Lefore, N.; Giordano, M.; Ringler, C. and Barron, J. 2019.
Sustainable and equitable growth in farmer-led
irrigation in sub-Saharan Africa: What will it take?
Water Alternatives 12(1): 156-168

Viewpoint – Sustainable and Equitable Growth in Farmer-led Irrigation in Sub-Saharan Africa: What Will it Take?

Nicole Lefore
Texas A & M University, College Station, TX, USA; nicole.lefore@ag.tamu.edu

Meredith Giordano
International Water Management Institute, Colombo, Sri Lanka; meredith.giordano@yahoo.com

Claudia Ringler
International Food Policy Research Institute, Washington, DC, USA; c.ringler@cgiar.org

Jennie Barron
Swedish University of Agricultural Sciences (SLU), Uppsala, Sweden; jennie.barron@slu.se

ABSTRACT: The rapid development of farmer-led irrigation is increasing agricultural productivity, incomes, employment and nutrition, but it might well not achieve its full potential. Small-scale irrigators tend to be younger, male and better-off. Women and resource-poor farmers – the majority of farmers in sub-Saharan Africa – are disadvantaged and often excluded from the numerous benefits to be gained from irrigation. Equity in access to water management technologies and practices is constrained by numerous factors, including high investment costs, absence of financial services, poor market integration, inadequate information services, and labour constraints. Lack of institutions for collective management of natural resources, such as water, further restricts access for resource-poor farmers, increasing inequity. In the absence of sustainable natural resources management approaches to agricultural intensification, this situation may become more acute as natural resources become increasingly valuable, and therefore contested. Realising the full potential of farmer-led irrigation requires contextualised policies, institutions and practices to improve equity, markets and sustainability and help ensure that sector growth is inclusive and beneficial.

KEYWORDS: Farmer-led irrigation, agricultural water management, equity, sustainability, sub-Saharan Africa

INTRODUCTION

Nearly a decade of research in sub-Saharan Africa and Asia points to the broad, positive effects of farmer-led irrigation on income, poverty alleviation and employment (Giordano and de Fraiture, 2014), to a potential for enhanced nutrition (Domenech, 2015; Passarelli et al., 2018) and greater resilience to seasonal weather variability and climatic shocks (Ward et al., 2016; Zorom et al., 2013).

For the purposes of this paper, we define farmer-led irrigation as being initiated, managed and financed by farmers themselves, mostly by individuals, but sometimes in small groups. The irrigated areas are typically small (e.g. less than 2 ha), the technologies are generally low-cost, and the farmers produce both high-value horticultural crops and staple crops (Beekman et al., 2014; de Fraiture and Giordano, 2014; Otoo et al., 2018).

Studies point to considerable potential for further expansion of farmer-led irrigation in sub-Saharan Africa (e.g. You et al., 2011; Giordano et al., 2012; Xie et al., 2014) with the potential of doubling or even tripling crop yields, generating additional net household revenues for millions of people. However, achieving this potential requires equitable access to affordable technologies, as well as changes in the market, institutional and social situation to ensure that a broad range of farmers can participate successfully and sustainably in the irrigation enterprise.

Most smallholder farmers cannot yet access water management technologies or the complementary inputs and markets required to benefit from irrigated production. The current trend in farmer-led irrigation is largely benefitting young, better-off male farmers (Namara et al., 2014; Colenbrander and van Koppen, 2014). Women and resource-poor farmers, who comprise the majority of farmers in sub-Saharan Africa, are particularly disadvantaged by high up-front investment costs, absence of proper financing products, weak land rights, poor market integration and inadequate information services (Theis et al., 2018). Limited access to information on irrigation, seeds, pest management, markets and equipment hinder smallholder farmers' ability to make informed decisions and maximise investments made into irrigation. Further, underdeveloped technology supply chains and financing mechanisms often prevent private-sector investment from meeting market demand (Merrey and Lefore, 2018; Hagos et al., 2018b). Significant, but rarely accounted for, labour requirements also pose disadvantages, particularly to women. Moreover, the uncontrolled spread of small-scale irrigation can have undesirable social and environmental consequences. If not managed and governed within the context of the wider landscape and other water users' needs, accelerated investments in smallholder irrigation could degrade water and soil quality, as well as create conflicts over shared natural resources (de Fraiture and Giordano, 2014; Theis et al., 2018).

In the absence of measures to address the equity, market and sustainability concerns, the sector is unlikely to reach its full contribution to food and nutrition security, resilience and wealth creation. This paper acknowledges both the promises and perils of farmer-led irrigation, focusing on key barriers that hinder farmer-led irrigation from reaching its potential. Following a discussion of the limits to expanding small-scale irrigation, we discuss institutions, policies and practices that could foster sustainability and equity. We outline the needed policy and institutional, finance and market, and technical interventions that cut across sectors and scales to help ensure that the proven benefits extend to broader groups of smallholders, including women and other disadvantaged farmers; and to address potential adverse effects of the ongoing, unregulated spread of farmer-led irrigation.

RISKS TO INCLUSIVE EXPANSION OF FARMER-LED IRRIGATION

While the potential to invest in smallholder irrigation in sub-Saharan Africa is large (Xie et al., 2014) most farmers are unlikely to immediately adopt irrigation due to a range of social, economic and environmental constraints (e.g. Adimassu et al., 2015; Cordingley et al., 2015; Bjornlund et al., 2017; Snyder et al., 2017; Theis et al., 2018). This suggests the need to better understand which farmers initiate irrigation and how they participate in the agricultural production sector to identify both the challenges and opportunities.

Access to appropriate technologies

Inequitable access to irrigation technologies stands out across the factors that constrain small-scale irrigation expansion. Irrigating household heads tend to be younger than those in non-irrigating households. They have more resources and better access to markets. Women and less advantaged male farmers are underrepresented in the use and ownership of small-scale irrigation equipment. Research in Ghana and Zambia suggests that motorised pump owners are more likely to be men, and in general, have a significantly higher wealth status (Namara et al., 2014; Colenbrander and van Koppen, 2014).

Lack of rural labour is also a major constraint to agricultural intensification (Houssou et al., 2018), including farmer-led irrigation, in many places; a few cases highlight the importance of surplus labour to expanded farmer-led irrigation (Woodhouse et al., 2017; Nkoka et al., 2014). Most studies on small-scale irrigation focus on motorised pumps, yet the most common irrigation practices among smallholder farmers in sub-Saharan Africa are labour-intensive manual devices. For example, in Ghana, 60% of households surveyed reported buckets as the most common technology for irrigation (Namara et al., 2014). Surveys in Tanzania and Ethiopia found that around 40% of irrigating households used buckets to lift water (Passarelli et al., 2018). Manual technologies enable farmers to begin producing in the dry season, but they do not necessarily save labour or time, or allow farmers to expand their irrigated areas. In Ethiopia, both women and men farmers stated a clear preference for labour-saving technologies in order to expand irrigated production and increase income (Nigussie et al., 2017).

Labour constraints affect both poorer men and women, but women tend to be more disadvantaged in relation to unequal access to different types of technologies. Women engage in more traditional, manual and labour-intensive methods, such as buckets and hoses, which are lower-cost and easier to obtain in the market while men tend to dominate more advanced and mechanised technologies, such as motorised pumps, sprinklers and drip kits. A qualitative study in Kenya and Tanzania found that women are less likely to access treadle pumps than men (Njuki et al., 2014). At the same time, women are more time-constrained than men, and financial resources and local norms can make it difficult for women to hire labourers to support irrigation and other on-farm tasks (FAO, 2011). The unequal access to labour-saving technologies threatens to worsen equality more generally, in that manual irrigation practices have high labour requirements and affect competing uses of time, such as child-care.

Undeveloped financial markets, supply chains and information networks

Additionally, while the cost of small-scale irrigation technologies, such as pumps, appear relatively low to potential returns, the overall investment in smallholder irrigation systems, including construction and maintenance of wells and water storage, is substantial (Beekman et al., 2014; de Fraiture and Giordano, 2014); the full set of costs can generally not be recovered in a single season. Farmers rarely use credit to invest in irrigation technologies, much less in small infrastructure, such as hand-dug wells and ponds; surveys carried out in Ghana, Ethiopia and Zambia, for example, found that more than 80% of owners of small-scale irrigation equipment used their own, or their household's savings, for the investment (Giordano et al., 2012). This finding reflects the conclusions of other studies, which show that wealthier, and often young or 'middle-aged' male farmers, are the primary investors in farmer-led irrigation (Namara et al., 2011); they are able to use their own resources or access both formal and informal credit.

The absence of appropriate financial products limits access to technologies, restricting investments for the majority of farmers who have fewer resources (Grimm and Richter, 2006, 2008). Rural finance institutions tend to be concentrated in regional or district capitals, failing to reach more rural and remote areas. Importantly, these institutions often do not offer appropriate finance products for irrigation technologies nor do they have capacity to assess risk and manage loans needed for those irrigation technologies (Merrey and Lefore, 2018). In some countries, such as Ghana, interest rates make loans unaffordable and would render irrigation investments unprofitable, while institutional barriers particularly restrict women from obtaining loans. In other countries, rural finance from a microfinance institution or cooperative is more accessible, but few farmers borrow for irrigation technologies. For example, in Ethiopia, up to 20% of rural households can access loans, but loan products tend to be for small amounts that can be repaid in one season with low risk to both lender and borrower and are fitting for small-scale trade or rain-fed production inputs but not suitable to purchase irrigation technologies that require larger loans and longer repayment periods. However, farmers who

have experience in and information about irrigation are more likely to borrow (Hagos et al., 2018a). Group lending was once considered a solution to high transaction costs and risk of lending to small farmers, but poor and women farmers are often excluded from such groups, because of perceived risks of non-payment (Hagos et al., 2018a). Consequently, group lending may actually deepen inequalities.

Underdeveloped supply chains for irrigation technologies and complementary inputs often reduce their availability and increase their cost for farmers. Private-sector irrigation equipment suppliers have a limited presence in most developing country markets; many do not target smallholder farmers due to perceptions around purchasing power and high transaction costs of supplying and servicing outside of large cities (Hagos et al., 2018b). In addition, manufacturers or importers face their own constraints relative to their profit objectives, and therefore fail to develop linkages with regional distributors and retailers, portending poor market reach outside main cities, as well as higher prices. Farmers are disadvantaged relative to suppliers, particularly by their lack of up-to-date market knowledge, which undermines their negotiating position and enables traders and brokers to take advantage of them (Giordano and de Fraiture, 2014; Bjornlund et al., 2017).

Women farmers, who are included in the projected millions of farmers who could engage in small-scale irrigation, are particularly disadvantaged in decision-making and related access to information, technologies and finance. Notably, at the household level, women are limited in the extent to which they can access and benefit from advanced irrigation technologies and practices following adoption by a household. Men often exclude women in the household from information and extension services, appropriate more expensive agricultural assets in the household, direct the use of technologies to men's plots, and are more likely to control and benefit from the sale of irrigated produce generated from advanced irrigation technologies (Theis et al., 2018). Women also tend to have limited decision-making power over when and how small-scale technologies are used, across seasons and water sources (Nigussie et al., 2017). A study on microfinance in Ghana also suggests the economic limitations of credit for women at the household level; women may be forced to give male household members the microfinance loans they receive (Ganle et al., 2014). In many cases, women also confront cumbersome customary requirements that reduce their access to family land on which to farm (Theis et al., 2018). These intra-household power dynamics further reduce the ability of, and incentives for, women to invest in irrigated production.

Long-term sustainability

If not managed and governed within the context of the wider landscape and other water users' needs, accelerated investments in smallholder irrigation could pose significant risks to environmental and human health. While a significant opportunity remains in some areas to expand groundwater irrigation, the potential for sustainable development has been exhausted in parts of southern and much of northern Africa (Altchenko and Vilholth, 2015; World Bank, 2018). Moreover, several studies point to the limitations of shallow groundwater in northern Ghana and in areas of Ethiopia, which calls for careful on-farm water management with the conjunctive use of groundwater and surface water sources to enable irrigation throughout the dry season (Worqlul et al., 2018; Bizimana et al., 2015). The emerging spread of affordable solar-pump technologies in Africa may enable irrigation access to the more than two-thirds of Africa's rural areas that are not yet linked to the electric grid, but could also lead to much more rapid drawdown of groundwater resources.

The proliferation of small-scale irrigation, like any irrigation development, can also result in the contamination of soil and water resources with agrochemicals and organic waste, posing health hazards to the human, animal and aquatic biota (Huang et al., 2006). Current projections suggest that Africa will experience the fastest increase in agricultural water pollution out to 2050, albeit from low levels (Xie

and Ringler, 2017) with agricultural intensification as a key contributor to this trend. Inappropriate use of chemicals for fertiliser and pest management is not uncommon, despite limited access to such inputs for many farmers. Some pesticides in use by small-scale farmers pose a high risk to aquatic organisms, including persistent organic pollutants that remain toxic in the food chain long after use (Pretty, 2018; Teklu et al., 2016). Establishment and enforcement of standards for agrochemical use and human and environmental safety guidelines are required (McCartney, 2007). However, many countries in sub-Saharan Africa lack national guidelines on allowable levels of agrochemicals in water sources, the technical facilities and experts required for testing and the institutional mechanisms to regulate, monitor and enforce standards.

Finally, the lack of rural institutions to manage natural resources collectively, including groundwater and surface water, will further restrict access by the resource-poor and will likely contribute to serious environmental degradation in some places. While farmers in some areas do manage irrigation water sources in collective systems, such as in Tanzania and Malawi, few such instances are documented and potential for expansion is likely limited (de Bont et al., 2018). In general, farmer-led irrigation tends to be managed by the household, often with little or no consultation within communities or with local water institutions (Nkoka et al., 2014). Moreover, most countries in sub-Saharan Africa lack effective institutions for water governance from local to watershed levels. Many of the existing institutions fail to integrate governance of groundwater sources, which excludes the numerous smallholder irrigators who rely exclusively on shallow groundwater. In addition, community involvement in managing water scarcity during drought or when groundwater tables decline has yet to be developed in many places (Skyllerstedt et al., 2018; Stein et al., 2011). At higher levels of governance, absent or ineffective institutions and regulatory mechanisms deepen the threats posed by a rapid increase in irrigated production. This trend may continue in the medium- to long-term as natural resources become increasingly valuable, and therefore contested.

POTENTIAL ENTRY POINTS TO MINIMISE INEQUITIES AND SUPPORT SUSTAINABLE EXPANSION

The prevailing inequity between richer, more socially and politically connected men and poorly resourced women and men farmers may be further deepened with the expansion of irrigation, as irrigating farmers become even more advantaged and their control over natural resources more entrenched. If not addressed, the current conditions will limit direct benefits to fewer farmers, and thereby prevent this form of irrigation from reaching the numbers of people who could benefit both directly and indirectly from more equitable irrigation development. This points to the need for interventions and support to ensure equitable access to irrigation technologies and practices, and ideally the complementary inputs needed for sustainably intensifying production. We outline below promising, non-exclusive entry points to minimise inequities and support sustainable expansion of farmer-led irrigation.

Access to financing

One important entry point is the provision of affordable and appropriate credit, which would allow irrigation development to remain farmer-led with minimal direct government intervention. Public and private rural finance providers, including rural banks, microfinance institutions, or cooperatives, currently fail to offer financial products targeted at small-scale irrigation investment on terms suitable to dry-season production. However, innovative options are emerging (Merrey and Lefore, 2018), including e-money combined with cellular or internet networks to reduce transaction costs. Such technologies, where available, could also open up opportunities for farmers to connect directly with pump rental and other service providers.

Lenders can also reduce their risks and costs while expanding their reach, such as through credit to organised commodity chains that are supporting farmer-led irrigation, such as coffee (e.g. Ethiopia) and cocoa (e.g. Ghana). Participation in such value chains reduces risk to lenders because the producers have guaranteed buyers, the organised commodity market systems enable more transparent and predictable pricing, and farmers are already organised into identifiable and formal groups and associations. In addition, lenders can reduce risk for their institutions and for producers through credit packages that combine loans with index-based insurance for crops and livestock (Jensen and Barrett, 2017).

Governments have a role to play in formulating broad programmatic and regulatory approaches. This includes setting limits for agricultural lending rates and other regulatory approaches as well as reducing risks to lenders (Otoo et al., 2018). Public-sector institutions, as well as development organizations, can support increased lending to irrigators through provision of training on loan assessment and monitoring to reduce transaction costs and risk. Such interventions do not require direct subsidies, but rather policies and financial mechanisms that increase available capital and reduce risk.

Finally, rental markets for pumps and other forms of irrigation service providers, such as for water delivery and mobile fuel and pump repair, offer promising opportunities for farmers unable to directly purchase irrigation technologies or access accessory services. Increasingly, smallholders who cannot afford to purchase their own pumps can rent one by the day or season. Various 'models' or modalities for the service provider approach have been documented and recommendations developed based on case studies in India and Burkina Faso (de Fraiture and Clayton, 2012). The rental and service provision market could also be supported through adapted microfinance products to farmers; as an example, smaller lenders could offer credit for short-term or seasonal equipment rental rather than extending large loans for purchasing irrigation pumps.

Improved supply chains

Private sector investors in both commodity value chains and the irrigation technology supply chain directly benefit from broader irrigation development. Commodity buyers can secure a more reliable supply of higher quality produce for retail sale or processing from irrigated production compared to rain-fed systems. At the same time, technology supply companies and associated service providers, such as installers and post-sales support, can expand their markets in new areas. Produce purchasers may provide contracted farmers with access to irrigation technologies as part of their contracts, and deduct payments for technologies at source; this could include subsidies on the technology if the reduced risk for crop failure and improved crop quality and volume add sufficient value for produce buyers (Otoo et al., 2018). An example is a project[1] implemented by the Global Partnership on Output-Based Aid (GPOBA) financed by the World Bank's International Finance Corporation (IFC), which is providing irrigation technologies, training and credit to a large cotton cooperative comprising small-scale farmers in the *Société Burkinabé des Fibres Textiles* (SOFITEX) in Burkina Faso. Produce buyers, microfinance institutions and irrigation technology suppliers may also partner to assess and share risk, while introducing irrigation to farmers, such as in the *Kenya Smallholder Solar Irrigation Project* (KSSI).

Newer technologies could expand the reach to more farmers in remote areas foregoing the need to access electricity or a steady supply of costly diesel fuel. Technology developers particularly for solar-based pumps, are innovating portable and robust designs to address distance to farms, plot size and well depth, among others. However, as noted above, technology supply chains for irrigation are nascent, including underdeveloped support services related to maintenance and repair. Private

[1] www.gpoba.org/news/irrigation-systems-introduced-small-scale-cotton-farmers-burkina-faso

companies are currently not investing broadly in market expansion in sub-Saharan Africa; public support is still needed to incentivise private investment in remote markets. One promising example is the solar-powered pump, which offers a greener, more versatile alternative for smallholder farmers than diesel or electric pumps (Woodhouse et al., 2017; Otoo et al., 2018). Some solar pumps include in-built mechanisms to control pumps remotely, which allows suppliers to enable or disable the pumps based on receipt of payments, including through e-money platforms. Technology suppliers find the option appealing because it can reduce their own risks. Rent-to-own packages using new technology options have been piloted with some success in various modalities by FuturePump, SunCulture and Kickstart in Kenya.

Removal or reduction in tariffs on imported irrigation technologies can increase the market for such technologies (Gebregziabher, 2012). However, while some countries in sub-Saharan Africa have provisions to promote agricultural technology adoption, few have effectively implemented such policies; implementation through customs, revenue and standards boards is often lacking. Ethiopia is an example where the government has approved import tariff removal and tax exemptions for agricultural machinery and is examining how to fully implement the policy in practice so that resource-poor farmers experience improved access and can purchase water technologies at lower cost in more areas. The modalities to implement the policy require further assessment to see if benefits from reducing tariffs and taxes are distributed, i.e. appropriate technologies should become available in small towns and markets at reduced prices within reach of disadvantaged farmers. Parallel public investments will likely be required to support market expansion and sustainability, for example, strengthening regulatory institutions, agencies to protect consumers and training of irrigation service providers for installation and repair, among others.

Focus on the needs and preferences of women farmers

Investments that target women need to consider post-adoption household decision-making dynamics about irrigation technologies; projects cannot assume that women immediately benefit because they are recipients of technologies and loans. Women and men within households both need access to information on technologies and associated inputs and marketing options, and there is a need to sensitise men regarding the value of women accessing, using and benefitting from such technologies. In addition, crop preferences of women should be considered, such as for continuously harvested crops that provide regular, small amounts of money over which women retain control (Theis et al., 2018). This also applies to interventions which seek to support crops that women grow traditionally, both in terms of ensuring men do not take over the crops and developing seed markets for such crops (e.g. traditional or local leafy greens).

Technology suppliers need to consider the trade-offs between technologies, and the benefits that may, or may not, accrue to women. While male farmers seem to favour technologies based on their potential to generate income, women prefer technologies that are multivalent: installed at or near the home there are technologies suitable for crops they prefer, that can be used for domestic and productive purposes and reduce labour (Nigussie et al., 2017; Theis et al., 2018). As noted above, women also require improved access to information, which can be achieved through various measures, such as engaging more women extension agents, implementing peer programs for provision of agricultural information, radio programming at times that women can listen to, among others. Group approaches have offered pathways to empowerment in other sectors, such as collective dairy-value chains. However, as noted above, groups do not necessarily increase equitable access to credit or overcome intra-household constraints on the use of credit. This suggests that group approaches would need to be piloted in the small-scale irrigation sector to identify ways to enable social equity within groups, as well as supporting broad intra-household access to technologies.

Measures to improve environmental sustainability

A range of measures are available to address risks to sustainability. For example, deficit, or supplementary irrigation, and conjunctive use of surface water and groundwater can reduce both depletion of water tables and negative effects on a range of associated ecosystem services and other environmental risks, such as soil erosion, water-logging and salinisation (Lebdi, 2016). Options also exist to address pest and disease challenges of new irrigators. As an example, irrigation scheduling can reduce over- and under-application of water resources and also reduce the risk of pest infestation. And sprinkler irrigation can dislodge cutworms from foliage, acting as an effective pest protection (Perfect, 1986).

The government has a particular responsibility for preventing and mitigating negative environmental consequences from the rapid expansion of irrigation, including supportive land and water rights legislation and regulations related to water pollution and other disease risk. At present, many countries in sub-Saharan Africa transitioning to agricultural intensification lack regulations, guidelines and often also access to productive and safe agricultural chemicals. Agrochemicals are increasingly used in intensified cropping systems, such as smallholder irrigation. Policy support and capacity development are needed to create health, safety and quality standards as well as accountable, transparent governance mechanisms to develop, implement and enforce regulations. While many examples exist of good but unimplemented policies, evidence also suggests some governments are going beyond empty policy statements to develop guidelines and monitoring mechanisms. Ethiopia provides one example where public institutions are evolving to address such challenges (Tamru et al., 2017). Among others, evidence on agricultural chemicals and other water pollutant levels is helping to inform basin authorities in the country on sources of pollution, risks to ecosystem and public health and needed interventions, such as promoting registered pesticides that have been tested to ensure compliance with standards and to minimise risk for the environment and human health, while introducing monitoring systems (Teklu et al., 2016).

Strengthening of institutions and governance

Interventions suggested above can improve equity in technology access, including through finance, and mitigate negative environmental externalities, but the institutional context must simultaneously be strengthened. Indeed, investments supporting farmer-led irrigation will not be effective without concomitant investments in formal institutions and community governance. Farmer-led irrigation is fundamentally different from conventional, communal irrigation development, and the existing public institutions or agencies, as well as local governing bodies are often not adapted to handle the associated challenges (de Fraiture and Giordano, 2014).

Providing public institutions, local authorities and communities with tools to monitor resources, such as water accounting and aquifer auditing, could result in more responsible stewardship. While not commonly associated with small-scale irrigation, making the tools accessible and affordable could improve sustainable management of water resources (Lebdi, 2016). For example, community-based management, using participatory monitoring and tools, such as games, offer potential governance mechanisms that can integrate public institutions and local communities across sectors for improved management of water and natural resources. Participatory games have been effective in improving natural resources governance in several African countries at river basin and watershed level (Rajabu, 2007; Lankford and Watson, 2007). In other contexts, these approaches have served as a conduit to increase information, encourage dialogue, and build community-based water management institutions (Meinzen-Dick et al., 2014, 2016, 2017).

Citizen science approaches have also proven effective in some contexts for creating linkages between formal monitoring and regulating institutions and local communities and users of both surface

water and groundwater resources, including cases in sub-Saharan Africa (Buytaert et al., 2014). However, these approaches assume that the formal institutions that rely on data supplied by communities provide the volunteers with training, measurement tools, and in some cases transportation, to effectively monitor resources and participate in collective governance institutions. In addition, a recent in-depth study in Ethiopia highlights the limits to citizen science approaches in contexts with underlying inequalities between men and women (Nigussie et al., 2018), suggesting the need for additional activities to facilitate inclusivity and women's empowerment.

Engagement of actors and institutions participating and invested in small-scale irrigation across sectors and scales will be critical to improve agency and accountability and reduce the cumulative impact of farmer-led irrigation on water resources (Woodhouse et al., 2017). Agricultural innovation platforms (AIPs), for example, provide an opportunity to involve the diversity of actors in irrigation schemes for learning, capacity development and experimentation (e.g. with crops, marketing, watering regimes); and can facilitate more cohesive networks, where the dynamics and feedbacks across actors, systems and processes lead to learning and adaptation, improved system efficiency and greater returns on investments (Pittock et al., 2017; Stirzaker et al., 2017; van Rooyen et al., 2017).

However, the effectiveness of institutional and other approaches depends in large part on the broader social and cultural landscape in which they operate. For example, projects aimed at supporting women's membership in collective management organisations, such as irrigation schemes, may not achieve the intended benefits if intra-household dynamics, cultural norms, and/or the role of "informal" networks are not taken into account (Yami, 2013; Woodhouse et al., 2017; Theis et al., 2018). Consequently, any intervention to support long-term, sustainable, equitable growth of farmer-led irrigation must be assessed within "the dynamics of actually existing irrigation in specific contexts" (Woodhouse et al., 2017: 225).

CONCLUDING REFLECTIONS

Farmer-led irrigation can provide large benefits for income, employment, nutrition, and food security with substantial potential for sustainably expanding irrigated production. Farmers are investing in their own irrigation systems, often as a preferred if not the only alternative to publicly supported schemes. The projected expansion in small-scale irrigation to millions of farmers could provide other cumulative gains in terms of economic growth and health outcomes. However, the current trend of farmer investment may not continue at this pace given the constraints to access small-scale irrigation by resource poor farmers. Inequalities in social structures, which are embedded in institutions and markets, are reflected in inequitable access to irrigation technologies and complementary inputs. The lack of institutions and regulations to manage pollution and scarcity of water resources from irrigation poses further risks to equity. Thus, as we argue here, inequality in access to irrigation technologies and practices may reduce the likelihood of realising the full potential of direct and indirect benefits of irrigation.

Irrigation development by small-scale farmers is complex with highly contextual challenges not easily addressed through a 'staple' project design, as is often applied in large-scale communal schemes. However, the public sector and donors can facilitate positive outcomes and minimise or mitigate negative consequences, but there is a risk of over-regulating and hindering farmer investments through attempts to control the development toward narrow and short-term outcomes. Promising entry points and interventions exist to enable more inclusive, sustainable farmer-led irrigation, though the specific pathways require further study and documentation. Pilots with rigorous impact assessments would help to understand the effectiveness of approaches in different contexts.

We also recognise that the interventions noted here do not address the underlying socio-political and economic factors, or the related institutional weaknesses that contribute to the existing inequities. Reaching the full potential benefits of, and equality from, farmer-led irrigation requires deeper

structural changes, that address linkages between domestic and global markets, accountability of political institutions, consultative decision-making opportunities, and reform of customary governance systems. These changes cannot be easily achieved through short-term projects or externally driven processes. Farmer-led irrigation can be a means for small-scale farmers to more productively and profitably engage in agricultural economies, but ensuring that the sector is inclusive and sustainable will require a long-term, delicate balance to sustain the sector's vibrancy and local innovation while mitigating the potential risks of unregulated growth.

ACKNOWLEDGEMENTS

The authors would like to thank Beverly McIntyre for review and comments, and Doug Merrey for examples of solutions in microfinance for farmer-led irrigation. The constructive comments and suggestions received from reviewers on earlier drafts are also gratefully acknowledged.

This paper was developed under the Feed the Future Innovation Laboratory for Small-Scale Irrigation funded by USAID. It forms part of the CGIAR Research Program on Water, Land and Ecosystems (WLE). The opinions expressed in the paper are those of the authors and do not represent the views of the Government of the United States.

REFERENCES

Adimassu, Z.; Langan, S. and Johnston, R. 2015. Understanding determinants of farmers' investments in sustainable land management practices in Ethiopia: Review and synthesis. *Environment, Development and Sustainability* 18(4): 1005-1023.

Altchenko, Y. and Villholth, K.G. 2015. Mapping irrigation potential from renewable groundwater in Africa – A quantitative hydrological approach. *Hydrology and Earth System Sciences* 19(2): 1055-1067.

Beekman, W.; Veldwisch, G.J. and Bolding, A. 2014. Identifying the potential for irrigation development in Mozambique: Capitalizing on the drivers behind farmer-led irrigation expansion. *Physics and Chemistry of the Earth*, Parts A/B/C, 76: 54-63.

Bizimana, J.; Clarke, N.P.; Dile, Y.T.; Gerik, T.J.; Jeong, J.; Leyton, J.M.O.; Richardson, J.W.; Srinivasan, R. and Worqlul, A.W. 2015. Ex ante analysis of small-scale irrigation interventions in Robit, Ethiopia. Technical report of the Innovation Laboratory on Small-scale Irrigation.

Bjornlund, H. and Pittock, J. 2017. Exploring the productivity and profitability of small-scale communal irrigation systems in sub-Saharan Africa. *International Journal of Water Resources* Development 33(5): 685-689.

Buytaert, W.; Zulkafli, Z.; Grainger, S.; Acosta, L.; Alemie, T.C.; Bastiaensen, J.; De Bièvre, B.; Bhusal, J.; Clark, J.; Dewulf, A.; Foggin, M.; Hannah, D.M.; Hergarten, C.; Isaeva, A.; Karpouzoglou, T.; Pandeya, B.; Paudel, D.; Sharma, K.; Steenhuis, T.; Tilahun, S.; Van Hecken, G. and Zhumanova, M. 2014. Citizen science in hydrology and water resources: Opportunities for knowledge generation, ecosystem service management, and sustainable development. *Frontiers in Earth Science* 2(26): 1-21.

Colenbrander, W. and van Koppen, B. 2013. Improving the supply chain of motor pumps to accelerate mechanized small-scale private irrigation in Zambia. *Water International* 38 (4): 493-503.

Cordingley, J.E.; Snyder, K.A.; Rosendahl, J.; Kizito, F. and Bossio, D. 2015. Thinking outside the plot: Addressing low adoption of sustainable land management in sub-Saharan Africa. *Current Opinion in Environmental Sustainability* 15: 35-40.

de Bont, C.; Komakech, H.C. and Veldwisch, G.J. 2018. Neither modern nor traditional: Farmer-led irrigation development in Kilimanjaro Region, Tanzania. *World Development* 116: 15-27.

de Fraiture, C. and Clayton, T. 2012. Irrigation service providers: Business plan. Colombo, Sri Lanka: International Water Management Institute (IWMI).

de Fraiture, C. and Giordano, M. 2014. Small private irrigation: A thriving but overlooked sector. *Agricultural Water Management* 131: 167-74.

Domenech, L. 2015. Improving irrigation access to combat food insecurity and undernutrition: A review. *Global Food Security* 6: 24-33.

FAO (Food and Agriculture Organisation of the United Nations). 2011. *State of food and agriculture 2010-2011: Women in agriculture: Closing the gender gap for development*. Rome, Italy: Food and Agriculture Organization of the United Nations. Available at: www.fao.org/docrep/013/i2050e/i2050e.pdf

Ganle, J.K.; Afriyie, K. and Segbefia, A.Y. 2015. Microcredit: Empowerment and disempowerment of rural women in Ghana. *World Development* 66: 335-345. http://dx.doi.org/10.1016/j.worlddev.2014.08.027

Gebregziabher, G. 2012. Water *lifting irrigation technology adoption in Ethiopia: Challenges and opportunities. AgWater Case Study*. Colombo, Sri Lanka: International Water Management Institute.

Giordano, M.; de Fraiture, C.; Weight, E. and van der Bliek, J. 2012. *Water for wealth and food security: Supporting farmer-driven investments in agricultural water management*. Colombo, Sri Lanka: International Water Management Institute.

Giordano, M. and de Fraiture, C. 2014. Small private irrigation: Enhancing benefits and managing trade-offs. *Agricultural Water Management* 131: 175-182.

Grimm, J. and Richter, M. 2006. *Financing small-scale irrigation in Sub-Saharan Africa. Financing Series. Part 1.* Eschborn, Germany: Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH.

Grimm, J. and Richter, M. 2008. *Financial services for developing small-scale irrigation in Sub-Saharan Africa.* Agriculture and Rural Development Notes 45568. Issue 41. Washington, DC: World Bank.

Hagos, F.; Gebrezigeaber, G.; Lefore, N. and Haileslassie, A. 2018a. *Credit access and adoption of small-scale irrigation technologies: Case of ILSSI sites in Ethiopia.* Technical Report to the Feed the Future Innovation Lab on Small-scale Irrigation. Colombo, Sri Lanka: International Water Management Institute.

Hagos, F.; Lefore, N.; Gelgu, B. and Haileslassie, A. 2018b. *Rapid assessment of supply chain of agricultural water management technologies in Ethiopia.* Technical Report to the Feed the Future Innovation Lab on Small-scale Irrigation. Colombo, Sri Lanka: International Water Management Institute.

Houssou, N.; Johnson, M.; Kolavalli, S. and Asante-Addo, C. 2018. Changes in Ghanaian farming systems: Stagnation or a quiet transformation? *Agriculture and Human Values* 35: 41-66.

Huang, B.; Shi, X.; Yu, D.; Öborn, I.; Blombäck, K.; Pagella, T.F.; Wang, H.; Sun, W. and Sinclair, F.L. 2006. Environmental assessment of small-scale vegetable farming systems in peri-urban areas of the Yangtze River Delta Region, China. *Agriculture, Ecosystems & Environment* 112(4): 391-402.

Jensen, N. and Barrett, C. 2017. Agricultural index insurance for development. *Applied Economic Perspectives and Policy* 39(2): 199-219.

Lankford, B. and Watson, D. 2007. Metaphor in natural resource gaming: Insights from the River Basin Game. *Simulation and Gaming* 38(3): 421-442.

Lebdi, F. 2016. Irrigation for agricultural transformation. Background paper for *African Transformation Report 2016: Transforming Africa's Agriculture*. African Center for Economic Transformation and Japan International Cooperation Agency Research Institute.

McCartney, M.P. 2007. *Decision support systems for large dam planning and operation in Africa.* Working Paper No. 119. Colombo, Sri Lanka: International Water Management Institute.

Meinzen-Dick, R.; Chaturvedi, R.; Domenech, L.; Ghate, R.; Janssen, M.A.; Rollins, N. and Sandeep, K. 2014. *Games for groundwater governance: Field experiments in Andhra Pradesh, India*. Arizona: Center for the Study of Institutional Diversity (CSD), School of Human Evolution and Social Change, Arizona State University (CSID Working Paper CSID-2014-006).

Meinzen-Dick, R.; Chaturvedi, R.; Domènech, L.; Ghate, R.; Janssen, M.A.; Rollins, N.D. and Sandeep, K. 2016. Games for groundwater governance: Field experiments in Andhra Pradesh, India. *Ecology and Society* 21(3): 38.

Meinzen-Dick, R.; Janssen, M.; Kandikuppa, S.; Chaturved, R.; Rao, R.K. and Theis, S. 2017. *Playing games to save water: Collective action games for groundwater management in India*. Tempe, Arizona: Center for Behavior, Institutions and the Environment (CBIE) (CBIE Working Paper #2017-001).

Merrey, D. and Lefore, N. 2018. *Improving the availability and effectiveness of rural and "micro" finance for small scale irrigation in sub-Saharan Africa: A review of lessons learned*. IWMI Working Paper No. 185. Colombo, Sri Lanka: International Water Management Institute.

Namara, R.E.; Hope, L.; Sarpong, E.O. and Owusu, D. 2011. *Analysis of the adoption determinants and dynamics of water lifting technologies for agriculture in Ghana: Implications for investment and public policy*. AgWater Solutions Project Case Study Report. Accra, Ghana: International Water Management Institute (IWMI).

Namara, R.E.; Hope, L.; Sarpong, E.O.; De Fraiture, C. and Owusu, D. 2014. Adoption patterns and constraints pertaining to small-scale water lifting technologies in Ghana. *Agricultural Water Management* 131: 194-203.

Nigussie, L.; Lefore, N; Schmitter, P. and Nicol, A. 2017. *Gender and water technologies: Water lifting for irrigation and multiple purposes.* Ethiopia: Africa RISING.

Nigussie, L.; Barron, J.; Haile, A.T.; Lefore, N. and Gowing, J. 2018. *Gender dimensions of community-based groundwater governance in Ethiopia: Using citizen science as an entry point*. IWMI Working Paper No. 184. Colombo, Sri Lanka: International Water Management Institute (IWMI).

Njuki, J.E.; Waithanji, E.; Sakwa, B.; Kariuki, J.; Mukewa, E. and Ngige, J. 2014. A qualitative assessment of gender and irrigation technology in Kenya and Tanzania. *Gender, Technology, and Development* 18(3): 303-340.

Nkoka, F.; Veldwisch, G.J. and Bolding, J.A. 2014. Organisational modalities of farmer-led irrigation development in Tsangano District, Mozambique. *Water Alternatives* 7(2): 414-433.

Otoo, M.; Lefore, N.; Schmitter, P.; Barron, J. and Gebregziabher, G. 2018. *Business model scenarios and suitability: smallholder solar pump-based irrigation in Ethiopia.* Agricultural water management – Making a business case for smallholders. IWMI Research Report 172. Colombo, Sri Lanka: International Water Management Institute (IWMI).

Passarelli, S.; Mekonnen, D.; Bryan, E. and Ringler, C. 2018. Evaluating the pathways from small-scale irrigation to dietary diversity: Evidence from Ethiopia and Tanzania. *Food Security*. Article in press. First published online on July 17, 2018. https: //doi.org/10.1007/s12571-018-0812-5

Perfect, T.J. 1986. Irrigation as a factor influencing the management of pests. *Phil. Trans. R. Soc. London A*. 316 (1537): 347-354.

Pittock, J.; Bjornlund, H.; Stirzaker, R. and van Rooyen, A. 2017. Communal irrigation systems in South-Eastern Africa: Findings on productivity and profitability*. International Journal of Water Resources Development* 33(5): 839-847.

Pretty, J. 2018. Intensification for redesigned and sustainable agricultural systems *Science* 362 (6417).

Rajabu, K.R.M. 2007. Use and impacts of the river basin game in implementing integrated water resources management in Mkoji sub-catchment in Tanzania. *Agriculture Water Management* 94(1-3): 63-72.

Skyllerstedt, S.; Barron, J.; Giordano, M. and Adimassu, Z. 2018. Building resilience to climate change: Piloting participatory pathways in rural landscapes. Unpublished manuscript.

Snyder, K.A.; Miththapala, S.; Sommer, R. and Braslow, J. 2017. The yield gap: Closing the gap by widening the approach. *Experimental Agriculture* 53(3): 445-459.

Stein, C.; Ernstson, H. and Barron, J. 2011. A social network approach to analyzing water governance: The case of the Mkindo catchment, Tanzania. *Physics and Chemistry of the Earth* 36 (14-15): 1085-1092.

Stirzaker, R.; Mbakwe, I. and Mziray, N.R. 2017. A soil water and solute learning system for small-scale irrigators in Africa. *International Journal of Water Resources Development* 33(5): 788-803.

Tamru, S.; Minten, B.; Alemu, D. and Bachewe, F. 2017. The rapid expansion of herbicide use in smallholder agriculture in Ethiopia: Patterns, drivers and implications. *The European Journal of Development Research* 29(3): 628-647.

Teklu, B.M.; Adriaanse, P.I. and van der Brink, P.J. 2016. Monitoring risk assessment of pesticides in irrigation systems in Debra Zeit, Ethiopia. *Chemosphere* 161: 280-291.

Theis, S.; Lefore, N.; Meinzen-Dick, R. and Bryan, E. 2018. What happens after technology adoption? Gendered aspects of small-scale irrigation technologies in Ethiopia, Ghana and Tanzania. *Agriculture and Human Values* 2018: 1-14.

van Rooyen, A.; Ramshaw, P.; Moyo, M.; Stirzaker, R. and Bjornlund, H. 2017. Theory and application of agricultural innovation platforms for improved irrigation scheme management in Southern Africa. *International Journal of Water Resources Development* 33(5): 804-823.

Ward, C.; with Torquebiau, R. and H. Xie. 2016. *Improved agricultural water management for Africa's drylands*. World Bank Studies. Conference Edition. Washington, DC: The World Bank.

Woodhouse, P.; Veldwisch, G.J.; Venot, J.P.; Brockington, D.; Komakech, H. and Manjichi, Â. 2017. African farmer-led irrigation development: Re-framing agricultural policy and investment? *The Journal of Peasant Studies* 44(1): 213-233.

World Bank. 2018. *Assessment of groundwater challenges & opportunities in support of sustainable development in sub-Saharan Africa.* World Bank: Washington, DC.

Worqlul, A.W.; Dile, Y.T.; Bizimana, J.; Jeong, J.; Gerik, T.J.; Srinivasan, R.; Richardson, J.W. and Clarke, N. 2018. Multi-dimensional evaluation of simulated small-scale irrigation intervention: A case study in Dimbasinia Watershed, Ghana. *Sustainabilty* 10: 1531.

Xie, H.; You, L.; Wielgosz, B. and Ringler, C. 2014. Estimating the potential for expanding smallholder irrigation in Sub-Saharan Africa. *Agricultural Water Management* 131: 183-193.

Xie, H. and Ringler, C. 2017. Agricultural nutrient loadings to the freshwater environment: The role of climate change and socioeconomic change. *Environmental Research Letters* 12(10).

Yami, M. 2013. Sustaining participation in irrigation systems of Ethiopia: What have we learned about water user associations? *Water Policy* 15(6): 961-984.

You, L.; Ringler, C.; Wood-Sichra, U.; Robertson, R.; Wood, S.; Zhu, T.; Nelson, G.; Guo, Z. and Sun, Y. 2011. What is the irrigation potential for Africa? A combined biophysical and socioeconomic approach. *Food Policy* 36(6): 770-782.

Zorom, M.; Barbier, B.; Mertz, O. and Servat, E. 2013. Diversification and adaptation strategies to climate variability: A farm typology for the Sahel. *Agricultural Systems* 116: 7-15.