BURLEIGH DODDS SERIES IN AGRICULTURAL SCIENCE

Advances in farmer-led irrigation development in Africa

Phil Woodhouse, University of Manchester, UK

burleigh dodds
SCIENCE PUBLISHING

Advances in farmer-led irrigation development in Africa

Phil Woodhouse, University of Manchester, UK

1 Introduction

The centrality of farmers' participation for successful irrigation has been a recurring theme within irrigation management literature for the past four decades (Uphoff, 1986; Bottrall, 1985; Chambers, 1989; Wade, 1988) but has assumed a particular significance in sub-Saharan Africa (SSA) in the twenty-first century. This is because the region's irrigation development and food production are widely perceived as lagging compared to other less-developed regions such as Asia and Latin America (AFDB et al., 2008; World Bank, 2011; FAO, 2020). A representative study presenting this argument (Svendsen et al., 2009) states that SSA's area equipped with irrigation infrastructure accounts for only 3.5% of total cultivated area, compared to almost 35% in Asia (Table 1). Moreover, in this regard SSA contrasts with arid North Africa and the Indian Ocean islands (mainly Madagascar and Mauritius) which are similar to the Asian profile of irrigation development. In these two regions irrigation development has approached its maximum potential, at 88% and 71% in North Africa and the Indian Ocean Islands respectively, compared to less than 20% across sub-Saharan Africa.

A number of studies in the 1980s (Moris and Thom, 1985; Diemer and Vincent, 1992; Adams, 1992) identified the reasons for poor irrigation performance in SSA as arising partly from flawed technical design, but particularly from a lack of understanding of how irrigation was to fit within the

http://dx.doi.org/10.19103/AS.2023.0123.14

Chapter taken from: Knox, J. (ed.), *Improving water management in agriculture*,
Burleigh Dodds Science Publishing, Cambridge, UK, 2023, (ISBN: 978 1 80146 274 7; www.bdspublishing.com)

Table 1 Indicators of irrigation performance in Africa (after Svendsen et al., 2009 Tables 3 and 11)

African agro-ecological region	'equipped' irrigation area/ total area cultivated	% use of 'equipped' irrigation area	Total area of water management/total area cultivated	'Equipped' irrigation as % of potential
Northern	28.1	80.4	28.1	88
Sudano-Sahelian	6.9	63.3	9.2	50
Gulf of Guinea	1.5	73.5	3.3	8
Central	0.7	47.5	2.8	1
Eastern	2.6	24.0	1.8	11
Southern	4.2	80.7	4.8	36
Indian Ocean Islands	30.4	99.4	30.7	71
Average Sub-Saharan Africa	3.5	71	4.5	18
Average Asia	33.6	66.9	34.3	

broader farming system and rural economy. This resulted in unforeseen labour shortages, failure of crop revenues to cover production costs, insufficient infrastructure maintenance and, consequently, low rates of use of irrigable areas. This kind of analysis supported a decade-long moratorium on new irrigation schemes in the region, until the new millennium witnessed continent-wide initiatives to increase African agricultural productivity. These included: the development of the Comprehensive Africa Agricultural Development Programme (CAADP) under the African Union's New Partnership for Africa's Development (NEPAD). The CAADP is organised through four pillars of which the first is 'extending the area under sustainable land management and reliable water control systems' (NEPAD, 2003). An increase in global food prices in 2008 highlighted failures to increase productivity of sub-Saharan African agriculture during the previous two decades and an alliance of five influential international organisations called for new large-scale investments into irrigation in the region (AFDB et al., 2008). Nonetheless, concerns about the high cost and low productivity of irrigation schemes in Africa remain (Inocencio et al., 2007). A recent study (Higginbottom et al., 2021) of 79 irrigation schemes in SSA shows the problem of poor productivity of irrigation persists, with a median of only 16% of the designed irrigable area in production and only a quarter of schemes attaining more than 80% of their designed production area while a fifth were completely inactive. The authors concluded that productivity had not increased over the previous six decades.

One response to this situation is to focus on rainfed production, exemplified by a World Bank assessment of potential for expanding commercial agriculture in 'Guinea savannah' zones in Africa, based entirely upon the premise of rainfed systems of production (World Bank, 2009). While there are undoubtedly gains achievable from improving rainfed agriculture, notably by improved soil management (Reij et al., 1996), there are reasons to argue that irrigation will be crucial for the future development of sub-Saharan agriculture. First, while less apparent than in arid North Africa, where irrigation is an obvious requirement, for the two thirds of sub-Saharan Africa that lie outside the equatorial humid zone, water is the key constraint to agricultural production. Annual rainfall may vary from as little as 400 mm in Sahelian zones to 1200 mm in 'Guinea savanna', but in all cases is strongly seasonal, being restricted to 4–5 months in a year. In addition to the long dry season, lack of moisture for crops arises from significant deficits ('meteorological' droughts) in total annual rainfall once or twice a decade, and high probability (in two out of three years) of dry spells at critical crop growth stages during the rainy season. This means that significant risk attaches to all other investments in agriculture if crops are dependent on rainfall alone (Rockström et al., 2003; Rockström et al., 2010). Studies on maize in semi-arid areas of Kenya and Tanzania suggests the crop may be expected to be exposed to dry spells of 10 days or longer in 74–80% of rainy seasons (Barron et al., 2003).

Historical and contemporary African agriculture includes many different 'indigenous soil and water conservation' strategies to reduce risks associated with low and unreliable rainfall. These include: digging pits and laying stone lines to increase interception and retention of rain (Reij et al., 1996); traditions of stream diversion for 'hill furrow' crop irrigation in the East African highlands (Adams and Anderson, 1988; Tagseth, 2008); cultivation of floodplains following a receding flood (e.g. on the Senegal and Niger rivers); and construction of terraces on hillsides and cultivation of raised beds in wetlands in Zimbabwe (Soper, 2006). More generally, crop planting is often split to occupy a variety of topographical positions and thus mitigate rainfall hazards: floods in lower lying sites in wet years, drought on higher, better-drained sites in drier years (Richards, 1985).

Under colonial administration in the early 20th century these aspects of water management in African agriculture were largely ignored. Instead, investment focused on large-scale infrastructure on major river floodplains, such as the Gezira scheme on the Nile in Sudan (Barnett, 1977; Ertsen, 2016) and the Office du Niger in Mali (Aw and Diemer, 2005), both built with the aim of settling small-scale tenant farmers within government-managed large schemes to produce cotton. Later, these schemes were used as the development model for rural resettlement programmes, such as at Mwea and Tana river in Kenya (Kenya Government n.d.). Irrigation investment increased particularly during the decade after independence of many African countries, accelerated by instances of famine due to extended drought periods in the 1970s. While researchers documented the poor performance of many of these investments in the 1980s, irrigation inventories (Hocombe et al., 1986; Underhill, 1984) started to reveal significant 'informal' irrigation practised by small-scale farmers using a variety of technologies, both modern (e.g. motor pumps and boreholes) and traditional (e.g. stream diversions using weirs and canals; managed flooding and drainage of valley bottoms). While official irrigation statistics have struggled to measure accurately the extent of this irrigation activity spread across many small plots (Venot et al., 2021), research over the past decade has generated increasing evidence that small-scale farmers across SSA are investing both capital and labour in a diverse range of irrigation methods. We may classify these loosely under four broad headings: (1) 'hill furrows', (2) management of seasonally flooded valleys, (3) use of small motor pumps and (4) re-use of urban wastewater.

Hill furrow irrigation, historically established in mountainous and Rift valley terrain of East Africa (Adams and Anderson, 1988; Grove, 1993; Adams et al., 1994; Tagseth, 2008) has been observed more recently in hilly terrain of central and northern Mozambique (Nkoka et al., 2014; Bolding et al., 2010). Research in the upper catchment of the Revué River in Mozambique (Bolding et al., 2010; Beekman et al., 2014) shows that typically several furrow irrigation systems take water from one stream, sometimes additionally capturing water from side streams, springs or neighbouring catchments. Beekman et al. (2014) suggest that these systems have recently expanded significantly, such that in the Mozambican border area of Zimbabwe there are currently more than 100 000 ha irrigated in this manner.

Low-lying land and valley bottoms are cultivated throughout SSA. Such areas have a variety of names in different countries including *bolis* in Sierra Leone, *fadama* in Nigeria, *bas fonds* in Niger, Mali and Burkina Faso, the Swahili term *mbuga* in East Africa and *vlei* in Zimbabwe and South Africa. In Southern African countries, they are also referred to as *dambos* (Bell et al., 1987). Characteristically high in fertility, they may be cultivated by digging channels and bunds to manage seasonal floodwaters or maintain high water tables to grow rice, by ridging and draining to grow other crops and by lifting water from the shallow water table to irrigate during the dry season. World Bank funding for pumps and boreholes has supported small-scale irrigation in the extensive fadamas of northern Nigeria since the 1980s (Carter et al., 1983; Carter, 1989), and by 2004 fadama irrigation was estimated at 114 000 ha (Vermillion, 2004), equivalent to more than half of Nigeria's official total 220 000 ha of irrigation. More generally, the wetland areas of SSA have been sites of agricultural intensification by small-scale farmers as cultivation has replaced dry season grazing (Woodhouse et al., 2000) wherever markets for high-value crops are accessible. They are now highly valued and sites of struggles for ownership of land (Woodhouse, 2003; Peters and Kambewa, 2007). Where such small-scale systems are very extensive, as in the upper catchment of the Great Ruaha River in Tanzania, they may significantly affect downstream water use and attract political opposition and state intervention (Lankford, 2004; Lankford et al., 2004; Lankford and Beale, 2007).

The re-use of urban wastewater for irrigation is the most ubiquitous form of small-scale irrigation development by farmers. Rising demand for fresh fruit and vegetables has driven an informal sector of small-scale horticultural producers in and around almost all African urban centres (Drechsel and Keraita, 2014). The use of wastewater, diluted or raw, creates health risks for both irrigators and consumers of the crops. Despite this, and often precarious access to land, small-scale producers have developed substantial irrigated areas in many African urban areas. In Ghana, where urban agriculture is officially recognised as a means of meeting food demands, Drechsel and Keraita (2014, 3) estimate that irrigated production of lettuce and cabbage for salad consumption involves 'up to 2000 urban vegetable farmers, 5300 street food sellers, and 800 000 daily consumers within the major cities plus an unknown number of traders'. Plot sizes may be very small, between 0.01 and 0.02 ha per farmer in Accra (Danso et al., 2014), and watering cans are the most common technology, although motorised pumps may be used to bring water from a more distant source to a reservoir nearer the fields (Keraita and Cofie, 2014).

The reduction in capital cost of imported small gasoline or diesel water pumps has had a major impact on irrigation by small-scale farmers in many different locations, often supplementing other irrigation technologies but also opening up new opportunities. Documented examples include: the fadama irrigation in Northern Nigeria referred to above, irrigation from Lake Victoria in Kenya (Hebinck et al., 2019); use of groundwater to irrigate in an area of failed surface irrigation in Kahe, Tanzania (de Bont et al., 2019a); and exploitation of land upstream of small reservoirs in Burkina Faso (Venot et al., 2012; de Fraiture et al., 2014). Namara et al. (2014) report that official data showed that in Ghana alone over 65 000 pumps and accessories were imported between 2003 and 2010, worth more than USD 8 million.

As observations of farmers' small-scale irrigation initiatives have proliferated, a number of terms have been used to characterise them, such as 'distributed irrigation' (Burney et al., 2013) and 'small private irrigation' (de Fraiture and Giordano, 2014; Giordano et al., 2012) as well as 'farmer-led irrigation development' (Nkoka et al., 2014). It is the latter term that has come to be widely used in irrigation policy (Woodhouse et al., 2017; Veldwisch et al., 2019; Wiggins and Lankford, 2019; IWMI, 2019; Izzi et al., 2021). It has been defined as:

> a process where farmers assume a driving role in improving their water-use for agriculture by bringing about changes in knowledge production, technology use, investment patterns and market linkages, and the governance of land and water. In the process, farmers exhibit entrepreneurial and risk-taking behaviour and interact with a range of other actors. (Woodhouse et al., 2017: 216)

This definition highlights the role of small-scale farmers in the *process* of irrigation development, rather than any particular technique of irrigation. This focus on process further emphasises that, while farmers are active in determining the purpose, location and methodology of irrigation, they do not act in a vacuum but engage with a variety of different government, non-government and commercial development agencies. While many commentators may regard farmers' irrigation initiatives as 'informal', the above definition makes clear that, from a farmer's perspective, they are neither 'spontaneous' nor 'unplanned', but rather constitute intentional development that requires work and investment.

2 Key issues and challenges of farmer-led irrigation development

Farmer-led irrigation development is a phenomenon that, once named, has come to be recognised widely across SSA and has become incorporated in policy frameworks (e.g. African Union, 2020) and investment programmes (e.g. World Bank. See: Izzi et al., 2021). We can identify five key areas in which research is needed to clarify the trajectory and impact of farmer-led irrigation development:

1. How significant is it quantitatively, in terms of land area irrigated?
2. What conditions drive farmer-led irrigation?
3. How is technological change achieved?
4. What outcomes are evident, in terms of productivity, sustainability and equity effects?
5. What policy challenges arise?

Each of these key knowledge gaps are briefly considered in the following sections.

2.1 What is the quantitative significance of farmer-led irrigation?

There are no definitive data for the overall extent of farmer-led irrigation development in SSA. Data for imports of pumping equipment (Namara et al., 2014) or the extent of hand-dug canals for 'hill-furrow' irrigation (Beekman et al., 2014) suggest that, in aggregate, such small-scale irrigation activities cover areas at least as large as formal, engineer-designed large-scale irrigation

Published by Burleigh Dodds Science Publishing Limited, 2023.

schemes. However, official statistics are often incomplete since data collected by government agencies tend to emphasise areas ‘fully-equipped’ with permanent irrigation infrastructure while ignoring small-scale irrigation using more improvised (e.g. temporary stream diversions) or portable (e.g. pump) technology.

Yet assessments of the potential benefits from irrigation in Africa highlight the greater returns from small-scale irrigation. In particular, modelling techniques integrating different datasets on crop yield potential, rainfall and hydrology (You et al., 2011; Xie et al., 2014) have assessed irrigation investment profitability for a number of economic scenarios in different agroecological zones. These indicated that, for internal rates of return (IRR) of greater than 12%, irrigation is expected to be profitable on 1.3 million ha of large-scale (dam-based) schemes but about 3.7 million hectares small-scale irrigation in five regions of sub-Saharan Africa (i.e. excluding North Africa and Indian Ocean Islands). This type of exercise is based on many assumptions one would want to question in specific contexts, and the authors of the work have underlined the high sensitivity of the analysis to cost assumptions. Moreover, Wiggins and Lankford (2019) argue such studies are likely to over-estimate potential irrigation because irrigable areas depend on water required. This means potential is greater in the rainy season (when irrigation is supplemental to rainfall) or where significant rainfall storage is available for dry season usage. More work is needed to evaluate the impact of such factors on irrigation in specific contexts.

Nonetheless, recent advances in the availability and increased resolution of satellite imagery has enabled remote sensing studies to detect smaller areas of irrigation. Such studies show that “broadly, in Africa areas receiving improved water management practices including irrigation are about 2 to 3 times greater than was previously thought. About half of these areas have some level of active water management which is beyond traditional definition of ‘rainfed’ but not yet ‘irrigated’” (IWMI, 2016). Studies in Tanzania (Venot et al., 2021) using radar remote sensing have also shown that areas of irrigated rice may be very much larger than official statistics record. These authors highlight that the discrepancy between official statistics and such remote sensing measurements derive from problems of official definition of ‘irrigation’ exclusively in terms of engineering infrastructure (see also Harrison, 2018). This makes it difficult for irrigation statistics to include much of the farmer-led irrigation development that does not have permanent infrastructure.

2.2 What conditions drive farmer-led irrigation?

Farmer-led irrigation development appears oriented primarily towards the production of crops for local sale, rather than for consumption within irrigators’ households. Irrigators focus on growing high-value vegetables and fruit for sale in urban markets or rice, which is a preferred staple in urban areas in many parts of Africa. A primary driver of farmer-led irrigation development is therefore urbanisation, estimated at about 50% across SSA but varying between about 33% and 70% in individual countries (OECD/SWAC, 2020). Moreover, the projected annual population growth rate of 2.45%, the highest in the global South, is primarily in urban centres. Access to these growing centres of food consumption, and hence the condition of road infrastructure, is therefore a major factor in stimulating small-scale farmers' irrigation initiatives.

Other factors that may catalyse farmer-led irrigation development are supply-chain development, particularly through reduction in barriers to importation of motor pumps (Namara et al., 2014; Dessalegn and Merrey, 2015) and provision of seasonal credit by crop purchasers (Veldwisch and Woodhouse, 2022), and immigration that may bring irrigation expertise as well as additional labour (Bolding et al., 2010). These observations mark a quite different perspective from that based on 'agro-ecological potential' that typically informs conventional irrigation planning. From a farmer-led perspective, irrigation development is primarily a matter of economic opportunities and the availability of means with which to develop land and water resources to exploit them.

More broadly, farmers' initiatives to develop irrigation cannot be viewed in isolation from their social, economic, ecological or political context. Woodhouse et al. (2017) document instances where farmers have lobbied government and non-government agencies to provide funding, material or technical support to upgrade their irrigation. In contrast, governments may see farmers' irrigation initiatives as contrary to their visions for agricultural development (De Bont et al., 2019b), or as having negative downstream impacts on other water users (Lankford et al., 2004; Walsh, 2012; Mdee and Harrison, 2017). To analyse and understand the contemporary dynamics of farmer-led irrigation development a dichotomy between 'external' and 'internal' (farmers' own) investment needs to be replaced by an understanding of irrigation development as a range of interactions between government, donor and non-government agencies, markets and the rural economy, and farmers.

2.3 How is technological change achieved?

Following from the discussion above, we can understand technological change in farmer-led irrigation as occurring within broad socio-technical networks that involve landholders, tenant farmers, intermediaries such as pump-owners, traders, masons and mechanics, and agents from governmental, non-governmental and international organisations. Evidence of farmers' initiatives in irrigation shows they copy water management technologies (the

Published by Burleigh Dodds Science Publishing Limited, 2023.

knowledge of which is being greatly enhanced by migration) and adapt them to local circumstances. Early examples of use of water pumps for irrigation in the Senegal River Valley during the 1970s trace the introduction of pumps to migrants returning from work in France (Adams, 1981; Diemer and van der Laan, 1987). Another example arose when Japanese technicians constructed the Lower Moshi irrigation scheme in Tanzania, small-scale irrigators copied the techniques of rice cultivation (using transplanting) and set up their own system of irrigation upstream (de Bont et al., 2019a).

Farmers may also build new relationships in order to tap into engineering advice and support, where available. For instance, in several West African countries petrol pump irrigation developed in a dynamic triangle of relations between pump owners, land owners and cultivators (De Fraiture et al., 2014). Namara et al. (2014, 197) describe in Ghana a network, functioning on market principles, in which 'pumps can be rented for a day, for a season, for a year or even on an hourly basis'. Hebinck et al. (2019) describe the role of mechanics and agro-dealers in supporting the effective spread of irrigation using petrol pumps in Western Kenya.

Farmer-led perspectives on irrigation may inform different technological choices from those of irrigation planners (Beekman et al., 2014). Farmers are likely to give priority to the ease of development, maintenance and operation, either individually or within a small group. This may lead, for instance, to a preference for developing irrigation using small streams on land with relatively steep slopes (because this combination makes it easier to move water around), or around stable open water sources or in wetland areas instead of looking for large flat areas and abundantly flowing rivers favoured by irrigation planners and development projects. The importance of understanding farmers' constraints and priorities in technological change is fundamental to the idea of farmer-led irrigation development as a process, rather than as a 'package' of technologies to be 'adopted' by small-scale farmers (Veldwisch et al., 2019). This needs to be emphasised particularly because the history of international funding support to irrigation development in Africa is replete with technologies, such as treadle pumps and drip irrigation that have commonly failed to achieve the impacts often claimed for them (Lankford, 2009; Venot, 2016; Merrey and Sally, 2017).

2.4 What outcomes: productivity, sustainability and equity effects?

Few systematic assessments of the impacts of farmer-led irrigation are yet available. However, those that have been undertaken show dramatic increases in income from crop production for irrigators compared to non-irrigating households (de Bont et al., 2019b). These are associated with ownership of assets and lower likelihood of food insecurity. These effects, set out in more detail below, raise the prospect of a growing differentiation between those who irrigate and those who do not. This impact may be partially mitigated by increasing demand for labour, as households that irrigate are much more likely to employ paid labour, but nonetheless points to processes of social change within communities where farmer-led irrigation development is taking place. These processes may include gendered intra-household re-distribution of burdens and benefits observed in earlier irrigation developments (Carney, 1998).

A recurring observation is that farmer-led irrigation development is associated with immigration from other rural areas (Woodhouse et al., 2017). Migrants may be seeking work as paid labour on irrigated plots or may be seeking land on which to start their own irrigated production. Farmer-led irrigation development is therefore associated with development of markets for labour and land. With regard to the latter, it is important to note that formal land tenure is not a prerequisite for irrigation development. To the extent that farmers' irrigation initiatives take place outside schemes formally demarcated by government, access to land will be governed by customary tenure (Woodhouse et al., 2017). Incomers wishing to irrigate may purchase or rent land from local customary landholders. A number of studies report land rental arranged for a growing season, sometimes involving partnerships between farmers/farm managers, landowners, and pump-owners (e.g. de Fraiture et al., 2014; de Bont et al., 2019a; Karimba et al., 2022).

While such arrangements are widely used, they seldom involve formal contracts and rely on social relationships for compliance. Particularly where such transactions are between local landholders and immigrants, issues of legitimacy and legality may arise if they are contested by others that feel they have claims to the land or water (Woodhouse et al., 2017; Chimhowu and Woodhouse, 2006; Peters and Kambewa, 2007; Chauveau et al., 2006). Such contestation may pose questions about the longer-term stability, sustainability, and equity dimensions of farmer-led irrigation development. More fundamentally, farmer-led irrigation development requires new forms of organisation to manage shared water resources (Komakech and van der Zaag, 2011; Komakech et al., 2012a,b), whether at local, regional or national levels.

2.5 Challenges for policy

Farmer-led irrigation development is a phenomenon that presents development agencies with both opportunities to raise productivity and food security and challenges to make this process socially equitable, environmentally sustainable and economically broad-based. A meeting of policy makers and researchers in 2018 noted that some countries have adjusted policy and budgets to support existing farmer-led irrigation activity. They cited the example of Ghana, where the government recognised that farmers' own irrigation initiatives covered about ten times the area of formal irrigation schemes and policy is focused on removing 'binding constraints', such as shortage of electricity supply (SAFI, 2018). In the years since that meeting, 'farmer-led irrigation' has been widely promoted by international agencies such as the World Bank, particularly in association with solar-powered water pumps (Lefore et al., 2021). However, not all governments are persuaded that small-scale irrigation initiatives are a productive use of water. De Bont et al. (2019b) document cases where government policy has defined farmers' irrigation initiatives as inefficient and emphasises the regulation and formalisation of small-scale farmers' irrigation initiatives in order to improve productivity and protect water resources. The 2018 SAFI meeting concluded that interventions by government and non-government agencies to address farmer-led irrigation development should address four main areas:

1. Framing farmer-led irrigation development as part of economic and social security strategies by:
    a. seeking ways to reduce vulnerability and spread benefits of irrigation among different social groups in rural communities;
    b. facilitating access to reliable markets for inputs (including technology) and agricultural produce;
    c. identifying and removing systemic constraints, such as transport infrastructure, electricity supply and taxation of key inputs.
2. Learning from existing cases of irrigation development by farmers by:
    a. analysing the dynamics and constraints of irrigation development in specific contexts;
    b. exercising caution over expectations for replicability of experience from one site to another;
    c. encouraging opportunities for farmer-to-farmer learning.
3. Informing policy through more accurate irrigation data, by:
    a. evaluating alternative, and possibly complementary, methods of mapping and measuring irrigation beyond formal 'schemes';
    b. revising irrigation statistics to enable recognition of location and extent of farmer-led irrigation development;
    c. identifying the status and support needs of farmer-led irrigation development.
4. Developing a supportive and accessible regulatory framework for small-scale irrigators by:

a. recognising small-scale irrigators as productive water users;
b. avoiding registration requirements that are costly and onerous for small-scale irrigators;
c. identifying 'good-enough' regulation that does not stifle local initiatives;
d. reviewing legislative and regulatory frameworks for water and agriculture to ensure they take account of farmers' irrigation initiatives and identify where state agencies confront capacity limitations to effective intervention;
e. exploring investment and technical strategies for intensification vs expansion of irrigation.

Wiggins and Lankford (2019) argue that interventions by government need to be tailored to the stage of development of farmers' irrigation activity. They outline a three-stage model in which irrigation is developed slowly in an initial phase when technology and/or market access are poorly established, through a second stage of rapid proliferation and adoption of irrigated production and a third stage in which irrigation has a significant impact on water resource availability. The development of regulatory and administrative capacity to address farmer-led irrigation development remains a critical challenge in many African countries. Responsibility for irrigation is often split, or even contested, between different ministries and capacity seldom exists to regulate effectively water use by multiple irrigators in river basins (Mdee and Harrison, 2019).

3 Case studies of farmer-led irrigation development in Tanzania and Mozambique

A survey of 2732 irrigating and non-irrigating households was undertaken at 18 study sites (Fig. 1) in Mozambique and Tanzania to obtain information on farmers' use of irrigation and its socio-economic significance for rural households. Sites were selected where farmer initiative was evident in determining the purpose, design, and management of irrigation – even though some sort of input or external assistance may have occurred in the past or following farmers' own initiatives (e.g. 'upgrading' by government agencies). The selected sites included instances where farmers have: developed irrigation during colonial times (Makanya, Parta); rehabilitated and extended irrigation abandoned by colonial settlers (Vanduzi, Messica); copied technology from neighbouring government irrigation schemes (Mandaka Mnono, Mijongweni); or purchased small motor pumps to introduce irrigation in new areas (Kahe [de Bont et al., 2019a], Tica, Zembe, Macate). The sites surveyed provided examples of a range of technologies: stream diversion for basin, furrow, or sprinkler irrigation; wetland management; and small motor pumping from surface or groundwater.

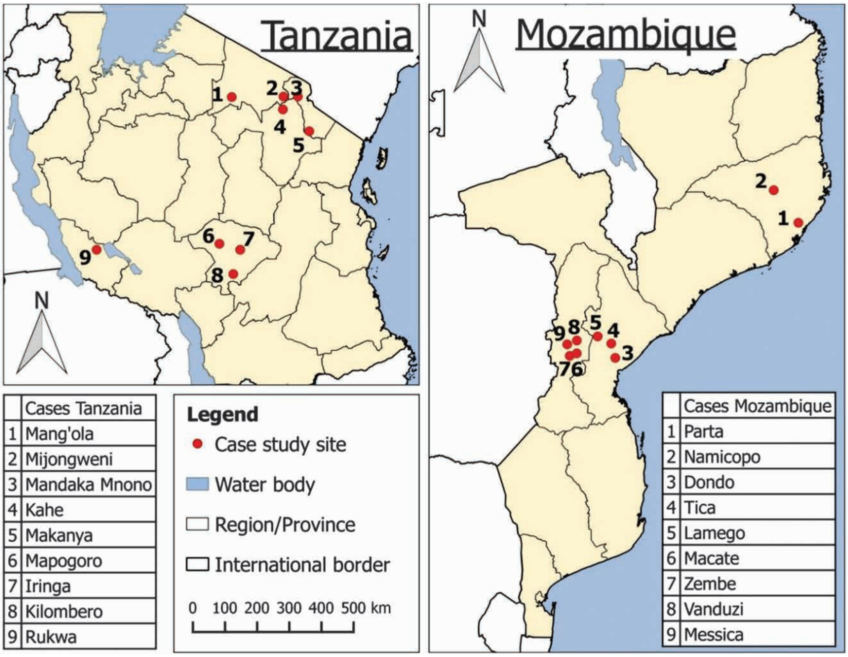

Figure 1 Overview of case study sites in Tanzania and Mozambique (from de Bont et al., 2019b).

Irrigators produced a variety of crops, including paddy rice, maize, and high-value horticultural crops for local and regional markets (tomatoes, cabbages and onions) or for export to Europe (green beans and baby corn).

Some of these areas have been recognised by the government and have received support to upgrade infrastructure (Vanduzi, Iringa, Mandaka Mnono, Mijongweni, Mapogoro), but many have not. One site has witnessed efforts by government to close down irrigation (Rukwa). Table 2 shows that areas irrigated average one to two hectares per irrigating household, although some individuals (for example, a customary chief in Messica and a businessman with rental property in a local town in Rukwa) may cultivate areas 10 times larger. The great majority of irrigating households in Mozambique have less than two hectares under irrigation, while this is less than one hectare in Tanzania. However, aggregate areas covered by such irrigation frequently reach hundreds or even thousands of hectares within an administrative district (Beekman et al., 2014). A study in Tanzania (Venot et al., 2021) found that areas of irrigated rice estimated from remote sensing data acquired by satellite were 36 600 ± 11 800 ha in Rukwa, or 2.6 to 5.5 times greater than recorded in official statistics. In the Shinyanga region, the study estimated 267 000 ± 37 000 ha of irrigated rice

Table 2 Summary of total and irrigated areas of crops grown by irrigating and non-irrigating households at 18 sites in Mozambique and Tanzania (de Bont et al., 2019b)

	Sample size (*N*)			Total cropped area per non-irrigating household (ha)		Total cropped area per irrigating household (ha)		Area of irrigated crops per irrigating household(ha)	
Case study site	Total	Non-irrigating	Irrigating	Mean	SD	Mean	SD	Mean area	Mean % irrigated
Mozambique	***1372***	***574***	***798***	***2.53***	***2.86***	***3.68***	***3.69***	***1.81***	***49.3***
Dondo	120	72	48	1.35	1.11	1.86	2.12	1.60	86.1
Lamego	192	61	131	2.79	2.05	2.74	1.47	1.07	39.0
Macate	197	86	111	2.86	3.72	4.42	4.62	2.15	48.5
Messica	245	94	151	3.98	4.67	5.69	5.37	2.92	51.3
Namicopo	43	21	22	1.48	1.80	1.32	0.55	0.82	62.0
Parta	100	39	61	1.21	1.26	1.73	1.26	0.71	41.0
Tica	136	73	63	2.10	1.18	2.87	1.96	1.44	50.3
Vanduzi	159	53	106	2.74	1.80	3.22	2.04	1.84	57.2
Zembe	180	75	105	2.54	2.15	4.61	3.75	1.95	42.4
Tanzania	***1361***	***445***	***916***	***0.69***	***1.10***	***1.35***	***1.78***	***1.19***	***87.9***
Iringa	151	54	97	0.76	0.65	0.82	0.84	0.82	100.0
Kahe	150	62	88	0.78	0.67	1.52	1.81	1.31	86.3
Kilombero	152	75	77	0.71	1.04	1.08	1.38	0.84	77.5
Makanya	149	25	124	0.47	1.06	2.06	1.36	2.02	98.0
Mandaka Mnono	152	43	109	0.32	0.36	1.26	1.46	0.92	72.7
Mang'ola	150	30	120	0.00	0.00	0.71	1.11	0.71	100.0
Mapogoro	153	34	119	0.54	0.86	1.62	2.10	1.26	77.9
Mijongweni	153	48	105	0.20	0.40	1.21	1.11	1.15	94.9
Rukwa	151	74	77	1.52	1.87	1.87	3.57	1.60	85.6

Table 3 Comparison of hiring of agricultural labour, and gross value of crop sales, by irrigating and non-irrigating households, and extent of contribution of sale of irrigated crops to total income of irrigating households (de Bont et al., 2019b)

Households	Gross value of crop sales (USD/household/year)				Percentage of irrigating households for whom at least half of total income is derived from sale of irrigated crops	Percentage of households employing agricultural labour	
	Non-irrigating		Irrigating			Non-irrigating	Irrigating
	Mean	SD	Mean	SD			
Mozambique	**51.9**	**178.4**	**703.8**	**2091.2**	**78.7**	**23.5**	**48.1**
Dondo	37.4	92.3	249.5	693.0	87.5	22.2	50.0
Lamego	18.0	57.7	99.1	471.5	72.5	27.9	41.2
Macate	114.8	345.1	676.9	2032.1	72.1	34.9	64.0
Messica	48.1	104.9	1240.0	2790.0	84.8	23.4	41.7
Namicopo	1.7	5.4	187.2	455.3	72.7	0.0	18.2
Parta	53.2	170.1	186.0	260.6	67.2	10.3	29.5
Tica	94.1	233.9	1254.0	4250.0	92.1	31.5	54.0
Vanduzi	21.7	58.0	1049.5	1944.8	88.7	28.3	60.4
Zembe	19.5	65.2	653.3	1123.2	70.5	10.7	49.5
Tanzania	**161.2**	**651.9**	**884.0**	**2458.4**	**90.8**	**29.9**	**72.6**
Iringa	33.9	113.7	634.1	1153.1	96.9	9.3	50.5
Kahe	36.3	117.2	635.3	2250.5	83.0	43.5	69.3
Kilombero	350.6	1119.3	937.9	2384.7	92.2	36.0	68.8
Makanya	9.9	30.5	370.5	402.9	87.9	8.0	77.4
Mandaka Mnono	18.4	55.4	739.9	977.6	85.3	39.5	85.3
Mang'ola	0.0	0.0	1180.2	3303.0	92.5	3.3	70.0
Mapogoro	9.4	33.0	1237.0	1211.4	97.5	26.5	82.4
Mijongweni	0.7	4.5	541.4	1092.6	84.8	12.5	77.1
Rukwa	539.9	1012.7	1920.1	5897.8	98.7	52.7	64.9

Table 4 Use of 'modern' inputs in irrigated and non-irrigated agriculture at 18 sites in Mozambique and Tanzania (de Bont et al., 2019b)

	Survey sample (N)		Applied manure from own livestock		Applied purchased fertiliser		Used improved seeds		Average intensification index[a]	
	Non-irrigated crops	Irrigated crops	Non-irrigated crops (%)	Irrigated crops (%)	Non-irrigated crops (%)	Irrigated crops (%)	Non-irrigated crops (%)	Irrigated crops (%)	Non-irrigating households	Irrigating households
Mozambique	**2323**	**1950**	**1.3**	**7.2**	**2.2**	**41.6**	**8.8**	**51.6**	**0.11**	**0.93**
Dondo	135	79	0	1.3	2.2	34.2	5.9	36.7	0.09	0.52
Lamego	358	204	0.3	6.4	0.6	10.8	6.1	22.5	0.09	0.23
Macate	357	306	0.6	5.6	0.3	23.9	9.5	33.7	0.11	0.73
Messica	353	356	2.5	3.9	3.7	63.8	14.2	49.4	0.23	1.27
Namicopo	91	60	8.8	35.0	1.1	5.0	2.2	46.7	0.08	0.81
Parta	205	81	0	0.0	0.0	0.0	0.0	0.0	0.00	0.00
Tica	280	167	0.7	1.2	5.4	33.5	11.1	56.3	0.13	1.12
Vanduzi	256	420	3.5	8.6	3.5	63.6	17.6	83.1	0.12	1.95
Zembe	288	277	0	13.4	2.4	49.5	4.2	65.7	0.06	1.17
Tanzania	**808**	**1786**	**6.1**	**3.6**	**15.2**	**49.1**	**22.3**	**38.2**	**0.75**	**1.51**
Iringa	60	101	0	1.0	1.7	9.9	3.3	3.0	0.06	0.81
Kahe	123	174	0.8	1.7	11.4	36.8	14.6	29.9	0.63	1.15
Kilombero	127	132	0	1.5	38.6	83.3	27.6	64.4	1.39	2.32
Makanya	44	377	0	4.5	2.3	3.2	18.2	30.8	0.60	0.83
Mandaka Mnono	116	215	7.8	0.9	16.4	88.8	42.2	48.8	1.19	2.20
Mang'ola	29	213	0	1.9	0.0	69.5	0.0	50.7	0.0	2.13
Mapogoro	90	141	1.1	0.7	2.2	70.2	15.6	5.0	0.35	1.17
Mijongweni	82	328	0	2.4	43.9	73.2	40.2	57.0	1.49	2.30
Rukwa	137	105	28	25.7	0.7	2.9	15.3	19.0	0.52	0.75

[a]Intensification index is calculated for each household as: for each crop, score 1 for 'buy fertiliser' or 'buy manure' + 1 for 'use improved seeds' + 1 for 'use pesticides'. Average score across all crops grown by the household = input intensification index for each household.

– up to 10 times higher than in official data. Almost all of this area is cultivated by small-scale farmers using hand-dug ditches and bunds to manage water levels to create and maintain flooded paddy fields.

The survey of irrigating and non-irrigating households used a random sample of about 150 households at each site, based on household lists obtained from administrative authorities and adjusted to ensure the sample contained a minimum of 50 of either irrigating or non-irrigating households at every site. Table 3 shows gross values of crop sales by irrigating households (uncorrected for production costs or amount of crop consumed by the household) are on average higher than those of non-irrigating households by factors of 5 (Tanzania) and 13 (Mozambique). These sales from growing irrigated crops account for at least half of household monetary income for the vast majority of those engaging in irrigation.

The data clearly show the commercial nature of farmer-led irrigation development. Most irrigated crops are grown for the market, and irrigating households are much more likely to use improved seeds and fertilisers (Table 4), and to hire agricultural labour (Table 3), compared to their non-irrigating neighbours. Inputs may be financed by credit from traders and corporate buyers (for local, regional, or export markets) in return for an undertaking from farmers to sell them the crop (Veldwisch and Woodhouse, 2022). Some sites show lower rates of input use by irrigating households, particularly where poor roads mean weak supply chains (e.g. Parta in northern Mozambique) or where water availability is less reliable (as at the spate irrigation site at Makanya, in Tanzania). Elsewhere, the increase in use of modern inputs (agrochemicals and improved seeds) is markedly and consistently higher for irrigated crops, and irrigating households are more consistent purchasers of these inputs (Table 4).

4 Conclusion

Evidence accumulating over the past two decades suggests that the poor performance of many official irrigation schemes in sub-Saharan Africa has distracted attention from the widespread adoption of irrigation by small-scale farmers in the region. This farmer-led irrigation development involves use of a variety of techniques. Some, such as ‘hill-furrow’ irrigation using streams in hilly areas, pre-date colonial administration while others, such as the use of small motor pumps, have been widely available for the past three or four decades. Farmers’ innovation and investment in adopting irrigation technology draws on a variety of sources of information, including equipment dealers, government and non-government technical services, and other farmers. Migrants are also important sources of information regarding irrigation techniques and agricultural innovations used elsewhere.

In aggregate, these irrigation initiatives by small-scale farmers appear likely to support areas of irrigated crops that are much larger than those irrigated by formal engineering schemes but are under-represented in official statistics that focus on areas served by permanent infrastructure. Farmer-led irrigation development is driven by growing local and regional food markets arising from urbanisation and rapid population growth in sub-Saharan Africa. Crop sales by households using irrigation developed by farmers' initiatives appear to be five to ten-fold higher than crop sales by non-irrigating households and therefore offers major scope and opportunity to transform agricultural productivity and food supply. A number of international agencies have recognised this, and 'farmer-led irrigation' is the subject of considerable funding efforts, such as the promotion of financial support for acquisition of solar water pumping equipment. Such funding initiatives emphasise the key role of improved agricultural water management in enabling people in Africa to adapt to changing constraints arising from climate change.

As small-scale irrigation initiatives by farmers multiply, a number of challenges arise over increasing differentiation both within and between households (those irrigating and not irrigating, for example) and also over increasing competition for limited water supplies among irrigators and between irrigators and other water users, such as urban domestic users, hydro-power schemes and ecological requirements. This presents new policy and regulatory challenges that will be very context-specific but for which African government agencies will require significant re-focusing of goals and development of new capacity.

5 Future trends in research

Recognition by development agencies of 'farmer-led irrigation development' as a discrete process dates back less than a decade. Research on technical and socio-economic aspects of irrigation in sub-Saharan has previously focused mostly on formal state-run schemes. However, research is now urgently needed to understand both the processes of technological change pursued by small-scale farmers and the scope for improved productivity, and avenues through which these can be supported by engineers and other science-based professions.

Research will also need to explore challenges to the sustainability of the current proliferation of small-scale farmers' irrigation initiatives. We can identify three aspects. First, what are the medium-term consequences of farmer-led irrigation development in terms of socio-economic change? Who are the 'winners' and 'losers' and what can be done to ensure that the raised incomes from irrigated crop production result in a broad-based benefit to rural communities? Second, how can institutions meet the evolving challenge of organisation and regulation of small-scale irrigation? While studies have identified farmers' capacity for organisation in using shared water resources, few have documented the interface of such farmers' organisations with local, regional or national government and non-government agencies. Third, is there a need to develop water storage infrastructure with a view to serving farmers' irrigation initiatives? In the past, infrastructure such as dams have been constructed to provide hydropower or irrigate large areas into which rural communities have been inserted as labourers or tenants. The proliferation of irrigation developed by farmers' initiatives raises the fundamental question of whether this logic may be reversed and infrastructure design re-thought as supporting such initiatives. These three aspects remain major gaps with important implications for the future sustainability of much farmer-led irrigation development.

6 Where to look for further information

- African Union Framework for Irrigation and Agricultural Water Management: https://au.int/en/documents/20200601/framework-irrigation-development-and-agricultural-water-management-africa.
- Agrilinks: https://agrilinks.org/post/building-better-solar-irrigation-market-ghana.
- DEGRP Synthesis Report. London: Foreign, Commonwealth and Development Office. https://odi.org/en/publications/farmer-led-irrigation-in-sub-saharan-africa-synthesis-of-current-understandings/.
- Food Policy Research Institute: https://www.ifpri.org/project/ilssi.
- International Water Management Institute (IWMI): https://www.iwmi.cgiar.org/what-we-do/farmer-led-irrigation/.
- The SAFI project. Studying African Farmer-led Irrigation: http://www.safi-research.org/.
- World Bank: Farmer-led irrigation: the what, why, and how-to guide https://blogs.worldbank.org/water/farmer-led-irrigation-what-why-and-how-guide.

7 References

Adams, A. 1981. The Senegal river valley. In: Heyer, J., Roberts, P. and Williams, G. (Eds.), *Rural Development in Tropical Africa*. London: Macmillan.

Adams, W. M. 1992. *Wasting the Rain: Rivers, People and Planning in Africa*. Minneapolis, MN: University of Minnesota Press.

Adams, W. M. and Anderson, D. M. 1988. Irrigation before development: Indigenous and induced change in agricultural water management in East Africa. *African Affairs* 87(349): 519–535.

Published by Burleigh Dodds Science Publishing Limited, 2023.

Adams, W. M., Potkanski, T. and Sutton, J. E. G. 1994. Indigenous farmer-managed irrigation in Sonjo, Tanzania. *Geographical Journal* 160(1): 17–32.

AFDB. 2008. Investment in agricultural water for poverty reduction and economic growth: A collaborative program of AFDB, FAO, IFAD, IWMI and the World Bank. Synthesis Report. Available at: http://www.fanrpan.org/documents/d00508/1-agric_water_investments_World_Bank.pdf.

African Union. 2020. Framework for irrigation development and agricultural water management in Africa. Available at: https://au.int/sites/default/files/documents/38632-doc-framework_for_irrigation_development_english.pdf (accessed 27 January 2021).

Aw, D. and Diemer, G. 2005. *Making a Large Irrigation Scheme Work: A Case Study From Mali. Directions in Development*. Washington, DC: The World Bank.

Barnett, T. 1977. *The Gezira Scheme: An Illusion of Development*. Abingdon: Routledge.

Barron, J., Rockström, J., Gichuki, F. and Hatibu, N. 2003. Dry spell analysis and maize yields for two semi-arid locations in east Africa. *Agricultural and Forest Meteorology* 117(1–2): 23–37.

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* 76–78: 54–63.

Bell, M., Faulkner, R., Hotchkiss, P., Lambert, R., Roberts, N. and Windram, A. 1987. *The Use of Dambos in Rural Development With Reference to Zimbabwe*. Loughborough: Loughborough University/University of Zimbabwe.

Bolding, A., Post Uiterweer, N. C. and Schippers, J. 2010. The fluid nature of hydraulic property: A case study of Mukudu, Maira and Penha Longa irrigation furrows in the upper Revue River, Manica District, Mozambique. In: Van der Zaag, P. (Ed.), *What Role of Law in Promoting and Protecting the Productive Uses of Water by Smallholder Farmers in Mozambique?* Delft: UNESCO, pp. 105–136. Challenge Program Project No. 66-IHE Institute for Water Education.

Bottrall, A. 1985. Managing large irrigation systems: A problem of political economy. AAU Occasional Paper No. 5. London: Overseas Development Institute.

Burney, J. A., Naylor, R. L. and Postel, S. L. 2013. The case for distributed irrigation as a development priority in sub-Saharan Africa. *Proceedings of the National Academy of Sciences of the United States of America* 110(31): 12513–12517.

Carney, J. A. 1998. Women's land rights in Gambian irrigated rice schemes: Constraints and opportunities. *Agriculture and Human Values* 15(4): 325–336.

Carter, R. C. 1989. The development of small-scale irrigation in sub-Saharan Africa. *Public Administration and Development* 9(5): 543–555.

Carter, R. C., Carr, M. K. V. and Kay, M. G. 1983. Policies and prospects in Nigerian irrigation. *Outlook on Agriculture* 12(2): 73–76.

Chambers, R. 1989. Managing canal irrigation: Practical analysis from South Asia. In: *Wye Studies in Agricultural and Rural Development*. Cambridge: Cambridge University Press.

Chauveau, J.-P., Colin, J.-P., Jacob, J.-P., Lavigne Delville, P. and Le Meur, P.-Y. 2006. *Changes in Land Access and Governance in West Africa: Markets, Social Mediations and Public Policies*. London: IIED/DFID.

Chimhowu, A. and Woodhouse, P. 2006. Customary vs private property rights? Dynamics and trajectories of vernacular land markets in Sub-Saharan Africa. *Journal of Agrarian Change* 6(3): 346–371.

Danso, G., Drechsel, P., Obuobie, E., Forkuor, G. and Kranjac-Berisavljevic, G. 2014. Urban vegetable farming sites, crops and cropping practices. In: *Drechsel and Keraita*.

de Bont, C., Komakech, H. C. and Veldwisch, G. J. 2019a. Neither modern nor traditional: Farmer-led irrigation development in Kilimanjaro Region, Tanzania. *World Development* 116: 15–27. https://doi.org/10.1016/j.worlddev.2018.11.018.

de Bont, C., Liebrand, J., Veldwisch, G.-J. and Woodhouse, P. 2019b. Modernisation and African farmer-led irrigation development: Ideology, policies and practices. *Water Alternatives* 12(1): 107–128.

De Fraiture, C. and Giordano, M. 2014. Small private irrigation: A thriving but overlooked sector. *Agricultural Water Management* 131: 167–174.

De Fraiture, C., Kouali, G. N., Sally, H. and Kabre, P. 2014. Pirates or pioneers? Unplanned irrigation around small reservoirs in Burkina Faso. *Agricultural Water Management* 131: 212–220.

Dessalegn, M. and Merrey, D. J. 2015. Motor pump revolution in Ethiopia: Promises at a Crossroads. *Water Alternatives* 8(2): 237–257.

Diemer , G. and van der Laan, E. 1987. *l'Irrigation au Sahel*. Paris: Karthala.

Diemer, G. and Vincent, L. 1992. Irrigation in Africa: The failure of collective memory and collective understanding. *Development Policy Review* 10(2): 131–154.

Drechsel, P. and Keraita, B. 2014. *Irrigated Urban Vegetable Production in Ghana Characteristics, Benefits and Risk Mitigation* (2nd edn.). Colombo: International Water Management Institute.

Ertsen, M. 2016. A matter of relationships: Actor-networks of colonial rule in the Gezira irrigation system, Sudan. *Water Alternatives* 9(2): 203–221.

FAO. 2020. *The State of Food and Agriculture: Overcoming Water Challenges in Agriculture*. Rome: The Food and Agriculture Organization of the United Nations. Available at: https://www.fao.org/3/cb1447en/cb1447en.pdf (accessed 7 March 2022).

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. Synthesis Report of the AgWater Solutions Project. Colombo: International Water Management Institute.

Grove, A. 1993. Water use by the Chagga on Kilimanjaro. *African Affairs* 92(368): 431–448.

Harrison, E. 2018. Engineering change? The idea of the 'scheme' in African irrigation. *World Development* 111: 246–255.

Hebinck, P., Bosma, L. and Veldwisch, G.-J. 2019. Petrol pumps and the making of modernity along the shores of Lake Victoria, Kenya. *Water Alternatives* 12(1): 13–29.

Higginbottom, T. P., Adhikari, R., Dimova, R., Redicker, S. and Foster, T. 2021. Performance of large-scale irrigation projects in sub-Saharan Africa. *Nature Sustainability* 4(6): 501–508. https://doi.org/10.1038/s41893-020-00670-7.

Hocombe, S., Kidane, P., Jazayeri, A. and Gadelle, M. 1986. *Irrigation in Africa South of the Sahara*. Technical Paper No 5. Rome, Italy: Food and Agriculture Organization Investment Centre, Food and Agricultural Organisation of the United Nations.

Inocencio, A., Kikuchi, M., Tonosaki, M., Maruyama, A., Merrey, D., Sally, H. and De Jong, I. 2007. Costs and performance of irrigation projects: A comparison of Sub-Saharan Africa and other developing regions. *IWMI Research Report*. Colombo, Sri Lanka: International Water Management Institute 109, p. 81.

IWMI (International Water Management Institute). 2016. *Irrigated Africa and Asia*. Colombo, Sri Lanka: IWMI. Available at: www.iwmi.cgiar.org/2016/02/irrigated-africa-and-asia/ (accessed 28 February 2022).

IWMI. 2019. Operationalizing farmer-led irrigation: Implementers dialogue. Available at: https://www.iwmi.cgiar.org/events/farmer-led-irrigation-development-fli-webinar-series/ (accessed 27 January 2021).

Izzi, G., Denison, J. and Veldwisch, G.-J. (Eds.). 2021. *The Farmer-Led Irrigation Development Guide: A What, Why and How-to for Intervention Design*. Washington, DC: World Bank.

Karimba, B. M., Duker, A., Prasad, P., Karimi, P., de Fraiture, C. and van der Zaag, P. 2022. Irrigation on the move: How transient farming partnerships facilitate the expansion of smallholder irrigation along ephemeral rivers in dryland areas of Kenya. *Agricultural Water Management* 265: 107526. https://doi.org/10.1016/j.agwat.2022.107526.

Kenya Government. n.d.a. Mwea irrigation scheme. Available at: https://www.irrigation.go.ke/projects/mwea-irrigation-scheme/ (accessed 22 January 2022).

Kenya Government. n.d.a. Tana irrigation scheme. Available at: https://www.irrigation.go.ke/projects/tana-irrigation-scheme/ (accessed 22 January 2022).

Keraita, B. and Cofie, O. O. 2014. Irrigation and soil fertility management practices. In: *Drechsel and Keraita*.

Komakech, H. C. and Van der Zaag, P. 2011. Understanding the emergence and functioning of river committees in a catchment of the Pangani basin, Tanzania. *Water Alternatives* 4(2): 197–222.

Komakech, H. C., Van der Zaag, P., Mul, M. L., Mwakalukwa, T. A. and Kemerink, J. S. 2012. Formalisation of water allocation systems and impacts on local practices in the Hingilili catchment, Tanzania. *International Journal of River Basin Management* 10(3): 213–227.

Komakech, H. C., Van der Zaag, P. and Van Koppen, B. 2012. Dynamics between water asymmetry, inequality and heterogeneity sustain canal institutions in Makanya catchment, Tanzania. *Water Policy* 14(5): 800–820.

Lankford, B. 2004. Irrigation improvement projects in Tanzania: Scale impacts and policy implications. *Water Policy* 6(2): 89–102.

Lankford, B. 2009. Viewpoint—The right irrigation? Policy directions for agricultural water management in sub-Saharan Africa. *Water Alternatives* 2(3): 476–480.

Lankford, B., van Koppen, B., Franks, T. and Mahoo, H. 2004. Entrenched views or insufficient science? *Agricultural Water Management* 69(2): 135–153.

Lankford, B. A. and Beale, T. 2007. Equilibrium and non-equilibrium theories of sustainable water resources management: Dynamic river basin and irrigation behaviour in Tanzania. *Global Environmental Change* 17(2): 168–180.

Lefore, N., Closas, A. and Schmitter, P. 2021. Solar for all: A framework to deliver inclusive and environmentally sustainable solar irrigation for smallholder agriculture. *Energy Policy* 154: 112313. https://doi.org/10.1016/j.enpol.2021.112313.

Mdee, A. and Harrison, E. 2017. Successful small-scale irrigation or environmental destruction? The political ecology of competing claims on water in the Uluguru Mountains, Tanzania. *Journal of Political Ecology* 24(1): 406–424. https://doi.org/10.2458/v24i1.20881.

Mdee, A. and Harrison, E. 2019. Critical governance problems for farmer-led irrigation: State capacity and institutional capability. *Water Alternatives* 12(1): 30–45.

Merrey, D. and Sally, H. 2017. Viewpoint: Another well-intentioned bad investment in irrigation: The Millennium Challenge Corporation's 'compact' with the Republic of Niger. *Water Alternatives* 10(1): 195–203.

Moris, J. R. and Thom, D. J. 1985. African irrigation overview: Summary. In: *Water Management Synthesis II Project*. Department of Agricultural and Irrigation Engineering, Utah State University.

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.

NEPAD (New Partnership for Africa's Development). 2003. *NEPAD*. Pretoria, South Africa: Comprehensive Africa Agriculture Development Program. Available at: http://www.nepad.org/foodsecurity/agriculture/land.

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

OECD and SWAC. 2020. *Africa's Urbanisation Dynamics 2020: Africapolis, Mapping a New Urban Geography, West African Studies*. Paris: OECD Publishing. https://doi.org/10.1787/b6bccb81-en.

Peters, P. E. and Kambewa, D. 2007. Social conflicts over access and transfer of land in Malawi and their implications for new land policy. *Journal of Modern African Studies* 45(3): 447–472.

Reij, C., Scoones, I. and Toulmin, C. (Eds.). 1996. *Sustaining the Soil: Indigenous Soil and Water Conservation in Africa*. London, UK: Earthscan Publications.

Richards, P. 1985. *Indigenous Agricultural Revolution: Ecology and Food Production in West Africa*. London, UK: Hutchinson.

Rockström, J., Barron, J. and Fox, P. 2003. Water productivity in rain-fed agriculture: Challenges and opportunities for smallholder farmers in drought-prone tropical agroecosystems. In: Kijne, J., Barker, R. and Molden, D. (Eds.), *Water Productivity in Agriculture: Limits and Opportunities for Improvement*. Wallingford, UK: CAB International, pp. 145–162.

Rockström, J., Karlberg, L., Wani, S. P., Barron, J., Hatibu, N., Oweis, T., Bruggeman, A., Farahani, J. and Qiang, Z. 2010. Managing water in rainfed agriculture – The need for a paradigm shift. *Agricultural Water Management* 97(4): 543–550.

SAFI. 2018. Policy brief: Farmer-led irrigation development and investment strategies for food security, growth and employment in Africa. Available at: http://www.safi-research.org/publications/farmer-led-irrigation-development-and-investment-strategies-for-food-security-growth-and-employment-in-africa/.

Soper, R. 2006. *The Terrace Builders of Nyanga*. Harare, Zimbabwe: Weaver Press.

Svendsen, S., Ewing, M. and Msangi, S. 2009. *Measuring Irrigation Performance in Africa*. IFPRI Discussion Paper 894. Washington, DC: International Food Policy Research Institute.

Tagseth, M. 2008. The expansion of traditional irrigation in Kilimanjaro, Tanzania. *The International Journal of African Historical Studies* 41(3): 461–490.

Underhill, H. 1984. *Small-Scale Irrigation in Africa in the Context of Rural Development*. Rome: Food and Agriculture Organization of the United Nations.

Uphoff, N. 1986. *Improving International Irrigation Management With Farmer Participation: Getting the Process Right*. Boulder, CO: Westview Press.

Veldwisch, G.-J., Venot, J.-P., Woodhouse, P., Komakech, H. and Brockington, D. 2019. Re-introducing politics in African farmer-led irrigation development: Introduction to a special issue. *Water Alternatives* 12(1): 1–12.

Veldwisch, G. J. and Woodhouse, P. 2022. Formal and informal contract farming in Mozambique: Socially embedded relations of agricultural intensification. *Journal of Agrarian Change* 22(1): 162–178.

Venot, J.-P. 2016. A success of some sort: Social enterprises and drip irrigation in the developing world. *World Development* 79: 69–81.

Venot, J.-P., Bowers, S., Brockington, D., Komakech, H., Ryan, C., Veldwisch, G. J. and Woodhouse, P. 2021. Below the radar: Data, narratives and the politics of irrigation in sub-Saharan Africa. *Water Alternatives* 14(2): 546–572.

Venot, J. P., de Fraiture, C. and Nti-Acheampong, E. 2012. Revisiting dominant notions: A review of costs, performance and institutions of small reservoirs in sub-Saharan Africa. *IWMI Research Report*. Colombo, Sri Lanka: IWMI, p. 144.

Vermillion, D. 2004. *Developing Water Users Associations for Small Dams and Fadama Areas in Nigeria*. Report to the Nigeria Country Programme of the FAO.

Wade, R. 1988. The management of irrigation systems: How to evoke trust and avoid prisoner's dilemma. *World Development* 16(4): 489–500.

Walsh, M. 2012. The not-so-Great Ruaha and hidden histories of an environmental panic in Tanzania. *Journal of Eastern African Studies* 6(2): 303–335.

Wiggins, S. and Lankford, B. 2019. Farmer-led irrigation in Sub-Saharan Africa: Synthesis of current understandings: DEGRP synthesis report. London: Foreign, Commonwealth and Development Office. Available at: https://odi.org/en/publications/farmer-led-irrigation-in-sub-saharan-africa-synthesis-of-current-understandings/.

Woodhouse, P. 2003. African enclosures: A default mode of development. *World Development* 31(10): 1705–1720.

Woodhouse, P., Bernstein, H. and Hulme, D. 2000. *African Enclosures? The Social Dynamics of Wetlands in Drylands*. Oxford: James Currey Publishers Ltd.

Woodhouse, P., Veldwisch, G. J., Venot, J.-P., Brockington, D., Komakech, H. and Manjichi, Â. 2017. African farmer-led irrigation development: Reframing agricultural policy and investment? *Journal of Peasant Studies* 44(1): 213–233. https://doi.org/10.1080/03066150.2016.1219719.

World Bank. 2009. *Awakening Africa's Sleeping Giant: Prospects for Commercial Agriculture in the Guinea Savannah Zone and Beyond*. Washington DC: The World Bank.

World Bank. 2011. *Africa's Future and the World Bank Strategy to Support It*. Washington, DC: The World Bank.

World Bank. 2021. Farmer-led irrigation: The what, why, and how-to guide. Available at: https://blogs.worldbank.org/water/farmer-led-irrigation-what-why-and-how-guide.

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 https://doi.org/10.1016/j.agwat.2013.08.011.

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. https://doi.org/10.1016/j.foodpol.2011.09.001.

Published by Burleigh Dodds Science Publishing Limited, 2023.