Catalyzing Farmers' Irrigation Investments: Recommendations to Scale Sustainable Rural Transformation

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Water for Food
DAUGHERTY GLOBAL INSTITUTE
at the University of Nebraska

Four female rice farmers plant rice in Bukittinggi, West Sumatra, Indonesia.

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Acknowledgments

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Robert B. Daugherty Water for Food Global Institute

The University of Nebraska founded the Robert B. Daugherty Water for Food Institute (DWFI) in 2010 to address the global challenge of achieving food security with less stress on water resources through improved water management in agricultural and food systems. The institute is committed to ensuring a water- and food-secure world while maintaining the use of water for other vital human and environmental needs.

The institute's approach is to extend the University of Nebraska's expertise through strong partnerships with other universities and public and private sector organizations. DWFI develops research, education, and engagement programs in a focused effort to increase food security while ensuring the sustainability of water resources and agricultural systems. The institute works locally and internationally, bridging the water and agriculture communities and worlds of small- and large-holder farmers to deliver innovative solutions to this complex global challenge.

See the DWFI website for more information at waterforfood.nebraska.edu and stay informed through the institute's Facebook page at facebook.com/waterforfoodinstitute, and on Twitter @water4food.

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Introduction: Farmer-Led Irrigated Agriculture

A female smallholder farmers cooperative harvests carrots in Rwanda.

Introduction: Farmer-Led Irrigated Agriculture

Smallholder farms in sub-Saharan Africa (SSA) number around 33 million, represent 80% of all farms in the region, and contribute up to 90% of food production in some SSA countries (Wiggins and Keats, 2013). Smallholder farmers face multiple challenges. Rain is unpredictable and weather-related disasters, such as droughts, floods, severe storms and heat waves are increasing. There is often a lack of infrastructure, such as roads, reliable transportation, storage facilities and access to markets. Consequently, many smallholder farmers and farming communities in SSA have unstable incomes, and are subjected to food and water insecurity. A study by Van Ittersum et al. (2016) revealed that meeting the growing cereal demand by 2050 would require sustainable expansion of the irrigated production area alongside efforts to close the yield gap and other components of intensification.

Farmer-led irrigation is defined by the World Bank as irrigation where farmers drive the establishment, improvement, and/or expansion of irrigated agriculture -- and influence the location, purpose and design of irrigation development through small-scale, on-farm, locally relevant, and market-oriented solutions. Farmer-led irrigation includes investments by individuals, or small groups of farmers themselves, in any irrigation technology and other complementary inputs, whether it is a watering can; a pump (human, gasoline, or solar powered); or drip irrigation. The term “farmer” includes a wide range of rural producers: women as well as men, subsistence as well as semi- commercial and fully commercial producers. It also covers entrepreneurs who provide irrigation and other support services to smallholder farmers. Giordano et al. (2012) estimate that scaling out of small-scale motorized pumps, for example, could benefit 185 million people in SSA resulting in net benefits of 22 billion USD. To scale-up farmer-led irrigation and promote sustainable economic growth, the international community needs to boldly advance sustainable and catalytic investments.

While not at the levels of the 70s and 80s, public investments in large-scale irrigation projects still attract investments in sub-Saharan Africa (Kikuchi et al., 2020). For the past two or so decades, many organizations, such as the World Bank, United States Agency for International Development (USAID), the Bill and Melinda Gate Foundation (BMGF), the African Development Bank (AfDB), the Islamic Development Bank, the Food and Agriculture Organization of the United Nations (FAO), the International Water Management Institute (IWMI[1]), the International Food Policy Research Institute (IFPRI) and others have been supporting efforts and research to develop solutions for smallholder farmers to adopt agricultural water management practices including irrigation. While at a local level these efforts have produced some success, they have rarely directly led to widespread adoption. That said, some farmers have increased their production levels, either through their own initiative or by adapting some of these introduced ideas (de Fraiture and Giordano, 2012). Recognizing this, many of the organizations mentioned, as well as increasing numbers of governments and other agencies are exploring the opportunities to support farmer-led initiatives[2], which have the potential to achieve better results due to localized investment and support.

1 International Water Management Institute.

2 https://www.worldbank.org/en/news/feature/2018/09/05/innovation-entrepreneurship-positive-change-join-the-farmer-led-irrigation-revolution

Historical Perspective: Farmer-Led Irrigation is not New

Farmers have been investing in irrigation for thousands of years because it enables them to reduce drought risks, diversify their crops and diets, and increase their production and income. They have been building wells, canals, and small dams; and have used watering cans and human- and animal-operated water lifting devices for centuries. In the 1980s and early 1990s, the International Irrigation Management Institute (IIMI, now IWMI) documented numerous cases of farmer-management irrigation systems ("FMIS") in Asia, the Americas and Africa, some of them hundreds of years old. Researchers also documented how FMIS schemes operated in Africa (e.g. Fleuret, 1985), For example, traditional small-scale irrigation systems developed and sustained by agricultural communities have existed in Ethiopia for centuries, surviving such disruptions as the collectivization efforts of the late 1970s, and as recently as 2004 made up 40% of the irrigated land (McCornick and Tadesse, 2004). Many of these schemes are "farmer-led" in the sense that groups of farmers co-invested in their construction and management. In rich countries, farmers have been purchasing mechanical pumps to irrigate their land for over a hundred years. Beginning in the 1960s, a "pump revolution" swept through South and East Asia, to an extent that the area irrigated from private technologies exceeds that irrigated by public irrigation systems in India (Shah, 2007; 2009). Elsewhere, including the North China Plain and parts of southern Europe, farmer-led irrigation has been a crucial aspect of agricultural intensification.

The pump revolution arrived in SSA more recently. In the late 1990s, a wide range of foot- or hand-powered pumps (e.g. treadle pumps), and small imported gasoline and diesel pumps began to appear. In some cases, SSA governments promoted the dissemination of pumps – usually with substantial subsidies. But currency and import policies generally made such pumps far more expensive than in Asia, and the support systems required for after-sales service has been slow to develop. In spite of these impediments, the area under private irrigation now exceeds that irrigated by government schemes in some SSA countries, for example Ghana (Giordano et al., eds., 2012).

International NGOs such as iDE[3] and Kickstart[4]; national research institutions such as the Kenya Agricultural Research Institute (KARI[5]); and international organizations such as FAO, played important roles in popularizing some individualized irrigation technologies (e.g. Kay and Brabben, 2000). Among manual water lifting devices, rope and washer, as well as treadle pumps, were found to have a positive impact on food security, poverty reduction and crop revenue in Zimbabwe, Kenya and Ghana. However, their labor intensiveness hampered potential adoption in some African countries like Malawi (Kamwamba-Mtethiwa et al., 2016). When using crop yield and profit indicators, motorized pump studies generally do report a positive impact on household consumption among other socio-economic factors (e.g. in Nigeria, Mali, Mauritania, Niger, Ethiopia). However, when factors such as labor, energy and water consumption are used, motorized pumps are sometimes rather negatively evaluated (e.g. in Mauritania, Nigeria, Kenya, South Africa, Ethiopia, Mali) (Kamwamba-Mtethiwa et al., 2016). Solar pumps are in growing demand in Asia (e.g. Bangladesh and India), but a relative new technology for SSA. The available literature on success rates of solar pumps is limited (Burney et al., 2010; Burney and Naylor, 2012; Otoo et al., 2018), but there are a growing number of pilot projects and pump manufacturers emerging (Merrey and Lefore, 2018a).

At the beginning of this century, researchers began promoting low-cost, low-pressure drip irrigation kits as a solution for poor African and Asian smallholders (e.g. Postel et al., 2001; Shah and Keller, 2002). In Africa, smallholder drip irrigation and pump kits were promoted as a poverty-alleviation tool (e.g. Burney

3 https://www.ideglobal.org/
4 http://kickstart.org/
5 https://www.kari.org/

and Naylor, 2012). International NGOs developed and disseminated low-cost drip irrigation kits and treadle pumps, often through heavily subsidized pilot projects or as part of drought response programs (Merrey et al., 2006; Burney et al., 2013). Subsequent published reviews of these technologies produced a mix of results: some positive cases, but more often, there were problems with their performance and sustainability. The long-term impacts and sustainability of low-cost drip irrigation kits has been especially disappointing (Merrey and Langan, 2014[6]) , with successful examples of going to scale being very rare. These were arguably not "farmer-led" initiatives, being largely driven by external actors.

Since 2012 there has been a succession of studies documenting the critical importance of producers' own investment initiatives in expanding irrigated agriculture and arguing that donors and policymakers need to prioritize supporting these investments (e.g. Giordano et al., eds., 2012; Burney et al., 2013; de Fraiture and Giordano, 2014; Woodhouse et al., 2016; de Bont, 2018; Lefore et al., 2019). Researchers used a variety of terms, such as "distributed irrigation systems," "unplanned," "spontaneous," "farmer-driven investments in agricultural water management" or "emergent" irrigation, or "small private irrigation" to refer to the same thing: "farmer-led irrigation" These papers urged policymakers and finance institutions to prioritize investing in supporting farmer-led irrigated agriculture.

By 2018, several key donors and financial institutions had begun to formally recognize farmer-led irrigated agriculture as an important opportunity. Two well-attended global conferences organized by the Robert B. Daugherty Water for Food Global Institute at the University of Nebraska[7] (DWFI) helped raise its profile (DWFI, 2016; 2017). Both conferences included special sessions on lessons being learned from the recent rapid growth in smallholder African farmer investments in irrigation and its potential for transforming food security and rural economies. Senior representatives from the World Bank and the United States Agency for International Development (USAID), as well as NGOs such as iDE and Kickstart, and research institutions such as IWMI, were active participants at both conferences and helped shape the relevant sessions.

In early 2018, the World Bank and DWFI organized a conference in Washington D.C focused on how organizations, institutions, agencies and businesses could best support farmer-led irrigation initiatives ("Water for Food International Forum – Farmer-led Irrigated Agriculture: Seeds of Opportunity[8]"). This was followed by a side event on farmer-led irrigation[9] attended by 200 people at the African Green Revolution Forum in September 2018 in Kigali, Rwanda. The World Bank jointly organized this event with AGRA and the African Development Bank. It showcased views from farmer representatives, politicians, the private sector, policymakers, academics, entrepreneurs, and international financing institutions – "galvanizing a coalition of support to legitimize farmer-led irrigation as a major development agenda, particularly for Africa." The "Kigali Declaration on Farmer-led Irrigation for Smallholder Farming Enterprises" calls for "political leadership and a policy environment to make farmer-led irrigation the norm in Africa" (AGRA, 2019). Most recently, in a session at Stockholm Water Week 2019 entitled "Innovation, Entrepreneurship and Inclusion: Africa's Farmer-Led Irrigation Revolution[10]", partners shared experiences and insights on improving access, opportunity and benefit to more farmers, including the resource-poor farmers. Clearly, farmer-led irrigation has arrived as a major focus of efforts to expand sustainable irrigated agriculture in SSA.

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6 Merrey 2017 discusses the persistence of repeated "pilot projects" to "test" low-cost drip irrigation kits even though there is no evidence that they are sustainable and profitable for most African smallholders.

7 https://waterforfood.nebraska.edu/

8 https://blogs.worldbank.org/water/igniting-action-farmer-led-irrigation-water-food-international-forum

9 https://blogs.worldbank.org/water/high-level-officials-urge-rapid-scale-farmer-led-irrigation-africa-green-revolution-forum

10 https://www.worldwaterweek.org/event/8435-innovation-entrepreneurship-and-inclusion-africas-farmer-led-irrigation-revolution

Recent Innovations: Identifying and Mainstreaming Viable Business Models

DWFI's April 2019 Water for Food Global Conference, "Water for a Hungry World: Innovation in Water and Food Security," (DWFI, 2019) furthered progress in farmer-led irrigation knowledge sharing. A session on "Supporting Profitable and Sustainable Farmer-led Irrigation" featured researchers from IWMI and representatives of the World Bank, USAID and the Clinton Foundation. The key message was the importance of working together and taking an integrated, holistic approach to supporting farmer-led irrigated agriculture. The participants highlighted challenges such as a lack of access not only to water, but also to quality inputs; opportunities such as exploitation of shallow groundwater for irrigation; and realizing the potential and limitations of solar power for irrigation. But session leaders agreed that long-term sustainable success will require designing solutions that sustain water resources, reduce upfront costs, and enhance social inclusion. The World Bank representatives described their institution's strategy: knowledge sharing and advocacy to make farmer-led irrigation more acceptable to African policymakers; and including farmer-led irrigation in its own investment pipeline. The World Bank is focused on reducing constraints to upscaling investments by smallholder farmers by making financing more easily available to the producers, and using a holistic

Solar panels power a sprinkler irrigation system in Rwanda.

approach that creates an enabling environment for productive farming, such as reducing transport costs, and providing technical training. USAID is integrating its work on agriculture, irrigation, nutrition, water and sanitation, and increasing resilience. Farmer-led irrigated agriculture is a major element.

Another session at the 2019 Water for Food Global conference showcased several business models for providing irrigation services, mostly in Rwanda. One model involved a mobile battery-powered pump to provide irrigation services that is charged through a bicycle-pedaling unit. The firm combines this with loans for farming inputs to support a profitable harvest and receives a share of the revenue after harvest. Another irrigation service business model involves supporting farmer cooperatives with financing combined with extension services and management support. An IWMI researcher described three solar pump business models to reduce the prohibitive upfront costs for smallholder farmers, to be piloted in Ghana and Ethiopia. All of these examples are at an early proof-of-concept stage and require piloting and testing with private and public sector actors to assess its inclusivity and sustainability.

There is evidence of a growing number of new business models aimed at making small-scale irrigation technologies available to African smallholders (Brozovic et al, in review). Lack of financing for the purchase of pumps or drip irrigation systems is a major impediment to progress: many smallholders want to obtain access to irrigation technologies, but even at a few hundred dollars they are still unaffordable; and there are few credit packages available to reduce this gap. But a recent survey discovered other business models, all still at an early stage, but showing a lot of promise (Merrey and Lefore, 2018a, b). The three most promising models from the survey are:

1. *Partnerships among finance and other institutions*, such as manufacturers, retailers and agricultural advisors. For example, the Water and Microfinance Initiative[11] in Senegal fosters partnerships between a microfinance institution and organizations that specialize in irrigated agriculture. By taking both forms of expertise into account, it designs an economically viable credit product. Note the "integrated" nature of this approach.
2. *"Pay-as-you-go" (or "rent-to-own") models* that spread out payments and enable farmers to begin benefitting immediately. They also minimize risk for lenders, because the irrigation technology serves as collateral. For example, Agriworks Uganda[12] requires farmers to first make a down payment to acquire the technology, then make three additional payments based on the income earned from using it. Internet-based options complement the "pay-as-you-go" model particularly well. By enabling lenders to monitor their technology and farmers to make payments online, internet-based services both reduce the transaction cost of lending and enable the expansion of irrigation technology to more remote areas.
3. *Contractor or utility models*, in which entrepreneurs offer irrigation services rather than selling equipment. For instance, a Nigerian start-up called Hello Tractor[13] uses a web-based platform to connect farmers with owners of small tractors, earning it the nickname "Uber for the farm." This is a possible model for "Uber for irrigation." Such service models deserve more attention as they are especially promising and could offer new employment opportunities as well.

These models show a variety of approaches to providing irrigation solutions, which offer farmers a choice in selecting the model that works best for their own farming situation. More research is needed to validate the effectiveness and impact of these and other emerging irrigation service models.

11 http://www.pamiga.org/pdf/pdfen-para367-pamiga-1417448145.pdf

12 http://agriworksug.yolasite.com/

13 https://www.hellotractor.com/home

Present and Future Challenges

The potential benefits of farmer-led irrigated agriculture are enormous: increased local and national food and nutrition security, higher incomes, and economic growth (Xie et al., 2014). Individual initiatives and investments are the classic bases for a dynamic economy. However, there are also significant potential downsides that, if not addressed, are no less transformational than the positive outcomes.

Potential to deplete and pollute water resources and other natural resources. Globally, in many agricultural breadbaskets, water resources are already being stressed, including groundwater in China, South Asia and parts of the Ogallala aquifer (WLE, 2015[14]; Famiglietti, 2014). Recent research has demonstrated that, in addition to relatively under-developed surface water resources, potentially useable groundwater resources are widespread in sub-Saharan Africa; but in many cases these are relatively shallow aquifers: easy to access, but with limited capacities (Pavelic et al., 2013; Worqlul et al., 2017). In some places, for example the eastern African highlands, there are numerous streams that can be – and are – being tapped by farmers. Without the local capacity and capabilities to manage these resources, there is a high risk that rapid expansion of pump irrigation will seriously deplete water resources, either undermining the viability of the investments in irrigated agriculture, or generating

14 http://www.iwmi.cgiar.org/Publications/wle/corporate/groundwater_and_ecosystem_services_framework.pdf

Farmer cut soya bean crop in a rural village at Salunkwadi, Beed in Maharashtra, India.

conflicts among water users (Altchenko and Villholth, 2015; Xie et al., 2014; see Dessalegn and Merrey 2014 for an example). Programs that encourage wide-scale adoption of solar-based water lifting devices without appropriate institutional governance may exacerbate this trend, with potentially disastrous consequences.

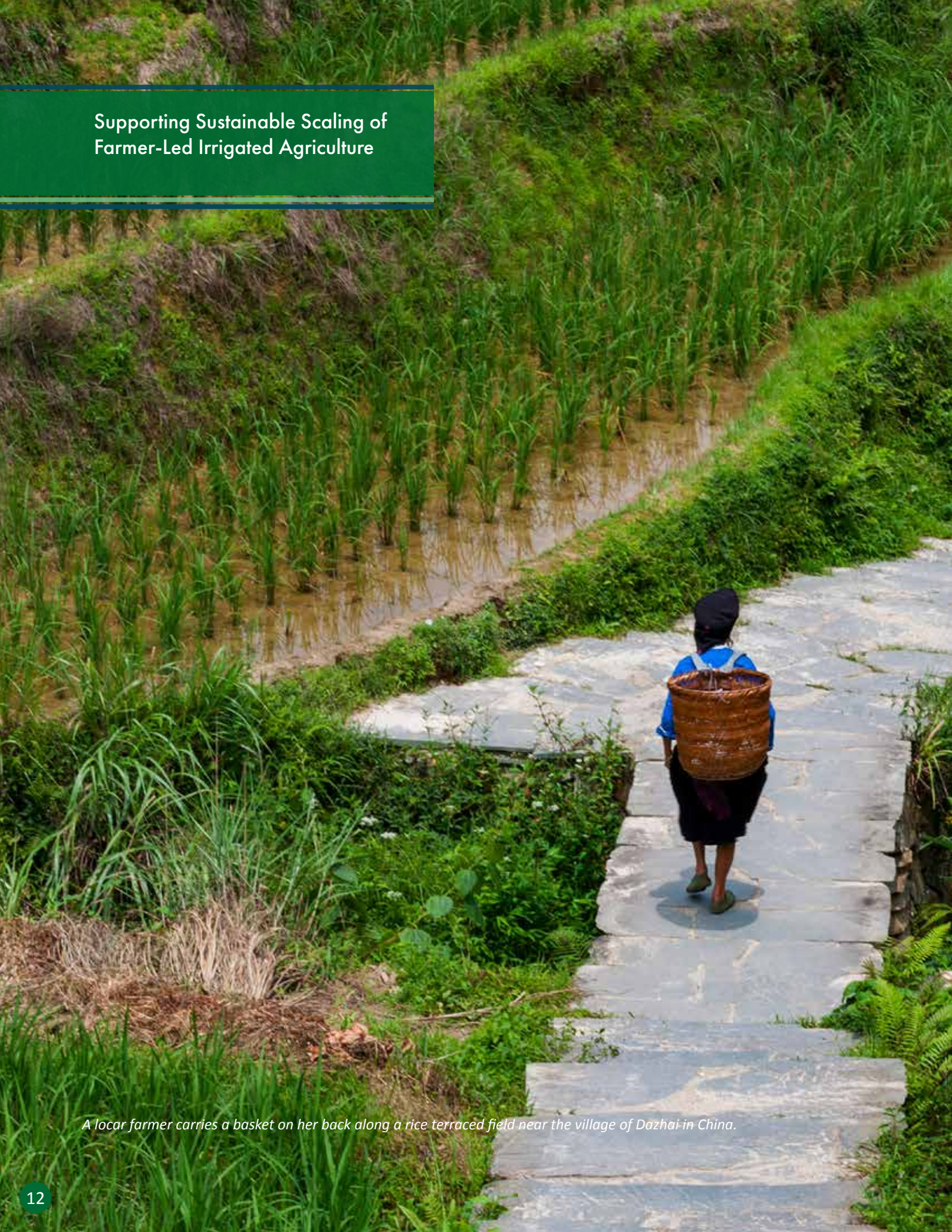
Along the rainfed-to-irrigated-agriculture continuum, rapid expansion of intensive agriculture and horticulture using larger amounts of fertilizer and pesticides increases the risk of contamination to the land and water resources (Lefore et al., 2019). For example, Teklu et al. (2016) found a high level of risk to aquatic ecosystems from pesticide use in an Ethiopian irrigation system. These risks are exacerbated if there is not adequate consideration for soil health and hydrological processes, as well as the potential impact on ecosystems, human health and other factors. Given this, intensification of agriculture, whether rainfed or irrigated, requires a pragmatic yet comprehensive monitoring, management and regulatory framework to mitigate potential negative consequences on ecosystems and human health.

Potential of ill-considered interventions undermining farmer-led irrigation. Invisibility has been a key characteristic, and perhaps advantage, of farmer-led irrigation until recently. Most African countries' government policies did not recognize it (de Bont et al., 2019; Veldwisch et al., 2019). Now that it has become more visible – and governments and investors are officially recognizing and support it – there is a risk that such support is inadequately designed and could undermine the process, including increasing the risks being assumed by small-scale farmers. Examples include subsidies creating perverse incentives and market distortions, elite-capture (thus exacerbating socio-economic inequities), and the temptation to over-regulate the sector. The very diversity of the people, strategies and local contexts covered by the term "farmer-led irrigated agriculture" makes arriving at uniform policies, implementation and investment strategies neither practical nor necessarily wise. By its very nature, it is challenging to directly invest in farmer-led irrigated agriculture. To reach the required scales, governments and other funders should invest in strengthening the enabling environment keeping in mind the local context. This would include the strengthening of supply chains, markets and inclusive finance modalities (e.g. de-risking private sector investments), creation of the necessary support services, development of entrepreneurial capabilities, and improving the institutional capacity to sustain various irrigation services business models.

Potential to decrease socio-economic disparities. The vast majority of farms in African countries are relatively small, cultivated by both men and women, and constrained to varying degrees by access to information, functioning markets and viable financial services. A small proportion of those farmers already have much of the capacity and resources to increase their agricultural productivity, including access to irrigation services and reaching local and even national markets. In some cases, often in collaboration with larger commercial operations, accessing international markets is an option.

An important premise with farmer-led irrigation is that, with suitably designed support to address their constraints, more smallholders can transition from near-subsistence agriculture to a more viable and productive enterprise that provides a better livelihood for the farm family, contributes to food and nutrition security and supports a more prosperous rural economy. That said, it is important to acknowledge that not all small-scale farms can be transformed under such a program. There are important pre-requisites for a viable agricultural enterprise, including the scale of the holding and availability of water and land resources as well as access to inputs and markets. For families with small-holdings that cannot sustain a viable agricultural enterprise, it will be necessary to foster other livelihood opportunities within agricultural value chains or job-markets outside of agriculture.

Supporting Sustainable Scaling of Farmer-Led Irrigated Agriculture



A locar farmer carries a basket on her back along a rice terraced field near the village of Dazhai in China.

Supporting Sustainable Scaling of Farmer-Led Irrigated Agriculture

Expanding access to improved agricultural water management, including irrigation, is an important strategy for increasing resilience and effective adaptation to the impacts of climate change. Supporting flexible, farmer-led irrigation development where it is feasible should be a central component of investment programs aimed at developing more resilient agricultural systems. Irrigated agriculture is especially profitable during the dry season to produce high-value food crops for the market as well as for family nutrition. Aside from its clear benefits in off-season production, it can support rainfed agricultural systems overcome challenges of increasing climate variability through supplementary irrigation.

Policies, institutions and investments for enhanced productivity, equity and sustainability.
Research has shown the critical importance of designing and implementing supportive policies; promoting effective governance and institutional arrangements; and implementing appropriate long-term investment programs to enable the policies and institutions to work.

Rural societies in many parts of the world are changing rapidly, requiring flexible, adaptive and inclusive approaches to agriculture, including irrigation. With ongoing feminization of agriculture, especially in areas where there is male-migration, women take on additional responsibilities to manage the farm. Well-designed programs aimed at improving women's access to land and water and services and technology can contribute significantly to inclusivity if they are based on deep knowledge of the local economic and socio-cultural context (WLE, 2018).

Youth are seeking new opportunities and are not attracted to subsistence farming. As the President of the African Development Bank recently noted, roughly 12 million youth enter the African labor market every year, but only three million actually find jobs. It is important to promote agriculture as a viable and profitable business opportunity and invest in *"agripreneurs"* (Adesina, 2017). The African Development Bank's Enable Youth Program[15] aims to support creation of 300,000 agribusinesses and 15 million jobs for youth over five years. There are now numerous programs providing training for youth to develop agriculture-focused businesses[16], supporting capacity building and, in some cases, making seed capital available. Small enterprises based on productive irrigated agriculture or related services offers an important and attractive opportunity to build quality careers. The examples from the 2019 Water and Food Global Conference discussed earlier are suggestive of the potential for increased productivity, but scaling-up based on lessons from these and other pilot efforts will help avoid missteps. Local startups, offering digital solutions, such as mobile irrigation services and other digital extension services, are frequently led by young entrepreneurs. Innovation and leadership development in digital innovations and solutions will help open doors to continued progress.

Beyond the basic needs of a sustainable water resource and other aspects of an enabling environment, farmers need access to financial services or other means, such as some form of out-grower arrangement, to access irrigation technologies or services; transparent, functioning markets where farmers can sell their produce at reasonable prices; and programs designed to more effectively include women and youth. At the 2019 Global Water for Food Conference, the USAID representative referred to farmer-led irrigation as an opportunity for farmers to "leapfrog" their productivity and thereby transform the poor rural economies of the "hinterlands" – if done sustainably. Obtaining financing for purchasing irrigation equipment is a major challenge in SSA, as most banks and micro-finance institutions do not offer credit for irrigation technologies as they exceed micro-credit limits or would require substantive collaterals, such as land and livestock. Some institutions have been experimenting with a variety of business models to make financing available. Examples include Volta Irrigation's model where they provide loans to farmers for inputs and

15 https://www.afdb.org/fileadmin/uploads/afdb/Documents/Generic-Documents/Enable_Youth_brochure.pdf

16 See this site for examples: https://ccafs.cgiar.org/fr/blog/youth-involvement-agribusiness-examples-africa#.XQ5pdPZFzIU (accessed June 22, 2019).

bicycle-powered irrigation units, charging a share of the harvest profit; IFC and EUCORD irrigation service, which provides farmer cooperatives with financing, combined with extension services and management support; and a Rwandan experiment involving cooperative center-pivot farming, where 1 to 60 farmers share cropland under a single pivot. The government provides the center pivot while the farmers share the operational costs. These are encouraging development that should be encouraged, monitored carefully for lessons, and if successful, assisted to scale out.

Government policies should be aimed at building an enabling environment to scale up promising models. While we applaud the growing number of new small business models being tested, capacity development programs creating "agripreneurs" are required to ensure a high success rate. Governments should design their rules and regulations to encourage innovative blended financing, training and technical support for both new businesses and smallholder farmers, and partnerships among financial institutions, irrigation equipment manufacturers, and wholesalers and retailers.

A challenge for governments, donors and international finance institutions is establishing financing arrangements that support the development of enabling environments, and catalyze and sustain farms and other associated business enterprises beyond the timeline of these investments. It is especially important to draw on past experience and lessons, ensuring the investments are viable, that water rights and land tenure are respected, and that we don't reproduce the negative externalities experienced elsewhere, such as the over-pumping of groundwater in Punjab and other parts of India. We suggest that investments in farmer-led irrigation expansion provide holistic program support: for example, a portion of the available funds could be used to strengthen supply chains and financing modalities that are contextually relevant and socially accepted; and strengthen access to agricultural inputs, value chains and markets. also Investments should include budgetary support for the complementary infrastructure necessary to make irrigated agriculture financially viable, such as roads, communication networks, and storage facilities, as well as local or digital agricultural extension services. As with large-scale irrigation investments, the "social" infrastructure is equally important. For farmer-led irrigation this should include strengthening water user associations and the inclusion of groundwater governance, as well as targeting specific solutions to ensure inclusion of vulnerable communities along the irrigated value chains. We recommend a substantial investment in supporting policy reforms, especially water and land rights, knowledge sharing, capacity strengthening, and action research through innovation scholarships within the public and private sector. Growing locally applied research capacities by providing long-term support will help achieve a dynamic innovative economy based on irrigated agriculture. One way to do this is to provide long-term support to research and development partnerships, fostering collaboration on research and building professional capacity. While some of this support can be from external partners, transboundary learning within the region should be promoted, as the Islamic Development Bank is presently supporting between Mauritania and Senegal (Jama, B. 2019).

Sustaining water and other natural resources over the long term as irrigation expands is also a complex and highly contextual challenge, especially groundwater. Aquifers are an invisible common property resource, all too often developed without characterization or understanding of its interconnectivity with the surface water.

The few well documented positive examples of sustainable aquifer management and reduction of non-

Volta Irrigation's model provides loans to farmers for inputs and bicycle-powered irrigation units and then charges a share of the harvest profit.

point agricultural pollution are primarily in developed countries with strong institutions, for example in the state of Nebraska, USA (Bleed and Babbitt, 2015; Sixt et al., 2019). But even in the USA, over-pumping of aquifers and agricultural pollution of waterways is challenging. In developing countries, with relatively weak institutions and limited financial resources, the challenge is especially daunting. Legislation, regulation and enforcement of standards and limits on water extraction, especially when combined with devolved responsibilities and accountability, work. However, in situations with limited capacity and resources in institutions, and large numbers of smallholder users, top-down efforts to effectively manage water resources are not practical.

The only approach that is likely to succeed in the medium to long term, for groundwater and surface water sustainability, is promoting local-level initiatives and institutional arrangements for managing water quantity and quality. Legislation, investments and relevant government agencies should be designed or strengthened to support such institutional development without imposing detailed and burdensome organizational arrangements. The emphasis needs to be on building local knowledge of aquifers and surface water resources, and people's interdependence on them; and supporting the emergence of practices and institutions that will contribute to sustainable resource management.

Finally, we emphasize the potential long-term benefits of investing in education, building local people's knowledge and advancing local institutions to achieve sustainable, equitable irrigated agriculture. We must avoid "quick fixes," for example large-scale subsidies that may achieve some gains in the short run, but ultimately, will distort and undermine the sustainability of agricultural systems and water resources. With a strong enabling environment, farmer-led irrigation can indeed underpin the transformation of African rural economies – but the challenge is to ensure the outcomes are inclusive, equitable, sustain natural resources, and lead to prosperity and human well-being.

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Front: A group of Rwandan smallholder farmers haul pipe for their portable sprinkler irrigation system.
Back:Villiage children in Rwanda