Nurturing Agricultural Productivity and Resilience in Drylands of Sub-Saharan Africa

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1 Introduction

In most African countries, agriculture accounts for about 70 % of the labour force, 25 % of the Gross Domestic Product (GDP) and 20 % of agribusiness (UNECA 2009). However, the natural resources base in SSA has not been exploited to improve food security and poverty. The region remains one of the most food-insecure parts of the world, where poverty is prevalent, food shortages are common, and food aid is the major coping strategy to feed people during food-deficit months. There has been some progress in Sub-Saharan Africa towards halving the proportion of its population that suffers from food insecurity, partly by helping farmer to access agricultural technologies and expand market opportunities. The prevalence of hunger in the region declined by 31 % between the base period (1990–1992) and 2015 (FAO 2015). For example, between 1990–1992 and 2012–2014, food availability in Ethiopia and Mozambique increased by 41 and 31 %, respectively (FAO 2015). However, much of Eastern and Southern Africa has been affected by unfavourable climatic and drought conditions which have undermined any progress toward improving food security and nutrition. For instance, in 2015–2016, Ethiopia and Zimbabwe have been suffering the worst drought in 50 years due to El Nino-associated extreme events. Maize stocks in Malawi—a net exporter of maize just a few years ago—declined to a quarter of its annual average after the worst harvest in seven years in 2012–2013. Meanwhile, maize prices have more than doubled recently (https://www.gov.uk/government/news/southern-africa-facing-disaster-as-food-crisis-looms).

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Food insecurity in the region is generally caused by low and stagnant agricultural productivity as expressed by low crop yields (Amede et al. 2014b) and rural poverty. For instance, about 55 % of smallholder farms in Malawi are less than 1.0 ha, with 25 % of these less than 0.25 ha (Dorward 1999). It is becoming increasingly difficult for these farmers to satisfy their basic household food requirements with the existing low-input, low-output production practices. The land resources base is no different for Ethiopia. Food production on such small plots commonly supplies six to nine months of the household food demand per year, but this can vary with weather conditions (drought or wet years). For the remainder of the year, resource-poor smallholder farmers depend on off-farm activities to raise the necessary cash for their household needs or rely on food aid. Some communities, sell their livestock, mainly goats and sheep, to cover the food deficit periods as is the case in Zimbabwe. Recent government initiatives for improving food security and tackling poverty in SSA region have had mixed results, and the potential effects of these policies on rural livelihoods are yet to be evaluated. For instance, land tenure policies in Mozambique are a major concern for farmers as they affect long-term investments (Amede unpublished data).

In general, rural poverty has decreased in most SSA countries—mainly those that have increased food availability and experienced economic growth (FAO 2015). For example, poverty rates in South Africa declined by 64 %, from 26 % in 2000 to 9 % in 2011, while Ethiopia declined by 33 % from 1999 to 2014 (World Economic Forum 2015). Investment in the agricultural sector in SSA was found to be more effective than other sectors in reducing hunger and poverty and contributing to economic growth. The agricultural sector has the potential to generate capital surplus, release labour for other sectors, and provide a stable food supply at affordable prices, thus contributing to the competitiveness of the economy as a whole and acting as a major stimulus for the demand of goods and services in other sectors (FAO 2015).

Key problems facing dryland countries include:

(i) Food production systems are highly fragile.
(ii) Some 16 % of the population lives in poverty.
(iii) Food imports are untenably high.
(iv) Water scarcity is a constant and growing problem.
(v) Adverse climate events (extreme heat and cold; drought and flooding) are aggravating vulnerability (Dryland Systems 2012).

This chapter describes the various dryland farming systems in Sub-Saharan Africa and reviews the different interventions required to increase productivity and curb the adverse effects of recurrent drought in the region. The various entry points to facilitate sustainable intensification of dryland systems at farm and landscape scales are also outlined.

2 Dryland Farming Systems

SSA farming systems can be classified into 13 broad farming systems, where each has a unique core concept or central tendency, and contains a substantial degree of subsystem heterogeneity (Garrity et al. 2012). Dry area production systems include a diverse mix of food, fodder and fiber crops; vegetables, rangeland and pasture species; fruit and fuel-wood trees; medicinal plants; and livestock and fish. They are found where precipitation is low and erratic, and water supply is often the most limiting factor to agricultural production (Dryland Systems 2012). The dryland systems in Eastern and Southern Africa (ESA) extend from north to south across the various countries, as presented in the aridity index (Fig. 1).

Maize (*Zea mays* L.) is the dominant crop in the dryland systems of ESA, with some 91 million ha cultivated. The maize mixed farming system has a higher agricultural population (just under 91 million in 2010) and more poverty than any other farming system in Africa. This farming system is the major food basket of the region, as well as the driver of agricultural growth and food security, though its production has peculiar characteristics with important distinctions across countries. Maize-based food constitutes about 50 % of the daily calorie intake in Zimbabwe, Kenya, Malawi, Zambia and Mozambique (Haggblade et al. 2009), which is much higher than other parts of Africa. Maize accounts for 60–70 % of the total cropped area in Zambia and Zimbabwe and > 90 % of the total cereal production (Mukanda and Moono 1999). However, about 40 % of Africa's maize growing area faces occasional drought stress which reduces yields by 10–15 % (Fisher et al. 2013), and about 25 % of the area suffers frequent drought with yield losses reaching 50 % (Abate et al. 2013). Because most of the farmland is allocated to maize—from 45.9 % in Mozambique to 69.8 % in Malawi—the risk of crop failure due to drought cannot be ignored. Moreover, most of the maize land in Southern Africa is covered with local landraces, which are commonly long maturing and low yielding; except in Zambia and Zimbabwe where mostly hybrid maize is grown (Kassie et al. 2012).

Maize is also an important crop in Eastern Africa, with annual plantings on 7.3 million ha (corresponding to 21 % of the arable area and 41 % of land under cereals). However, there are some marked regional variations in growing maize, the largest area allocated to maize compared to all other cereals being in Kenya and lowest in Ethiopia where maize comes second after teff (*Eragrostis teff*) (Erenstein et al. 2011). Maize yields in East Africa average only 1.6 t ha^{-1}. Ethiopia has substantial areas sown to sorghum (*Sorghum bicolor*), wheat (*Triticum aestivum*), barley (*Hordeum vulgare*), teff, chickpea (*Cicer arietinum*), faba bean (*Vicia faba*), enset (*Ensete ventricosum*) and coffee (*Coffee Arabica, Coffee robusta*).

Most of the farmed land in ESA is rainfed, though there is an increasing trend for irrigation agriculture. Crop yields are generally low and below global averages, though productivity varies between countries. For instance, maize yields are close to 3 t ha^{-1} in Ethiopia but < 2 t ha^{-1} in Mozambique (Abate et al. 2013). Despite the availability of virgin land, yield is generally low in Mozambique due to poor agronomic practices. For example, the planting density of maize is very low in small-scale

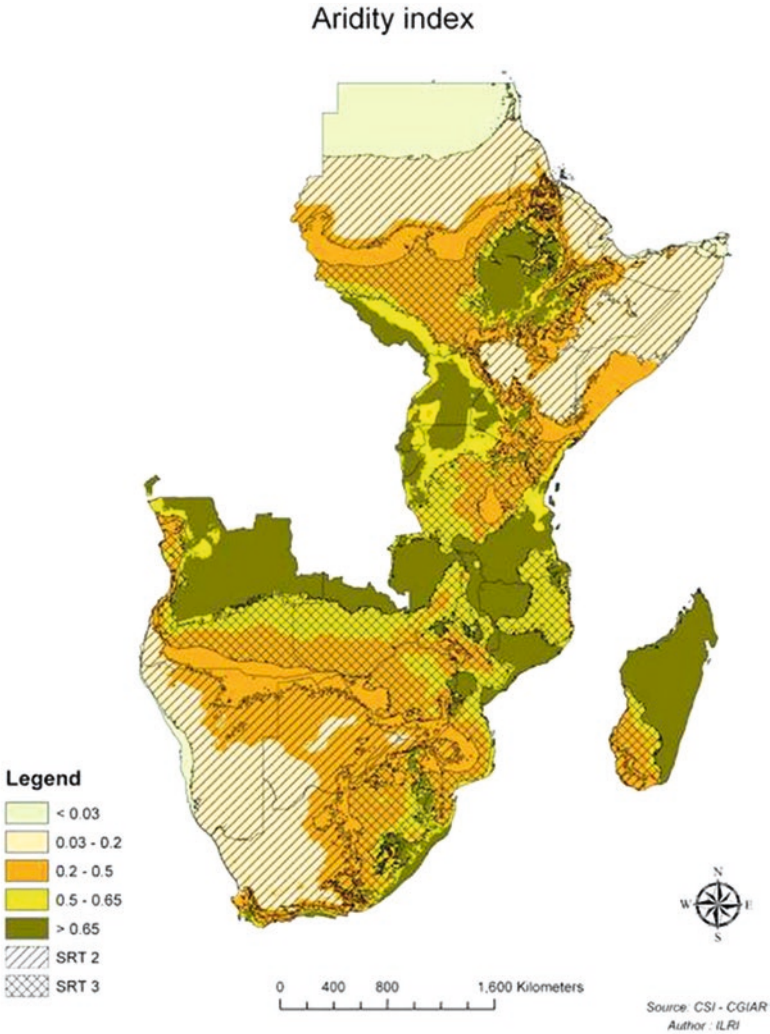

Fig. 1 The distribution of dryland systems in Eastern and Southern Africa (ESA). Values between 0.2 and 0.5 are considered semiarid. (Source: http://geoagro.icarda.org/en/cms/category/maps/15/regional)

farmers' fields in Mozambique, often as low as 40 % of the recommended density, which significantly reduces farm productivity. Most farmers practice low-input low-output (low-risk) agriculture, with very low economic and agronomic yield per unit of land and water, which could be stated as low water productivity.

Other important food crops in ESA are cassava (*Manyhot esculenta*), millet (*Panicum miliaceum*), beans (*Phaseolus vulgaris*), sweet potato *(Ipomoea batates*), Irish potato (*Solanum tubersum*), groundnut (*Arachis hypogaea*) and pigeon pea

(*Cajanus cajan*). Cotton (*Gossypium hirsutum*), tea (*Camellia sinensis*), macadamia nuts (*Macadamia*), tobacco (*Nicotiana tabacum*), sesame (*Sesamum indicum*) and grain legumes are also grown as cash crops in various countries.

Livestock is an integral part of the farming systems in Eastern and Southern African regions. The savannah pasturelands support a large number of animals, mainly cattle and goats, that represent an important livelihood strategy given the high risk of crop production due to the relatively low and unreliable rains and high evapotranspiration rates.

The frequency of drought, decline in soil fertility, and changing market opportunities became major drivers for farmers to change from traditional, commonly long-maturing varieties to early-maturing varieties which can be grown in degraded soils. Drought is the most significant challenge for the people in Malawi, Zambia and Zimbabwe (Kassie et al. 2012) creating food insecurity and affecting rural livelihoods.

Although various reasons have been given for rural poverty and food insecurity in Southern and Eastern Africa, possible solutions/intervention areas to achieve food security and sustainable agriculture are presented below.

3 Adopting Climate-Smart Agriculture

Africa, in general, and the dryland systems of Southern and Eastern African regions, in particular, are considered the most vulnerable to climate variability and change compared to the rest of the world, due in part to the lack of financial, institutional and technological capacity to respond to these changes. Climate change, whether due to natural variability or as a result of human activity (http://www.gao.gov/new.items/d07285.pdf), is threatening livelihoods due to increased greenhouse gas emissions and the subsequent warming of the Earth's surface. Long- and short-term climate data in ESA shows that temperatures have increased over the last 40 years (IPCC 2007), consistent with the global trend of temperature rise. Between 1988 and 1992, more than 15 drought events were reported in various parts of Southern Africa, with an increase in the frequency and intensity of El Niño and La Niña episodes (IPCC 2007).

In Eastern Africa, particularly in Ethiopia, decadal climate variability has been related to ENSO (El Niño/Southern Oscillation, the interaction between the atmosphere and ocean in the tropical Pacific) and the Southwest monsoon over the Arabian Sea (Camberlin et al. 2001). Deep convection over India establishes a temperature gradient that drives a tropical upper level easterly jet over the Arabian Sea. When the jet surges, boreal summer rainfall over Ethiopia tends to increase. Ethiopian rainfall is suppressed following an active tropical cyclone season in the south-west Indian Ocean. However, the rainfall varies with altitude, location and regional monsoon situations. Spatially drought frequency and magnitude also varies considerably from one region to the other. Understanding and predicting inter-annual, inter-decadal and multi-decadal variations in climate is important for planners and development actors. However, it is difficult to realistically predict mainly because there is a lack of historical data in the region, particularly at district level. This variability is however likely to increase with the onset of climate change, and some trends are already observable. The implication is that more and more communities will be exposed to climate change related extreme events, including drought and flood.

A wide variety of weather systems may bring extreme weather to the ESA region—including tropical cyclones and cut-off lows (low pressure centers aloft) that bring widespread flooding to countries including Mozambique, Malawi and Zambia (Davis 2011)—which destroy agricultural enterprises and livelihoods. Climate, especially rainfall, varies from intra-seasonal, through inter-annual to decadal and multi-decadal regimes (Kandji et al. 2006) with annual rainfall variability reaching 40 %. Climate variability and associated drought is the most frequently-recurring cause of food insecurity in the region. Of the 24 El Niño events recorded between 1875 and 1978, 17 corresponded to rainfall decline in the region (Rasmussen 1987) and the 1991–1992 El Niño caused a severe drought, putting millions of people on the brink of famine. The recent floods in downstream parts of the Zambezi River, particularly in Malawi, Zambia and Mozambique, which were mainly caused by La Niña, affected humans and livestock through drowning and landslides, reduced crop production, displaced people, and damage to assets and infrastructures (Kandji et al. 2006). Recently, in early 2013, flooding displaced about 200,000 people from their homes in the Mozambique lowlands. In contrast, periods of sustained anti-cyclonic circulation and subsidence can cause heat waves and prolonged dry spells over the Southern African region, which is expected to worsen in the future (Davis 2011). The impacts will likely include increases in surface and ocean temperatures, a rise in sea level, glacial melting, and more extreme weather events, such as droughts and floods, and less precipitation in some areas (Freimuth et al. 2007)—resulting in reduced agricultural productivity over time and space.

The capacity of small-scale farmers to adapt to climate change is strongly linked to their ability to change to water-efficient agronomic practices and drought-resistant crop types, diversify their crop choices, and improve land and water management at the farm and landscape scales. Watershed management—which is an integrated strategy for increasing vegetative cover, improving water yield, reducing erosion effects, and efficiently using available resources—is becoming an important intervention to enhance the resilience of systems and minimising climatic shocks. Strategies that aim to increase production and income can help to reduce the impact of climate shocks on rural communities. It is assumed in this case that increased production/productivity will lead to increased income, which will be used to support food security, enable investment to protect farms and landscapes, and allow households to acquire productive assets, shelter and safety nets during climate shocks (Amede et al. 2014b). Increasing production usually requires an expansion of the area under cultivation, provision of irrigation to expand the cropping season and/or application of critical inputs (fertilisers, seeds and pesticides) along with agronomic improvements. Increasing farm productivity entails producing more per unit of land, labour and inputs such as water, which implies maximizing efficient use of scarce natural resources. Careful balancing of how this maximization is achieved can help increase the productivity of ecological services while minimising the risk of their depletion. Approaches that combine both production and conservation objectives, for example conservation agriculture (or climate-smart agriculture) and other conservation-based approaches, provide win–win scenarios for communities.

In countries where agricultural resource efficiency is very high, the carbon sequestration capacity of the landscape also tends to be relatively high. The global progress in increasing cereal yields per hectare and producing more meat and milk per animal, and more farm outputs per unit of labour through agricultural intensification, has reduced the encroachment into forests and grasslands, which are critical for mitigating climate change effects. However, improved natural resource management practices for mitigating climate change are commonly adopted by farmers when farmers get short-term benefits from investments interms of increased yield and income (Wichelns 2006).

The key investments required by small-scale farmers to promote drought resilience are summarized below.

3.1 Improved Water Management in Dryland Environments

The threat of water scarcity in SSA is real, due to the expanding agricultural needs, and is exacerbated by the increase in climate variability and inappropriate land use (Amede et al. 2009). Competition for water between different uses and users is increasing at global, national and community scales although agriculture will remain the largest water user. Up to 70 % of the water from rivers and groundwater globally goes into irrigation (http://www.lenntech.com/water-food-agriculture.htm). Irrigation in SSA is the lowest of all countries worldwide despite the increasing need to improve food security and minimise climatic variability. In SSA, the water needs for the future for food production and livelihoods will triple by 2025 compared to the year 2000 (Rockström et al. 2004). About 75 % of the additional food required over the coming decades could be met by increasing the production levels of the subsistence farmers' up to 80 % of those of high-yield farmers, which could be achieved mainly through improved water management (CA 2007). However, major trade-offs are forecast between agriculture and ecosystem services, including trade-offs between increasing food security and safeguarding ecosystems (de Fraiture et al. 2007; Bossio 2009). These demands will include water allocated to ecosystem services. Moreover, focusing solely on irrigation and agricultural production could result in freshwater shortages for wetlands and other aquatic ecosystems (Postel 2000), and degraded water quality, with serious impacts on terrestrial and aquatic ecosystems.

Irrigated agriculture is becoming an increasingly important intervention in response to the increasing food demand in dryland systems, managing climate variability, farm employment and reducing poverty. Irrigation, along with improved agricultural water management practices, could provide opportunities to cope with the impacts of increasing climatic variability and enhance the productivity per unit of land, which would significantly increase the annual production volume of crops (Awulachew et al. 2005). A substantial yield gap still exists between achievable and actual yields both in terms of yield per unit of land but also yield per unit volume of water that should be exploited to ensure food security. Current yields from rainfed crops are only about 50 % of those on irrigated land when all other inputs remain the same. If ESA countries are to achieve their stated aims of food self-sufficiency and food security, the current production shortfalls call for drastic measures to improve water productivity in both irrigated and rainfed systems.

With irrigation, non-productive water depletion could be reduced by improved irrigation water management, which includes choice of water-efficient enterprises, minimising conveyance, drainage losses, and multiple uses of water for household use, fishing and irrigation (Amede et al. 2014a). Irrigation farming is becoming a necessity in the drought-stricken regions of SSA to: (i) reduce the vulnerability of farmers to annual rainfall variability and the associated crop and livestock risks; (ii) increase agricultural production per unit of land, water and labour investments, thereby reducing the expansion of farming to less productive hillsides and valley bottom wetlands; (iii) enable communities to produce high-value enterprises in homesteads and selected plots thereby enhancing the capacity of communities to reinvest on their farms, demand better services and production inputs, and strengthen collective action for broader land and water management; and iv) become an incentive to mobilise communities to better manage upper watershed and command areas. In Ethiopia, there is a strong association between small-scale irrigation (SSI) and the protection of upper slopes from erosion, landslide and gully formation. In the last two decades, irrigation has become an incentive to rehabilitate catchments through area enclosure, soil and water conservation, and to enrich the natural vegetation.

There are huge opportunities for developing SSI in various river basins from the Nile in the east to Limpopo and Zambezi basins in Southern African regions. In Mozambique, it is estimated that about 1.7 million ha of land has irrigation potential within the Zambezi basin (FAO 1997), while in Ethiopia this potential is expected to be 5.1 million ha (Awulachew et al. 2005).

However, irrigation development in SSA is still in its infancy (Fig. 2) and is only likely to be exploited if policy incentives are in place that would improve water access, reduce irrigation costs and increase farm returns. Despite irrigated agriculture starting in the region during the colonial era to produce cash crops (e.g. sugar cane, tobacco, tea), by the 1960s it remained highly localised, contributing to <5 % of food production, much lower than the global average. About 5.2 million ha of land are irrigated in SSA, representing 3.3 % of cultivated land, which is much lower than the irrigated share of crop lands in other continents. In Ethiopia, for example, 4.3 % of its estimated potential area is irrigated which contributes about 3 % of total food crop production in that country. Moreover, existing irrigation schemes are not giving the expected returns, due to excessive siltation, poor agronomic and water management practices, and the failure of local institutions to

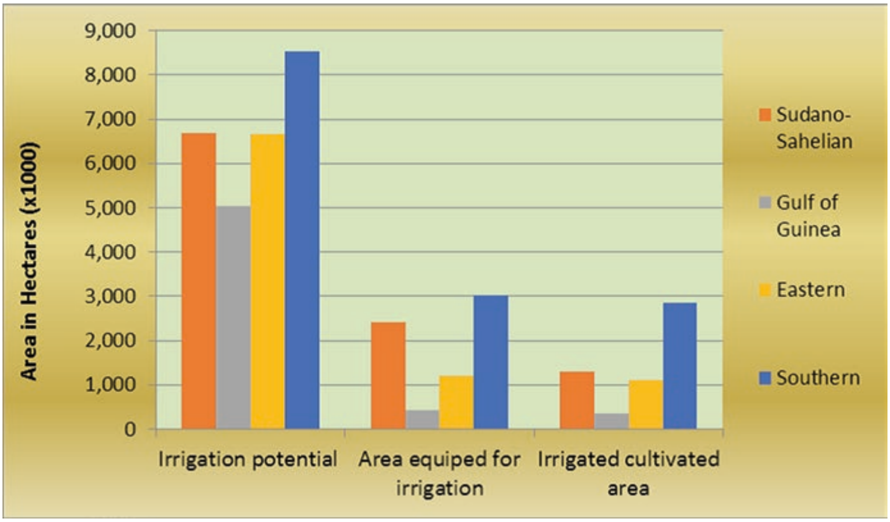

Fig. 2 Potential, equipped and actual irrigated areas in the SSA dryland countries. (Source: Ward and Ringler, IFPRI, undated)

sustainably manage them (IFAD 2004). However, there is increasing government interest and investment to develop the water resources for irrigation and other uses.

Zambia has enormous irrigation potential with estimates of about 2.75 million ha of land (FAO 2006) and a large portion of it in the Zambezi basin. However, the total area currently under irrigation is only about 10 % of this potential and is mostly practiced by large-scale and medium-scale farmers using surface water irrigation (Evans et al. 2012). About 15,000 ha of land is irrigated with motor pumps despite the region having high ground water potential that could be exploited by increasing access to motor pumps (Amede et al. 2014a). Most of the smallholder irrigation schemes produce food crops, such as rice, maize and horticultural crops, but they usually underperform due to poor scheme infrastructure, inadequate water supply, and inefficient use of available water (MoAFS 2011). The high rainfall from December to March commonly saturates the soil and creates seasonally waterlogged low-lying dambos. There is potential to develop and expand small reservoirs in the region for multiple uses, namely livestock drinking, fishery, household irrigation and other domestic uses (Evans et al. 2012).

Mozambique has multiple river basins, with most of the rivers having highly seasonal, torrential flow regimes, with high flows for 3–4 months and low flows for the remainder of the year, corresponding to the distinct wet and dry seasons (FAO 2006). Of these basins, the Zambezi basin is the most important as it accounts for about 50 % of the surface water resources in the country and about 80 % of its hydropower potential, including the Cahora Bassa Dam (FAO 2006) which is the second largest dam in Africa. The main source of water for irrigation in Mozambique is surface water. Irrigation in Mozambique is in its infancy despite being a downstream country with large seasonal flows from the region's big rivers, including the

Limpopo and the Zambezi. The irrigation potential is estimated to be >3 million ha but only a small part of it is being developed, primarily for large-scale production of sugarcane, rice and vegetables in the downstream central and southern provinces. With the increasing market opportunities in regions like Tete, Mozambique and its surroundings, thanks to the expanding mining sector, SSI could help farmers to produce high-value agricultural products, access regional markets, and improve their capacity to respond to emerging demands and climatic shocks. Vegetables, fruits, dairying and small ruminant production are feasible entry points. In terms of irrigation technology, motor pumps could play an important role in getting water to farmers' fields yet the governments in the Mozambique, Malawi and Zimbabwe are promoting treadle pumps because of their low maintenance requirements and operational costs. Both surface and groundwater irrigation could be the future of farming, particularly in countries like Mozambique and Zambia given the large areas of farm land suitable for irrigation.

3.2 Rainwater Management

The majority of farming populations in ESA region rely mainly on rainwater. On an annual basis, there is generally sufficient rainfall to support full-season crops, but variability in temporal and spatial distribution calls for improved rainwater management (RWM). RWM is an integrated strategy to systematically map, capture, store and efficiently use runoff and surface water emerging from farms and watershed in a sustainable way for both productive purposes and ecosystem services (Amede et al. 2011). It has three major components, namely water storage, water management and water productivity. Interventions aim to reduce unproductive water losses (runoff, evaporation, conveyance losses, deep percolation) as well as improve the water productivity of respective enterprises to increase returns per unit of water investment (Amede et al. 2014b).

Small-scale farms in the region often occupy fragmented, marginal and rainfall-dependent lands that are commonly prone to erosion, droughts, floods and fluctuating market prices. Improving soil and water conservation is the first action to improve the water supply for agriculture, i.e. to make more rainwater available for plants (Rockström 2000). Hence, strategies to reduce rural poverty will depend largely on improved RWM across space and time. Interventions are required not only to minimise risk but also to improve water storage and productivity for increased water access for food production and environmental services.

Access to groundwater is beyond the reach of most farmers, mainly due to financial constraints. However, RWM has the potential to provide enough water to supplement rainfall thereby increasing crop yields, reducing the risk of crop failure (Oweis et al. 2001) and providing a water supply for livestock. Enhancing and stabilising crop yields and livestock production for farmers in these crop–livestock systems will encourage farmers to invest in rainwater harvesting and the accompanied nutrient management at the plot, farm and landscape scales. The choice of a certain agricultural enterprise or management would also influence water productivity as it affects the quantity and quality of water used to grow crops, forage, and pasture. Improved vegetative soil cover and strategic selection of cropping pattern (e.g. close row spacing), cropping system (e.g. intercropping and agroforestry) and crop (variety) (e.g. crops with early development of a closed canopy) could reduce unproductive water losses such as evaporation and runoff and increase productive transpiration of rainfed systems (Bouman 2007).

A promising RWM intervention to minimise drought effects is conservation agriculture (CA), a crop management system using three basic principles in a mutually-reinforcing manner (Thierfelder et al. 2013), namely: i) minimum soil disturbance, i.e. no soil inversion with the plough or hoe; ii) surface crop residue retention as mulch with living or dead plants; and iii) crop rotations and associations of different crop species over time. Initial research from the 1990s in the region largely focused on the effects of CA on soil quality, soil erosion, carbon, weeds and water dynamics. These studies highlighted that reduced tillage and mulch cover reduced erosion and increased soil moisture, which led to overall greater yields, especially in dry years (Thierfelder et al. 2013). CA is becoming an attractive intervention in Southern Africa (e.g. Zambia), particularly in areas where there is limited competition for biomass between livestock feed and CA, and where there are large amounts of crop residue produced per unit area, particularly on mechanised farms. CA has been practiced for generations in Southern Ethiopian enset–coffee based systems, particularly for high-value crops grown around homesteads. The application of CA principles may vary from system to system and farmer to farmer.

3.3 Improved Soil Fertility Management for Sustainable Productivity

Soil fertility has declined in SSA, partly due to nutrient mining for generations, which has been aggravated by soil erosion and poor agronomic management. The other major causes include the high cost of fertilisers and the failure of traditional methods for maintaining soil fertility (e.g. fallowing), which is almost non-existent given the scarcity of land and high population pressure. The soils in SSA are also mostly unstable, fragile and prone to erosion.

The two most important nutrients for crop production in the region are nitrogen and phosphorus, although crops also respond to the application of potassium, particularly in Nitisols located in high rainfall regions. However, fertiliser use in the SSA is very low compared to other continents (Fig. 3).

In most dryland systems in SSA, fertiliser application may not be an option given the market distortions (e.g. middle men, government monopoly) and low financial capacity of farmers. ICRISAT and its partners have been promoting microdose fertiliser application since the early 1990s (Twomlow et al. 2008). Microdose is about reducing costs but improving fertiliser use efficiency by applying about 25 % of the recommended NP fertilisers close to the plant roots. While the application of

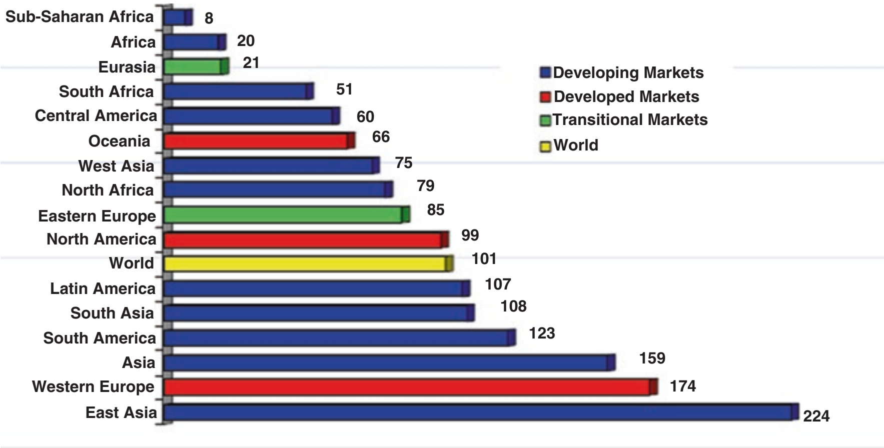

Fig. 3 Fertilizer use per ha by markets and sub-continents (2004–2005) (Roy 2007)

judicious amounts of fertilisers and improved nutrient management are the major components of soil fertility management, investment in chemical fertilisers is limited in SSA for various reasons: (1) chemical fertilisers are expensive while agricultural products are sold relatively cheaply such that it may not cover the cost of investment; (2) most of the nutrient movement is facilitated by erosion, which commonly emerges from upstream, communal lands. However, there is rarely an institution or a community strategy committed to manage these resources as there is limited incentive for individuals to invest labour and money to manage them; (3) farmers manage multiple enterprises of crops, livestock and/or woodlots which are interdependent on each other. Hence priority is given to those which have a direct impact on farmer income rather than those contributing to longterm food security. In some cases, the trade-offs among components is much stronger than the benefits in terms of environmental services (e.g. effect on water, nutrients and so on) and yet they could be economically attractive in the longer term. In this case, farmers single out enterprises with better economic benefits regardless of the negative impact on other system components and future production scenarios.

Moreover, fertiliser efficiency is very low due to soil erosion, recurrent drought and inappropriate choice of crop varieties. Farmers are also reluctant to apply chemical fertilisers for food crops due to high fertiliser costs, which are higher in landlocked African countries (e.g. Ethiopia, Zambia) than coastal countries. Most importantly, there is limited market regulation to ensure the quality of inputs (Amede et al. 2014a). There is a general concern that the chemical fertilisers currently available could be adulterated. There is also a lack of expert knowledge on what fertiliser mix would best fit where within the different agroecological zones and landscapes. For instance, ammonium sulphate could aggravate acidity if applied to soils with low pH while it may be appropriate on saline or sodic soils. Moreover, the major fertiliser inputs that have been applied to date are predominantly nitrogen and phosphorus which create long-term nutrient imbalances. Costly ameliorative measures such as liming and corrective fertiliser compounds are currently in demand though small-scale farmers cannot easily cover the costs of these measures. Application of conventional fertilisers may not necessarily improve crop yield unless accompanied by supplementary plant nutrients and expert advice on fertiliser use on a case-by-case basis.

In an IFPRI review on the rate of returns from agriculture-related investments in the region, fertiliser returns did not make it to the list of priorities, while improved crop varieties had a return of 35 to 70 % (Alston et al. 2000). The low returns could be due to other yield-limiting factors. Low soil water holding capacity accompanied by high evapotranspiration could reduce nutrient uptake and yield. In some soils, e.g. calcareous savannah soils, the most important yield determinants could be micronutrients (e.g. zinc) while in high rainfall areas aluminium toxicity and P-fixation is to be expected. Moreover, the drier parts of SSA experience recurrent soil water deficits that reduce crop yields, when the drought period coincides with flowering (maize) and key tuber extension (root crops).

Fertilizer subsidies (e.g. Malawi and Ethiopia) have made a huge difference in terms of increasing crop yields and improving food security in the region however these subsidies have been phased out. In 2006–2007, maize yields in Malawi improved significantly, and some was even exported (Amede et al. 2014a). Other African governments were interested in copying the 'Malawi green revolution' but enthusiasm quickly faded when the direct financial support of donors to the Ministry of Agriculture and farmer organizations dwindled, and the government removed fertilizer subsidies. Moreover, investing in fertilizer and seed alone will not solve the food crisis in the long term unless a parallel investment in complementary services, including market infrastructure and marketing system, is established that will allow producers to connect to wider markets.

There are ongoing continent-wide initiatives to characterise soil quality and develop fertiliser recommendation domains for the whole SSA region. The Africa Soil Information Service (AfSIS) Online Map Tool is an interactive mapping application that can display more than 30 maps of soil and related environmental characteristics for Africa. http://blogs.ei.columbia.edu/2012/12/12/new-understanding-of-soil-quality-throughout-africa/. The tool creates an online map that allows users to examine soil characteristics from existing, legacy soil maps and data as well as a new collection of soil samples gathered by AfSIS in the past four years. The Ethiosis, a localised tool for Ethiopia, can also create maps indicating soil nutrient availability in major regions. These maps should be converted to usable tools to guide farmers toward agronomically-efficient and economically-viable fertiliser application schemes.

3.4 Integrated Watershed Management

Resource degradation is a serious problem facing the agricultural systems of SSA. Given the extent of land degradation (Fig. 4), particularly in the Eastern African highlands, reducing poverty and improving livelihoods may not be achieved

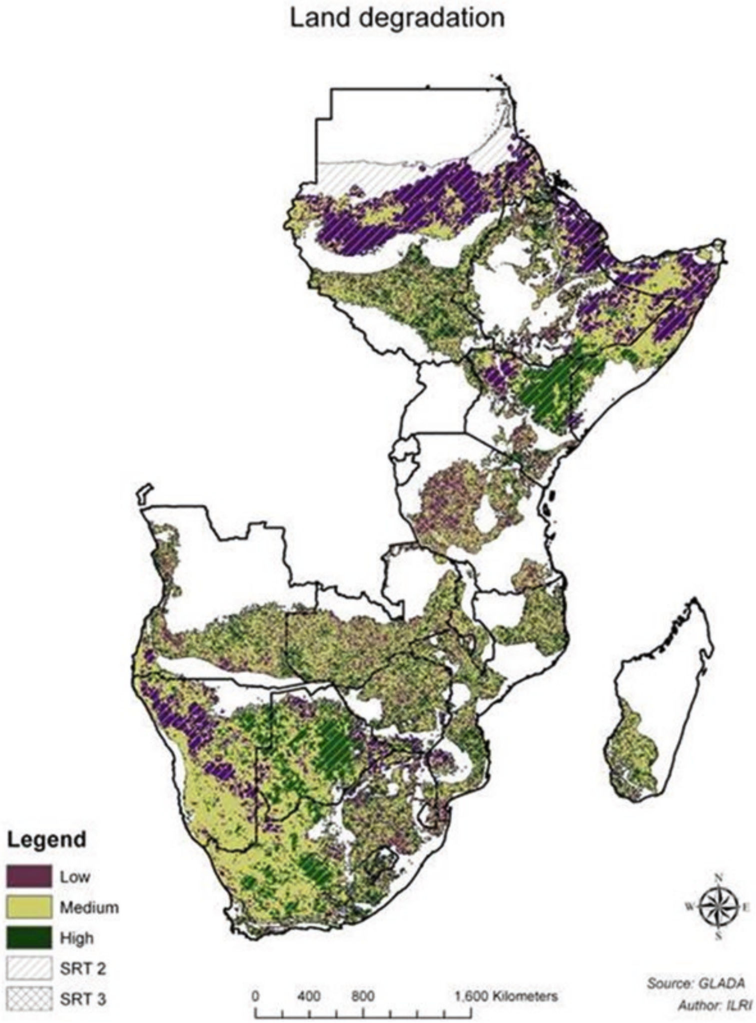

Fig. 4 The level of land degradation in Eastern and Southern Africa (Source: http://geoagro.icarda.org/en/cms/category/maps/15/regional)

without addressing this major system constraint. The proximate drivers of land degradation include forest clearance and surface soil exposure (high removal of vegetative cover), detrimental cultivation practices with emphasis on small-seeded crops that require fine tillage, and overgrazing (Gebreselassie et al. 2015). Due to land shortages and the lack of alternative livelihoods, farmers cultivate land that slopes more than 60 % with shallow and stony soils prone to erosion.

Water erosion is considered the major source of nutrient depletion, with N, P and organic carbon nutrient losses estimated to be 74, 5.5 and 539 kg ha^{-1} year^{-1}, respectively, with N and P losses estimated at more than $US 300 million per year

(Saka et al. 1999), based on fertiliser prices prevailing in the 1990s. A study by Nakhumwa (2004) showed that the severity of soil erosion and its increasing trend equated to gross annual losses of $US 6.6–19.0 million. In Mozambique, average nutrient losses from agricultural fields is estimated to be 34, 6 and 25 kg ha^{-1} $year^{-1}$ of N, P, K, respectively (Folmer et al. 1998), which is threatening agricultural production given the very low application rates of chemical fertilisers. This value could be even higher in the mountainous parts of Eastern Africa, where rainfall is higher, erosion is more severe, and farmers rarely adopt soil and water conservation practices.

Oldeman (1998) estimated that about 10 % of cumulative productivity losses in the last 60 years in Africa resulted from human-induced soil degradation, associated losses of soil carbon, and accelerated water depletion. About 65 % of agricultural cropland and 31 % of permanent grazing land in Africa were degraded in the same period (Scherr 1999). Gross fertiliser use also fell by 9 % in the late 1990s (Wichelns 2006). These low-input agricultural practices in the region have led communities into a downward spiral of poverty, deforestation, resource degradation and local conflicts, all of which affect the adaptation capacity of communities to climate change. For example, cultivation with low-input methods (no fertiliser) in the humid savannah zones of SSA induced a 30 % loss of soil organic matter after 12 years and 66 % after 46 years, with rice yields declining from 1 t ha^{-1} to 300 kg ha^{-1} (Barrett et al. 2000), substantially decreasing the soil carbon stock due to loss in soil organic matter. The return of crop residues to the soil alone is not sufficient to offset these losses. Soil carbon decline and recurrent spatial and temporal climate variations, aggravated by the lack of water storage capacity, hinder the effective use of water and nutrients by plants, leading to frequent crop failures which, in turn, contribute to substantial poverty and resource degradation.

One area of intervention to minimize nutrient losses and enhance sustainable and climate-smart agriculture is improved watershed management. Integrated watershed management (IWSM) reduces erosion, regulates runoff, reduces unproductive water losses (runoff, evaporation, conveyance losses, deep percolation) from a system, and increases the water use efficiency of respective enterprises (Amede et al. 2011). It capitalises on rainwater harvesting principles, by storing and efficiently using water in the soils, farms, landscapes, reservoirs and other facilities. Experiences from the Eastern African highlands (German et al. 2012) showed that watershed management is an effective strategy to improve vegetation cover on hillsides, reduce the negative effects on downstream farms and water facilities, and manage the consequences of climate change (e.g. floods and drought) by combining water management with land and vegetation management at landscape scales. Research results from Tigray, Ethiopia showed that IWSM decreased soil erosion, increased soil moisture, reduced sedimentation and runoff, set the scene for some positive knock-on effects such as stabilisation of gullies and riverbanks, and rehabilitated degraded lands. IWSM also increased the recharge in subsurface water (Alemayehu et al. 2009). IWSM approaches would increase the resilience of systems by capturing, storing and efficiently using runoff and surface water emerging from farms and landscapes for production and ecosystem services. This is particularly critical for

SSA, where about 70 % of the land falls within drought-prone arid, semiarid zones. Unlike conventional approaches, it focuses more on the institutions and policies than on the technologies. On the other hand, there has been limited experiences and institutional arrangements to date to employ watershed management practices in the region.

IWSM could be used efficiently for fostering sustainable land management practices, which need a suitable policy framework to consider the interests of present and future generations. Moreover, watershed management interventions should be selected based on context-specific and intensification levels of the farming systems (German et al. 2012). The proximate factors that significantly determine the likelihood of adopting watershed management technology include climate and agroecological zonal characteristics. Communities residing in warm humid/subhumid, cool, arid semiarid agroecological zones or cool humid/subhumid are less likely to adopt watershed management technologies compared to those located in warm, arid/semiarid agroecology (Gebreselassie et al. 2015). This is partly because of the urgency of the system to produce food and fodder in the drylands, while in warm, humid areas the probability of getting alternative food and feed sources is usually high.

3.5 Improved Livestock Management Under Changing Climates

The farming systems in SSA are largely crop–livestock systems, whereby livestock production is integrated into crop production in both rainfed and irrigated systems. The only exception, where livestock predominates as a livelihood strategy is the pastoral and agropastoral systems, which is beyond the scope of this review. In the semiarid parts of the region, livestock provide around 45 % of the families' income for the poorest and nearly 60 % for the better-off households (World Bank 2006). Poor livestock keepers are overwhelmingly most abundant (only next to Nigeria) in Ethiopia and Tanzania with 12.4 and 10 million poor livestock keepers in dryland mixed systems, respectively (Dryland Systems 2012). On the other hand, in areas with cereal mixed systems, farmers keep some livestock mainly for draught power, sale in times of need, and as a reserve for bad times. There has been a significant increase in the number of livestock in Southern Africa; for instance, in Mozambique (by 28 %) between 1999 and 2009, following recovery from long war or drought. Poultry has also been growing at a rate of 52 % annually for five consecutive years (FAO 2013), facilitated by government policy for import replacement (Technoserve 2011). In Malawi, 57 % of households owned or kept livestock or poultry, with male-headed households' owning more than female-headed households. In general, households in Southern Africa are more likely to have kept fewer livestock than households in other African dryland systems, partly due to resource scarcity (NSO 2010). The very poor households commonly keep some chickens and pigs, while those with medium resource status can add goats and cattle. The better-off households can afford dozens of cattle and goats and large numbers of chicken (Amede et al. 2014a).

Livestock numbers in SSA are projected to increase by 2.5- to 5-fold, from 200 M head in 2005 to 500–970 M head in 2050 (Cork et al. 2005), which will put huge pressure on water and land resources unless productivity per unit of water investment increases significantly (Amede et al. 2009). Although the livestock revolution offers a chance for smallholders to benefit from the rapidly growing market and raise their incomes, it may have negative environmental, social and health impacts if not managed well (Steinfeld et al. 2006). How livestock production triggers and aggravates water resource degradation in the drylands includes:

1. By satisfying the increasing feed demands, pastures and arable land for growing feed expand into protected and natural ecosystems.
2. Overstocking and inadequate watering points degrades rangelands.
3. In peri-urban environments, soils and water resources become contaminated from manure and wastewater mismanagement.
4. Growing feed crops demand intensification, which may lead to resource mining and soil degradation (Steinfeld et al. 2006).

Several factors undermine the potential contribution of livestock systems to rural livelihoods, of which shortage of feed and veterinary services are the major ones. Livestock mortality is commonly caused by feed shortages during drought years, lack of drinking water, and the prevalence of animal diseases. Newcastle disease in poultry, African swine fever in pigs and Trypanosomiasis in cattle are the most prevalent livestock diseases in the region (World Bank 2006). These diseases commonly cause mortality but also reduce meat and milk productivity, reduce animal traction power, and affect overall productivity and profitability of livestock systems. Most of the feed is obtained from the natural pasture and crop residues. Quality feed is usually allotted to draught oxen, mainly in the peak farming months, when land preparation and planting operations are commonly practiced. In systems where oxen plough is common (e.g Ethiopia), crop residues are the major feed source. Crop residue from pulses is considered a quality feed resource and it is fed mainly to oxen and milking cows mixed with cereal straw. Crop residues from cereal fields are low in metabolisable energy and protein content (Blummel et al. 2014). This problem can be addressed to some extent by mixing crop residues with various forage legumes, which can enhance rumen fermentation and the availability of energy from the total diet. Improved forages provide a good source of energy throughout most of the year. Despite recognition by farmers of the potential contribution of forage legumes to crop–livestock farming systems, their integration is relatively slow. Growing feed is a new concept for most farmers; they are used to collecting natural forages from roadsides, weeding crops, fallow lands or forests. Some farmers also fear that forages will become weeds. For farmers who are convinced of the value of improved forages, the lack of availability of seeds and planting materials often forms a bottleneck. Steinbach (1997) indicated that six other factors affect the integration of forage legumes into subsistence farming systems:

- Available arable land per capita
- Number of crops that can be grown per year
- Market access to animal products
- Labour availability
- Farmer's perceptions of the risks and
- Rewards of investing in their livestock enterprises

Extensive grasslands in pastoral and agropastoral systems have multiple uses in addition to being an important source of livestock for stock raisers and herders. Most grasslands are important catchment areas, and the management of their vegetation is of prime importance for the water resources of downstream lands (FAO 2009). For instance, in the Nile basin, about 70 % of the water is depleted through grassland pastoral and agropastoral systems. Grassland management, which encompasses erosion control, controlled grazing, availability of strategic watering points for livestock drinking, and different forms of water harvesting structures could be effective adaptation strategies to minimize drought effects. Minahi et al. (1993) stated that grasslands are almost as important as forests in the recycling of greenhouse gases and that soil organic matter under grassland is of the same magnitude as in tree biomass; while the carbon storage capacity under grasslands could be increased by avoiding overgrazing. Improved grazing management can increase soil carbon stocks by an average of 0.35 t C ha^{-1} $year^{-1}$ but under good climate and soil conditions improved pasture and silvopastoral systems can sequester 1–3 t C ha^{-1} $year^{-1}$ (FAO 2009). It is estimated that 5–10 % of global grazing lands could be placed under C sequestration management by 2020 (FAO 2009).

There is evidence that developing multiple watering points in the various niches of dryland systems, thereby reducing long walks for livestock, would enhance livestock productivity and reduce land degradation caused by livestock free movement. In Northern Ethiopia, North Wollo Zone, reducing livestock walking from 9 km to 2 km per day reduced the energy spent for walking from 1956 to 584 MJ ME^{-1} TLU^{-1}, which is equivalent to 343 litres of additional milk per lactation period (Descheemaeker et al. 2010).

There is increasing conflict between livestock keepers and crop producers, particularly in sorghum–millet based subsystems, concerning access to pasture land and watering points, which is getting worse in seasons of drought and feed scarcity. In general, the livestock sector has potential for growth to improve the livelihoods of rural communities in the region. However, the sector receives limited policy attention regarding access to markets, veterinary services, watering points, household credit, and overall marketing and processing infrastructure. On the other hand, there is increasing opportunity to invest in livestock systems due to increasing demand for livestock products to feed the growing middle-class population, particularly in Southern Africa, where mining has become a major economic activity.

4 Land Tenure and Use

There are three major categories of land tenure system in the dryland regions of SSA, namely public land, private land and customary land (Amede et al. 2014a). These tenure systems vary from country to country depending on their historical perspectives. In Ethiopia, the land belongs to the state while farmers have unrestricted user rights. In some other countries, land belongs to the government, but the land under customary tenure could represent up to 85 % of the total land holdings (e.g. Mozambique) (Nabhan et al. 1999). In Zambia, the land tenure system is both customary and state land/leasehold tenure. State land tenure is defined as reserved or gazetted land (national forests, local forests and parks), towns and permanent commercial farms, while customary land means traditional land or "open land" (non-gazetted) where traditional chiefs and their village headmen decide on how the land is to be used (Olson 2007). National and foreign investors can obtain concessions (effectively leases, known as DUATs) for unused land for 100 years, subject to community consultations. Communities and individuals have permanent occupation rights. The Land Law recognizes customary rights and gives them formal legal rights, while encouraging the growth of private sector in the regions (De Wit and Norfolk 2010). Land that is not under any form of use is considered community property, which is under the jurisdiction of the local chief (Saka et al. 1999). However, the governments can declare customary land as public land as deemed necessary and allocate it to investments when the need arises.

This land policy creates insecurity in local communities, putting pressure on the farming systems, reducing fallow periods and the time required for soil fertility replenishment, and squeezing crop and livestock farmers to increasingly smaller landholdings. Moreover, the system of land inheritance varies, whereby the patrilineal or matrilineal system of inheritance is practiced depending on the cultural setups of the respective communities. The consequence is increasing land scarcity, the major cause of local conflicts. For instance, in 2006–2007 in Malawi, 47 % of villages had conflicts over land; 29 % between family groups and households, 20 % between villages, and 5 % between villages and estates (NSO 2010). These conflicts are partly due to the weak institutional capacity to enforce land laws in the respective countries. The general trend is that state ownership has been increasing in the region with the view to expand investments and public ownership of resources. The implication is that there are limited incentives for farmers and investors to invest in their farm unless there is certified land security.

5 Capacitating Local Institutions

The extension system in both regions is generally weak and disorganized in terms of reach and effective service supply. Although there are differences in the extension capacity among countries, the capacity is weak and rarely supported by the required infrastructure. Besides the fact that most of the districts are far from the centre of powers of the respective countries, with poor road infrastructure, the reach of small-scale farmers is aggravated by the limited number of extension staff on the ground (except in Ethiopia where there are about 65,000 extensionists in the field), limited financial capacity, and limited access to farm inputs. In Southern Africa, access to technologies and good practices is limited mainly to large- and medium-scale farmers. Moreover, the common perception that there will be transfer of knowledge from large- and medium-scale to resource-poor farmers is unrealistic due to the fact that better-off farmers rely more on high-value commercial crops with different levels of input-output farming while small-scale farmers are primarily growing subsistence food crops with low-input/low-output scenarios.

Given the weak public institutions in the region to facilitate dissemination of technologies and best practices to wider communities, there is a need to build strong local institutions. Various local institutions are filling the gaps and are engaged in input distribution, marketing and collective action at various levels in all countries in the region. The traditional authorities, sub-traditional authorities, group village chiefs and village chiefs play an important role in the agricultural sector, particularly in organizing communities, disseminating agricultural intervention and guiding farmer organizations (Amede et al. 2014a). The paramount chief is the highest order of the traditional institutions, which has a very strong influence on both policies and local investment flows to the localities.

The current farmer associations in the respective countries need to be organized and facilitated to ensure that their engagement enables local action and creates a wider movement to improve land, water and vegetation management at farm and watershed scales. The current institutional setup rarely entertains community priorities in the planning and implementation of development projects and programmes. Moreover, most programs in the region are run and managed by large NGOs, with top-down approaches, without creating local capacity and institutional innovation. Although the NGOs play a vital role in organizing small-scale farmers, there is still a significant risk that if these international NGOs leave the scene, there will be little capacity left to carry on the development process. There appears to be multiple and parallel initiatives in the region, sometimes with conflicting approaches. Various donors and NGOs promote different philosophies, objectives and activities on the ground, which do not necessarily align with government development directions. There is also poor linkage within the government structure between ministries and local governments. For instance, in Mozambique, beyond the fact that the government extension service was understaffed, there appears to be little effort to create linkages between the various officers at different levels. The major hurdles across the different hierarchy seem to be poor communication, lack of a joint forum for learning and planning, and weak monitoring systems. The formation of local and national forums would serve as a platform for sharing knowledge, identifying gaps and providing comprehensive policy recommendations that would help to avoid past mistakes.

6 Conclusions and Future Research Thrusts

Dryland systems in SSA have been affected by recurrent drought, which has been aggravated by climate change, the decline in soil fertility, and poor agronomic management of production systems. There are proven interventions that should be promoted to help communities to minimise the drought effects and develop sustainable and resilient dryland systems. However, these interventions are either not reaching the intended farmers on time, in the required amount and knowledge detail, or the inputs are beyond the financial reach of poor, smallholder farmers. There is also limited access to markets for farmers to invest in inputs and produce more than what is required for their household consumption. The livestock sector is also receiving limited policy attention regarding access to markets, veterinary services, watering points, household credit, and the overall marketing and processing infrastructure. As the research capacity to develop context-specific agricultural technologies is limited, there is a need to develop the innovation capacity of the local communities by providing various capacity building courses and on-the-job training. Key development investments are required to curb the recurrent effects of drought in the regions, including strengthening the extension system in the respective countries, developing agriculture-friendly policies, developing high-yielding drought-resistant crop varieties, developing SSI facilities using surface and groundwater options, and creating alternative water sources to satisfy feed and food demands. In all these interventions, strong policy support is needed regarding subsidies, improving market infrastructure, capacity building, and the development of function extension systems.

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