	55	40	30
Agroforestry	20	45	25	45	35	50	55
Plating high yielding varieties	30	25	15	40	35	50	40
Practicing crop rotation	20	30	15	40	30	40	20
Small-scale irrigation	20	5	8	10	10	10	10

Source: Extracted from Mkonda et al. (2018) and Ayanlade et al. (2017)
Abbreviations: *CS* Coast, *A* Arid, *SA* Semi-arid, *P* Plateau, *S&WH* Southern and Western Highlands, *NH* Northern Highlands, *All* Alluvial

capacity of agricultural systems under climate change scenarios (Yanda 2015; Mkonda and He 2017c).

On the other hand, 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 (Bationo et al. 2006; Birch-Thomsen et al. 2007; Solomon et al. 2007). Among others, these mitigations includes; reduced or more efficient use of chemical fertilizers, management of water sources especially wetlands, reduced tillage, planting of biofuels and trees for fuel wood, use of improved feeding practices for livestock, and planting of fast-growing tree plantations (Glaser et al. 2001; Giller et al. 2009; FAO 2013).

9.10 Experience from Other Countries

Although agricultural sustainability is important all over the world, the Sub-Saharan African and other dryland parts of the world need it the most (Pretty et al. 2006). Most of these areas encounter food shortage and prolonged environmental degradation. These problems are caused by poor yields and unfriendly agricultural systems, respectively. Subsequently, this scenario has led to shrinking of farm sizes and inequitable land distribution patterns, depleted soils and limited use of fertilizer and soil amendments (either organic or inorganic). Besides, unreliable rainfall and lack of irrigation capacity, and limited access to improved varieties and seed distribution systems have equally magnified the extent of the problem (Hartemink et al. 2008; Okeyo et al. 2014).

Moreover, FAO (2013) pointed that most small-scale farms in Africa are less than 2 hectares and they are dependent on household members as a sole source of labour force. This situation embolden monoculture which is purely unsustainable for environmental conservation. To underpin this discussion, the study merely earmarked both sustainable and unsustainable agricultural systems that are practiced in East, West and Southern Africa.

According to various reports by FAO (2013) and IPPC (2014), east Africa is among the worst vulnerable regions in Africa, and this vulnerability is intensified by climate change impacts which have been hitting the region for a couple of years. For some couple years, the region has been implementing numerous climate based agricultural project to conserve the environment and improve yields (Mkonda and He 2017a). Mainly, the implementations of these projects are largely funded by FAO together with other local and international organs. However, the funding of most of these project have not been sustainable.

With this regard, most of these projects have not assured sustainable food security and environmental conservation in these areas due to a number of ecological factors (Solomon et al. 2007). Actually, high diversity in agroecological zones impedes the implementation of these projects and this is amplified by climate change impacts. For example, in Kenya, Rusinamhodzi et al. (2011) pointed out that the adoption of conservation agriculture under rain-fed maize production has increased yields in most lowland farms. However, this has been contrary in upland and dry areas (i.e. northeastern). In addition, Kimaro et al. (2015) asserted the same when proposing the optimization of yields along the Uluguru Mountain in Tanzania.

Furthermore, agroforestry systems (such as woodlots) has significant contributions to ecological improvements tenable for agricultural sustainability in various tropical areas (Christensen 1988; 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. This ecological situation can also play important functions in supporting agricultural sustainability in these areas. Lastly, these studies concluded by endorsing organic soil management against long-term chemical fertilization which appeared to affects the ecosystems especially in arid and semi-arid agroecological zones (Mkonda and He 2017b).

On the other hand, the Southern African countries such as Zimbabwe, Zambia, Malawi, Botswana, Mozambique and Angola; agricultural intensification has been in place to rise yields and environmental conservation (Wall et al. 2013). Among others, intensive agriculture in this region includes crop production, livestock rearing, forestry and fish farming (Nyong et al. 2007; Duru 2015). For example, Malawi attempts to improve fishing industry by applying different techniques like animal manure to feed the fish in the ponds (Thierfelder and Wall 2009).

Fortunately, this program has significantly increased yields especially *"tilapia"* that eventually raised income through selling. In this regard, the region is practicing both traditional and modern agricultural systems (Bationo et al. 2006). However, majority of the farming systems are traditionally practiced and they include extensive (i.e. shifting cultivation and nomadic herding) and intensive and specialized types of farming (such as compound farms and terrace farming). In this aspect, shifting cultivation is an extensive agricultural system (mainly *slash-and-burn*) is dominant in rural areas. However, the system degrades the environment as it involves serious deforestation (Pretty et al. 2006; Blythe 2013).

Likewise, the growing demand of organic products in the world market has raised the desire to adopt organic farming (Thierfelder and Wall 2009). Predominantly, this system gives little yields but of high value, and products are more marketable in developed countries than in the region (Wall et al. 2013). To a certain extent organic agriculture can conserve the environment by does not ensure food security in the region.

West Africa is another important region where agricultural sustainability need restoration to improve food security and environmental conservation (Nezomba et al. 2010). Despite the diversity of agricultural system in the region, the *fallow system* is predominantly practiced in rural areas. Here, important crops such as yams, sorghum, millet, maize and cassava are considerably cultivated in the region depending on the ecological zone (Nyong et al. 2007). In this aspect; *fallow system* 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. Considerably, these agricultural systems have not supported AS in the region.

For example, in Liberia, the traditional agriculture of the *Loma people* involves 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). This soil is created from the deposits of charred and fresh organic matter, including manure, bones, ash, charcoal and ceramics. However, the sustainability of 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.

Mali is another study country from West Africa. The country is highly vulnerable to the threat of declining soil fertility and food security (Karlen et al. 2003; Kalra et al. 2013). Despite of numerous strategies to rise soil fertility (i.e. new green revolution) in the region, little has been achieved. With this respect, agricultural sustainability has not been considerably sustained in the area. Therefore, Mali is in need of long-term solutions for small-scale farmers to optimize crop production and environmental conservation.

Another example is picked from India, the Asian country. This is 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 differences in agricultural systems responsible to meet food security and environmental conservation. Despite of that, these agricultural systems have to sustain agricultural sustainability in the region.

Another aspect that prompts agricultural differences in India is population density. The 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 (Kalra et al. 2013; Kareemulla et al. 2017). Thus far, population necessitates the intensive agriculture rather that organic and extensive farming. Intensive agriculture can give more yields in a small geographical area but with serious environmental consequences. With this respect, India has still a long way to sustain agricultural sustainability.

China is another good example from Asia that can serve for the purpose of this study. The country is the most populous country in the Planet and has significant contributions to global agricultural sustainability (Tilman et al. 2002; Li et al. 2010). With diverse climatic region, China applies different farming systems to meet this spatial biophysical characteristics with respect of feeding the huge population and conserve the environment. In this respect, the intensive high-yield agriculture is dependent on addition of fertilizers, especially industrially produced ammonium (NH_4) and nitrate (NO_3). This is done to accrue high yields for food and industrial raw materials (Sharma and Minhas 2005).

Unfortunately, only 30–50% of applied nitrogen fertilizer 40%, 41% and ~45% of phosphorus fertilizer 42 is taken up by crops (Li et al. 2010). 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 in China, the agricultural systems in most dry areas is limited of irrigation (IPCC 2000; Sharma and Minhas 2005; Li et al. 2009). In arid land of northwest China, water consumption for agriculture accounts for approximately 90% of the total water uses but the average available water is less than 1635 × 108 m^3 per year, only 5.8% of the China average level (Li et al. 2010). Now that, this tells that AS is promising where there is no shocks or immediate demand of environmental services (Huang et al. 2012). However, in other areas where environmental resources are stressful, it has been difficult to optimize yields without degrading the environment. Therefore, agricultural sustainability in the country is not easily sustained.

Europe is another example of the region to be picked for this study. According to European Union (2012), Europe plays great roles in both practicing and funding numerous AS projects around the globe. The continent 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. This report further elaborates that, increasing demand of organic products at global level has raised organic agriculture in Europe. It is envisioned that 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 corns 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. Generally, Europe has played a significant role in funding, donating and supporting the sustenance of AS in other parts of the world especially Africa, South America, and southeastern Asia.

9.11 Conclusion

This study assessed the influence of various agricultural systems on agricultural sustainability in various agroecological zones of Tanzania, and other parts of the world. It found that, most agricultural systems and practices can optimize yields although are not environmentally friends. For example, in most rural areas traditional agricultural systems like shifting cultivation, monoculture and fallows are the dominant. On the other hand, the study exhibited that funds from developed countries especially from Europe has helped to support agriculture that can increase yields and conserve the environment. However, this has not adequately helped the sustenance of agricultural sustainability in most agroecological zones. Therefore, agricultural sustainability can only be attained when integrative agricultural systems are adopted in the area. This will improve soil fertility that in turn increase yields. By doing so, the two major aspects (i.e. yields optimization and environmental conservation) will be attained.

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