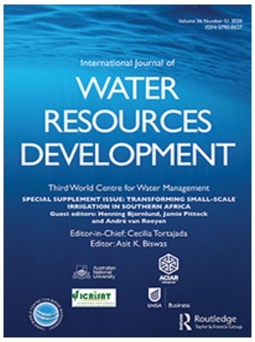

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Transforming failing smallholder irrigation schemes in Africa: a theory of change

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ABSTRACT
Drawing on the results of the Transforming Irrigation in Southern Africa project, we assess positive transitions in smallholder irrigation schemes. The project's theory of change is evaluated. Soil monitoring tools and agricultural innovation platforms were introduced in five irrigation schemes in Mozambique, Tanzania and Zimbabwe. The synergies between these interventions increased both crop yields and profitability. This empowered farmers, improved equity, and accelerated social learning and innovation. The resulting, iterative cycles of change improved governance, sustainability and socio-economic outcomes. The challenges of scaling these interventions up and out are outlined.

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Africa; agricultural innovation platforms; smallholder irrigation; social learning; soil-water monitoring; theory of change

Introduction

Smallholder irrigation schemes in sub-Saharan Africa (SSA) have performed badly and failed to lift farmers out of poverty, enhance food security or improve local or national economies. At the same time, limited land and water resources have been used inefficiently and contributed to environmental degradation and detracted from other opportunities for sustainable development.

Farmers across SSA have used agricultural production systems adapted to local biophysical and socio-economic conditions, and using agricultural water management, for several millennia (Bjornlund et al., 2020a, 2020b). These systems were disrupted during the precolonial activities of European traders and intensified under colonialism. This disrupted complex production systems – with multiple income and subsistence activities, managed by local communities – into centralized top-down production systems focused on a few export crops, which disconnected the local communities from the decision-making processes. The colonial governments controlled production and marketing, expatriating most of the benefits and leaving little for local development, neglecting the production of traditional crops, and resulting in poor nutrition. The impact of these disruptions has never been adequately addressed by later independent governments, largely due to forces outside their control. Hence, despite some early post-independence

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developments, agricultural production in SSA has continued to perform poorly compared to other developing regions (Bjornlund et al., 2020a, 2020b).

Africa is now facing the daunting challenge of feeding 1.5 billion people by 2030 and 2 billion by 2050 (NEPAD, 2003). Currently, an estimated 530 million people live in rural areas and depend primarily on rainfed agriculture with low yields. Yet irrigated agriculture in SSA is underdeveloped and has underperformed compared to other regions of the world.

FAO (2017) statistics suggest that around 6.3 million hectares in SSA were 'equipped' for agriculture in 2017, out of an estimated suitable area of 40 million hectares (You et al., 2011). Due to lack of data and for political reasons, these statistics are likely to greatly underestimate a range of farmer-led irrigation, using water diverted from mountain streams, shallow groundwater in valley bottoms, pumped irrigation from local water bodies, and peri-urban agriculture using waste water (Bjornlund et al., 2020b; Veldwisch et al., 2019; Woodhouse et al., 2017).

Governments and donors across Africa are investing in massive expansion of irrigated agriculture, assuming this will reduce poverty for smallholder farmers and increase food security (Sullivan & Pittock, 2014). However, irrigation in SSA has experienced many challenges, with i) irrigation failing to provide adequate return on investment; weak market integration and weak water governance institutions; and significant degradation and abandonment of irrigated land (Bjornlund et al., 2017; Stirzaker & Pittock, 2014). While there are real opportunities to expand the area under irrigation, we need to increase the physical and economic land and water productivity of existing schemes. Having learnt the lessons from the failures of the past, we can apply better practices in the design of new schemes and the refurbishment of old ones.

Irrigated agriculture may overcome many limitations to food security in Africa by enabling more reliable crop production under climate variability and change. To achieve this, the Transforming Irrigation in Southern Africa (TISA) project has two propositions. First, irrigation must be commercially focussed to generate sufficient profits to sustainably maintain the extensive water infrastructure and stop the cycle of decay, refurbishment, and decay (Stirzaker & Pittock, 2014). Second, enhanced market access for smallholder farmers is needed to create independence from governments and provide the incentives and confidence for farmers to innovate and expand the benefits from agriculture (van Rooyen et al., 2017).

This special issue presents research findings from the project Increasing Irrigation Water Productivity in Mozambique, Tanzania and Zimbabwe through On-Farm Monitoring, Adaptive Management and Agricultural Innovation Platforms, later renamed Transforming Irrigation in Southern Africa. The project was based on the premise that the transition from subsistence- to business-focussed farming is essential to maintain infrastructure for sustainable irrigation (Shah et al., 2002). To achieve this, it is critical to consider irrigation schemes as complex systems, where simple linear interventions will not result in sustained development, and working exclusively with farmers is insufficient. It is critical to identify the most effective leverage points in these systems to start the process of change at the scheme level and interact with higher political levels to support systemic change (van Rooyen et al., 2020).

In particular, this article evaluates the effectiveness of TISA's theory of change (ToC; Figure 1) in explaining research outcomes from the interventions made in five irrigation

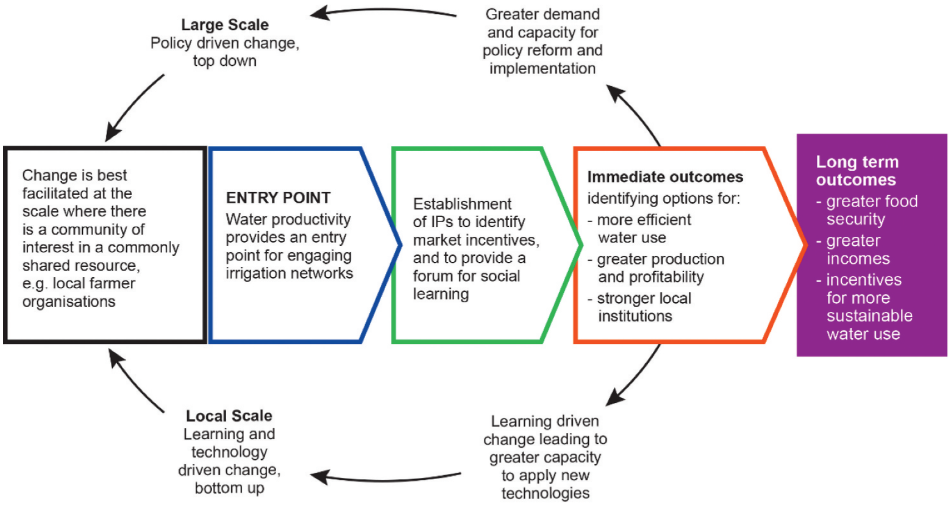

Figure 1. The 2013 theory of change for transforming smallholder irrigation schemes by setting them on a path of continuous improvement in profitability and sustainability (from Stirzaker & Pittock, 2014).

schemes in Mozambique, Tanzania and Zimbabwe in 2013–17. This evaluation draws on articles in this special issue and other project publications. A ToC has been defined as a logical sequence of changes that are anticipated to lead to a particular outcome, forming a pathway towards impact (Vogel, 2012). In a scoping process among research partners in 2012–13, the ToC for TISA was developed (Figure 1). Irrigation schemes are influenced by multiple stakeholders interacting across various scales. A successful ToC must articulate the roles and influence of important stakeholders like farmers, market agents and governments, as well as scales such as the farm plot, irrigation scheme and government jurisdiction, based on collaborative and iterative processes (Aragón et al., 2010; Vogel, 2012). The ToC emphasized that social learning by stakeholders working together would be crucial for influencing the system (Aragón et al., 2010).

Starting with water management as a key feature of irrigation schemes as systems, the ToC considered higher physical and economic water productivity as the entry point. However, physical water productivity was not initially seen by farmers as a major concern, and as shall be elaborated, other drivers of change in farmer behaviours were identified. The project utilized two separate interventions to investigate what leverage points could change farmer behaviours to transform schemes with continuous improvement for profitability and sustainability:

- soil monitoring tools for farmer learning around soil moisture and nutrient dynamics for more efficient decision-making with respect to water and fertilizer application; and
- agricultural innovation platforms (AIPs) to bring together irrigators and stakeholders to generate a vision for the scheme and identify barriers to higher profitability, actions to overcome them and who to best implement them.

Water productivity is a term that can be defined in several ways. Simplistically, agricultural 'water productivity is the ratio of the net benefits from crop [and other] systems to the amount of water used to produce those benefits' (Molden et al., 2010, p. 528). There are subsidiary definitions. Physical water productivity is the ratio of agricultural produce to the volume of water used. Economic water productivity is the value derived per unit of water consumed, and this value can be considered in monetary or other terms (Molden et al., 2010). In monetary terms, economic water productivity is synonymous with profitability. In our research we have applied both subsidiary definitions. Farmers have provided data on changes in physical productivity in the form of crop yield where, as a result of using soil monitoring tools, they have applied less water (such that this data are for both physical land and water productivity). To test our thesis that the irrigation schemes will only be sustainable if they are profitable, we have also considered economic productivity, drawing on farmers' data on their gross margins and incomes. Changes in profitability were particularly influenced by decisions to grow different crops and better engage the agricultural value chains as a result of AIP processes.

Further, in the water productivity equation, the denominator is expressed as either water supply or depletion (Molden et al., 2010). In this research we have used indirect supply measures, namely the number and duration of irrigation events, to judge field-level water consumption. This is because our interventions are intended to have maximum simplicity to empower farmers to apply, learn and innovate rather than seeking to measure every litre. In this context, we have sought to change water productivity at the farmer and irrigation scheme scale rather than engage the contested debates on basin-scale irrigation efficiency and return flows (Grafton et al., 2018).

Methods

The research takes TISA's 2013 ToC for transforming smallholder irrigation schemes (Figure 1; Stirzaker & Pittock, 2014) and begins by defining each of seven elements of change it contains. Each of these elements is then assessed to see whether by 2017 there was evidence of the hypothesized changes. The evidence is drawn from a number of sources. The deployment of soil monitoring tools with farmers from 2014 changed irrigation management practices at five schemes. AIP processes enabled farmers to engage regulators and other stakeholders in the agricultural value chain to innovate further. Foundational data is from household surveys conducted by TISA at the start of the research (2014) and four years later (2017) to assess changes in farming practices and the well-being of farm households at five irrigation schemes following TISA project interventions (Bjornlund et al., 2018; Chilundo et al., 2020; Mdemu et al., 2020; Moyo et al., 2020). More detailed, quantitative assessments of aspects such as changes in inequality (Manero et al., 2020), as well as qualitative assessments of AIP processes and changes in institutions, are also used to assess the extent of the changes (van Rooyen et al., 2020). Published research from this project, in this issue and elsewhere, is cited and provides more detailed descriptions of the methods. After assessing the elements of the ToC and the long-term outcomes, we consider whether these interventions can readily be scaled up and out to achieve beneficial changes.

Seven elements of the ToC

This assessment begins by defining the elements of change in the ToC.

Scale for facilitating change

We hypothesize that change is best facilitated at a scale where a common pool resource is managed by a community of interest, and there is the potential for or existence of institutions for cooperative management (Ostrom et al., 1999). In the case of irrigation schemes, the common resources include water supply and irrigation infrastructure. Each of the three countries had laws that gave local farmer organizations responsibilities and opportunities to manage these resources. The organizations have different names in different countries and in the academic literature, including 'irrigation associations', 'irrigation management organizations' and 'water user associations'. This project engaged with farmer organizations and relevant government agencies at six irrigation schemes in the three countries (Table 1).

Entry point for change facilitation

We proposed that water productivity was an entry point for change facilitation (Figure 1; Stirzaker & Pittock, 2014). Farmers were provided simple-to-use tools to measure soil moisture, fertility and salinity. Importantly, these tools were in the hands of the farmers, who had the opportunity to learn themselves how to best use their land and water to maximize crop production. This contrasts with the top-down agricultural extension model of information provision practiced in these countries. The tools were intended to provide data that could be used to generate agronomic benefits; farmer confidence in their own knowledge and skills; and community willingness to engage in more complex and longer-term change processes (Stirzaker et al., 2017).

AIPs and market incentives

We argued that the main reason that irrigation schemes were failing was the objective of food security through self-sufficiency, exacerbated by poorly developed markets, so that farming was barely profitable, if at all (Pittock et al., 2017; Stirzaker & Pittock, 2014). Consequently, farmers were paying high prices for inputs while receiving low prices for their produce. AIPs were proposed as a way for each farming community to identify their challenges and opportunities and develop a shared vision for their future. An AIP is a forum established to foster interaction among a group of relevant stakeholders around a shared interest. The stakeholders perform different but complementary roles in the development, dissemination and adoption of knowledge for socio-economic benefit. AIP processes seek to harness innovations related to technology and institutions. To promote these innovations, partnerships along and beyond agricultural value chains must be fostered to bring on board actors with a special mix of skills (Makini et al., 2013; van Rooyen et al., 2017). Typically these actors would include agricultural input suppliers or service providers, transport and storage service providers, and major produce buyers and processors. They may also include government and non-government experts in agronomy, business planning and regulation.

Table 1. Overview of the six TISA irrigation schemes.

Country/irrigation scheme	Area (ha)	Water source and access	Major crops	Average plot size per farmer (ha)	Farmer population	Farmers with tools (%)
Mozambique						
Associação de 25 Setembro, District of Boane, Maputo Province	40	River, pumped	Vegetables (cabbage, green beans, tomatoes), maize	1.0	38	68
Khanimambo, District of Magude, Maputo Province#	16	River, pumped	Vegetables, maize	0.59	27	0
Tanzania						
Kiwere, Iringa District, Iringa Region	194	River, gravity canal	Tomato, onions, leafy vegetables, green maize, rice	0.78	168	42
Magozi, Iringa District, Iringa Region	939	River, gravity canal	Rice, tomatoes, leafy vegetables	1.24	1,850	0*
Zimbabwe						
Mkoba, Vungu District	10	Dam, gravity canal	Maize, vegetables	0.11	75	35
Silalatshani, Insiza District	442^	Dam, gravity canal	Maize, wheat, sugar beans, groundnuts	0.41	845	24
Total	**1641**				**3003**	

#Irrigation infrastructure at Khanimambo was rendered inoperable by a flood, so research was not completed here.
* Magozi produces rice using flood irrigation, so soil moisture monitoring tools could not be used.
^ Research focussed in Landela, one of five blocks at the Silalatshani irrigation scheme.

Immediate outcomes

We hypothesized that once farmers experience immediate, positive outcomes it would raise confidence and interest, triggering a virtuous cycle of improvement. We expected the immediate outcomes to include more efficient water use, greater productivity, and strengthening of local organizations. Two self-reinforcing feedback loops were expected to be triggered as a result (Figure 1).

Local-scale learning

We postulated that the positive gains from initial interventions would give individual farmers and their organizations the confidence and skills to innovate further, resulting in higher agricultural productivity and more functional institutions and leading to more and more gains. If this occurs, identification and adoption of iterative innovations, and progressive increases in measures such as agricultural incomes, should take place (Stirzaker et al., 2017; van Rooyen et al., 2017).

Large-scale policy change

We proposed that the positive gains from initial interventions would give farmers the confidence and skills to demand more appropriate support services from government agencies, which in turn would change practices and provide better support for agricultural activities.

Long-term outcomes

From this virtuous cycle of change, we expected three key, long-term outcomes: more sustainable water use, greater food security and higher farm incomes.

Assessing the seven elements

Scale for facilitation of change

We proposed that change is best facilitated at a scale where there is a community of interest in a common pool resource: namely, the water supply for irrigation using scheme infrastructure. We found that the scale of impact differed between the soil monitoring tools and AIPs.

Soil monitoring tools

The number of soil monitoring tools distributed to farmers in a given scheme was determined by the availability of the tools in relation to the number of farmers. The various schemes received different proportions of soil monitoring tools (Table 1). The most important finding was that the learning by farmers with tools was high, leading to behavioural change, which soon spread to many farmers who did not have the tools, through farmer-to-farmer learning (Table 2; Parry et al., 2020). While the relationship between the number of soil monitoring tools in a scheme and the resulting changes varied from scheme to scheme (Table 2), we can say that as little as 24% tool ownership (Table 1), in combination with farmer-to-farmer learning, resulted in rapid change (in less than three years) in irrigation behaviour by at least two-thirds of the farmers in each scheme (Table 2). It is important to consider the incentives behind the reduction of irrigation frequency. That not irrigating one's plot saves significant time, and understanding that less irrigation reduces leaching of nutrients, are important drivers of changing irrigation intensity. Higher yields reinforce this learning and strengthen these feedback mechanisms. The outcome is higher physical water productivity, but since most farmers on gravity-fed canal systems are not paying for water by volume, saving water is not the primary driver of change.

It was critical that these behavioural changes empowered the farmers to change the institutions determining the timing of irrigation (van Rooyen et al., 2020). If farmers cannot influence the relevant authority to offer flexible water supply, then individual farmers reducing their water application may not result in larger-scale water savings. While this project significantly reduced water use, these results stimulate new research questions. Is there a ratio of minimum number of soil monitoring tool owners to non-owners that would enable more effective use of the tools? To what extent and at what speed will farmer-to-farmer learning from tool use continue to cause more and more farmers to change their behaviour? And what proportion of farmers will not change?

Agricultural innovation platforms

The scale at which AIPs focus their work is vital for success (van Rooyen et al., 2020). Focussing at a small scale (i.e. at the plot level of a few farmers) will not capture the larger system dynamics and the importance of stimulating production at the aggregate level; and small-scale change will not attract the interest of input and output markets. On the

Table 2. Change in irrigation schemes following Transforming Irrigation in Southern Africa project interventions, 2013–17.

	Irrigation scheme and country (%)				
Elements of change	25 Setembro, Mozambique	Kiwere, Tanzania	Magozi, Tanzania*	Mkoba, Zimbabwe	Silalatshani, Zimbabwe
Information					
Information needs had increased	74	77	89	n/a	n/a
Changes due to tools					
Knew what the Chameleon and WFD tools measured	93	n/a	n/a	86	70
Changed their irrigation practices	86	65	n/a	46	41
Changed their fertilization practices	68	74	n/a	67	32
Proportion of farmers with tools	47	n/a	n/a	35	24
Farmers who reduced the frequency of irrigation	85	40	n/a	60	65
Farmers who reduced the duration of each irrigation event	56	42	n/a	4	12
Yields and cropland					
Increased yields	313 (green maize)	28 (green maize)	29 (rice)	86 (% of farmers)	76 (% of farmers)
Households that changed practice and also increased yields	83	93	n/a	86	77
Farming previously unfarmed irrigated land (% yes)	n/a	91	86	n/a	n/a
Increased income	88 (farm)	94 (all)	63 (all)	43 (all)	56 (all)
Off-farm income better	60	55	43	47	49
Increased spending on farm inputs	61	93	86	64	65
Investment in farm implements	46	66	65	35	31
Spending increase on irrigation/scheme maintenance	18	31	49	28	48
Spending of extra income on food	67	62	54	52	36
Spending of extra income on education	61	20	19	68	55
Spending of extra income on health	61	14	18	n/a	n/a
Spending of extra income on investment in home	64	1	13	56	36
Maintenance and water allocation					
Participate more in scheme maintenance than four years ago	89	100	99	82	87
More willing/prepared to pay for water than four years ago	64	100	100	69	76
More able to pay for water than four years ago	79	98	99	61	79
The process of water allocation and use is fairer than four years ago	86	79	87	70	75
Reduction in conflict					
Within the household	n/a	89	88	68	70
Between farmers on the same canal	n/a	82	82	52	43
Between head-end and tail-end users	n/a	83	83	56	35
Between the scheme and other water users	n/a	89	82	52	35

* Tools were not used at Magozi, as they grow rice with flood irrigation.
Sources: Bjornlund et al. (2018), Chilundo et al. (2020), Mdemu et al. (2020), Moyo et al. (2020).

other hand, working at too large a scale may focus attention on larger market and support structures but lose the engagement of farmers. The appropriate scale is one which can capture the multitude of plot-level dynamics, while also attracting stakeholders from input and output markets, support services and local institutions that make the system function while generating sufficient pressure to convince a higher level of governance to make systemic changes.

Moreover, to ensure strong leverage, it is important to aim at a scale large enough to increase the footprint on the ground (i.e. maximize the number of farmers) while simultaneously working with the smallest number of actors at the higher levels of organization.

To evaluate or determine the best scale of the AIP, it is important to consider the functions of the AIP processes: removing barriers to production and improving access to markets to increase profitability, and facilitating communication and trust between stakeholders. Thus, the AIP should operate at a level where its actors represent a community of interest so it can form meaningful collaborations.

To reach the most farmers on the ground, TISA focused at the scheme level (or the block level in a very large scheme like Silalatshani), as this may be the smallest scale to engage without losing stakeholders at higher levels. The scheme is the operational unit for many actors and processes, including input suppliers (water, seeds, fertilizer, finance, information and farmer organizations) and output buyers and processors, decision-making and governance, scheme payments, and tenure management. How far can one go up the scale without losing touch with the base, and without including too many actors who may be irrelevant to one another? The scheme level proved to be appropriate, as our interventions did indeed cause systemic changes at higher levels of governance (Chilundo et al., 2020; Mdemu et al., 2020; Moyo et al., 2020; van Rooyen et al., 2020). In the very large scheme at Silalatshani, project interventions at one of five blocks were sufficient for government agencies to change water scheduling and cropping policies for the whole scheme.

Much of the higher-level governance systems operate at the district scale, influencing several schemes. Similarly, input and output markets may operate at this level, but the diversity of commodities produced may require the inclusion of a different range of value chain players.

This raises the question: What are the minimum conditions that allow niche-level innovations to break into the space of the regime (Geels, 2002)? In Zimbabwe, this was assisted by the government staff at higher levels becoming interested in the changes. Similarly, in Mozambique, the engagement of the Director of Irrigation facilitated the change process. In Tanzania, there was significant change at the district government scale, but frequent leadership changes in the National Irrigation Commission and a focus by funders on new irrigation schemes, in line with their approved sector support strategies, limited changes by national institutions.

Entry point

When intervening in complex systems such as irrigation schemes it is critical to carefully consider which entry point to use. It is particularly critical to consider the entry points that drive feedback mechanisms and institutional design, which leverage change in a range of other potential entry points to bring about systemic change. Van Rooyen et al. (2020) provide a discussion of this in the context of the TISA project.

As the project commenced, we found the need to slightly adapt the ToC. First, in the initial AIP meetings, it became apparent that in half of the schemes there were 'deal breaker' issues that needed to be resolved before farmers would effectively engage in the project. These issues are threshold levels from a regime systems perspective and were addressed first. Second, significant synergies between ToC elements 2 and 3 emerged. Simply using the term 'productivity' in element 2 fails to acknowledge that productivity can be measured in terms of yield (physical water productivity) or in monetary terms (economic water productivity) (Molden et al., 2010). Increased productivity was therefore split between elements 2 and 3, with physical productivity being the focus of element 2, while element 3 focused on converting higher physical productivity into higher economic productivity.

The deal breaker in Silalatshani was an unpaid water bill to the Zimbabwe National Water Authority (ZINWA), which was beyond the farmers' ability to pay and caused by the transfer of the debt from devaluated Zimbabwean dollars to US dollars. To force farmers to pay the bill, ZINWA stopped water delivery at critical stages of the growth season, and farmers saw their investment in inputs being lost; hence, those who could abandon the scheme in pursuit of other livelihood options did so. To address this, a ZINWA representative from Harare was invited to the first AIP meeting. It became clear to them that the scheme would never resume operations unless a solution was found. ZINWA then negotiated a payment structure with the farmers that enabled the project to proceed (Moyo et al., 2020, 2017).

In 25 Setembro in Mozambique and Magozi in Tanzania, the deal breaker was the condition of the supply infrastructure. In Mozambique, the poor quality of supply canals resulted in slow supply and high transmission losses. The water supply to tail-end users was uncertain and costly, as farmers had to buy diesel to run the pump until the water reached their plot. On the strength of the discussion at the first AIP meeting, the Mozambican government decided to fund the lining of the main canal, and farmers actively started to engage in the project (Chilundo et al., 2020; De Sousa et al., 2017). At the Magozi scheme in Tanzania, the AIP discussions facilitated enlargement of the intake and the water right (Mdemu et al., 2020, 2017). In these cases, engagement via the AIPs of scheme farmers identified elements of the socio-ecological systems that were at subcritical levels and enabled interventions to move to a more desirable state.

The two interventions, the soil monitoring tools and the AIPs, addressed different aspects of increasing yield and system efficiency. The tools facilitated farmer learning about soil moisture and nutrient dynamics (Parry et al., 2020; Stirzaker et al., 2017), which resulted in their (roughly) halving water application, better managing fertilizers and significantly increasing yield. Activities initiated by the AIP increased yield in two ways. First, it supported and accelerated the learning process, both for farmers with and without the soil monitoring tools, through test plots of higher yielding varieties, soil analysis for better fertilizer application, and focus groups to discuss the learning from the soil monitoring tools (Parry et al., 2020). Second, it connected farmers to providers of better-quality fertilizers, seeds and pesticides.

The combined impact of the two interventions significantly increased yield and had several additional benefits. It reduced the time farmers spent irrigating, leaving more time for other farm activities such as weeding, which reduced the competition for water and nutrients, further increasing yield. Many also invested the time in off-farm income activities that increased household income and the ability to buy high-quality inputs, further increasing yield. It also significantly reduced water use, increasing the supply for tail-end and downstream users. This substantially reduced conflicts over water use within the schemes, and in Tanzania also with downstream users. For further details, see Table 2 and Chilundo et al. (2020), Moyo et al. (2020), and Mdemu et al. (2020).

AIPs and market incentives

The AIP processes enhanced synergies between the technical and the soft interventions in TISA (van Rooyen et al., 2020). The common vision developed by each AIP provided everybody with a clear path for themselves. In multistakeholder processes, a commonly understood and accepted vision provides the framework for each stakeholder to determine their role and contribution to the success of the overall process. Those who may have acted to obstruct progress are often able to see how they can turn from villain to hero. Similarly, transparent processes allow all stakeholders to see who is holding the system back and stimulate otherwise unwilling actors into positive responses. Farmers found the visioning a powerful process and expressed the value of being able to dream and plan. Poorer farmers seldom have the luxury of reflecting on their current situation and future aspirations. Drawing this out on paper and accompanying it with a narrative of how to achieve these future states allow farmers time, often for the first time, to reflect and plan a possible future (van Rooyen et al., 2017).

While most problem analysis deciphers the technical interventions, the visioning exercise focuses on the processes required to reach the desired state. It is in this context that the AIPs identify opportunities for training, stimulate further learning, evaluate changes, adapt interventions and readjust future activities based on results. Some of the actions emerging from the AIP meetings could have been initiated by other institutions. For example, an agricultural extension agency could undertake gross margin analyses with farmers. However, the AIP process was powerful in increasing the legitimacy of decisions because it was undertaken by the farmers, and backed by key stakeholders, as part of a deliberate approach to achieve their vision for their community.

Soil monitoring tools were not used in the Magozi rice-growing scheme in Tanzania, which provides a case study where an AIP was the sole intervention. Magozi illustrates how major, systemic change can arise from an AIP visioning process, which was encapsulated in a community business plan. The key changes included successfully securing permission to divert more water to enable irrigation of a large part of the command area that could not be reliably supplied; agreeing to grow fewer, more profitable varieties to secure a high volume for sale and attract higher prices; improving agronomic practices; establishing a machinery hire cooperative; and building a rice mill for processing and a storehouse to enable sales at more profitable times (Mdemu et al., 2020). All these changes facilitated higher economic productivity. Water diversions increased from the Little Ruaha River, and we did not quantify water productivity. However, farmers report that their average rice yield increased by 29%, and gross margins increased by 22%, and 86% of farmers cropped previously untilled land within the irrigation command area (Mdemu et al., 2020). Nevertheless, Mdemu et al. (2020, p. 20) found that ‘while positive outcomes were still attained in Magozi, where only an AIP was implemented, there is some evidence from Kiwere that suggests outcomes are greater when both interventions are introduced together'.

The AIP's strongest influence in bringing about transformational change is its capacity to link relevant, but often distant, actors with one another such that they realize each other's relevance in their own business (van Rooyen et al., 2020). Over time, these linkages will strengthen to a point where external facilitation is no longer required to maintain the constellation of actors, and the AIP becomes redundant (see Figure 11 in Bjornlund et al., 2018).

Immediate outcomes

Positive outcomes from the soil monitoring tools plus AIP interventions were identified in all schemes (Chilundo et al., 2020, for Mozambique; Mdemu et al., 2020, for Tanzania; Moyo et al., 2020, for Zimbabwe) and are summarized in Table 2. Some of these changes were expected, but others were not.

Between 70% and 93% of farmers in each of the schemes that deployed soil monitoring tools knew what they measured, even though only 24–47% had soil monitoring installed in their fields. Subsequently, 41–86% of farmers reported changing their irrigation practices, and 32–74% changed fertilization practices. Notably, 40–85% of farmers reduced their frequency of irrigation, and 4–56% reduced the duration of irrigation events. Further, 61–93% spent more on farm inputs. Crop yields increased a lot – from a 28% increase in green maize at Kiwere to 313% in 25 Setembro (Table 2).

With greater profits from cropping, household income increased for 43–94% of farmers, and because of less time spent irrigating, 43–60% increased their off-farm income too (Table 2). A notable outcome was the improved livelihoods of the poorest farmers. Over the period of study, the incomes of the poorest sections of the farming population increased. At low levels of local economic growth the relative income inequality increased, but then it dropped as growth increased (Manero et al., 2020).

The changes observed are not linear, which is characteristic of complex systems. The initial entry points have created positive feedback, leading to continual improvement (Bjornlund et al., 2018; van Rooyen et al., 2020). There are several examples of immediate outcomes. Reducing the water applied to fields gave farmers at the tail end of canals enough water to grow crops, reducing conflict among farmers within the irrigation schemes by 64–83%. Together with a 64–100% increase in farmers' willingness to pay fees, this resulted in a 82–100% increase in farmers' willingness to engage in collective action such as infrastructure repair and bulk purchase of inputs, further improving irrigation profitability. Importantly, these changes are lifting farmers out of poverty, with most farmers reporting spending more on education, food, health, and farm development (Table 2).

Local-scale learning by farmers and their organizations

Training was only conducted if those being trained had an immediate opportunity to apply their new skills in their own context and would benefit from doing so, as this made behaviour change more likely. Feedback loops proved critical in sustaining change and link with complex adaptive systems (leverage points 7 and 8 for change as detailed in van Rooyen et al., 2020).

The soil monitoring tools were designed to produce data to facilitate farmer learning about the dynamics between water application and the fertility of their soil (leverage point 6, structured information flow in van Rooyen et al., 2020), and initiate a process of farmer-to-farmer learning to spread the impact beyond those having the soil monitoring tools in their fields. The AIP processes, through engaging and bringing together critical actors and initiating transparent processes, further facilitated farmer and farmer-to-farmer learning (Chilundo et al., 2020; Mdemu et al., 2020; Moyo et al., 2020; Parry et al., 2020). This included discussion of soil monitoring data in focus groups; gross-margin analysis to inform selection of more profitable crops; test plots where farmers experimented with different seeds, fertilizer application and irrigation techniques; and visits to other schemes to learn how to enhance governance (leverage point 4, system self-organization).

Collaborative mapping of the schemes (in Tanzania and Mozambique) illustrates the benefits of farmer learning triggering continuous improvement (Pittock et al., 2018). Through this transparent process, farmers learnt the exact area of each plot and the extent of scheme infrastructure and so understood the differences in their water fees and their maintenance responsibilities. This reduced conflict over payment of fees and increased participation in maintenance work (Table 2).

TISA interventions have improved equity, empowering more people to learn and contribute to their farming communities (Manero et al., 2020; Parry et al., 2020). There are signs of equity improvements with respect to women and youth involvement in farming. Women have been the most rapid adopters of high-value crops, and there has been a substantial shift from male-dominated to joint household decision making and more female decision making (Bjornlund et al., 2019). There is evidence of young people returning to profitable schemes. In Mozambique, unused irrigation plots were reallocated to young farmers (Chilundo et al., 2020).

Parry et al. (2020) analyze the learnings across all schemes and place them within a theoretical framework. What is evident is that given the opportunity to learn, gain experience in prioritizing and addressing their own issues, and adopt a more commercial farming mindset, farmers will continue to innovate. This became a virtuous feedback loop where innovation brought benefits that enabled further positive change, which occurred independent of governments. The implementation of the business plan developed by the Magozi farmers illustrates this confidence and independence.

Large-scale policy change by government

Particularly in Mozambique and Zimbabwe, governments have undertaken numerous policy changes that were informed by TISA, which are reported in this special issue and by Mwamakamba et al. (2017). For instance, project interventions at Silalatshani enabled production of a more diverse range of higher-value crops in place of mandated staple commodities. Based on this economic success, the Ministry of Agriculture no longer requires adherence to a cropping calendar, so farmers are free to innovate and produce more profitable crops (van Rooyen et al., 2020).

Perhaps more importantly, the project interventions have led to sub-national policy changes at the local to provincial scales (often by district governments), as illustrated at

Silalatshani by the agreement on how to resolve the water debt owed to ZINWA (described above and by Moyo et al., 2017). Our further hypothesis is that these local-to-provincial-scale governance innovations generate examples that may catalyze further national reforms in the future.

Long-term outcomes

There are reasons to believe that the interventions are sustainable in the long term. However, questions remain as to whether they can be scaled out ('horizontally') to other schemes and scaled up in terms of levels of governance and value chains to permanently change the broader irrigated agricultural systems.

Social learning has improved the confidence and changed the mindset of most farmers from subsistence towards commercial farming. Their practices have changed to negotiate favourable agreements in the value chain; use agricultural resources more efficiently; and select more valuable crops and higher-yielding varieties. The farmers have learned how to identify and prioritize problems and implement solutions. Higher profitability will drive further adoption and innovation, regardless of government involvement.

Autonomous out-scaling of innovations at the district scale is already evident. For example, starting from the Landela block of the Silalatshani scheme (where the soil monitoring tools were initially installed), agronomic practices were improved, and farmers in adjacent blocks and schemes started to grow more profitable crops. This out-scaling was driven by farmer-to-farmer learning, entrepreneurial agricultural extension staff, and the input supply and output buyers attracted to the Landela block.

The outcomes with respect to changes in government policy have been mixed. We hypothesized that government staff might have viewed the empowerment of farmers through project interventions as undermining their roles and status. To the contrary, farmer demand for technical information from agricultural extension staff increased with innovation (Table 2), and officers have expressed greater job satisfaction. The Zimbabwean government is collaborating in a new pilot to extend the project's interventions into nearly 30 public irrigation schemes in Matabeland North Province, mainstreaming new practices into the operations of the relevant agencies. If successful, further scale-up is proposed. The government has also informally adjusted several policies as a result of TISA, reducing water fees and allowing more flexible water supply and crop choices. Informed by the situation at 25 Setembro, the Mozambican government adopted new regulations for irrigation associations (Mwamakamba et al., 2017). The new regulations include measures to assign ownership and management to each piece of infrastructure; plan and budget for operations and maintenance of scheme infrastructure; and allow reassignment of unused irrigation plots to new farmers (Chilundo et al., 2020; van Rooyen et al., 2020). They are exploring adoption of project interventions into their major irrigation expansion programme. Despite strong district-government engagement, management instability in a key government agency has hindered up-scaling in Tanzania. Government fees and bureaucracy for importing the soil monitoring tools has significantly hindered tool deployment.

Can these interventions be scaled out and up?

This initial international research, soil monitoring tools and AIP project interventions cost AUD3.2 million (~USD2.2 million) over four years in irrigation schemes with ~3,000 farmers (Table 1). Are these complex adaptive system changes so attractive to value chain participants and governments that adoption will spread out and up in a cost-effective and self-sustaining manner? Research is funded to test this from 2017 to 2021; the initial results are mixed.

A sustainable business model for commercial production and access to soil monitoring tools is the focus of ongoing research and development in the Virtual Irrigation Academy project (https://via.farm/). During TISA the soil monitoring tools were provided free to farmers. Researchers provided follow-up service to deal with training and repair or replacement of damaged equipment. In a self-sustaining commercial system, there will be costs in tool manufacture, retailer supply and margins, farmer training and service provision. Abebe et al. (2020) found that farmers who experienced access to the soil monitoring tools in the pilot phase would be willing to pay only a portion of the manufacturing cost of the current prototype. Farmers may be willing to purchase soil monitoring tools collectively, depending on the commercial prices, or make a co-payment for subsidized access to tools.

Hence, there is a strong argument that the soil monitoring tools and AIP approach should be supported by the public sector. National governments and donors are investing very large sums in the establishment and rehabilitation of irrigation schemes. The minor additional costs of the provision of soil monitoring tools and institutions like AIPs are worthwhile to ensure that this investment succeeds. Further, the public interest in seeing poverty reduced, food security improved and scarce water resources used efficiently warrants subsidizing soil monitoring tools and AIPs. In this case, the additional functionality of wi-fi connectivity – which can collect and store soil moisture data semi-automatically from the latest model of Chameleon in the Virtual Irrigation Academy cloud platform – is likely to be necessary to provide a service to governments and other organizations. This would allow these organizations to monitor and improve the performance of the irrigation schemes they have funded.

However, the Virtual Irrigation Academy platform requires some manual uploading of information, such as crop type, yield, and gross margins. Our experience thus far is that farmers and extension staff enthusiastically make on-the-spot decisions with data from the soil monitoring tools, and generate the range of benefits discussed in this article. However, without incentives they will not reliably upload the data required for more systematic and aggregated analysis. Further work is required to identify how to sustainably provide such incentives.

The out- and up-scaling of AIPs raises other questions. It has been argued that AIPs require skilled and independent facilitators and should be context-specific (Makini et al., 2013). The costs of undertaking AIPs at each irrigation scheme would be prohibitive. In each of the communities involved in the project we found extension officers and farmers who had the required facilitation and leadership skills, and who also had the trust of the people to facilitate AIP processes (as well as some who did not). Government extension agencies will be critical as proponents of self-sustaining innovation systems, because they are mandated to do so and have some resources to undertake this work. However, extension staff will need to be aware of how to manage their roles as proponents of government policies, versus facilitators of AIP processes, where unorthodox ideas are welcomed. There is also a risk that the skilled extension staff will be promoted and not replaced.

TISA is testing whether the number of AIPs required can be minimized by out-scaling successful innovations from existing scheme-level AIPs to adjacent, similar irrigation schemes; or establishing AIPs at the district scale to involve multiple irrigation schemes with similar circumstances. As AIPs are scaled up, we will be assessing at what point it is best to engage and enhance an existing governance organization (e.g. a regional development committee) versus establishing a new AIP.

Conclusion

The agricultural water management research in SSA presented in this special issue shows that application of simple-to-use soil monitoring tools provided critical information for farmer learning. The AIP processes reinforced this learning and innovation by connecting farmers to input and output markets, which enabled the rules of the irrigation systems to be changed. Together, these interventions fostered the development of positive feedback loops in the complex irrigation systems. They demonstrate that multiple interventions are required to transition failing irrigation systems towards a sustainable and profitable state. The failures of irrigation in Africa can be largely ascribed to the central control exerted by governments, whose goals and objectives often do not align with the needs of irrigation communities.

Learning was a critical contributor to the project's impacts. Individual farmers learnt by holding soil monitoring tools in their hands and making immediate and informed decisions. This led to experimentation and further adaptation, such as reducing application of water. At other scales, farmer organizations and local governments learnt, as did extension officers and government officials, leading to systemic changes.

We conclude that the ToC based on water productivity, measured in terms of both yield and profits, as an entry point has largely worked. Specifically, changing the irrigation paradigm from subsistence to commercial-oriented production has created a profit-driven virtuous cycle of change. This has been reinforced by farmers applying pressure on government agencies for policy change, leading to improved sustainability and socio-economic outcomes.

We are not arguing that this combination of soil monitoring tools and AIPs is essential to improve irrigation scheme performance in every instance. In the case of the Magozi rice scheme in Tanzania, significant improvements in crop yield and profitability were obtained without the soil monitoring tools. We did not test the use of tools in other institutional settings, such as out-grower schemes, but we expect this could result in similar socio-economic benefits without AIPs. We do, however, find that there were positive synergies where the soil monitoring tools and AIPs were deployed together.

This research found benefits from multiple interventions to strengthen farmers' problem-solving skills and market development. In particular, the social and economic value arising from the synergies among AIPs, soil monitoring tools and scheme mapping was demonstrated.

TISA has developed the capacity of a range of local actors to engage in adaptive processes for more productive irrigation schemes through their institutions, replacing central control with more collaborative governance. Future projects for more sustainable irrigation need to consider where power lies and who makes the decisions, in order to empower those affected to contribute their knowledge and innovations.

New research is needed to assess/test how measures from TISA can be scaled out and up in a cost-effective manner with support from government agencies. In the 2017–2021 phase of the project the ToC has been revised to hypothesize how reform can be catalyzed at different scales. In particular, the next level of research and application is across the irrigation sector at the district scale (subnational district, province or county). There is also a need to understand how to further enable national irrigation agencies to apply lessons to enhance policies and practices.

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References

Abebe, F., Wheeler, S., Zuo, A., Bjornlund, H., Chilundo, M., Mdemu, M., & van Rooyen, A. (2020). Irrigators' willingness to pay for the access to soil moisture monitoring tools in South Eastern Africa. *International Journal of Water Resources Development, 36*(S1), S246–S267. https://doi.org/10.1080/07900627.2020.1755956

Aragón, A. O., Macedo, G., & Carlos, J. (2010). A 'Systemic theories of change'approach for purposeful capacity development. *IDS Bulletin*, *41*(3), 87–99. https://doi.org/10.1111/j.1759-5436.2010.00140.x

Bjornlund, H., Parry, K., Pittock, J., Stirzaker, R., van Rooyen, A., Moyo, M., Mdemu, M., de Sousa, W., Cheveia, E., Munguambe, P., Kimaro, E., Kissoly, L., Chilundo, M., Zuo, A., & Ramshaw, P. (2018). Transforming smallholder irrigation into profitable and self-sustaining systems in southern Africa.

In K Water and IWRA (Eds.), *Smart water management* (pp. 330–387). Korean Water Resources Corporation and International Water Resources Association.

Bjornlund, H., van Rooyen, A., & Stirzaker, R. (2017). Profitability and productivity barriers and opportunities in small-scale irrigation schemes. *International Journal of Water Resources Development*, *33*(5), 690–704.

Bjornlund, H., Zuo, A., Wheeler, S., Parry, K., Pittock, J., Mdemu, M., & Moyo, M. (2019). The dynamics of the relationship between household decision-making and farm household income in small-scale irrigation schemes in southern Africa. *Agricultural Water Management*, *213*, 135–145. https://doi.org/10.1016/j.agwat.2018.10.002

Bjornlund, V., Bjornlund, H., & van Rooyen, A. (2020a). Why agricultural production in Sub-Saharan Africa remains low compared to the rest of the world: A historical perspective. *International Journal of Water Resources Development, 36*(S1), S20–S50. https://doi.org/10.1080/07900627.2020.1739512

Bjornlund, V., Bjornlund, H., & van Rooyen, A. (2020b). Exploring the factors causing the poor performance of most irrigation schemes in post-independence sub-Saharan Africa. *International Journal of Water Resources Development, 36*(S1), S54–S101. https://doi.org/10.1080/07900627.2020.1808448

Chilundo, M., de Sousa, W., Christen, E., Faduco, J., Bjornlund, H., Cheveia, E., Munguambe, P., Jorge, F., Stirzaker, R., & van Rooyen, A. (2020). Do agricultural innovation platforms and soil moisture and nutrient monitoring tools improve the production and livelihood of smallholder irrigators in Mozambique? *International Journal of Water Resources Development, 36*(S1), S127–S147. https://doi.org/10.1080/07900627.2020.1760799

de Sousa, W., Ducrot, R., Munguambe, P., Bjornlund, H., Cheveia, E., & Faduco, J. (2017). Irrigation and crop diversification at 25 de Setembro irrigation scheme, Mozambique. *International Journal of Water Resources Development*, *33*(5), 705–724. https://doi.org/10.1080/07900627.2016.1262246

FAO. (2017). *FAO stat land use*. Food and Agriculture Organisation of the United Nations.

Geels, F. W. (2002). Technological transitions as evolutionary reconfiguration processes: A multi-level perspective and a case-study. *Research Policy*, *31*(8), 1257–1274. https://doi.org/10.1016/S0048-7333(02)00062-8

Grafton, R. Q., Williams, J., Perry, C. J., Molle, F., Ringler, C., Steduto, P., Udall, B., Wheeler, S. A., Wang, Y., Garrick, D., & Allen, R. G. (2018). The paradox of irrigation efficiency. *Science*, *361*(6404), 748–750. https://doi.org/10.1126/science.aat9314

Makini, F. W., Kamau, G. K., Makelo, M. N., Adekunle, W., Mburathi, G. K., Misiko, M., Pali, P., & Dixon, J. (2013). *Operational field guide for developing and managing local agricultural innovation platforms*. KARI, ACIAR, AusAID.

Manero, A., Bjornlund, H., Wheeler, S., Zuo, A., van Rooyen, A., Mdemu, M., van Rooyen, A., & Chilundo, M. (2020). Growth and inequality at the micro scale: An empirical analysis of farm incomes within smallholder irrigation systems in Zimbabwe, Tanzania and Mozambique. *International Journal of Water Resources Development, 36*(S1), S224–S245. https://doi.org/10.1080/07900627.2020.1811959

Mdemu, M., Kissoly, L., Bjornlund, H., Kimaro, E., Christen, E., van Rooyen, A., Stirzaker, R., & Ramshaw, P. (2020). The role of soil water monitoring tools and agricultural innovation platforms in improving food security and income of farmers in smallholder irrigation schemes in Tanzania. *International Journal of Water Resources Development, 36*(S1), S148–S170. https://doi.org/10.1080/07900627.2020.1765746

Mdemu, M., Mziray, N., Bjornlund, H., & Kashaigili, J. (2017). Productivity barriers and opportunities at the Kiwere and Magozi irrigation schemes in Tanzania. *International Journal of Water Resources Development*, *33*(5), 725–739. https://doi.org/10.1080/07900627.2016.1188267

Molden, D., Oweis, T., Steduto, P., Bindraban, P., Hanjra, M. A., & Kijne, J. (2010). Improving agricultural water productivity: Between optimism and caution. *Agricultural Water Management*, *97*(4), 528–535. https://doi.org/10.1016/j.agwat.2009.03.023

Moyo, M., van Rooyen, A., Bjornlund, H., Parry, K., Stirzaker, R., Dube, T., & Maya, M. (2020). The dynamics between irrigation frequency and soil nutrient management: Transitioning small-scale irrigation towards more profitable and sustainable systems in Zimbabwe. *International Journal of Water Resources Development, 36*(S1), S102–S126. https://doi.org/10.1080/07900627.2020.1739513

Moyo, M., van Rooyen, A., Moyo, M., Chivenge, P., & Bjornlund, H. (2017). Irrigation development in Zimbabwe: Understanding productivity barriers and opportunities at Mkoba and Silalatshani irrigation schemes. *Journal of Water Resources Development*, *33*(5), 740–754. https://doi.org/10.1080/07900627.2016.1175339

Mwamakamba, S. N., Sibanda, L. M., Pittock, J., Stirzaker, R., Bjornlund, H., van Rooyen, A., Munguambe, P., Mdemu, M. V., & Kashaigili, J. J. (2017). Irrigating Africa: Policy barriers and opportunities for enhanced productivity of smallholder farmers. *International Journal of Water Resources Development*, *33*(5), 824–838. https://doi.org/10.1080/07900627.2017.1321531

NEPAD. (2003). *Comprehensive Africa Agriculture Development Programme*. New Program for Africa's Development. African Union Development Agency.

Ostrom, E., Burger, J., Field, C. B., Norgaard, R. B., & Policansky, D. (1999). Revisiting the commons: Local lessons, global challenges. *Science*, *284*, 278–282. https://doi.org/10.1126/science.284.5412.278

Parry, K., van Rooyen, A., Bjornlund, H., Kissoly, L., Moyo, M., & de Sousa, W. (2020). The importance of learning processes in transitioning small-scale irrigation schemes. *International Journal of Water Resources Development, 36*(S1), S199–S223 https://doi.org/10.1080/07900627.2020.1767542

Pittock, J., Bjornlund, H., Stirzaker, R., & 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. https://doi.org/10.1080/07900627.2017.1324768

Pittock, J., Ramshaw, P., Bjornlund, H., Kimaro, E., Mdemu, M. V., Moyo, M., Ndema, S., van Rooyen, A., Stirzaker, R., & de Sousa, W. (2018). *Transforming smallholder irrigation schemes in Africa: A guide to help farmers become more profitable and sustainable*. (ACIAR Monograph No. 202). Australian National University and Australian Centre for International Agricultural Research.

Shah, T., van Koppen, B., Merrey, D., de Lange, M., & Samad, M. (2002). *Institutional alternatives in African smallholder irrigation: Lessons from international experience with irrigation management transfer*. International Water Management Institute.

Stirzaker, R., Mbakwe, I., & 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. https://doi.org/10.1080/07900627.2017.1320981

Stirzaker, R., & Pittock, J. (2014). The case for a new irrigation research agenda for sub-Saharan Africa. In J. Pittock, R. Q. Grafton, & C. White (Eds.), *Water, food and agricultural sustainability in Southern Africa* (pp. 91–107). Tilde University Press.

Sullivan, A., & Pittock, J. (2014). Agricultural policies and irrigation in Africa. In J. Pittock, R. Q. Grafton, & C. White (Eds.), *Water, food and agricultural sustainability in Southern Africa* (pp. 30–54). Tilde University Press.

van Rooyen, A., Moyo, M., Bjornlund, H., Dube, T., Parry, K., & Stirzaker, R. (2020). Identifying leverage points to transition dysfunctional irrigation schemes towards complex adaptive systems. *International Journal of Water Resources Development, 36*(S1), S171–S198. https://doi.org/10.1080/07900627.2020.1747409

van Rooyen, A. F., Ramshaw, P., Moyo, M., Stirzaker, R., & 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. https://doi.org/10.1080/07900627.2017.1321530

Veldwisch, G. J., Venot, J.-P., Woodhouse, P., Komakech, H., & Brockington, D. (2019). Re-introducing politics in African farmer-led irrigation development: Introduction to a special issue. *Water Alternatives*, *12*(1), 1–12. http://www.water-alternatives.org/index.php/alldoc/articles/vol12/v12issue1/475-a12-1-1

Vogel, I. (2012). *ESPA guide to working with theory of change for research projects*. Ecosystem Services for Poverty Alleviation Programme.

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

You, L., Ringler, C., Wood-Sichra, U., Robertson, R., Wood, S., Zhu, T., Nelson, G., Guo, Z., & Sun, Y. (2011). What is the irrigation potential for Africa? A combined biophysical and socioeconomic approach. *Food Policy*, *36*(6), 770–782. http://dx.doi.org/10.1016/j.foodpol.2011.09.001