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Water management for sustainable agricultural intensification and smallholder resilience in sub-Saharan Africa

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ABSTRACT

Water management strategies and allocation policies that support agricultural intensification across agro-ecological zones and hydrologic basins are required for building resilient agrarian communities in sub-Saharan Africa. We provide an overview of the research and investments needed to enhance agriculture in the region, with a focus on technology and institutions, while describing opportunities for improving rainfed crop production. We discuss a range of water management practices in three river basins that were part of the Challenge Program on Water and Food research on Basin Development Challenges from 2009 to 2013. Our main message is that technical and institutional innovations in water management are required for creating and sustaining resilient agrarian communities in sub-Saharan Africa. Such innovations are best designed and implemented in consultations involving researchers, households, investors, and other participants with a management or regulatory responsibility. It is in this collaborative spirit that we introduce this Special Issue of Water Resources and Rural Development, in which several authors present results of studies on agricultural water management in the region, with recommendations for better planning and implementation of interventions to benefit smallholder farmers.

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1. Water scarcity in African river basins

Water is central to sustainable agricultural intensification, as it directly affects several dimensions of sustainability, including social, economic, health, and environmental aspects (WWAP, 2015). Competition for water is increasing, in both local and transboundary settings. Yet, in Africa, just 5% of the renewable water resource potential is developed, and freshwater resources are unevenly distributed in time and space (Vörösmarty et al., 2005). Some countries have abundant water resources, while others must cope with notable physical or economic water scarcity (Molden, 2007). A river basin can be characterized as both scarce and abundant at the same time, depending on the reliability of its water supply and the water uses considered (Harrington and Vidal, 2014). Scarcity in this context is defined as "a failure to achieve the right amount of the right quality of water for the right purpose at the right time for the right people (Vidal et al., 2014)." Even where water is abundant, extreme weather events, such as flooding and drought, can reduce the effective abundance of water in the near term.

The threat of water scarcity can be attributed to several factors, including urbanization, industrialization, climate variability, expanding agricultural needs, and the inappropriate use of land and water resources. According to FAO (2009), the demand for water for agricultural, industrial, and urban needs in Africa will increase by 40% by 2030. Moreover, agricultural output in SSA must double by 2050 to provide sufficient food for the increasing population (WWAP, 2015). Without substantial improvements in water productivity or shifts in production patterns, consumptive water demand in agriculture will increase by 70%–90% by 2050 (Molden, 2007). In addition, increasing population density and the encroachment of communities on to forest lands, wetlands, and critical watershed, have increased sediment loads and depleted the nutrient status of production systems, while affecting downstream investments, including irrigation schemes, hydropower dams, and roads (Amede et al., 2014; UNEP-GEF, 2013). Yet, there is limited investment and policy guidance regarding agricultural water management, such as the coordinated monitoring of the impacts of water policies and institutional arrangement at basin levels (Amede et al., 2014). Improvements in water allocation and management are needed across river basins in Africa to enhance water access and availability (Cook et al., 2012; Harrington and Vidal, 2014).

Water availability and soil fertility influence the sustainability and livelihoods of rural communities. Inadequate access to water and degraded soils expose communities to recurrent food insecurity, poverty, and potential conflicts. As most of the African continent is drought-prone and vulnerable to climate change, effective adaptation strategies are needed. The effects of recurrent drought are most notable in rainfed systems, where adaptive capacity is limited and local institutions are not yet well prepared to respond to emerging climate shocks. Improvements in land and water management practices in both rainfed and irrigated settings are needed to reverse the downward spiral toward poverty in the region.

2. Agricultural water needs for sustainable intensification

Sustainable intensification of agriculture is needed to meet the growing demand for food. However, increasing production is not sufficient to ensure food security. The equitable distribution of food and the preservation of ecosystem services also are essential. The availability of water to meet increasing food demands is the focus of much of the discourse on agricultural water management, particularly in regions with increasing competition for water and where it is difficult to negotiate transboundary water agreements (FAO, 2011). It is estimated that by 2050, rising population and incomes will result in about a 70% increase in global demand for agricultural production (FAO, 2011). While additional water resources will be needed for crop production, there is a trade-off between the resulting agricultural benefits and the benefits foregone in alternative uses of the water. Achieving sustainable intensification of agriculture will require increased irrigation, improved water use efficiencies, and higher yields, even as intersectoral competition for water increases. Physical constraints for water resources are exacerbated by external drivers, such as climate change, competition with other sectors, and socio-economic changes.

More than 80% of agricultural growth to 2050 is expected to come from increased productivity on lands already cultivated (FAO, 2011). Hence, sustainable land and water management are required to bridge existing productivity gaps. A key challenge for policy makers is to determine how much water can be allocated to productive uses, while not degrading critical ecosystems (Vaux, 2012).

Falkenmark and Rockstrom (2010) have identified four means for augmenting water supplies to the levels needed when food and water requirements exceed the production capacity of present croplands and permanent pasture. These include: (1) expanding the area in production to optimize the use of rainfall, (2) capturing and storing rainwater from adjacent lands, (3) increasing water and crop productivity, and (4) optimizing international trade in agricultural products.

There are many innovative technologies and non-technology options for improving water productivity in agriculture. Technologies include methods for enhancing rainwater capture and use, on-farm storage, and improved land and crop management practices. Non-technological solutions include social and institutional innovations that can bring about the needed change. Sustainable intensification must be implemented through integrated planning and management approaches that are scalable from local levels and that address the inherent risks in climate change mitigation and adaptation strategies. Integrated rainfed production practices such as conservation agriculture, crop-livestock systems, and irrigated agriculture that is adaptable to local climate and market demands are needed also.

3. Investing in rainfed systems

Most farmers in sub-Saharan African rely on rainfed agriculture for their livelihoods. In recent years, rainfall variability has adversely impacted agricultural production, as erratic rainfall patterns have caused crop failures, with negative implications for the livelihoods of already impoverished farmers (Douxchamps et al., 2012, 2014; Hanjra and Gichuki, 2008; Terrasson et al., 2009). Several studies in the Volta basin have noted a delay in the onset of the rainy season (Jung and Kunstmann, 2007; Lacombe et al., 2012), while others have noted the increased incidence of dry spells during the cropping season (Battisti and Naylor, 2009; Kasei et al., 2010; Lacombe et al., 2012). The impacts of recurrent drought in East Africa include abrupt changes in the length of growing periods, the timing and duration of wet and dry seasons, crop failures, and livestock mortality. Looking forward, drought mitigation measures in favor of agriculture will place new pressures on ecosystems in sub-Saharan Africa. Policy makers in the region will need to evaluate inherent trade-offs in efforts to increase food security, while sustaining ecosystem services (Bossio, 2009; de Fraiture et al., 2007).

It is imperative to explore opportunities for adapting to the current and increasing variability in rainfall, to enhance food security at local and regional levels. Many rainwater management technologies and practices are available across Africa to minimize the negative impacts of drought (Amede et al., 2014). Rainwater management (RWM) is an integrated development strategy that enables actors to systematically map, capture, store, and efficiently use surface water from farms and watersheds in a sustainable manner for both agricultural and domestic purposes (Amede et al., 2011). It has three major components: water storage, water management, and water productivity (Amede et al., 2014). Integrated rainwater management aims to reduce unproductive water losses (runoff, evaporation, conveyance losses, deep percolation), while increasing the water use efficiency of respective enterprises, and increasing returns per unit of investment (Amede et al., 2011). The approach considers not only technologies, but also the institutions and policies that promote effective rainwater management. It not only capitalizes on rainwater harvesting principles, but also advocates increased water storage and improvements in water productivity at several scales: in the soils, on farms, across landscapes, and in reservoirs. Managing water, germplasm, and vegetation at the landscape scale is an effective strategy for addressing the potential consequences of climate change (Mati, 2010). Rainwater management can satisfy water demands during dry spells and create opportunities for multiple use, by capturing and storing water in the rhizosphere and in the landscape. Rainwater harvesting enhances social welfare, while also strengthening social capital in communities (UNEP-SEI, 2009).

Storage of rainwater is often perceived as requiring large dams, yet many storage systems are small, simple, and well suited for use in locations where large storage dams are not feasible. Beginning with soil moisture, which is relatively small and evaporates quickly, there are renewed interests in *in-situ* rainwater management techniques that enhance infiltration and increase water retention in the soil profile. Water and soil conservation measures vary with location, but generally follow the same principles of capturing and storing water to enhance agricultural productivity. Rainwater harvesting can improve crop yields significantly, with larger impacts in low rainfall years (Bouma et al., 2016).

4. Benefiting from rainwater harvesting for productive uses

Water harvesting can be accomplished using open surfaces and paths, roads, rocks, and storage in structures, such as ponds or underground tanks (Guleid, 2002; Mati, 2005; Nega and Kimeu, 2002). Flood flows can be harvested from valleys, gullies, and ephemeral streams, and stored in ponds, weirs, and small reservoirs, as practiced across the Sahel. Pans and ponds are particularly popular in community water harvesting projects in East and Southern Africa, as they can be produced at low cost, using local materials and community labor (Malesu et al., 2006).

Small reservoirs promote diversification of agricultural activities through multi-purpose use, including dry season irrigation, livestock and household watering, supplementary irrigation during dry spells, fishing, and groundwater recharge (de Fraiture et al., 2014; Douxchamps et al., 2012, 2014). The volumes of water stored range from thousands to millions of cubic meters, although substantial water is lost from many small reservoirs due to high evaporation demands. Modeling of the water balance of Boura Lake in Southern Burkina Faso reveals that only 20% of the volume of water in the reservoir, estimated at 4.2 and 3.5 million cm^3 for the years 2012 and 2013, respectively, is available to meet water demand, while up to 60% is lost to evaporation (Fowe et al., 2015). Of the 20% of reservoir volume utilized by community members, irrigation accounts for the bulk of water withdrawals (73%), while domestic and livestock uses are comparatively small (e.g., 3% for livestock). Yet the lake has sufficient water to satisfy the competing and multiple uses of community members, despite high evaporation. This suggests that the Boura Lake reservoir can be managed more effectively to expand irrigation and support other productive water uses (Fowe et al., 2015).

In assessing the performance of small reservoirs for irrigation in the Volta Basin, Poussin et al. (2015, this issue) find inadequate agronomic and economic performance at two sites, due largely to the lack of reservoir maintenance, sub-optimal crop management, and poor product marketing. Moreover, despite the large volume of water in the reservoir, water quality is degraded by agricultural intensification in upstream areas. High levels of pesticide residues have been measured in Boura Lake and in Bama Lake, which is considered an impacted reservoir, due to the proximity of anthropogenic activities (Cecchi et al., 2013). Trade-offs involving agricultural intensification and the health status of aquatic ecosystems must be thoroughly considered to ensure the sustainability of the economic benefits and ecosystem services (Cecchi et al., 2013).

Small-scale irrigation plays a critical role in adapting to climate variability and improving household incomes in sub-Saharan Africa. Yet, there are challenges with the management and performance of small-scale irrigation. Based on the assessment of 52 small-scale irrigation schemes and three case study sites in Ethiopia, Amede (2015, this issue) reports that most schemes do not operate at full capacity, due to design failures, excessive siltation, poor agronomic and water management practices, and weak local institutions. The performance of the schemes varies with the quality of the scheme design, the experience of the communities in irrigated agriculture, access to reliable markets, the level of institutional support by government institutions, and the community's organizational capacity. The perceived benefits of small-scale irrigation include more than drought management and higher yields (Amede, 2015, this issue). They also include reduced farm-level vulnerability to annual rainfall variability and associated risks, and the reduced expansion of farming on to less productive hillsides and valley bottom wetlands. The schemes also enable communities to develop high value commodities and to strengthen collective action for broader catchment management. They also provide an incentive to improve the productivity of rainfed systems in favor of market opportunities. These irrigation interventions are particularly critical in sub-Saharan Africa, where about 70% of the land is in drought-prone, arid or semi-arid zones.

Mati (2010) observed that the productivity and profitability of smallholder agriculture with water management technology in East Africa increased crop yields from 20% to more than 500%, while the net returns on investment increased by up to ten times. In addition, the gains were linked to poverty reduction, employment creation, and environmental conservation. Moreover, most rainwater management interventions are technologically effective and proven to improve water access and the productivity of small-scale farmers. In South Africa, Botha et al. (2015, this issue) find that appropriate rainwater harvesting and conservation techniques are superior to conventional tillage for improving cropland and rainwater productivity.

In the Volta basin, Douxchamps et al. (2015, this issue) show that in communities with crop-livestock systems, household welfare varies with differences in agricultural water management strategies. Prominent strategies include *Zai*, stone bunds, contour bunds, terraces, inter-row cropping, and small reservoirs. *Zai* and stone bunds are practiced by more than 70% of households in Ouahigouya, Burkina Faso (Morris and Barron, 2014). More than 40% of respondents to a survey in Lawra, Ghana have built terraces and small reservoirs (Douxchamps et al., 2015, this issue). The increase in agricultural water management intensity is significantly related to an increase in livelihood assets. However, strong financial support and external facilitation are required to achieve such results with improvements in agricultural water management strategies (Amede et al., 2012; Douxchamps et al., 2014).

5. Addressing technical, social, and institutional barriers

De Bruin et al. (2015, this issue), in an analysis of 33 case studies in four countries of the Volta and Limpopo basins, report factors that led to the sustained application of agricultural water management strategies and subsequent improvements in the wellbeing of farmers. The most important factors enabling the adoption and use of improved water management methods are the farm-level costs and potential financial returns, appropriate design, technical support, capacity development, and a sense of ownership among the communities (De Bruin et al., 2015, this issue; Pretty et al., 2011).

While the potential benefits of agricultural water management interventions on rural livelihoods and the national economy are well established, there is limited institutional capacity in the region to scale-up successful interventions to respond to emerging drivers of change. The lack of an enabling environment for the sustainable use of water resources is common in many African countries. There is a large stake in shifting the focus from relief to development, from short-lived and quick-impact objectives to long-term, all encompassing, environmentally sustainable and consciously monitored rainwater management interventions (Amede et al., 2014).

Constraints such as material availability (e.g., stones and manure), workload and cost, traditional customs and unfavorable land tenure systems (Douxchamps et al., 2012, 2014) have resulted in low adoption rates of successful interventions (Botoni and Reij, 2009; Ouedraogo et al., 2010). In a survey of nearly 15,000 household ponds (and a few shallow wells) in the Amhara region, Ethiopia, only 22% were functional, 70% were not functional, and the balance had been destroyed. This was attributed to major technical, social, and environmental problems (Wondimkun and Tefera, 2006). In Ghana, agricultural extension officers described the performance of 32% and 45% of small reservoirs in the country as very poor and poor, respectively (Venot et al., 2012). They identified design and infrastructure problems as the main causes for the poor performance of small reservoirs. While in-field rainwater management techniques are implemented and managed by individual farmers, the construction and management of small reservoirs require active communal and stakeholder participation to achieve efficiency (Faulkner et al., 2008). In addition, external funding often is required to support construction (Venot et al., 2012).

There is also limited market incentive to encourage farm-level investments. Poussin et al. (2015, this issue) find that inadequate market access is the major limitation affecting the performance of small-scale irrigation schemes. As the papers in this special issue demonstrate, the factors motivating improvements in rainwater management practices have biophysical, economic, and social dimensions (Douxchamps et al., 2015; Poussin et al., 2015). Targeting and extending successful interventions remains a major challenge (Barron, 2013). There is limited knowledge regarding which interventions are likely to be successful, and in which locations. Moreover, replicating successful agricultural water management interventions in new locations requires consideration of economic, biophysical, institutional, and cultural factors.

Barron et al. (2015, this issue) apply a Bayesian network modeling approach in which they combine several sources of knowledge and qualitative and quantitative data regarding institutional, social, and biophysical characteristics of an area, to assess the likelihood of success of water management interventions in the Volta and Limpopo basins. The authors describe a decision support tool, Targeting Agricultural Water Management Interventions (TAGMI), to identify potential sites for extending successful interventions. Using a probabilistic relationship, the authors calculate the likelihood of success (or failure) of three interventions: soil and water conservation, small-scale irrigation, and small reservoirs. TAGMI currently offers a map-based visualization of the Bayesian country model results, conveying spatial differences in the likelihood that water management interventions will be adopted successfully across districts (Barron et al., 2015, this issue).

Weak institutional linkages, sectoral polices, and fragmented investments have affected cross-institutional learning, local action, and policy implementation in managing water resources for resilience. On the positive side, various national and regional institutions in SSA are engaged in land and water management, although there has been limited opportunity for them to share experiences, identify gaps, and provide key insights to policy makers. Innovation platforms provide space for a wide range of stakeholders to exchange knowledge, learn, and develop joint initiatives to solve agricultural development challenges (Amede and Sanginga, 2014).

Successful innovation can only happen when stakeholders have a sustained interest in working together to acquire new knowledge and find solutions. The research community cannot bring about innovation on its own (Greenough, 2013). Successful integrated water resources management depends on interactions involving many actors at different scales, which often is beyond daily considerations (Amede, 2015, this issue; CPWF, 2013). Several approaches are available to facilitate such interactions. In the Volta basin, for example, a companion modeling approach that engages many actors in dialogue regarding natural resources management has enhanced interactions and allowed a collective decision-making process to unfold (CPWF, 2013).

6. Taking on the challenge of ensuring water for food

To overcome technical and institutional challenges and realize the desired impact of water management interventions, the Challenge Program on Water and Food (CPWF) has supported several ‘research for development projects’ that identified priority developmental needs through active consultations with stakeholders in the Volta, Nile, and Limpopo basins. From 2009 to 2013, the CPWF implemented more than 30 projects through its Basin Development Challenges (BDC), which investigate the wide range of methods and approaches needed to enhance water availability and increase food security in the basins. In summarizing the key messages of the BDC program, Harrington and Vidal (2014) suggest that water management is the primary challenge in the selected river basins, rather than water scarcity. Water for food production is a complex issue that calls for both technical and institutional innovations, with the latter requiring long-term, adaptive interventions involving researchers, policy makers, and local communities.

The CPWF’s Basin Development Challenges in three African basins focused on improving rainwater and small water infrastructure management in riparian countries (Ghana, Burkina Faso, Ethiopia, South Africa, Zimbabwe, Mozambique, and Botswana) to reduce poverty and improve livelihood resilience. This special issue presents a selection of papers and insights from the African BDC research program. The authors describe their research involving agricultural water management practices in several African river basins.

In the past, the public process for describing donor interest and discussing government policies regarding water investments has largely involved single events in which stakeholders are informed of plans already in place. In recent years, there has been a notable change in governance structures, yet sectoral integration and evidence-based planning are still in their infancy. Sustained collaboration with many stakeholders can enhance national and basin-level knowledge and thinking, while also encouraging the sharing of experience between institutions, development practitioners, researchers, and local stakeholders (Cofie, 2013; CPWF, 2013). This engagement, supported with scientific research, helps build capacity and consensus regarding the research focus, and generates results with greater relevance, for better use in policy and planning. Moreover, changing water management practices, and making them more productive, requires joint learning, as evidenced in the development of the TAGMI tool (Barron et al., 2015, this issue; De Bruin et al., 2015, this issue). Access to water (through *in-situ* rainwater harvesting, conservation measures, and small-scale irrigation) coupled with services, information, and market access results in higher yields (Botha et al., this issue) and improved livelihoods (Douxchamps et al., 2015, this issue). Conversely, the poor condition of small-scale irrigation schemes, improper agronomic and water management practices, and weak local institutions cause poor irrigation performance (Amede, 2015, this issue; Poussin et al., 2015, this issue).

Future management of water for agricultural intensification will require more than technical solutions. Adequate institutional innovations are needed also, to enhance the resilience of agrarian communities and ensure household food security, particularly in the context of impending climate change.

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