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AGRICULTURAL WATER MANAGEMENT IN THE CONTEXT OF CLIMATE CHANGE IN AFRICA

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COMMON ACRONYMS

AfDB	African Development Bank
ASAL	Arid and Semiarid Lands
AWM	Agricultural Water Management
CA	Comprehensive Assessment
CAADP	ComprehensiveAfrica Agriculture Development Programme
CBOs	Community-based Organizations
CPWF	Challenge Programme on Water for Food
FAO	Food and Agriculture Organization
IPCC	Intergovernmental Panel on Climate Change
IFAD	International Fund for Agricultural Development
IPTRID	International Programme for Technology and Research in Irrigation and Drainage
IWRM	Integrated Water Resources Management
NBI	Nile Basin Initiative
NEPAD	The New Partnership for Africa's Development
NGOs	Non-government Organizations
WUAs	Water User Associations
UNEP	United Nations Environment Programme
RWH	Rainwater Harvesting
SADC	Southern Africa Development Community
SIWI	Stockholm International Water Institute
SSA	Sub-Saharan Africa
SSI	Small Scale Irrigation
WEMA	Water Efficient Maize for Africa
WAIPRO	West African Irrigation Project
WOCAT	World Overview of Conservation Approaches and Technologies

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ABSTRACT

Agricultural systems in Africa are commonly characterized as low-input and drought-prone.Farming has evolved as a function of the interaction of agro-ecological, cultural, social, political-economic, and other factors. The effects of climate change are likely to be acutely felt in Africa, where communities, governments, and local institutions are not yet well prepared to respond to the emerging challenges associated with climate change. A wide variety of practices to adapt to climate variability and change have already been employed at the community level in Africa, but these are usually unique to specific localities and have not been disseminated widely. Agricultural water management (AWM) offers a way of facilitating water-centered development to simultaneously reduce poverty, increase food security, and adapt to climate variability and change. It focuses on ecosystems rather than on commodities, on underlying processes (both biophysical and socio-economical) rather than on simple relationships, and on managing the effects of interactions between various elements of production systems. AWM aims to decrease unproductive water losses from a system and to increase the adaptive capacity of communities and institutions. The water thus saved can be freed up for other purposes, including for environmental services, thus making the best use of a limited resource. Implementation of AWM techniques would improve the profitability of smallholder agriculture by increasing crop and livestock yields by factors of up to five-fold. Net returns on investment could double. However, adoptions of AWM techniques demand multi-institutional engagement and the collective action of institutions at various levels.

The policy and institutional framework delineated in the ComprehensiveAfrica Agriculture Development Programme (CAADP)of the New Partnership for Africa's Development(NEPAD) recommends sustainable land management and reliable water control systems, along with improved soil fertility, although most countries in Africa do not at present have comprehensive AWM policies. The fact that AWM issues are relevant to several sectors has resulted in overlapping policies, duplication of efforts, and inefficient use of resources. Moreover, it is sometimes not clear who “owns”AWM. Weak institutional capacities at various levels and poor market access areother factors that, to date, have limited the adoption of improved water management as a response to climate change and for other purposes. Moreover, the regional organizations in Africa now need to go beyond defining a common initiative to facilitating coordinated regional actions to improve water resource governance. Such actions must foster efficient and equitable sharing of water by riparian countries. Some successful AWM examples that have increased agricultural productivity and that can be employed to adapt to climate change in Africa are discussed in this paper.

Key Words: agricultural water management, water-centred development, climate change adaptation, ecosystems, Africa

1. INTRODUCTION

African agriculture is a mosaic shaped by the interaction of a wide range of agro-ecological, cultural, social, political and economic factors. However, the amount and distribution of rainfall, temperature, altitude, the resource base, food habits, and socio-economic realities have undoubtedly played very important roles in shaping farming systems. The African continent can be roughly divided into five agro-ecologies, with overlapping transitional zones (Dudal, 1980). The humid zone stretches from west to central and eastern Africa with a mean annual rainfall commonly exceeding 1500 mm/year, temperatures ranging between 24°C and 28°C, and a growing period of more than 270 days (Bationo, 2006). This zone includes the wet central region of the Congo basin, which receives about 37 percent of all precipitation in Africa (Frenken, 2005). The sub-humid zone covers most of the Central, Western and Southern Africa, with one or two rainy seasons of varying length and a growing period ranging from 180 to 269 days. The semi-arid zone covers areas between the sub-humid wooded savannah and the arid zones, with rainfall between 200 and 800 mm/year and a growing period of 75 to 179 days (Bationo, 2006). This zone includes the vast areas of the Sahel and eastern Africa, where pastoral and agro-pastoral production systems are pre-dominant. The arid zone covers extensive areas with average annual rainfall below 200 mm. Sedentary agriculture is rarely practiced in this zone, which includes the vast deserts of the Sahara, the Namibian, the Kalahari, and the Karroo (Dudal, 1980).Overall, arid and semiarid lands (ASAL) in Africa cover about 41 percent of the land area, although in some countries the ASAL cover about percentup to 90 percent (e.g., in Northern Africa). The Mediterranean zone covers extreme northern and southern Africa, two of the most water stressed parts of the continent. These regions are already drought prone, and about 75 percent of the annual renewable water derives from rivers in other African regions. Figure 1presents the average annual total water balance of Africa, showing where most of the surplus rainfall above evapotranspiration exists.

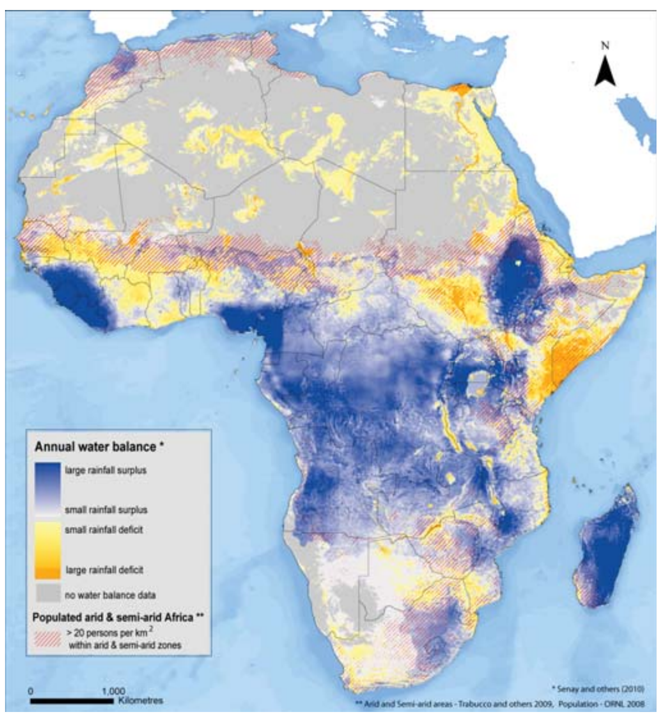

Figure 1. Annual water balance (rainfall minus evapotranspitration) of Africa (UNEP, 2010)

This diversity in agro-ecology is reflected in the type of agricultural production systems in each zone, although enterprise choices and intensification levels are partly governed by non-climatic factors, including investments on irrigation facilities, market access, agricultural policies, and institutional arrangements.There is a general understanding that the effect of climate variability and climate change in Africa would be most felt in the relatively well water-endowed regions of the continent (about 25 percent), where communities, governments, and local institutions are generally not well prepared to respond to emerging climate challenges. The poor and vulnerable populations of Sub-Saharan Africa (SSA) will likely face the greatest risk (IPCC, 2007). Poverty is highly regionalized, with SSA one of the poorest areas in the world, sharing with Asia 70 percent of the world's poor (Namara, *etal.,* 2010). With more than 90 percent of the continent dependent on rainfed agriculture (green water), the impacts of climate change on food security and livelihoods could be extreme unless effective measures are taken to adapt to climate change at farm, landscape, and basin scales.

The IPCC (2007) has indicated that climate changeis impacting SSA (mainly as a result of human action) more than any other continent because its economies are largely based on weather-sensitive crop-livestock and agro-pastoral production systems. Impacts are also a function of the low adaptation capacity of SSA countries to climate change and variability. Climate-change-induced agricultural drought commonly denotes a prolonged period without precipitation sufficient to meet crop water requirements. This causes a reduction in soil water content and thereby leads to plant water deficits. It is mainly a result of a variable supply of rainfall across seasons, poor water holding capacity of soils, and improper management of water resources (Amede, 2006). In many parts of Africa, farmers and pastoralists must contend with extreme natural resource challenges and constraints, includingpoor soil fertility, pests, crop diseases, and a lack of access to inputs and improved seeds. These challenges are often aggravated by periods of prolonged drought or floods. Based on various studies and scenarios, the impacts of climate change may include changes in the length of growing periods; changes in the onset, seasonality, and intensityof rainfall; and variability of dry spells, each of which have major implications on agricultural productivity and livelihoods. Other impacts may include the reduction of land area suitable for rainfed agriculture, increases of arid and semi-arid areas (perhaps by about 5-8 percent, or 60-90 million hectares, by 2080), disappearance of wheat production from Africa (also by about 2080), and a reduction of yield by up to 50 percent by 2020 (IPCC AR4-WGII, 2007). Major trade-offs have also been forecast between agriculture and ecosystem services, implying that Africans may be faced with the painful choice of choosingbetween increasing food security on the one hand and safeguarding ecosystems on the other (de Fraiture, *et al.,* 2007; Bossio, 2009).

According to recent estimates by the FAO (2009), the demand for water for farming, industrial, and urban needs in Africa will increase about 40 percent by 2030. Climate change is likely to intensify the current challenges of water scarcity and water competition within and between communities and nations, particularly in those countries linked by transboundary aquifers and rivers. The threat of water scarcity is a fact, and such scarcity will likely reduce crop and livestock productivity and farm incomes and increase the vulnerability of communities to climatic and market shocks (Amede, *et al*., 2006). The negative effects of water scarcity have been aggravated by land degradation, poor water management, and limited institutional and household capacities to store and efficiently utilize the available water resources. Moreover, rural poverty, andthus the weak financial capacity of communities to invest in water and agricultural inputs, has hindered the adoption and dissemination of good water management practices. The capacity of communitiesneeds to be strengthened, and technologies that can minimize water loss and maximize water productivity must be more widely disseminated. For instance, in the Sahel region of West Africa climate variability has forced traditional farmers to adapt their farming systems to more water scarce conditions by managing their water supplies better and by diversifying production systems. Recognizing the various challenges, the 2005 Commission for Africa report called for a doubling of the region's irrigated area by 2015 (You, 2008).

A wide variety of practices to adapt to climate variability and change have already been employed at the community level in Africa, but these are usually unique to specific localities and have not been disseminated widely.Kundewicz,*et al.* (2007) grouped adaptation mechanisms into 'supply side' and 'demand side' interventions. The supply side strategies include exploiting ground water potential, increasing water storage in reservoirs and dams, desalinating sea water, harvestingrainwater, and transferring water between river basins. Demand-side interventions include improving the water productivity of crops and livestock, recycling and reuse of waste water, saving irrigation water by choosing more water-efficient crops, improving performance of schemes, and reducing water use through adapting 'virtual water' as a cross-regional strategy (Allan, 2001).

Adaptation could be complicated by the transboundary nature of many water resources. Africa's 63 international transboundary river basins cover about 64 per cent of the continent's land area and contain 93 per cent of its total surface water (UNEP, 2010). Five river basins in Africa are shared by eight or more countries (the Congo, Niger, Nile, and Zambezi River Basins and Lake Chad) and 30 are shared by more than two countries (Wolf,*et al.*, 1999). Moreover, water resource management in Africa is widely done with immediate national interestsin mind without consideration ofpossible future climate. Significantly, the vulnerability of many African communities to future climate change has increased (Ngigi, 2009). The challenges posed by climate change, along with increased competition for water resources,suggest that integrated water resources management (IWRM)should be implemented throughout Africa.

Agricultural water management (AWM), is itself a broad concept that includes all deliberate human actions to optimize water use for agriculture and thus to produce food, feed, fiber, and livestock products. It is applied in both rainfed systems and irrigated agriculture using best fit technologies, policies, and institutions to sustainably manage water and land resources. AWM embraces a range of practices as appropriate, including *in situ*moisture conservation (e.g., mulching) and *exsitu* water management (e.g.,dryland farming, rainwater harvesting, supplementary irrigation, full-scale irrigation, and various techniques of wetland development) (Awlachew, *et al*., 2005). AWM management techniques offer a way of facilitating water-centereddevelopment and thus help to reduce poverty, increase food security,protect the environment, and adapt to climate variability and change. It focuses on ecosystems rather than commodities, on underlying processes (both biophysical and socioeconomic) rather than simple relationships, and on managing the effects of interactions among various elements of the production system (Merrey and Gebreselassie, 2010). Greater use of AWM and associated agricultural intensification and land use efficiency could greatly assist the countries of Africa address the many challenges they will face in providing water in a changing climate.

The Challenge Programme on Waterfor Food (CPWF) has developed a strategy called 'Rainwater management' tooperationalize the concept of AWM. The programme is designed to sustainably manage both rainfed (green)and surface (blue)water to improve livelihoods and ecosystem services at landscape scales (Amedeand Haileslassie, 2011). Rainwater management systems (RWMs) are integrated strategies that enable stakeholders to systematically map, capture, store, and efficiently use runoff and surface water from farms and watersheds for agriculture, domestic needs, and ecosystem services. The aim is to decrease unproductive water losses from runoff, evaporation, conveyance, seepage, and deep percolation and to improvewater productivity so as to increase returns per unit of investment. Unlike conventional approaches, integrated RWMs focus more on the institutions and policies than on technologies. They use rainwater harvesting principles and also promote water storage and water productivity in soils, farms, landscapes, and reservoirs. They combine water management practices with land and vegetation management. Enhancing and stabilizing crop yields and livestock production of farmers in crop-livestock systems would encourage farms to invest in rainwater and nutrient management at plot, farm, and landscape scales.Improved vegetative soil cover, the choice of crops and cropping systems, and the integration of livestock into these systems can reduce unproductive water losses (Amede,*et al*., 2009).

2. INTERVENTIONS FOR AGRICULTURAL WATER MANAGEMENT

2.1 Technologies for AWM and Adaptation

AWM and related practices may be classified according totheir operational objectives as follows(Awulachew,*et al*., forthcoming):

- According to functions: e.g., those used for crops, livestock, fisheries, and soil and water conservation;
- According to stage of water management: i.e., rainfall/runoff capture, storage, lifting, conveyance, and water use/applications;
- According to application: supplementary irrigation, full irrigation, or drainage;
- According to water sources: surface,rainfall, runoff, ground water, natural, or manmade sources;
- By spatial scale of management: single farm/field, scheme, watershed, and basin scales;
- By scale of user: household, community, or large scale; and
- By ownership: small holders, private, public, commercial,or public/private partnership.

While AWM technologies can be specific interventions, they can also be combinations (or suites) of technologies used, for example, in water quantification and control, conveyance, field applications, drainage, and re-use. Table 1 shows AWM technology suites by scale of application.

The net impact of agricultural water management on poverty dependson how well these technologies work (Namara, *et al.*, 2010). To respond to the possible effects of climate change on African agriculture the following sections provide examples of interventions that could be scaled up to improve access to AWM. The examples include integrated interventionsat watershed scales.

2.2 Integrated watershed management

Integrated watershed management is a strategy to manage natural resources at the watershed level that takes into accountnaturally occurring biophysical processes, social institutions, and human activities within a watershed. Although hydrology is a key integrator, other resources, including land, vegetation, and animals, and social institutions are also managed. It is used to address resource management issues that cannot be addressed by a single farmer or a community(German *et al*., 2007) and typically has multiple objectives (e.g., conservation, food security, and income generation). German, *et al*. (2007) haveidentified several forms ofintegration in a watershed. Thus interactions between various landscape unitscan be managed to benefit several landscape-level components (e.g., trees, water, livestock, crops, soils, and land). Or, a multi-disciplinary approach may be taken, integrating biophysical, social, market, and policyinterventions.

Managing water at the watershed scale also entails managing run-off, controlling soil erosion, and improving vegetative cover. Such multiple benefits can help minimize the effects of climate variability in a locality. Improving vegetation cover has direct relevance to climate change mitigation as more carbon is then sequestered. Increasing the vegetation cover will also produce more biomass. Better water and nutrient management using watershed approaches could capture more $CO_2$from the atmosphere and contribute to mitigating the negative effects of climate change and variability.

Box 1. Watershed management in Southern Ethiopia. Farmers in Areka, Southern Ethiopia rated soil erosion as one of the major landscape problems, decreasing productivity and increasing vulnerability to climate variability. Despite earlier attempts to curb soil erosion by the government and other development actors, there was little change on the ground until a regional programme called African Highlands Initiative (AHI) arrived in the district. The shortcoming of the earlier approach was that it was seen as imposed initiatives. AHI and Areka research centre, Ethiopia organized consecutive community meetings to create awareness and sought solutions together. Then, soil bund was selected as practical solution for minimizing erosion and reducing removal of seed and fertilizer from the farm lands. Farmers' research groups (FRG), which were established to test interventions, were used to organize farmers and collectively constructed bunds, experimented on fodder crops and established by-laws for sustainable maintenance of the conservation structures. Farmers started to get more crop yield and dry season fodder for their livestock. This was further expanded by grazing management and landscape water management interventions, which has developed overtime as integrated watershed management programme, which is now used a learning site for the district officers and regional governments.

Table 1. AWM Technologies Suites Classified by Scale of Application (Awulachew et al, forthcoming)

Scale	Water source	Water Control	Water Lifting	Conveyance	Application	Drainage & Reuse
Small-holder farm-level	Rain water	• In situ water • Farm ponds • RainColumn Green Wall • Cistern and underground ponds • Roof water harvesting • Recession agriculture	• Treadle pumps • Water cans	• Drum • Channels • Pipes	• Flooding • Direct application • Drip	• Drainage of water logging • Surface drainage channels • Recharge wells
	Surface water	• Spate and flooding • Diversion • Pumping	• Micro pumps (petrol, diesel) • Motorized pumps	• Channels • Canals • Pipes (rigid, flexible)	• Flood & Furrow • Drip • Sprinkler	• Surface drainage channels • Drainage of water logging
	Ground water	• Spring protection • Hand dug wells • Shallow wells	• Gravity • Treadle pumps • Micro pumps (petrol, diesel) • Hand pumps	• Channels • Canals • Pipes (rigid, flexible)	• Flood & Furrow • Drip • Sprinkler	• Surface drainage channels • Drainage of water logging • Recharge wells
Community or catchment	Rain water	• SWC • Communal ponds • Recession agriculture • Sub-surface dams	• Treadle pumps • Water cans	• Drum • Channels • Pipes	• Flooding • Direct application • Drip	• Drainage of water logging • Surface drainage channels
	Surface water	• Spate and flooding • Wetland • Diversion • Pumping • Micro dams	• Micro pumps (petrol, diesel) • Motorized pumps • Gravity	• Channels • Canals • Pipes (rigid, flexible)	• Flood & Furrow • Drip • Sprinkler	• Surface drainage channels
	Ground water	• Spring protection • Hand dug wells • Shallow wells • Deep wells	• Gravity • Treadle pumps • Micro pumps (petrol, diesel) • Hand pumps • Motorized pumps	• Channels • Canals • Pipes (rigid, flexible)	• Flood & Furrow • Drip • Sprinkler	• Surface drainage channels • Recharge wells and galleries
Sub-basin, Basin	Surface water	• Large dams	• Gravity • Large scale motorized pumps	• Channels • Canals • Pipes (rigid, flexible)	• Flood & Furrow • Drip • Sprinkler	• Surface drainage channels • Drainage re-use

Africahas vast areas of agricultural land in its highlands, where productivity is constrained by steep slopes, high runoff rates, soil erosion, and loss of nutrients and rainwater. Examples include the highlands of Ethiopia, Madagascar, Rwanda, Burundi, Kenya, and Tanzania (Lundgren, 1993). Land degradation in these fragile highlands is commonly aggravated by deforestation and expansion of crop lands to vulnerable hillsides (e.g., the Kabale hillsides in Uganda, to the Ruwenzori Mountains in Rwanda, and to fragile Ethiopian highlands). Estimates from a national-level study in Ethiopia indicate that total soil loss due to erosion is about two billion tyr^{-1} (FAO, 1986), and this is estimated to cause annual onsite productivity losses of 2.2 percent of the national crop yield (Woldeamlak, 2009). FAO (1986) has also reported that soil erosion was annually taking out of production about 30,000ha of croplands in Ethiopia. The highest rate of soil loss occurs from cultivated fields and is estimated to be on average about 42 $tha^{-1}yr^{-1}$ (Hurni, 1993).

Erosion effects across Ethiopia are expected to decrease due to the high priority given by the Ethiopian government to land management in the last 15 years using watershed management strategies.Some regions in Ethiopia (e.g.,Tigrai) have achieved considerable success in managing upper catchments, mainly through the 'SafetyNet' programme. This is a programme designed to improve the food security of the poor while facilitating the engagement of local communities in improving natural resources management through exchanging food and/or money for work. The programme relies heavily on existing local arrangements, including community representatives and leaders, disaster prevention committees, local byelaws, and local government (see Box 1).In selecting households, the programme considers assets, income, and livelihood criteria and the ability to do physical work. The work includes soil and water conservation, planting trees on degraded slopes, protecting landscapes from livestock grazing(e.g., through 'area enclosure'), and creating local institutions to sustainably manage landscapes. Although adoption rates have varied, the benefits tothe upper catchments protected in the late 1990s at selected highland sites are clear(Descheemaeker, *et al*., 2006).In irrigation schemes where extensive soil conservation has beendone, erosion and siltation have been reduced

Box 1. Watershed management in Southern Ethiopia. Farmers in Areka, Southern Ethiopia rated soil erosion as one of the major landscape problems, decreasing productivity and increasing vulnerability to climate variability. Despite earlier attempts to curb soil erosion by the government and other development actors, there was little change on the ground until a regional programme called African Highlands Initiative (AHI) arrived in the district. The shortcoming of the earlier approach was that it was seen as imposed initiatives. AHI and Areka research centre, Ethiopia organized consecutive community meetings to create awareness and sought solutions together. Then, soil bund was selected as practical solution for minimizing erosion and reducing removal of seed and fertilizer from the farm lands. Farmers' research groups (FRG), which were established to test interventions, were used to organize farmers and collectively constructed bunds, experimented on fodder crops and established by-laws for sustainable maintenance of the conservation structures. Farmers started to get more crop yield and dry season fodder for their livestock. This was further expanded by grazing management and landscape water management interventions, which has developed overtime as integrated watershed management programme, which is now used a learning site for the district officers and regional governments.

considerably, and head works and canals continue to serve without the need for frequent maintenance (Amede, 2004).

The greatest benefits have been found where physical measures have been accompanied by innovations that have brought short-term benefits with respect to fodder, fuel wood, water, and other resources. The introduction of multipurpose legume trees with feed, fodder, and wood values in farm niches (including farm borders, soil bunds, and farm strips) is becoming importantfor sustainable watershed management (Amede and Haileslassie, 2011). These practices increase the vegetation cover, minimize erosion, and improve watershed functions. The establishment of farmer groups was found to be an effective approachfor identifying farm and landscape niches where trees could be integrated in the watershed without competing with other enterprises (Box 1).

2.3 Rainwater harvesting systems

Lal (2001) reported that the primary limiting factor for crop-yield stabilization in sem-iarid regions is the amount of water available in the crop rooting zone.Rainfall intensity in SSA can often be greater than the infiltration rate and the water holding capacity of the soil, which can trigger an excess of runoff.Moreover, rainfall in most North African countriesis so low that rain and water control and management are critical.Rainwater harvesting (RWH) is defined as capturing storing seasonal excess runoffand diverting it for household and agricultural uses.Traditional or improved structures may be used. In SSA where rainfall is low and unpredictable, and where it is also expected to decline due to climate change,rainwater storage in farm ponds, water pans, subsurface dams, and earth dams is gaining in importance as a supplement to irrigation (Ngigi, 2009) and livestock watering. It is also an effective strategy to manage floods, particularly in high rainfall areas. RWHcould be used to satisfy water demands during dry spells and to create opportunities for multiple use.The importance and distribution of rainwater harvesting structures in Africa is well documented (Mati, *et al.,* 2008; Malesu, *et al.*, 2006). It is particularly important in eastern and southern Africa, where about 70 percent of the land is in arid, semi-arid, and dry sub-humid zones and where excess runoff occasionally occurs.

The potential for enhancing and stabilizing crop yields and livestock production in crop-livestock systems encourages farmers to invest in rainwater harvesting and nutrient management at plot, farm, and landscape scales and has been strongly promoted in the drought-prone pastoral and agro-pastoral systems in East Africa and the Sahel. Quantitative studies in a drought-prone district in Southern Ethiopia have shown that rainwater harvesting has improved the capacity of communities to deal with recurrent drought (Desta, 2010).Using rainwater harvesting, farm households have started to diversify cropping systems, introduce new vegetables and perennial crops, and increase their household income.

Water storage is clearly an important strategy for use in adapting to climate change in Africa.Many RWH technologies can be implemented by individual farmers with minimum training and facilitation. For adaptation, the focus is likely to shift to increasing water storagein ponds, pans, tanks, and subterranean aquifers and to supplemental irrigation of crops. Some of these practices are described in more detail below.

2.3.1. ***In situ*rainwater harvesting**

Rainwater harvesting includes *insitu* water harvesting methods that concentrate soil water in the rhizospherefor more efficient use by plants.*Insitu* water harvesting means rainwater is conserved where it falls, whereas water harvesting systems involve transfer of runoff water from a "catchment" to the desired area or storage structure (Critchley and Siegert,1991).Land and water conservation interventions on sloping lands includebench/fanyajuuterraces, retention ditches, stone lines, vegetative buffer strips, contour bunds, and other activities that reduce loss of runoff water. They are primarily used to reduce soil erosion and to improve rainfall infiltration and conservation in the soil profile (Bossio*et al.*, 2007). The main limitation of thistechnique is its high labour demand, especially on steep slopes where proper structural measures are required. Some amount of training and site-specific design/layout is also needed. In one example from the AnjenieWatershed of Ethiopia (Akalu and adgo, 2010), long-term terracing increased yields of teff, barley, and maize significantly. In contrast, cultivation on steep un-terraced hillsides had negative gross margins. Similarly, Vancampenhout, et al. (2005) obtained positive yield results and increased soil water holding capacityusingstone bunding on field crops in the Ethiopian highlands. Fox and Rockstrom (2003) reported that *insitu* RWH had a significant effect on grain yield, and by using this system in Burkina Faso they were able to increase the yield of sorghum from 715 kg ha^{-1} to 1,057 kg $ha.^{-1}$Micro-basin water harvesting structures (e.g., half-moons, eye-brow basins, and trenches) have also been proven to be effective in improving tree survival and growth in degraded lands. Experiences from northern Ethiopia have shown that these structures improved tree survival and growth significantly compared to non-treated landscapes (Derib, *et al.*, 2009). The seedlings grown in micro-basins were thicker, taller, and more productive than those grown in normal pits, suggesting a need to integrate tree planting with soil water management.

Some of these interventions have been developed and used by communities in Africa for centuries, including, for example, by the Konso tribes in southern Ethiopia and by communities in Burkina Faso. Zaï is a traditional practice developed by farmers in Burkina Faso that has been adapted for use in the wider Sudano-Sahelianzonefor rehabilitating degraded fields that have been eroded and crusted over and thus with infiltration ratestoo low to sustain vegetation (Roose,*et al.*, 1999;). Zai pits lead to water and nutrient concentrations around the root zone (Amede, *et al*., 2011b). However, in an experiment in the semi-arid Yatenga region of northern Burkina Faso (where rainfall is from 400 to 600 mm annually), Roose and Barthès (2001) showed that water harvesting by concentrating runoffproduced higher benefits (mineral nutrients were also added).Similarly, in a different agroecologysetting in Eastern AfricaAmede, et al. (2011b)reported that Zai pits increased crop yield by upto 500 percent for potatoes,including on high rainfall hillsides where runoff washigh and water infiltration low due to the steep slopes and soil crust. The benefit was especially obvious in outfields, where management and the application of farm inputs by farmers was limited. Baron and Rockstrom (2003) also observed that maize yield can be tripled by employing conservation agriculture, which facilitates water infiltration and reduces evaporation. Mati (2010) observed that the productivity and profitability of smallholder agriculture through use of water management technologies increased crop yields by factors ranging from 20 to over 500percent, while net returns on investment increased by up to ten-folds. Also, it was observed that these gains were linked to poverty reduction, employment creation, and environmental conservation.

2.3.2Water storage in ponds, pans, and underground tanks

There is substantial potential for increased ground level storagein large parts of SSA. Already, water is harvested from open surfaces,paths, and roads and stored in structures such as ponds or underground tanks (Guleid, 2002; Nega and Kimeu, 2002; Mati, 2005). Flood-flow harvesting from valleys, gullies, and ephemeral streams is also done, and the water is stored in ponds, weirs, and small dams. Pans and ponds are particularly popular in community-scale projects, as they can be made cost-effective using local materials and community labour(Malesu*et al.*, 2006). The main difference between ponds and pans is that ponds receive some groundwater contribution, while pans rely solely on surface runoff. Thus, pans, which range in size from about 5,000 to 50,000 m^3 (Bake, 1993), are constructed almost anywhere as long as physical and soil properties permit. In areas where seepage is a problem, small storage facilities can be lined with clay grouting, concrete, or geo-membrane plastics. Water harvesting with small storage ponds could make major contributions to household incomes and rural poverty reduction (Box 2). For instance, in Ethiopia, water harvesting and storage in small ponds for use in supplemental irrigation of vegetables and seedlings at MinjarShenkoraresulted in average net incomes of US$155 per 100 m^2 plot (of onion seedlings), while incomes from bulb onions grown in the field provided an equivalent of US$1,848 $ha,^{-1}$ adding up to US$2,003 ha^{-1} from the onion crop alone (Akalu and adgo, 2010). Other studies, Gezahegn, et al. (2006) and Nega and Kimeu (2002) assessed small scale water harvesting technologies in Ethiopia and found that returns on investment were high.

In an attempt to assess of the use of AWM technologies, Awulachew,*etal*(2009) found that low access to ponds and shallow wells was strongly associated with poverty. Asurvey of nearly 15,000 household ponds (and a few shallow wells) in the Amhara region of Ethiopia found that only 22 percent were functioning. Seventy percent were not functioning at all, and the balance had been destroyed. This was attributed to major technical, social, and environmental problems (Wondimkunand Tefera, 2006). One of the constraints to adoption of AWM technologies was targeting. Kassahun (2007) found that households headed by women,typically poor households, were not benefiting from RWH ponds. Moreover, Merrey and Tadelle (2010), after reviewing the wide range of literature in Ethiopia, concluded that the low performance of water harvesting structures resulted from top-down quota-driven programmes, a failure to identify proper locations at farm and landscape scales, water losses through seepagerelated to use of inappropriate base materials, excess surface evaporation, and lack of water lifting technologies.In some African countries (e.g., Zambia) groundwater has been important for developing reliable and better quality water supplies for rural communities (Hiscock, *et al.*, 2002).

2.4 Small earth dams and weirs

When larger quantities of water are to be stored, larger dams are more appropriate. These could be earthen dams constructed on- or off-stream, where there are large sources of channel flow (Gould and Nissen-Peterssen, 1999). Volumes of water storage range from thousands to millions of cubic meters. Reservoirs with volumes of less than 5,000 m^3 are usually called ponds. Due to the high costs of construction, earthen dams are usually constructed with donorfunding or governmentsupport. However, there have been cases of smallholder farmers digging earthen dams manually as in Mwingi District of Kenya (Mburu, 2000). Earthen dams can provide adequate water for irrigation projects as well as for livestock watering. Low earthen dams, called "malambo," are common in the Dodoma, Shinyanga, and Pwani regions of Tanzania (Hatibu, *et al*., 2000). They typically collect water from areas of less than 20 km^2 for a steep catchment to 70 km^2 for flat a catchment. Some of these are medium-scale reservoirs used for urban water supplies or irrigation. Sediment traps and delivery wells may help to improve water quality but, as with water from earthen dams, the water in such wells and traps is not usually suitable for drinking without treatment.

2.5 Sand and Sub-Surface dams

The semi-arid zones of Africa are subject to flooding during the rainy season, providing an opportunity for rainwater harvesting. Where seasonal rivers carry a lot of sand (sand rivers or "lugga," ″wadi,"and ″khor") the sand formation can be used to store water for use during the dry season (Nissen-Peterssen, 2000). The most convenient way to harvest water in a sand river is by either sand or subsurface dams. Local materials for construction are usually available and the only extra cost is that of cement and labor. It is a cost-effective method for providing water for drinking and also for irrigation. Because the water is stored under the sand, it is protected from significant evaporation losses and is also less liable to contamination. Another advantage of sand river storage is that it normally represents an upgrading of a traditional and, hencesocially acceptable water source. Nissen-Peterssen (2000) distinguished between three types ofsubsurface dams: (i) sand dam built of masonry, (ii) subsurface dams built of stone masonry,and (iii) subsurface dams built of clay. The construction of river intakes and hand-dug wellswith hand pumps in the river bank can further help to improve the quality of water.

2.6Water harvesting and storage in the soil profile

This involves harvesting runoff for crops from land, roads, and paved areas and channeling it to specially treated farmlands for storage in the soil. The cropped area may be prepared as planting pits, basins, ditches, bunded basins (majaluba), semi-circular basins (demi-lunes), or simply ploughed land (Hai, 1998; Mati, 2005; Ngigi, 2003). Storing rainwater in the soil profile for crop production is sometimes referred to as "green water" and forms an important component for agricultural production (Box 2). The design of a run-on facility depends on many factors, including catchment area, volume of runoff expected, type of crop, soil depth, and availability of labour (Hatibu and Mahoo, 2000). The source of water could be small areas or "micro-catchments" or larger areas. The latter involves diverting runoff from external

Box 2: Water Harvesting for Rice Production in Shinyanga, Tanzania

In Tanzania, farmers make excavated bunded basins, locally known as 'majaluba,' which hold rainwater for supplemental irrigation of crops. This system is practiced in the semi-arid areas where rainfall amounts range from 400 to 800 mm per year. About 35 percent of the rice in the country is produced in this way under smallholder individual farming in the Shinyanga, Dodoma, Tabora, and Lake Regions. In many cases, majaluba utilize direct rainfall, but sometimes farmers combine the system with runoff harvesting from external catchments. Generally, rice yields are higher, attaining 3.43 t ha^{-1} with the use of harvested water for irrigation as compared to 2.17 t ha^{-1} obtained without supplemental irrigation. These systems have increased household incomes by 67 per cent from US$ 430 ha^{-1} without runoff harvesting to 720 US$ ha^{-1} with the technology (Kajiru et al, 2010). The main constraint is that with or without runoff harvesting, the majaluba system is predominantly rainfed, with water storage in the soil profile (green water). Consequently, climatic uncertainties and prolonged dry spells could adversely affect the system unless it is augumented by other storage infrastructure,e.g.,ponds.

catchments such as roads, gullies, and open fields into micro-basins, including paddies,where the profile can hold water relatively well (Box 2). The cropped land for these systems is usually prepared in different shapes and designs, such as trapezoidal bunds, semi-circular and contour bunds, planting pits, negarims, T-basins, and various types of channeling and conservation of runoff (Critchley et al., 1999; Mati, 2005, Duveskog, 2001).

2.7 Spateflow diversion and utilization

Spate irrigation or floodwater diversion involves techniques in which flood water is used for supplemental irrigation of crops grown in low-lying lands, sometimes far from the source of runoff. Spateflow irrigation has a long history in the Horn of Africa and still forms the livelihood base for rural communities in arid parts of Eritrea, Ethiopia, Kenya, Somalia, and the Sudan (SIWI 2001; Negassi*et al.*, 2000; Critchley, *et al.*, 1992). It is also practiced in other dry areas. For instance, in Tanzania spate irrigation has increased rice yield from 1 to 4 t ha^{-1}using RWH systems (majaluba) (Gallet*et al.*, 1996). Spate irrigation is primarily practiced in the dry countries of Tunisia, Morocco, and Algeria in North Africaand in Somalia, the Sudan, and Eritrea in the Sudano-Sahelian region (Frenken, 2005). Although spateflow irrigation has high maintenance requirements, its applicability is valid for large areas of the Sahel and Horn of Africa, where other conventional irrigation methods may not be feasible.Spate irrigation holds promise for use in adapting to climate change, considering that flash floods, which can be harnessed and used wherever possible, may become more common.For climate change adaptation, spateflow irrigation techniques will require improved local diversion structures, soil moisture management, field preparation, and land and water tenure.

3. LARGE AND SMALL SCALE IRRIGATION

Despite the presence of large river basins, streams, and groundwater-rich valley bottoms in most parts of Africa, irrigated agriculture still contributes lessthan 10 percent of agricultural production in Africa. With increasing population, decreasing farm size, and the unreliability of rainfall in most years, irrigation has been getting greater emphasis in policy discussions in Africa. The level of irrigation water withdrawal varies from region to region and from country to country in Africa. About 60 percent of the estimated 15.4 million ha under irrigation is in North Africa and the Sudano-Sahel region. Egypt accounts for 54 percent of irrigated land in North Africa.(Wichelns, 2006).Frenken (2005) reported that more than 70 percent of Africa's irrigation is in the Congo, Nile, West Coast, Niger, and Zambezi River Basins. Irrigated agriculture is becoming increasingly important for managing climate variability and for meeting the demands of food security, employment, and poverty reduction. In combination with improved water management practices,it will not only provide a means to cope with climate variability, but will also enhance productivity per unit of land and thus increase annual production volumes significantly (Awulachew, *et al*., 2005).

Irrigated farming is becoming a necessity in the drought-stricken regions of SSA (Amede and Haileslassie, 2011)as it reduces the vulnerability of farmers to rainfall variability; increasesagricultural production per unit of land, water, and labour; enables communities to produce high value on their farms;and strengthens collective action for broader land and water management (Boxes 3 and 4). However, except for a few North African countries,the amount of irrigated land in Africa is low (Figure 2).As most irrigation schemes in Africa currently rely mainly on surfacewater, there exists huge potential for using groundwater for irrigation.To expandirrigable land in Africa, particularly at the household level, communities should explore groundwater opportunities. The greater use of groundwater has also been suggested as an adaptation option(Kundzewicz, *et al.,* 2007).

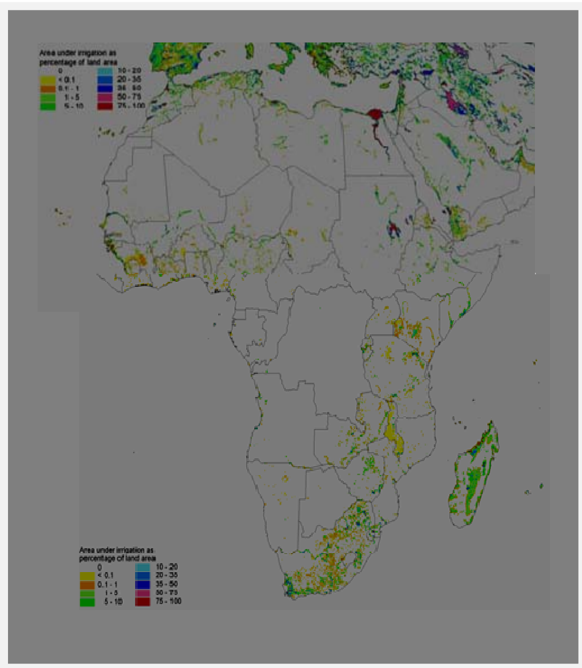

Figure 2. African irrigation map (Siebert*et al*., 2007)

Groundwater can be an important elementof AWM. Water-lifting devicesfor small-scale irrigation are both technology- and place-specific. The main technology components are the type of power source, type of pump or lifting device, delivery arrangements (i.e., static liftor instantaneous discharge). Place-specific factors include the condition of the soil, farm type, and the local economy.In most cases, small-scale irrigation has significantly increased crop yields, improved incomes, and achieved higher agricultural production than non-intervention (Amede, 2004; Box 3). Micro-irrigation systems are also used to improve water management. Such systems use low-head, drip irrigation kits supplied to smallholders. Many types of drip irrigation systems are in use in SSA (Ngigi, 2008). Kits range from 20-liter buckets to 200-liter drums or mini-tank systems and operate at 0.5-1.0 m water head. A majority of the kits target market gardens and vegetable production. This type of irrigation is used in combination with fertilizers.In general, irrigation farming is expected to reduce the exposure of farmersto climate variability, stabilize crop and livestock yields, and improve food security. It raises agricultural production and rural incomes, improves crop diversification, and promotes market-oriented agriculture (Amede, 2004; Boxes 3 and 4). It also enhances the capacity of local communities to demand better services.

There is a perception that irrigation investments in Africa are more expensive than elsewhere, although the cost of developing schemes varies from location to location within and between countries, ranging from 2,500 USD/ha to 14,500 USD/ha. However, Inocencioeta,*et al*. (2005) showed that the cost was considered high because of the exaggerated costs of some failed schemes. Some irrigation schemes in Africa failed to give the intended returns partly because of poor design and destruction of unprotected upper catchments but also because they lacked the necessary management and maintenance arrangements and because there were no incentives for farmers to efficiently manage the schemes. It has now been shownthat, in fact, irrigation in Africa is not more expensive than it is in Asia. For example, in a detailed analysis of the performance of irrigation in Ethiopia done by Awalachew and Ayana (2011), about 87 percent of irrigation schemes operate well. However, only 47 percent of the planned beneficiaries have benefited from these schemes.

Box 3. Small scale irrigation in Ethiopia (Amede, 2006)

An impact evaluation of IFAD SSI in four administrative regions of Ethiopia, namely Tigray, Southern regions, Oromia, and Amhara, showed that in about 60 percent of the schemes crop yield under irrigation was higher by at least 35 percent compared with non-irrigated farms. Benefits were much higher in farms where external inputs (fertilizer, improved seeds, and pesticides) were used. With access to irrigation, farmers replaced early maturing varieties by high yielding maize cultivars, shifted towards growing diverse crops (in some sites up to 10 new marketable crops, predominantly vegetables). The real challenge was to determine how to scaleup the success stories to the 35 percent non-performing schemes. This requires protecting schemes from boulders, improving irrigation efficiency, creating local capacity, and promoting collective action in local communities to sustainably manage the natural resources.

There is a perception that irrigation investments in Africa are much more expensive than elsewhere although the cost of developing schemes varies from location to location within a country and between countries ranging from 2500 USD/ha to 14500 USD/ha. However,Inocencioeta,*et al*. (2005) showedthat the cost was considered high because of the exaggerated costs of some failed irrigation schemes. Someirrigation schemes in Africa failed to give the intended returns not only because of poor design and destruction by unprotected uppercatchments, they failed because of lack of the necessary institutional arrangements to manage and to maintain them and absence of incentives measures for farmers to efficiently manage the schemes and use the water efficiently. They have then showed from correctly sampled data that in fact irrigation in Africa is not more expensive than in Asia.In a detailed analysis of the performance of irrigation in Ethiopia done by Awulachew and Ayana (2011), about 87 percent of the irrigation schemes are operating well but only 47 percent of the planned beneficiaries have benefited from the implemented irrigation schemes. The major reasons for under-performance of irrigation systems are related to siltation of the main and secondary canals, limited use of good agronomic practices, and lack of funds for maintenance and for pest and diseasescontrol,particularly for high value crops. To improve performance, appropriate policies are needed that will promote the development of local institutionalcapacity,improve market incentives, and facilitate flow of investment. It may alsobe appropriateto consider shifting away from large irrigation projects in favor of smaller-scale projects, considering the poor performance of many of the larger state-controlled ones.

A wide range of irrigation technologies and methods are available. These include surface irrigation methods, like the furrow and small basin methods, andlow pressure and pressurized systems, such as sprinkler,drip, and water-lifting technologies/pumps (Box 5). These are operated bygravity head, manual pumping, motorized pumps, and wind and solar pumps.However, in these systems water loss is a major challenge and a reason for the low irrigation efficiency and limited returns from irrigation investments in Africa. Water loss occurs through conveyance, canal seepage, evaporation of surface water, inappropriate scheduling and planning, leakage in heads and storage, and consumption of water by weeds and other crop competitors. After studying the amount of irrigation water loss in small scale irrigation schemes, Derib,*et al.* (2011) reported that the average water loss from main, secondary, field canals was 2.58, 1.59, and 0.39 $l\ s^{-1}$per 100 m,representing 4.5, 4.0, and 26 percent of the total water flow, respectively. Most of this water was lost through evaporation and canal seepage.

<u>Box 4. Small Scale Irrigation in West Africa.</u>

Small scale irrigation (SSI) contributes to poverty alleviation by enhancing productivity and promoting economic growth and employment (García-Bolanos*et al.,* 2011). Low-cost motorized and treadle pumps have had a large impact in West Africa. SSI in Lomé (Togo), Kumasi (Ghana), Niamey (Niger), and Bamako (Mali), appears to be energy efficient. Itsaves labour, adapts well to the yield limitations of low-cost hand-dug wells, is mobile, and can reduce irrigation costs per m^3 by 40 percent or more (Van't Hof and Maurice 2002). The data compiled by Danso et al. (2003) in Ghana on individual profits from mixed SSI vegetable production in open-space urban agriculture show that monthly net income ranges between US$10 and more than US$300 per farmer, mostly depending on the size of the farm. In Dakar (Senegal), Faruqui, et al. (2004) estimated average annual gross income of US$620 and net income of US$365 per farmer generated by SSI.Zallé (1997) estimated in Bamako (Mali) monthly net income of from US$10 to US$400,dependingfarm size and the use of hired labor.The majority of farmers earned an average of US$40. In Burkina Faso, farmers involved in SSI can obtain a 30 to 50 percent increase in crop yields, and 20 to 35 percent increase in farm income (WAIPRO, 2009). The greatest factor influencing farmers' profits is the ability to produce at the right time what is in short demand (Cornish and Lawrence, 2001). Thus, low-cost, small-scale irrigation is an effective adaptation measure to climate change.

There are a variety of ways to achieve on-farm efficiencies in irrigated agriculture, depending on the size, the availability of water sources, and the sources of energy and technologies for pumping (FAO, 2007). In general, if irrigation is to be used to help farmers adapt to climate change, they must be able tomaintain their irrigationinfrastructuretechnicallyandfinancially.

4. CROP AND LIVESTOCK WATER PRODUCTIVITY

In order to improve water availability for agriculture, some actions in addition to improving irrigation are needed. Improving water productivity would enable production of more livestock and produce more cropsper drop from less water, which would reduce future water demands, limit ecosystem degradation, and reduce competition for water among multiple uses and users (CA, 2007). To increase agricultural water productivity water use by forests, livestock, fisheries, and crops is assessed. Molden and Oweis (2007)estimated that if water productivity could be increased by 40 percent over the next 25 years, it would be possible to reduce additional global diversion of water to agriculture to zero. However, the concept of "more crop per drop,"a key concept of high water productivity, was recently criticized for being too narrow by not accommodating non-crop water uses. (Rijsberman, 2006).The water saved from agriculture could be used to improve environmental services and to help African communities adapt to climate change.

Improving crop water productivity produces more grain per unit of water used. This might be achieved through genetic manipulation for water use efficiency and/or recovery of water lost from the rhizosphere through evaporation and seepage. Thus, the concept is different from crop water use efficiency, which is estimated from the proportion of CO_2 fixation and plant transpiration. Most annual crops in SSA have water productivity of below 300 g of grain per cubic meter of water. In well managed farms (including within Africa) crop water productivity can reach as much 2 kg per cubic meter of water (Molden and Oweis, 2007). Low water productivity is mainly due to the low level of agricultural inputs (fertilizers) and poor agronomic management practices (Amede, *et al*., 2011a).

Box 5.Water-lifting technologies in West Africa.

In Nigeria, about 50,000 small pumpsets for lifting water have been introducedacross the country (IPTRID, 2004). This technology has played an important part of the economy, especially for resource-poor people with farm sizes from 0.5 to 2.5ha. Water sources are often shallow groundwater. In Ghana, the scale is smaller, and in Mali, there is considerable use of motorized pumpsets, often rented or leased (Arby, 2001). The pumpsets representa huge potential for improving rural livelihoods. From the viewpoint of Nigerfarmers, the system is financially

Agricultural water demand goes beyond crop requirements. One key intervention that would improve agricultural water productivity is integrating livestock water needs into overall water management, including in the design, planning, and implementation of irrigation schemes (Amede*etal.,* 2009). According to Steinfeld,*et al.* (2006), livestock production aggravates water resource degradation in four ways:1)by the need to satisfy increasing feed demands; 2) through overstocking and inadequate watering points; 3) by mismanagingmanure and wastewater; and 4) by intensifying demand to the point that it leads to resource mining and soil degradation.

Although water for livestock might be the most obvious water use in livestock production systems, it constitutes only a minor part of the total water consumption for this production (Peden, *et al*., 2009). Major water consumption by livestock production is associated with transpiration of water in feed production, which is generally about 50 to 100 times the amount needed for drinking (Peden, *et al.,* 2009). Livestock systems depending on grain-based feeds, as is the case in the developed world, are more water-intensive than systems relying on crop residues and pasture lands, as is the case in SSA and South Asia. Strategic allocation of livestock watering points could improve livestock water productivity and increase returns per animal by up to 100 percent. For instance, in the drought-prone areas of Ethiopia, reducing the distance livestock must walk to watering points from 12 km to 3 km increased milk gains by 250 lt per lactation period per cow (Descheemaeker, *etal*., 2011).Using the Livestock Water Framework, Peden, *et al.* (2009) andAmedeetal. (2009) identified nine strategies to increase livestock water productivity. These could be grouped into the natural resources sphere of influence, the animal sphere of influence, and the socio-political sphere of influence. Interventions include water management, feed type selection, improving feed quality and quantity, improving feed water productivity, grazing management, increasing animal productivity, improving animal health, and having supportive institutions and enabling policies. Integrating improved forage into various crop-livestock and agropastoral systems is also keyto improving water productivity.

Moreover, in most African basins (for instance in the Nile Basin) about 70 percent of water is depleted through grassland pastoral and agropastoralsystems(Cook *et al.,* 2009). Grassland management, which includes erosion control, grazing control, making strategic watering points available for livestock,and different forms of water harvesting structures are adaptation strategies to minimize effects of climate change and variability. Minahi, *et al*.(1993) stated that grasslands are almost as important as forests in recycling greenhouse gasses and that soil organic matter under grassland is of the same magnitude as in tree biomass. The carbon storage capacity under grassland could be increased by avoiding overgrazing. Improved grazing management can lead to an increase in soil carbon stocks by an average of 0.35 t C ha^{-1} yr^{-1}, but under good climate and soil conditions improved pasture and silvopastoral systems can sequester 1 to 3 tons C $ha^{-1}yr^{-1}$ (FAO, 2009). It is estimated that 5-10 percent of global grazing lands could be placed under carbon sequestration management by 2020 (FAO, 2009).

5. CLIMATE-PROOF CROP VARIETIES

Drought denotes a prolonged period without considerable precipitation that may cause a considerable reduction in soil water and thereby cause plant water deficits. In Africa,farmersexperience drought in four different ways that may happen alone or in combination (Amede, 2006). These include:

a) *Unpredictable drought*.This occurs when the total amount of precipitation is comparable to that in normal years, but plants are exposed to stress at any stage of growth because of unpredictable and/or uneven rain fall distribution. Unpredictable drought is a common phenomenon in the Great Rift Valley of eastern and southern Africa. This is where crop varieties with physiological plasticity and water-stress tolerance are needed. They may include crops like sorghum, millets, and teff.

b) *Full season drought.* This occurs when the amount of rainfall is much lower than in normal years across the phenological stages, and hence plants do not get enough water to cover the atmospheric demand throughout the growing period. This commonly happens in most of Sub-Saharan Africa (e.g., in northeastern Ethiopia, the Sudan, and North Africa). This is where drought resistant, less-water-demanding cropsare most suitable, and these include pigeon peas, barley, chickpeas, and millets.

c) *Terminal drought.* This occurs when there is enough water for early establishment and growth of crops, but later growth stages suffer soil water deficits. This is often the case for the relay crops of the Rift Valley. For instance, the common practice of relay planting of beans in maize fields in eastern Africa commonly exposesbean cropsto terminal drought.These are areas where early maturing varieties of maize, wheat, beans, and other legumes do best.

d) *Intermittent drought*. This occurswhen there is a predictable short dry spell within a growing season and thus plants are exposed to drought only at one stage of growth. This is also very common in regions with extended growing periods. In this case, agronomic management, including adjusting planting dates, mulching, supplementary irrigation, and other best practices,is more useful than selection of varieties.

Various physiological traits have been associated with drought resistance, and the major drought resistance mechanisms in field crops are classified as drought avoidance (drought resistance with high plant water potential) and drought tolerance (drought resistance with low water potential). To date, no traits are known that confer global drought tolerance (Amede, 2006).Moreover, short-term responses to water stress at the cellular and sub-cellular level may not be beneficial to yields.Despite the growing demand for drought-resistant cultivars, breeders in Africa have been slow in achieving this goal due to the challenge in identifying traits that reflect true drought resistance. Adoption of crop varieties and forage with increased resistance to heat stress, shock, and drought is critical for minimizing the effects of climate change. For example, a private-public partnership, the African Agricultural Technology Foundation,is developing water efficient maize for Africa (WEMA). The project plans to develop maize varieties tolerant to drought and other stress factors. Some are concerned, however, that the initiative uses biotechnology besides conventional breeding and marker-assisted breeding techniques (www.aatf-africa.org).

Another key strategy to mitigate the effects of climate change is improving the vegetative cover of African landscapes and increasing the potential of agriculture in carbon sequestration. However, the landscapes void of vegetation are commonly degraded by erosion and by anthropogenic activities and maynot be able to support good vegetation growth without employing soil and water management practices.

6. POLICIES AND INSTITUTIONAL FRAMEWORKS TO IMPROVE ADAPTATION TO CLIMATE CHANGE

Good water management calls for the collective action of multiple institutions, from local communities to federal ministries and regional authorities. The policy and institutional framework delineated in the ComprehensiveAfrica Agriculture Development Programme (CAADP) of the New Partnership for Africa's Development(NEPAD) for AWM in SSA recommends extending the area under sustainable land management, developing reliable water control systems, especially for small-scale water control, building up soil fertility and the moisture holding capacity of agricultural soils, and expansion of irrigation. (NEPAD, 2003).Regional policies, such as the Southern Africa Development Community (SADC) Water Policy and the Land and Water Management Policy of the Nile Basin Initiative, make similar recommendations. A review of the nature, functions, and gaps of organizations and policies in three countries in East Africa, viz. Ethiopia, the Sudan, and Uganda indicates that the organizational structure affecting agricultural water management stretches from the local to the national level (Amede, *et al*., 2009). In most countries, various national policies support agricultural water development. Some of these are now being reviewed. For instance, in a study of water policies, Mati,*et al*. (2007) examined 78 policies from Eritrea, Kenya, Madagascar, Malawi, Mauritius, Rwanda, the Sudan, Tanzania, and Zimbabwe relevant in some way for AWM. They found that most countries have developed national and local policies addressing poverty reduction, economic growth, agricultural productivity,food security and environmental sustainability.

A review of thesepolicies indicated that there is no policy that specificallyaddresses AWM in any of the nine countries. Instead, statements on AWM were included in the existing policy documentsof many different ministries or sectors. The scattering of AWM issues across sectors has resulted in policies that overlap, duplication of efforts,inefficient use of resources, and lack of clear ownership of AWM issues (Mahoo, *et al.*, 2007). We argue here that support is needed to reform AWM policies and to better integrate them into thepolicy frameworks of African governments, thus making them more responsive to the challenges posed by climate change.

There is also some disconnection between research and development andinadequaterecognition of the complexity of resource degradation and what this means for food security.In the context of climate change, it is now increasingly recognized that integrated, holistic research is needed. This may include technological, social, policy, and institutional interventions for improving adaptation to climate change and for sequestering carbon while increasing productivity of water, nutrients, and labour for food security and environmental sustainability. New approachesto climate change research are needed that will consider the well-being of poor men and women farmers. Such approaches demand wideinteraction and strong collaboration among stakeholders at local and higher levels. These goals could be realized if research leads to improved water productivity and to higher incomes for farmers.

At local levels, communityirrigation schemes include traditional water masters, modern water user associations (WUAs), and water cooperatives. In some cases, these different organisations exist side by side and play competitive roles. Strengthening water user associations to manage and use water efficiently has proven to be an important strategy to sustain irrigation schemes (Amede, 2004). While the current capacity of farmers in most African countries to operate and maintain irrigation schemes and other water infrastructure is weak, it is unsustainable in the long term to rely solely on funds from governments or development partners (e.g., IFAD, AfDB). This calls for the implementation of strategies to produce alternative sources of income at the local level, including possibly the introduction of water pricing policies. Water pricing will improve irrigation efficiency and institutional performance at local and regional scales and will create a sense of community ownership of investments in water. While building local capacity to optimize irrigation water use and distribution, water pricing is a key foundation for enhancing local capacity and improving irrigation efficiency and water productivity (Molle and Berkoff, 2007). Water pricing could work by having beneficiaries pay charges or fees for accessing irrigation water and related servicesbased on area size and volume supplied. The fee could be used for the operation and maintenance of the irrigation infrastructure, covering costs of water user associations and modernization of irrigation facilities. Moreover, current extension support of irrigation agronomy is far from responding to the needs of farmers. Another option proposed by some development partners (e.g., IFAD) is the establishment of farmer-led research groups in SSI to promote research on irrigation constraints, including irrigation frequency, pest and disease management, spot application of chemical and fertilizers, management of perishable seeds, and related issues. This is best done through the support of the regional agricultural research institutions. Participatory experimentation would give farmers and practitioners opportunities to tryout interventions and develop water, crop, and livestock management skills.

At the national level, poor market opportunities are commonly identified as disincentives for improving the productivity of irrigation schemesand water harvesting structures (Amede, 2004). Lack of road infrastructure and the saturation of markets with similar agricultural products are two important marketing constraints. Numerous water investments in SSAare not accessible during the rainy season. Intensified cropping requires fertilizer input, while diversification requires new seeds. Inaccessibility to these inputs can impact farm sustainability. In many cases, farmers are currently entirely dependent on government for inputs.For instance, in Burkina Faso the government provides farmers with subsidized fertilizer and irrigation equipment as part of the small scale irrigation programme. There is also a need to establish strong national and regional water institutions, with multidisciplinary teams to support irrigation and rainwater management experts. However, government ministriescommonly lack the required manpower and facilities to engage much beyond occasional workshops and management of donor funds.

Lack of an enabling environment for the sustainable use of water resources is another feature common to most African countries. Many Africans wish to shift from a focus on relief to a focus on development, from short-lived and quick-impact responses, to long-term, all encompassing, environmentally sustainable interventions. However, recurring needs in recent years in places like the Horn of Africa seem to have causedNGOs and CBOs to lose sight of long-term development objectives. Coordination has been limited in guiding local organizations toward more integrated,climate proof crop-water livestock development. Generally, existing sectoral policies within Africae.g., for food security, irrigation, watershed management, etc.) rarelyconsider climate change. Comprehensive and integrated policies that do consider the climate change-water interaction are highly desirable.

7. CONCLUSION AND WAY FORWARD

A number of possible agricultural water management and adaptation options have been discussed in this paper. These include rainwater storage for surface and underground reservoirs, various irrigation schemes to optimize water and crop productivities, dryland farming and best agronomics practices, livestock water productivity, seed genotype improvements, and improvements in policies and institutional frameworks. Despite uncertainty about the impacts of climate change on agriculture and water resources, many of the water-related challenges discussed in this paper will increase with climate change. If water resource management decisions are taken without consideringclimate change, then mal-adaptation may result.AWM embraces a range of practices, including *insitu*moisture conservation and *exsitu* water management, and offers a way of facilitating water-centered development to simultaneously reduce poverty, increase food security, achieve environmental protection, and adapt to climate variability and change. The potential of using alternative and renewable energy, such as wind and solar power, will help to secure agricultural systems in an environmentally and economically sound manner.Improving crop, livestock, and water productivity is a key strategy in the AWM agenda. Employing crop physiological resistance mechanisms and improving vegetative cover can assist with carbon sequestration. There is a strong need to support African fast-track policy reformsand infrastructure and institutional frameworks for AWM. Regional coordination with respect to transboundary water resourcesis especially important and will greatly assist dealing with the impacts of climate change in the agricultural water sector.

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