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Managing vulnerability to drought and enhancing livelihood resilience in sub-Saharan Africa: Technological, institutional and policy options

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ABSTRACT

Agriculture and the economies of Sub-Saharan Africa (SSA) are highly sensitive to climatic variability. Drought, in particular, represents one of the most important natural factors contributing to malnutrition and famine in many parts of the region. The overall impact of drought on a given country/region and its ability to recover from the resulting social, economic and environmental impacts depends on several factors. The economic, social and environmental impacts of drought are huge in SSA and the national costs and losses incurred threaten to undermine the wider economic and development gains made in the last few decades in the region. There is an urgent need to reduce the vulnerability of countries to climate variability and to the threats posed by climate change. This paper attempts to highlight the challenges of drought in SSA and reviews the current drought risk management strategies, especially the promising technological and policy options for managing drought risks to protect livelihoods and reduce vulnerability. The review suggests the possibilities of several ex ante and ex post drought management strategies in SSA although their effectiveness depends on agro-climatic and socio-economic conditions. Existing technological, policy and institutional risk management measures need to be strengthened and integrated to manage drought ex ante and to minimize the ex post negative effects for vulnerable households and regions. A proactive approach that combines promising technological, institutional and policy solutions to manage the risks within vulnerable communities implemented by institutions operating at different levels (community, sub-national, and national) is considered to be the way forward for managing drought and climate variability.

1. Introduction

Agriculture is the dominant form of land use globally involving major economic, social, and cultural activities and providing a wide range of ecosystem services. Because of its nature, however, agriculture remains highly sensitive to climate variations. The vast majority of smallholder farmers in sub-Saharan Africa (SSA) are dependent on rainfed agriculture for their livelihoods, and they are often afflicted by the vagaries of weather and climate (Gautam, 2006). Among the climatic factors, rainfall variability has a large impact on the livelihoods of the poor as well as the economies of most of the African countries (Gautam, 2006; Hellmuth et al., 2007). For millions of poor people in SSA, variability and unpredictability of climate is a major challenge and poses a risk that can critically restrict options and limit their development (Hellmuth et al., 2009).

Droughts and floods alone account for 80% of the loss of life and 70% of the economic losses in SSA (Bhavnani et al., 2008). Frequent drought conditions have reduced the GDP growth of many African countries (Jury, 2000; World Bank, 2005a; Brown et al., 2011) and threatened their development gains (Hellmuth et al., 2007). Drought has both direct and indirect impacts. Drought directly affects production, lives, health, livelihoods, assets and infrastructure that contribute to food insecurity and poverty. However, the indirect effects of drought on environmental degradation and reduced household welfare through its impact on crop and livestock prices could be larger than its direct effects (Zimmerman and Carter, 2003; Holden and Shiferaw, 2004). In the past five decades,

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drought has become a major problem of Africa and it has caused depletion of assets, environmental degradation, impoverishment, unemployment and forced migrations (Hellmuth et al., 2007; Bhavnani et al., 2008; Scheffran et al., 2012).

Although drought accounts for only 8% of natural disasters globally, it poses the greatest natural hazard in Africa accounting for 25% of all natural disasters on the continent occurring between 1960 and 2006 (Gautam, 2006). Over the four decades since the 1960s, Africa stands first in drought frequency with a total of 382 reported drought events that affected 326 million people (Gautam, 2006). Regions of highly variable rainfall in Africa include the Sahel, the Greater Horn and Southern Africa. These regions experience frequent and sometimes prolonged droughts that lead to famine associated with drought in combination with inadequate socioeconomic entitlements, exacerbating vulnerabilities of households and national economies (Hansen et al., 2004). Over the last five decades, the frequency of droughts has increased steadily in East Africa but declined in West Africa (Gautam, 2006).

Eastern and southern Africa regions are characterized mainly by semi-arid and sub-humid climates with a pronounced dry season in part of the year. Therefore, in contrast to West Africa, the variability of rainfall in these regions is concentrated on relatively short time scales in a year and it has a direct connection with global processes such as El Niño/La Niña-Southern Oscillation (ENSO) (Nicholson, 2001).[1] ENSO events have a strong influence on the inter-tropical convergence zone (ITCZ), regional monsoon wind circulation, and patterns of rainfall anomalies over many parts of SSA (Dilley and Heyman, 1995; Jury, 2000; Singh, 2006). The impacts, however, vary significantly from season to season and across countries depending on geographic conditions. For example, El Niño episodes are often associated with the above normal rainfall conditions over the equatorial parts of eastern Africa during October to December and below-normal rainfall over much of the Horn of Africa during the June to September rainfall season. On the other hand, La Niña events often give rise to below-normal rainfall over much of the Greater Horn of Africa during October to December and March to May and above-normal rainfall during the June to September rainfall season (Janowiak, 1988; Singh, 2006).

Drought has a covariate or widespread nature which can cross national borders making informal risk management arrangements ineffective (Gautam, 2006; Vicente-Serrano et al., 2010). This has led to an increase in the number of people affected, rising economic costs and increasing humanitarian assistance for the rising numbers of affected populations (Gautam, 2006). The effects of natural climatic variability and drought conditions are further accentuated by the looming threat of climate change that is projected to increase extreme events and drought frequencies in many parts of Africa. Alternative agricultural investment options and policy and institutional innovations with varying profitability and success exist for managing climatic risks (Rosenzweig and Binswanger, 1993; Shiferaw and Okello, 2011). The main purpose of this paper is to highlight the state of vulnerability to drought and its impacts in SSA and present the promising technological, institutional and policy options for drought risk management to reduce vulnerabilities and livelihood impacts in the region.

[1] El Niño and La Niña refer to the warming and cooling of sea-surface temperatures (SST) in the equatorial Pacific Ocean, respectively which influence atmospheric circulation and consequently rainfall and temperature in specific areas around the world. Since the changes in the Pacific Ocean (represented by "El Niño/ La Niña") and the changes in the atmosphere (represented by "Southern Oscillation") cannot be separated, the term ENSO is often used to describe the ocean-atmosphere changes (Singh, 2006).

2. Drought vulnerability and impacts

2.1. Vulnerability

Understanding people's vulnerability to drought is complex because this depends on both biophysical and socioeconomic drivers of drought impact that determine the capacity to cope with drought (Naumann et al., 2013). Vulnerability is defined in many ways and it has different meanings when used in different disciplines and contexts (e.g., Chambers, 1989; Smit et al., 1999; Brooks et al., 2005; Adger, 2006; Füssel, 2007). In this paper, drought vulnerability is used to highlight the socioeconomic and biophysical characteristics of the region that makes it susceptible to the adverse effects of drought.

The vulnerability of a society to climate disasters such as drought depends on several factors such as population, technology, policy, social behavior, land use patterns, water use, economic development, and diversity of economic base and cultural composition (Wilhite and Svoboda, 2000; Naumann et al., 2013). As Amartya Sen argued, prevalence of drought and decline in food availability should not necessarily lead to famines and loss of livelihoods. Whether food availability decline would lead to disaster will depend on *capability failure* which in turn depends on market access and people's social, economic and political entitlements (Sen, 1999). In SSA, rainfed agriculture provides about 90% of the region's food and feed (Rosegrant et al., 2002) and it is the principal source of livelihood for more than 70% of the population (Hellmuth et al., 2007). Because of heavy dependence on rainfed agriculture, about 60% of Sub-Saharan Africa is vulnerable to frequent and severe droughts (Esikuri, 2005).

Although expanding irrigation is an important strategy to reduce the vulnerability of agriculture to climate risks, water resources are inextricably linked with climate and the prospect of global climate change has serious implications for water resources and regional development (Riebsame et al., 1995). Although Africa has a huge water resource, there is large variation in its spatial and temporal distribution. Moreover, many African countries are expected to face water stress, scarcity and vulnerability by 2025 (Fig. 1) indicating that water resources are highly dependent on, and influenced by, climate.

Furthermore, unsustainable use of land and other resources increase the vulnerability of people in SSA. Millions of smallholder farmers and pastoralists earn a living in degraded areas which make them highly vulnerable to droughts and other climate hazards. Land degradation often stems from the nexus between poverty and lack of capacity to invest in more sustainable agricultural practices and change extractive land-use systems (Holden et al., 1998; Shiferaw and Okello, 2011). Poverty makes people vulnerable and limits their choices. Therefore, apart from climate, human activity is one of the major factors responsible for environmental degradation in SSA that slowly depletes productive natural assets and increases vulnerability to drought and climatic variability.

Another widely accepted reason for the aggravation of drought vulnerability and impacts in Africa is the continuous increase in population growth which has huge implications when complemented with poverty and inadequate policies (Tadesse, 1998). High population growth increases pressure on limited and fragile land resources and leads to unsustainable resource exploitation, resulting in environmental damage. If crops fail, subsistence farmers have few or no alternative means to provide food for their families. When they run out of alternatives, the poor are forced to exploit land resources, including fragile ones for survival, and inevitably they become both the victims and willing agents of environmental degradation and desertification. In general, high level of chronic poverty contributes to low adaptive capacity to

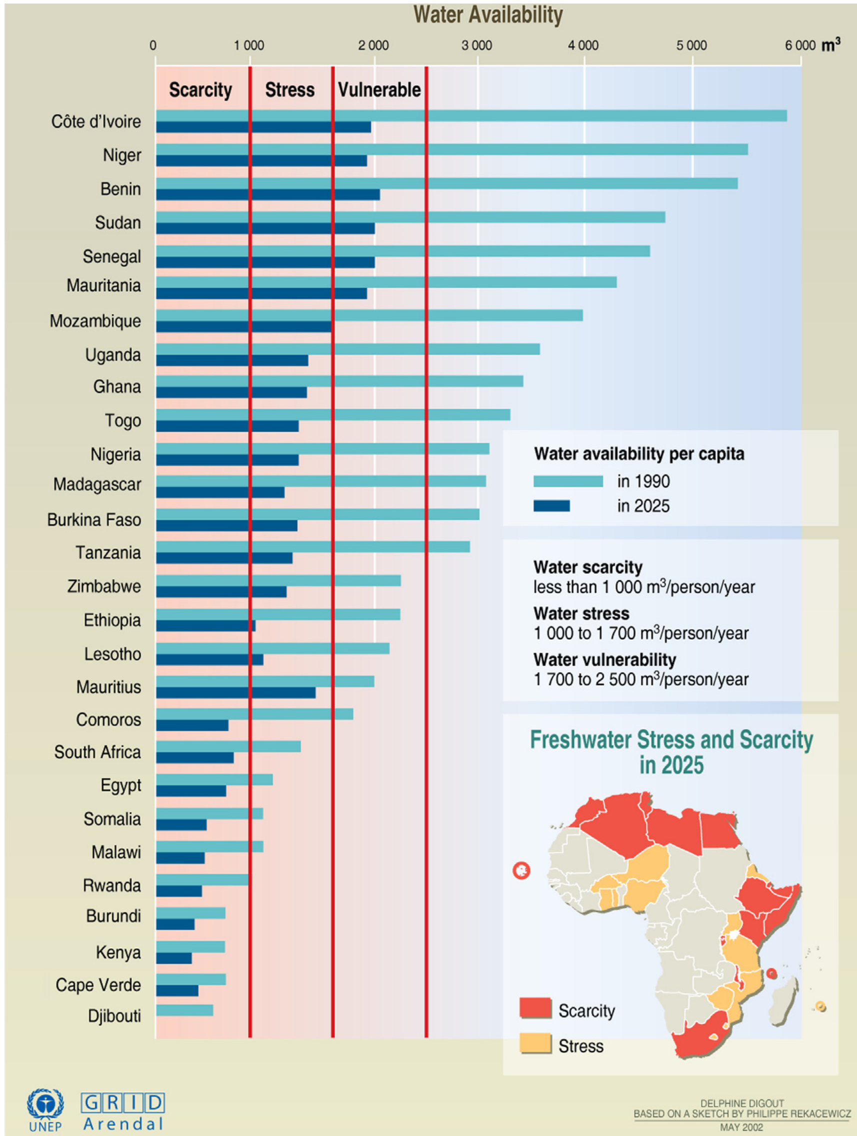

Fig. 1. Per capita water availability in 1990 and 2025 in Africa.
Source: Adapted from UNEP/GRID-Arendal, 2002.

drought and threatens the lives and livelihoods of the poor more than other social groups (Hellmuth et al., 2007).

An increase in vulnerability to drought hazard may result from an increased frequency and severity of drought, increased societal vulnerability, or a combination of the two. Using a drought vulnerability indicator (DVI) computed at country level, Naumann et al. (2013) classified Somalia, Burundi, Niger, Ethiopia, Mali and Chad as countries with higher relative vulnerability to drought. The ability to cope with drought also varies from country to country and from one region, community or population group to another.

2.2. *Drought vulnerability and climate change*

Another factor that is increasing drought vulnerability and impact in Africa is climate change. Climate change threatens both frequent and severe extreme events in Africa (Bang and Sitango, 2003; IPCC, 2007) and in many parts of the world. For example, analysis of long-term records of drought events compiled by NMSA (1987) over several centuries in Ethiopia indicates shortening of the return periods of droughts at exponential rate (Fig. 2). The increased frequency of drought observed in eastern Africa over the last 20 years is likely to continue as long as global temperatures continue to rise (Williams and Funk, 2011). This poses increased risk to more than 18 million people in the Greater Horn of Africa alone who frequently face potential food shortages. Moreover, climate change will greatly exacerbate weather risk-poverty relations as poverty limits the capacity of people to manage weather risks while the same risks contribute to locking people under poverty (Hellmuth et al., 2009).

In recent years, individual countries are paying increasing attention to drought-related issues due to ever increasing exploitation of water resources and associated water scarcity coupled with the growing concern that future climate change will exacerbate the frequency, severity, and duration of drought events and associated impacts (Wilhite and Pulwarty, 2005). This has brought drought risk management to the forefront in policy discussions although the mix of options available and their effectiveness remains poorly understood.

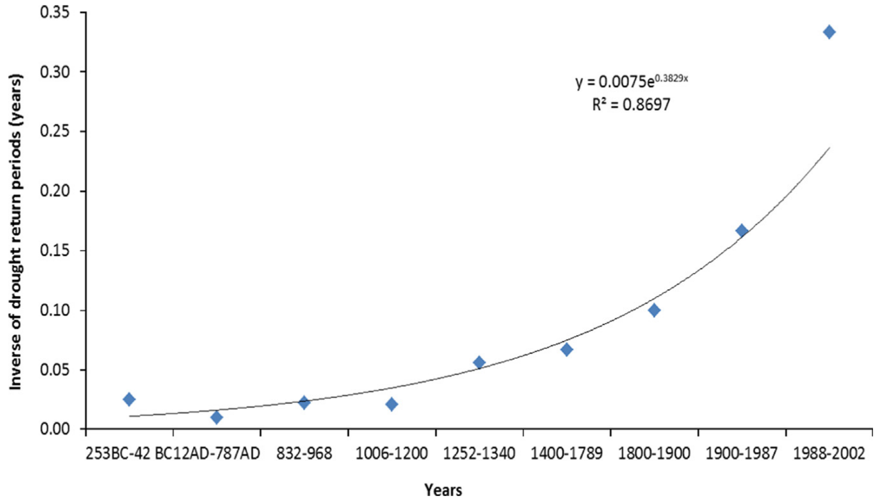

Fig. 2. Trends in drought return periods in Ethiopia.
Source: Adapted from Tesfaye and Assefa (2010) and NMSA (1987).

2.3. Impacts of drought

The impacts of drought can be both ex post and ex ante. Ex post impacts refer to the losses that follow a climate shock while ex ante impacts refer to the opportunity costs associated with conservative strategies that risk-averse decision makers employ in advance to protect themselves against the possibility of climate shocks (Hansen et al. 2004). The major conservative ex-ante responses of farmers to climate risks documented by Hansen et al. (2004) include use of less risky but less profitable crops or cultivars, avoidance of potentially risky improved production technologies, under-use of fertilizers, and shifting household labor away from farming to non-productive but more liquid assets as precautionary savings. Because of high relative risk aversion, poorer households are often impacted more by ex-ante responses to climate variability than wealthier ones even in good years (Zimmerman and Carter, 2003).

The economic and environmental impacts of drought may be direct or indirect, and can be expressed in different forms (Hansen et al. 2004; Hellmuth et al., 2007; Bhavnani et al., 2008). These may include productivity loss in crops, rangelands and forests; increased fire hazards; reduced water levels; increased livestock and wildlife mortality rates; and damage to wildlife and fish habitats (loss of biodiversity). These effects may finally manifest themselves in the form of reduced income for farmers and agribusiness; increased food prices; unemployment; reduced tax revenues; increased conflict, outmigration and displacement; malnutrition and famine; disease epidemics and greater insect infestations; and spread of plant diseases and increased wind erosion.

Between 1971 and 2001 alone, drought affected more people than any other natural disaster in Africa (UNEP/GRID-Arendal, 2005). Many parts of Sub-Saharan Africa face risk of 10–40% probability of failed seasons during the major cropping calendar (Fig. 3). The African continent suffered from the worst famines in the mid-1980s which affected 20 countries critically resulting in the migration of 10 million people in search of food and water and endangered the lives of 35 million people (Tadesse, 1998). In east Africa and the Sahel, the 1984 long-term drought resulted in widespread starvation and famine (Tadesse, 1998). Among sub-regions, East Africa accounted for over 70% of the total affected people from 1964 to 2006; and within East Africa, Ethiopia suffered the most (39% of all affected). Zimbabwe, Malawi, Mozambique, and Kenya all accounted for 9–12% of the total affected people (Gautam, 2006). In recent years, more than 10 million people across the Horn of Africa went hungry due to death of livestock as a result of extended drought in 2011 (AMCEN, 2011).

Severe livelihood and food security stresses due to climate shocks may force households to liquidate productive assets such as livestock or land in exchange for food, default on loans, withdraw children from school, and/or engage in exploitive environmental management practices to survive (Hansen et al. 2004). One of the characteristics of drought impact is that households that suffered a previous shock emerge more vulnerable to the next shock until lost assets can be restored. A study in Ethiopia showed that a substantial portion of the immediate impact of the drought of the early 1980s on farmer income and consumption persisted for more than a decade (Dercon, 2004). At the macro-level, climate variability affects food security through its broader influence on investment, adoption of agricultural technology, aggregate food production, market prices and economic development which in turn determine the ability of individuals, communities and nations to produce and purchase food (Zimmerman and Carter, 2003; Hansen et al. 2004).

3. Drought risk management

Risk management in general refers to strategies to avoid adverse outcomes while pursuing positive goals (Hansen et al., 2004). Drought risk management (DRM) is part of the general climate risk manage (CRM) approach which refers to climate-sensitive decision making (Hellmuth et al., 2007). Using as much information as they can get, farmers make decisions that aim to minimize climate risks and exploit climate opportunities. Climate risk management is being practiced at various levels and with varying effectiveness across SSA (Hellmuth et al., 2007). The major drought risk management practices and efforts are presented below.

3.1. Ex-ante drought risk coping strategies (reducing risk exposure)

Drought coping strategies can be classified into ex ante and ex post, according to whether they help reduce risk a priori or for minimizing undesirable outcomes after the shock has occurred (Owens et al., 2003; Skoufias, 2003). Farmers living in drought affected areas modify their production practices to provide 'self-insurance' so that the likely impact of adverse consequences is reduced to an acceptable level (Hansen et al., 2004; World Bank, 2005b; Pandey and Bhandari, 2009). Although they can be costly in terms of forgone opportunities for income gains because of the choice of safer but low-return activities by farmers, ex-ante strategies help reduce income fluctuations and they are considered as

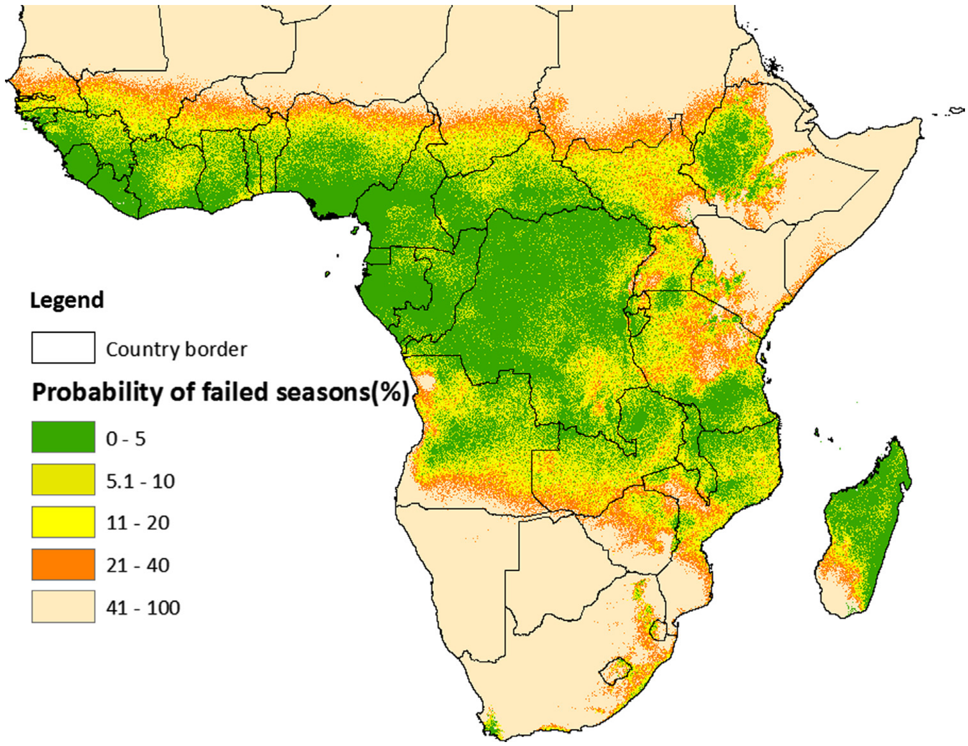

Fig. 3. Probability of years in which growing season is likely to fail due to drought in sub-Saharan Africa.
Source: Adapted from Thornton et al. (2006).

consumption-smoothing strategies (Pandey and Bhandari, 2009). ex ante strategies can be achieved in two ways: by reducing risk through diversification and by applying flexible decision-making. Diversification involves reduction of income shortfalls by engaging in livelihood strategies that have negatively or weakly correlated returns which may involve diversification of crops and livestock, spatial diversification of farms, and diversification from farm to non-farm activities. Maintaining flexibility in decision making is also an adaptive strategy that allows farmers to switch between activities as the situation demands. Examples include plant population adjustments, splitting fertilizer doses and temporally adjusting other input uses based on climatic conditions (Pandey and Bhandari, 2009).The most common ex-ante coping strategies of farmers in Africa include careful choice of crop varieties (e.g. drought tolerant and short maturing varieties), temporal adjustments of cropping patterns and adjusting planting dates and crop establishment methods; changing weeding and fertilization practices; and use of soil and water conservation practices. In drought-prone areas farmers use these strategies in different combinations and some of these strategies have become an integral part of the farming system and may not be easily identified as coping mechanisms (Pandey and Bhandari, 2009).

3.2. Ex-post risk coping strategies (adaptation and minimizing impacts)

Ex post strategies are designed to prevent shortfall in consumption when income drops below the required level as a result of climatic shocks. Depending on the severity of the shock, farm households employ a wide range of ex post drought coping strategies which range from reduction in selling of food, reduced consumption, and increased borrowing to higher rates of seasonal out-migration, default on loans, withdrawal of children from school, distress sale and liquidation of productive assets such as livestock, land, trees and other assets. Households often initially respond in terms of forced reduction of expenditures on certain 'non-essential' items such as clothing, social functions, food and medical treatment, adjustments in food balance and move progressively to reliance on public relief and safety-net programs and exploitive environmental management practices (Skoufias, 2003; Hansen et al., 2004; Pandey and Bhandari, 2009). Despite these adjustments, farmers may not be able to maintain their normal-year level of consumption under severe drought years (e.g. Sahelian droughts in the 1980s) in Africa. As a result, households may be forced to reduce the number of meals per day and the quantity consumed per meal with women and children bearing the burden of drought disproportionately (e.g. Tesfaye and Assefa, 2010; AMCEN, 2011). Exposure to frequent distress from climatic shocks progressively leads to depletion of assets and weakens the ex post adaptation options, making households unable to adapt to and manage even smaller perturbations in production conditions.

3.3. Integrated technologies and institutional innovations

In many parts of Africa, drought needs to be viewed as a long-term development challenge that requires a multi-sectorial and multi-dimensional response (Esikuri, 2005; Gautam, 2006). Thus, strategies for managing drought and enhancing resilience of farmers and agribusiness to weather shocks require integrating technological, institutional and policy options (Fig. 4). The integrated strategies will have direct positive effects on reducing sources of risk (production and market) and vulnerability and thereby increasing livelihood resilience. The integrated technological, institutional and policy interventions offer the best option for strengthening livelihoods through improved agricultural productivity and building the capability of households to diversify incomes to manage drought-induced shocks in consumption. Access to risk-reducing and productivity-enhancing technologies, diversification of livelihoods, better access to markets and market information, and improved infrastructure are crucial strategies for reducing vulnerability and effectively managing climate variability and extremes (Hellmuth et al., 2007). Improving farmer decisions using climate information, improving farmer access to credit using

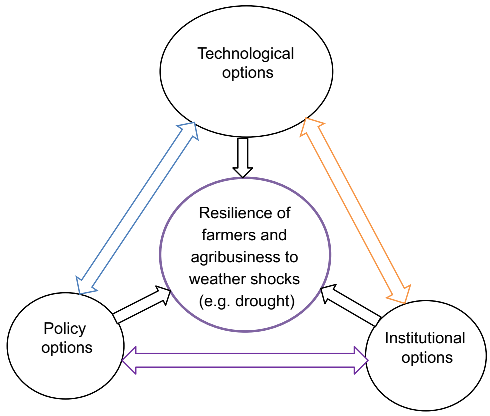

Fig. 4. Strategies for managing drought and enhancing resilience.

index insurance, use of early warning systems and monitoring information to forewarn and encourage optimal ex ante strategies and organize safety-net and social protection programs will create resilient communities in the face of drought. Some of the key technological, institutional and policy options and strategies for drought mitigation and adaptation are presented below.

3.3.1. *Drought stress tolerant improved varieties*

Use of drought tolerant crop varieties has been one of the major strategies for managing water limitation in agriculture (e.g., Xoconostle-Cazares et al., 2010), and long years of plant breeding activities have led to yield increase in drought affected environments for many crop plants (Cattivelli et al., 2008). Drought tolerance in crops such as maize, pearl millet, cowpea, groundnut and sorghum played important role in fighting the worst droughts in the last half of the 19th century in the Sahel (e.g., Hall, 2007).

By exploiting drought-tolerance genes, several national and international research institutions have scored important gains in improving the drought tolerance of major grain crops in Africa. Some examples are presented below.

3.3.1.1. Millet and sorghum. Millet and sorghum are key cereal grain crops in the drylands providing food, feed, fuel, and construction material. The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and national partner organizations have made important gains in improving the drought tolerance of millet and sorghum in many regions. For example, about 34% of the millet area and 23% the sorghum area in southern Africa have been planted with improved varieties (CGIAR, 2006).

3.3.1.2. Multipurpose grain legumes. Legume crops are vital sources of low-cost protein for smallholder farmers and generate farm income, serve as quality livestock feed and restore soil fertility. Cowpea followed by groundnut is the most widely grown grain legume in the dry areas of Africa, and several countries have released improved cowpea varieties with support from the International Institute of Tropical Agriculture (IITA) (CGIAR, 2006). Drought tolerant varieties of common bean and chickpea are also grown in highly variable rainfall areas of Africa (e.g., Tesfaye and Walker, 2004).

3.3.1.3. Maize. Most farmers in Africa rely on rainfall to grow maize; so dry conditions often have disastrous consequences. Continuous development and evaluations of maize germplasm from the International Maize and Wheat Improvement Center (CIMMYT) and IITA at different sites located in different regions in Africa resulted in the development of several drought tolerant (DT) maize hybrids and open-pollinated varieties (OPVs) which have been deployed by partners in various countries. The Drought Tolerant Maize for Africa (DTMA) project, led by CIMMYT, and being implemented in collaboration with IITA and national agricultural research systems (NARS) in 13 African countries (Angola, Benin, Ethiopia, Ghana, Kenya, Malawi, Mali, Mozambique, Nigeria, Tanzania, Uganda, Ethiopia, Zambia, and Zimbabwe), uses conventional breeding to develop and disseminate varieties that can provide a decent harvest under reduced rainfall and insurance against the risks of maize farming (Table 1). DT maize occupied close to 1.5 million ha in Africa in 2010 (Table 1), maintaining at least 1 t ha^{-1} more yield than the local varieties under drought stress conditions. Moreover, the performance of the DT maize varieties under normal or optimal conditions is comparable with the best checks being grown in African countries. The DT varieties have also at least 30–40% yield advantage over commercial materials under severe stress, and similar performance under optimal conditions (Fig. 5). On-farm trials as well as modeling drought tolerant maize varieties indicate that new DT varieties can perform better than standard checks (e.g. SC513) and provide a yield advantage of 5–25% in many maize growing areas of Africa (Fig. 6). The modeling study also suggests wide adaptability of the newly developed DT varieties over diverse environments.

Table 1
Number of drought tolerant maize varieties released, quantity of seed produced, estimated area covered, households and beneficiaries of drought tolerant maize in 13 African countries.
source: adapted from Abate (2013).

Country	Varieties released[a]	Seed (ton)	1000 (ha)[b]	1000 Households[c]	1000 Beneficiaries[c]
Angola	7	511	204	51	358
Benin	6	132	53	13	92
Ethiopia	10	1544	618	154	1081
Ghana	12	79	32	8	55
Kenya	2	5050	2020	505	3535
Malawi	17	4416	1766	442	3091
Mali	7	98	39	10	69
Mozambique	9	855	342	86	599
Nigeria	21	3245	1298	325	2272
Tanzania	14	2376	950	238	1663
Uganda	7	1572	629	157	1100
Zambia	18	3422	1369	342	2395
Zimbabwe	13	7468	2987	747	5228
Total	**143**	**30,768**	**12,307**	**3077**	21,538

[a] Varieties were released between 2007 and September 2013.
[b] 1 t enough for 40 ha.
[c] Assumes that an average farmer plants 10 kg seed; average family size 7 people.

A study conducted on the potential impact of DT varieties for the period 2007–2016 indicated that DT maize could generate US$ 0.53 and US$ 0.88 billion from increased maize grain harvests and reduced risk over 10 years, assuming conservative and optimistic yield improvements, respectively (La Rovere et al., 2010). The same study further indicated a benefit for 4 million people to escape poverty and many millions more to improve their livelihoods if all the existing varieties were replaced with improved drought tolerant varieties.

The released DT varieties have a combination of traits, including shorter anthesis-silking interval (ASI), reduced bareness (or increased number of ears per plant), reduced evapo-transpiration, functional stay green during grain filling, etc. that allow them to thrive under drought stress conditions (Bruce et al., 2002; Edmeades, 2008). Early maturity is also an important trait in areas where the season is short and terminal drought is common (Barnabás et al., 2008; Lopes et al., 2011). DT varieties developed by CIMMYT and IITA represent all maturity groups, including extra-early, early, intermediate and full season.

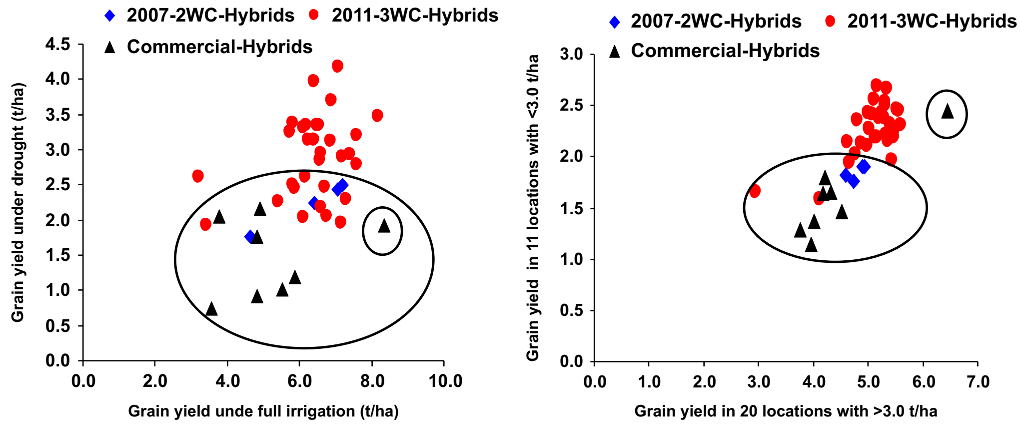

Fig. 5. Performance of there-way cross hybrids in West Africa under induced drought stress in 2012 and in 11 stressful and 20 favorable testing sites in 2011 as compared to two-way cross and commercial hybrids.

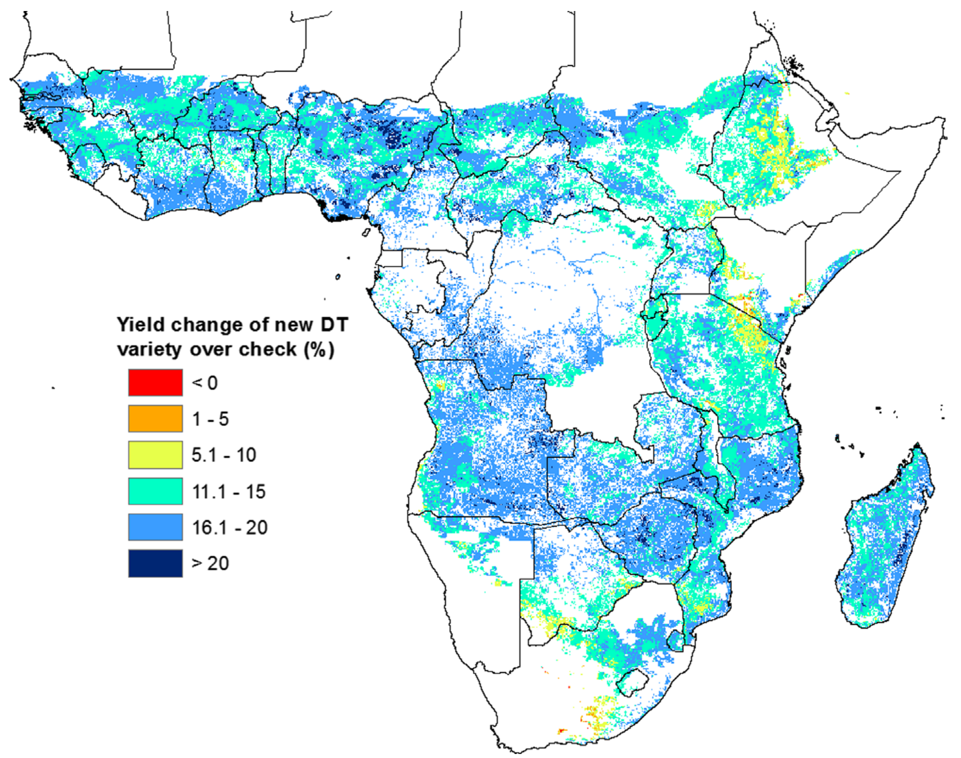

Fig. 6. Performance of newly released drought tolerant variety (CZH0616) over standard check variety (SC513) across maize growing areas of sub-Saharan Africa.

The potential benefits of DT varieties depend on level of adoption of the released varieties by farmers and availability, and timely supply of seeds at affordable prices. The amount of seed produced for DT maize varieties in Eastern, Western, Southern and Central Africa was 10,000 t in 2011, 30,000 t in 2012 (including 17,000 t of new DT maize varieties) and is targeted to reach 70,000 t by 2016 (Badu-Apraku et al., 2012). The adoption of DT varieties is believed to be the major determinant of benefits from the varieties and the return on investment (La Rovere et al., 2010). In general, adoption of improved seed has continued to rise gradually in sub-Saharan Africa, currently representing an estimated 44% of maize area in eastern and southern Africa (outside South Africa), and about 60% of maize area in West and Central Africa (Smale et al., 2011). Partnership with nearly 110 seed companies in SSA under DTMA has been critical for the success of seed scale-up and improved adoption of DT maize varieties.

Climate projections suggest that elevated temperatures, especially in the drought-prone areas of sub-Saharan Africa and rainfed regions in South Asia, are highly likely to result in significant yield losses in tropical/subtropical maize (Cairns et al., 2013a). Recent studies indicated that current tropical/subtropical maize germplasm developed for drought tolerance in SSA may not perform well under drought stress and at elevated temperatures, and tolerance to either drought or heat stress may not lead to tolerance to a combination of these two stresses. Nevertheless, a few inbred lines combining tolerance to drought and heat stress, most notably La Posta Sequia C7-F64-2-6-2-2 and DTPYC9-F46-1-2-1-2, were identified and are presently being utilized in developing new germplasm with combined tolerance to the two stresses in sub-Saharan Africa and Asia (Cairns et al., 2013b).

The finding that tolerance to combined drought and heat stress in maize was genetically different from tolerance to individual stresses has major implications in breeding heat stress resilient maize cultivars. Several DT parents developed by CIMMYT and widely used in hybrid maize breeding in eastern and southern Africa were found to be highly susceptible to drought stress under elevated temperatures; a notable example is CML442 × CML444 that is extensively used as the female parent in several commercial hybrids (Cairns et al., 2013b). Intensive efforts should thus be made to ensure that the most widely used drought tolerant inbred lines and hybrids also possess tolerance to heat stresses, especially for deployment in drought-prone areas where temperatures are predicted to increase.

New plant breeding strategies that utilize high-density genotyping based on next-generation DNA sequencing technology, coupled with high throughput field-based precision phenotyping, genomic selection (GS) and doubled haploid (DH) technology, could significantly increase genetic gains, and accelerate the development of improved stress resilient varieties. The development and availability of tropicalized haploid inducers (Prasanna et al., 2012), coupled with the recent establishment of a centralized maize DH facility in Kiboko (Kenya) by CIMMYT for the benefit of both public and private sector institutions engaged in maize research and development in SSA, are important for improving maize breeding efficiency in Africa.

3.3.2. *Improved soil fertility and water management*

Soil nutrient depletion has become one of the major constraints to food security in sub-Saharan Africa because of low crop productivity that causes declining per-capita food production (Stoorvogel and Smaling, 1990; Sanchez, 2002). One of the reasons for under-investment in soil fertility inputs in rainfed production systems in Africa is climate variability (e.g., Vlek et al., 1997; Snapp et al., 2003) mainly because nutrients are not used efficiently when water availability is inadequate which results in considerable variability in profitability of fertilizer use and optimal application rates from year to year and season to season (Piha, 1993; Dimes et al., 2003). One of the options for addressing this problem lies in seasonal climate forecasting which presents opportunity for increasing the efficiency of both water and nutrients through adaptive fertilizer management (Hansen et al., 2004).

Retaining and using variable rainfall efficiently is a key strategy in order to improve food security in regions that are dependent on rainfed agriculture. If combined with both historic and predictive climate information, a range of field-, farm- and community-scale water harvesting and water conservation management strategies can stabilize yield and provide benefits under variable climate (Hillel, 2004; Hansen et al., 2004). Adaptive crop management that matches crop characteristics, production activities and input use to rainfall variations is one way to enhance efficiency of water use.

Water storage capacity and irrigated area in Africa are the lowest of any region in the world. However, in recent years, there is an increasing focus on well-designed, less costly and participatory large-scale irrigation projects that play a role in reducing the rainfed dependency of agriculture in many countries in SSA (Gautam, 2006).

3.3.3. *Sustainable intensification*

Use of fertilizer and restorative crop management practices remains relatively low and inefficient in many developing countries, particularly in sub-Saharan Africa (Smale et al., 2011). Many farmers in this region lack the capital to purchase adequate amounts of fertilizers and agrochemical inputs. This implies that the chance of improving crop productivity and reducing risk on smallholder farmers' fields with their current production system and practice seems to be very limited. There is a need to more formally and deliberately support and promote the inclusion of agronomic and natural resources management practices as critical elements of a balanced agricultural intensification package.

In recognition of this problem, alternative innovations that increase productivity using locally available inputs and practices are being explored. For example, CIMMYT and its partners are engaged in increasing yield and market access for African farmers through a project called Sustainable Intensification of Maize–Legume Cropping Systems for Food Security in Eastern and Southern Africa (SIMLESA). The project aims to increase food security and incomes through improved productivity from more resilient and sustainable maize-based farming systems. Sustainable intensification practices (SIPs) have tremendous potential for enhancing the productivity and resilience of agricultural production systems while conserving the natural resource base (Godfray et al., 2010; Pretty et al., 2011). The SIPs can include minimum tillage, crop diversification (intercropping and rotations, growing different cultivars/varieties at different farm plots that have different environmental response), use of manure, complementary use of organic fertilizers, and investment in soil and water conservation (Lee, 2005; Pretty et al., 2011).

Empirical evidence in Ethiopia, Kenya, and Malawi has shown that adoption of individual or combination of SIPs significantly increase crop income and water use efficiency and reduce application of external inputs and downside risk exposure and cost of risk (Teklewold et al., 2013; Kassie and Teklewolde, 2013). In Ethiopia, the adoption of SIPs options increased net maize income by about 9–35% compared with non-adoption of these options (Fig. 7a). This increases further to 47–67% when SIPs options were combined with complementary inputs (e.g., improved maize varieties). Similar results were found in Malawi where certain combinations of SIPs options provided higher benefit than adopting them individually (Fig. 7b). These options also reduced the downside risk or risk of crop failures (Kassie and Teklewolde, 2013).

Conservation agriculture (CA) has recently been presented as a mechanism for sustainable intensification of smallholder agriculture. It involves three principles based on minimum mechanical soil disturbance, permanent soil cover with organic mulch, and crop rotations that need to be adapted to local conditions (FAO, 2008). CA offers potential benefits to farmers by stabilizing yields, avoiding the need for tillage and allowing early planting with the first rains and reduced soil erosion (Giller et al., 2011). In general, increased growth and productivity of crops, more efficient use of water and soil nutrients and savings in the cost of fuel and labor are expected through reductions in tillage, enhanced surface retention of adequate crop residues and appropriate crop rotation practices (Hobbs and Govaerts, 2010; Thierfelder et al., 2013). Although CA systems are increasingly promoted in Africa as an alternative for enhancing resilience and increase food production on the basis of more sustainable farming practices, its adoption has generally been limited. Unlike other components of CA, the adoption of minimum/zero tillage and residue retention particularly remain very low in eastern and southern African countries (Table 2). The reasons for low adoption are complex but often related to inadequate awareness of the practice by smallholders, tradeoffs in use of crop residues for other uses including feeding livestock, lack of suitable and low-cost zero-till equipment and chemicals for weed control, and the long gestation period involved for CA systems to enhance productivity and generate benefits to smallholders (Corbeels et al., 2014). Thierfelder et al. (2013) report results from rare long term field experiments across locations in central and southern Malawi. The results summarized across four locations indicate that yield benefits of CA over conventional tillage systems were greater especially from the 5th season although, in some instances, greater yields on CA were recorded almost immediately (Thierfelder et al., 2013) (Fig. 8). These results provide some evidence for adapting CA systems to the

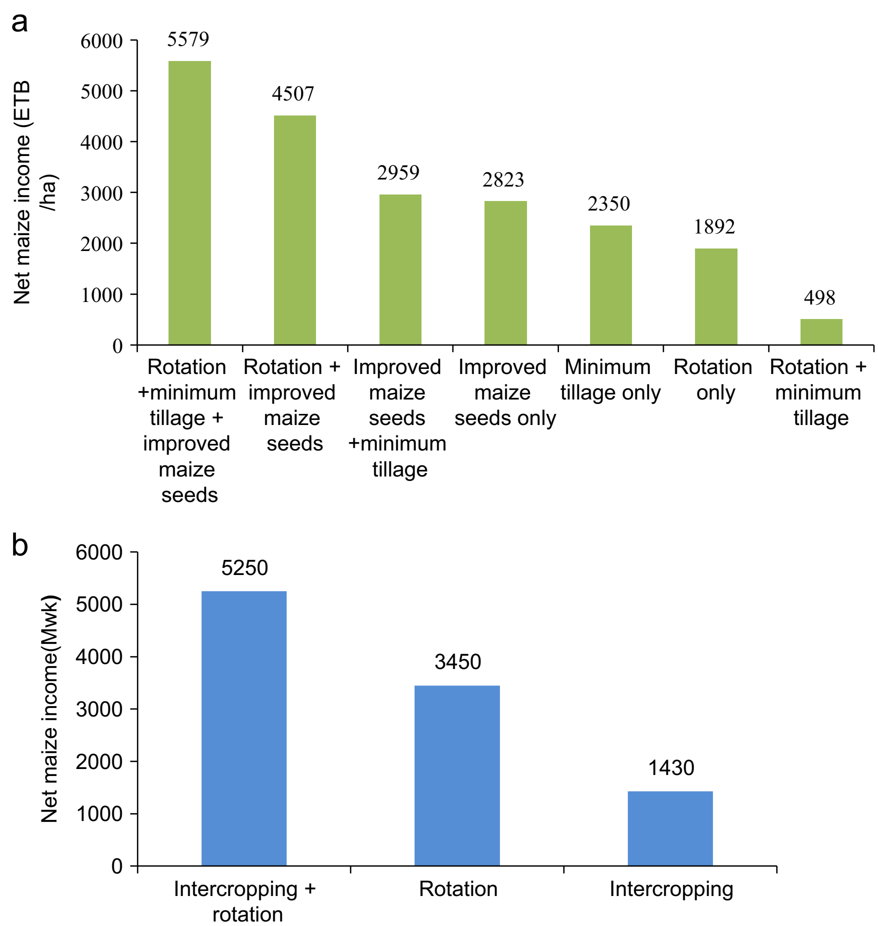

Fig. 7. (a) Impact of CA options and complementary input on maize net income in Ethiopia (Teklewold et al., 2013). (b) Impact of CA options on net crop income in Malawi (Kassie and Teklewolde, 2013).

Table 2
Adoption of crop intensification and diversification practices in eastern and Sothern Africa region (% farmers).
Source: SIMLESA Project Survey, 2011

Technology	Malawi	Ethiopia	Tanzania	Kenya	Mozambique
Maize–legume intercropping	27.5	19.3	66.2	71.9	68.8
Maize–legume rotations	40.6	32.7	32	83.2	7.8
Reduced/zero-tillage	2.6	14.9	14.5	1	23.7
Crop residue retention	91.9	28.5	67.9	72.4	91.2
Fertilizer adoption	95.1	81.7	5.1	87.9	37.1
Manure adoption	36.7	58.2	32.5	65.3	6.1

local agro-ecological and socioeconomic conditions of the farmers and the need to carefully target communities for a stepwise and incremental adoption of the different components.

3.4. Institutional and policy options for drought management

3.4.1. Weather index insurance

In developed countries risk transfer approaches such as insurance have played a role in mitigating climate risk but they have generally not been available in developing countries where insurance markets are limited and are not oriented towards the poor (Hellmuth et al., 2009). Recent advances in climate science help in the development of a new type of insurance called weather index insurance (index insurance) that offers new opportunities for managing climate risk in areas where such services were difficult to deliver due to high transaction costs related to poor infrastructure and the classical adverse selection and moral hazard problems in providing financial services. Access to risk transfer services will help protect resource-poor farmers against climate variability while promoting the uptake of productivity-enhancing technologies. Index insurance is type of insurance that is linked to an index, such as rainfall, temperature, humidity or crop yields, rather than actual loss which is difficult to observe (Alderman and Haque, 2006; Hellmuth et al., 2009). The advantages of index insurance include lowers transaction costs, financial viability for private-sector insurers and affordability to small farmers, less adverse selection and moral hazard than traditional insurance, and applicability in rural areas where existing weather stations will allow observing changes in rainfall levels (World Bank, 2005b; Gautam, 2006; Alderman and Haque, 2006; Hellmuth et al., 2009). The index is often linked to changes in agricultural productivity using some regression estimates to trigger payout of indemnities when the weather parameter goes below a certain level. The ability to organize systems that take advantage of global insurance markets to transfer the correlated risks associated with low-probability, high-consequence events makes index insurance potentially useful for managing drought risk (World Bank, 2005b).

Index insurance has been piloted with small farmers in several countries, including Nicaragua, Mexico, India, and Ukraine outside of Africa, and in Malawi and Ethiopia in Africa (Gautam, 2006; Hellmuth et al., 2007) showing mixed but promising results for scale-up. However, application of index insurance in many places is hindered by high basis risk associated with the lack of good site-specific rainfall data for precise actuarial modeling (to make

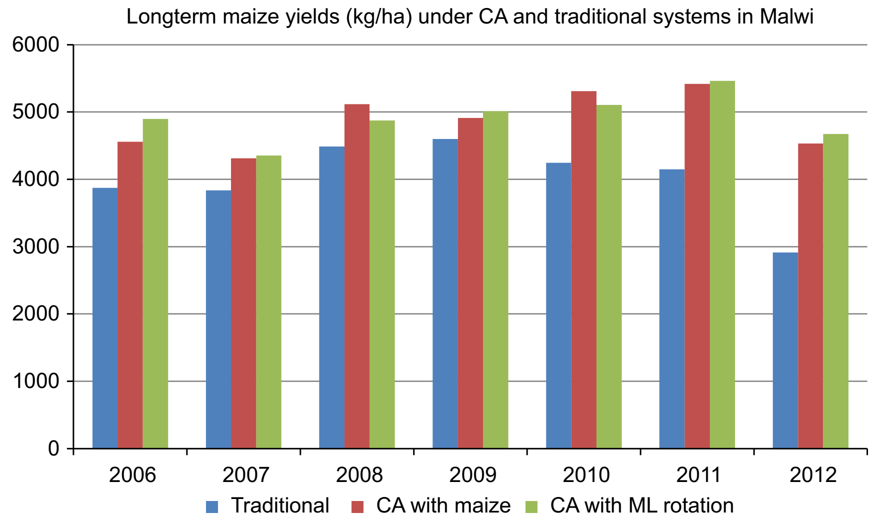

Fig. 8. Average response of maize yields to conservation agriculture and traditional land management practices across four locations in Malawi (based on Thierfelder et al. (2013) and their results in four locations). CA=conservation agriculture; ML=maize-legume.

insurance payouts closely correlated with actual losses), better understanding of micro-climates and weather cycles, and the need for better weather forecasts. Poor client awareness, failure to create a proposition of real value to the insured and weaknesses in offering timely and compensating payouts have undermined trust and overall demand for index insurance.

Therefore, significant improvements in calculating the index, presenting the product to clients and investment in weather data collection, processing and dissemination are required to facilitate scaling and wider use of index insurance in SSA.

3.4.1.1. Input/output market development. Adoption of agricultural technologies, farm intensification and the production of marketable surpluses often depend on the profitability of market production. Market failures in input–output markets and climate-induced variations of aggregate production lead to large fluctuations – triggering cycles of high and low food prices with variable effects on net-buyers (poor consumers) and net-sellers (Hansen et al., 2004). Input market reforms and investment inroads, seed production and marketing for drought tolerant varieties and fertilizer production and distribution will increase availability and affordability of key inputs to increase agricultural production and reduce soil mining and land degradation. Secure rights to land and access to rural finance markets (credit, insurance, savings) can also play an important role in buffering against risk, providing incentives for conservation investments and sustainable intensification (Shiferaw et al., 2008). In general, efficient input/output markets will play major role against climate risk by stabilizing prices and smoothing consumption during drought years.

3.4.1.2. Climate information and early warning system. Improved drought management and preparedness depends on access to climate information and early warning systems. The value of climate information lies in its ability to provide evidence of risk of a major climate shock in advance which help in anticipating the costs and the scale of measures that may be needed at the national and regional level (World Bank, 2003). Climate information systems can contribute to strengthening institutional capacity and coordination to support generation, communication and application of early warning systems.

As a component of disaster risk reduction, early warning systems in Africa have provided the information necessary to allow for early action that can reduce or mitigate potential disaster risks. Climate information is also important to governments and private traders to better manage imports, exports and strategic grain storage in a manner that stabilizes prices in the market and at the farm gate (Hansen et al., 2004). in situations where credit risk is not functional, seasonal forecasts could also offer opportunities to improve availability and terms of credit to farmers by identifying the years when production conditions are good and risk of default to the lender is reduced. Combining forecast-based credit with insurance markets to spread the risk associated with rainfall variability and forecast uncertainty is a promising intervention (Fafchamps, 2003). Although short- and long-term climate forecasting has shown promising application in climate risk management in SSA, it still needs considerable institutional strengthening, technical capacity building, and investment in data and equipment (World Bank, 2003).

3.4.1.3. Safety nets. Safety nets are meant to protect vulnerable populations from persistent impacts of shocks by providing livelihood support and contributing to immediate food security, often through community-driven public works schemes and transfers to vulnerable households (World Bank, 2005b; Gautam, 2006). While safety nets protect vulnerable populations during periods of adverse weather conditions, another form of safety nets called ‘cargo nets’ (Barrett, 2004) assist the poor to increase investment to take advantage of favorable conditions which could help them to invest the returns in productive assets for the future (Hansen et al., 2004). In many countries including Ethiopia, Kenya, Mali, Nigeria, Burkina Faso, and others, safety nets have provided crucial ‘insurance’ when the primary source of income of a large number of households suffers a severe shock during times of drought (Gautam, 2006). The productive safety net project in Ethiopia serves a productive function in addition to social protection in the event of drought shocks (Alderman and Haque, 2006). Safety nets could also be enhanced to serve large population using index insurance to automatically trigger payments to affected districts (World Bank, 2005b).

3.4.1.4. Extension and communication. Extension for sustainable intensification and drought management has largely been missing in many SSA countries. Many households do not have relevant climate and technological information or access to key inputs that reduce exposure to drought risk. In order to properly respond to climate variability, smallholder farmers in Africa require timely access to information that is customized to their needs and scale of decision-making. ex ante education and services provided by agricultural extension help familiarize farmers with the consequences of climate risks and assist them to adopt appropriate innovations to deal with it (World Bank, 2005b). Equitable access is usually a major concern when targeting the poor and food-insecure. Therefore, climate interventions targeting drought-prone and vulnerable areas need to be integrated into agricultural extension systems and rural communication. This will require communication of climate information through coordinated efforts of several key institutions, including meteorological services, agricultural extension services, environmental agencies, NGOs, producer organizations and the media (Hansen et al., 2004). Such coordination and collaborated delivery of coherent information to farmers and resources users is currently weak in many countries in SSA.

3.5. Livelihood diversification

Farmers in Africa have traditionally adapted to climate risk by diversifying across crops and risk management options (Dercon, 1996; Ellis, 2000). Farmers generally diversify their production systems by employing activities that are less sensitive to drought and/or temperature stresses and activities that take full advantage of beneficial climate conditions. For example, farmers time their planting and inputs based on their best estimates of the cropping season; and they reduce risk exposure by diversifying their livelihoods. Farmers diversify their cropping practices using a mix of crop species both in space and time (e.g., intercropping of different crops species, strip cropping, double cropping), growing different cultivars at different sowing dates and farm plots; combining less productive drought-resistant cultivars with high-yielding but water-sensitive crops. Nevertheless, managing droughts effectively in vulnerable areas requires diversifying livelihood strategies and income generating options within and outside agriculture especially into income generating options through non-farm enterprises and employment opportunities. This will require greater investments in infrastructure, road networks, electricity, communication and market development.

4. Conclusion

Drought remains to be the most important threat to food production and food and nutritional security in SSA. Drought represents one of the most important natural factors contributing to malnutrition and famine that affects the most vulnerable communities, especially women, children the elderly. Its effects are inter-temporal and long-lasting. Risk of drought prevents farmers from adopting profitable technologies and practices that are perceived risky, hence creating a nexus that increases the cycle of vulnerability and depletes the capability to overcome hunger and poverty. This is mainly because small-scale farmers often prepare for the possibility of climatic shocks by engaging in conservative risk management strategies ex ante at the cost of low productivity and profitability gains. This inability to accept and manage risk and accumulate and retain wealth locks vulnerable populations in poverty.

Traditionally, farm households have used a mix of strategies to shield themselves from drought-induced shocks. One common strategy that they employ to mitigate drought is to avoid or prevent it as much as they can. These traditional methods are often insufficient and fail to protect livelihoods in drought-prone regions and have at times made the situation worse by undermining investments in new technologies and practices. At the economy-wide level, covariate risk of drought often causes food shortages and inflationary trends that spark high food prices, creating dependence on food aid and/or costly food imports that aggravate food insecurity. New strategies and policy options are needed to break the nexus between poverty and vulnerability to climatic risk and to build the capability to manage drought-induced shocks at the household and national levels.

Based on an extensive review of the recent practice and experiences in Africa, we conclude that promising technological, policy and institutional options exist for effective drought management in SSA. Integrated strategies that combine agricultural technologies for drought management including drought-tolerant crops and varieties, improved crop management practices and water conservation methods, climate forecasting and early warning systems, weather information communication, weather-index insurance systems, output/input market development and price information that will enhance drought risk management. Moreover, there is a need to shift from crisis management to ex-ante drought risk management by countering environmental degradation, restoring degraded ecosystems, and investments in irrigation infrastructure to better manage extended droughts. Price stabilization, strategic food reserves and social protection policies that enhance access to life-saving and productive safety-nets will prevent disinvestment and depletion of assets and enhance post-drought recovery, adaptation and resilience of livelihoods in affected areas.

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