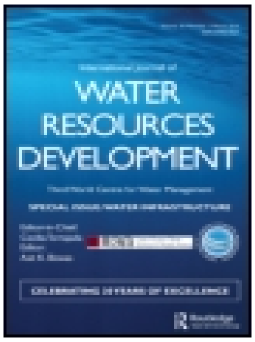


International Journal of Water Resources Development

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/cijw20

# 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

M. Mdemu , L. Kissoly , H. Bjornlund , E. Kimaro , E. W. Christen , A. van Rooyen , R. Stirzaker & P. Ramshaw

**To cite this article:** M. Mdemu , L. Kissoly , H. Bjornlund , E. Kimaro , E. W. Christen , A. van Rooyen , R. Stirzaker & P. Ramshaw (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, DOI: 10.1080/07900627.2020.1765746

**To link to this article:** https://doi.org/10.1080/07900627.2020.1765746



Published online: 30 Jun 2020.

INTERNATIONAL JOURNAL OF WATER RESOURCES DEVELOPMENT
https://doi.org/10.1080/07900627.2020.1765746



# 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

M. Mdemu[a], L. Kissoly[b], H. Bjornlund[c], E. Kimaro[a], E. W. Christen[d], A. van Rooyen[e], R. Stirzaker[f] and P. Ramshaw[g]

[a]School of Spatial Planning and Social Sciences, Ardhi University, Dar es Salaam, Tanzania; [b]Department of Economics and Social Studies, Ardhi University, Dar es Salaam, Tanzania; [c]School of Commerce, University of South Australia, Adelaide; [d]Penevy Services Ltd, New South Wales, Australia; [e]International Crops Research Institute for Semi-arid Tropics, Bulawayo, Zimbabwe; [f]Commonwealth Scientific and Industrial Research Organization, Canberra, Australia; [g]Fenner School of Environment and Society, Australian National University, Canberra

**ABSTRACT**

Smallholder irrigation is an important pathway towards better livelihoods and food security in sub-Saharan Africa. This article assesses the contribution of farmer-friendly soil and water monitoring tools, and agricultural innovation platforms, towards household income and food security in two small-scale irrigation schemes in Tanzania. Quantitative and qualitative data from farmer's field books, household surveys and focus groups were used to assess the impacts of the two interventions. The two interventions together contributed to enhancing smallholders' food security and household income in the two schemes, as did the agricultural innovation platform on its own.

**ARTICLE HISTORY**
Received 17 October 2019
Accepted 3 May 2020

**KEYWORDS**
Smallholder irrigators; monitoring tools; agricultural innovation platforms; food security; income; Tanzania

## Introduction

Food and nutrition security continue to be at the top of the development agenda for Tanzania, where smallholder farming provides over 70% of the food supply (Reincke et al., 2018). Development of this sector is regarded as an important pathway towards improving the livelihoods of rural households, and irrigation is given a high priority as a way of achieving these outcomes (Mdemu et al., 2017). This is consistent with the general expectations for developing countries, where strengthening small-scale irrigation schemes has been identified as having significant potential for enhancing agricultural productivity, improving food security and incomes, and reducing poverty (Burney & Naylor, 2012; De Fraiture & Giordano, 2014; Wichelns, 2014).

However, efforts to improve irrigation productivity and profitability in small-scale irrigation schemes in Tanzania are hampered by multiple barriers, including inadequate water availability and inequitable distribution of water between head-end, middle and tail-end users; poor access to quality inputs, financing and output markets; inadequate

**CONTACT** M. Mdemu mak_mdemu@yahoo.co.uk

This article was originally published with errors, which have now been corrected in the online version. Please see Correction (http://dx.doi.org/10.1080/07900627.2020.1791407)

access to good agronomic practices; and weak irrigator organizations (IOs) (Mdemu et al., 2017; Nkhoma, 2011). Consequently, most schemes have failed to deliver the expected outcomes (Mdemu et al., 2017; Pittock et al., 2017). Such failures have prompted researchers and decision makers to recognize irrigation schemes as complex systems that require multiple and simultaneous interventions to improve their sustainability and contribute to productivity and profitability (Denison & Manona, 2007; Pittock et al., 2017; Van Rooyen et al., 2020). Makoi and Matekere (2018) observed that the development of small-scale irrigation, where it is led by farmers, is constrained by the slow pace of implementation of relevant policies and regulations, as well as inadequate capacity and participation of the private sector.

This article reports on two interventions introduced as part of the research-for-development project Increasing Irrigation Water Productivity in Mozambique, Tanzania and Zimbabwe through on-Farm Monitoring, Adaptive Management and Agricultural Innovation Platforms, subsequently renamed Transforming Irrigation in Southern Africa. This project aims to increase irrigation water productivity and profitability, and the focus in this article is the Kiwere and Magozi small-scale irrigation schemes in Iringa District, Tanzania.

This article assesses the ability of the two interventions, soil water and nutrient monitoring tools and agricultural innovation platforms (AIPs), to improve food security and household income in the two schemes. The finding also contributes to understanding of the strategies required to increase the effectiveness of the national irrigation policy. As the tools were only provided to one scheme, this article also compares the impact of both interventions introduced simultaneously and the use of the AIP alone.

The article first provides an overview of irrigation development in Tanzania, followed by a description of the study area, the data collected and the two interventions. It then discusses the actions taken through the AIP approach and analyzes how the interventions have changed irrigation and other farm management practices and how these changes have influenced yield, water supply, and water use conflicts. Finally, the article illustrates how these changes have influenced household income and food security.

## Irrigation development in Tanzania

The total land area suitable for irrigation development in Tanzania is 29.4 million ha, of which 2.3 million is of high potential, 4.8 million of medium potential, and 22.3 million of low potential (JICA & MAFC, 2002; United Republic of Tanzania [URT], 2010). Only about 460,000 ha are currently supplied by improved irrigation infrastructure (constructed intake and lined main canal) (Oates et al., 2017; URT, 2014). This low level of irrigation development is typical in most countries in sub-Saharan Africa (You et al., 2010). For Tanzania, this situation is largely attributed to the poor performance of earlier investments in the irrigation sector. Initial phases of irrigation development in the 1960s were comprised of large state-managed schemes for food security and for commercial purposes. However, these schemes performed dismally, due to factors including poor management, unprofitability, inadequate access to input and output markets, and reliance on government support (Inocencio et al., 2007; Mdemu et al., 2017; Rosegrant & Perez, 1997). Hence, poor maintenance and dilapidated infrastructure characterized most schemes towards the end of the 1990s (Kadigi et al., 2012).

The poor performance of the large state-managed irrigation schemes led in the late 1990s to a shift in emphasis towards farmer-managed, small-scale irrigation schemes. The focus was on scheme modernization through enhancing institutional capacity, engaging communities and improving water intakes (World Bank, 1996). However, various barriers have inhibited their development into productive and profitable systems. For large schemes, the barriers included incomplete irrigation infrastructure; poor governance; and non-water-related barriers such as poor access to farm inputs, information and finance, and inadequate knowledge of crop production, storage and marketing (Mdemu et al., 2017).

Cognizant of the challenges, the National Irrigation Policy of 2010 highlights critical issues for irrigation development: increased investment and effective management; enhanced role of the private sector; sustainable utilization of land and water resources; and reliable and sustainable crop production (URT, 2010). Further, the policy clearly stresses the critical role of irrigation development to enhance food security and reduce poverty through increased productivity and sustainable crop production. There have been positive institutional developments, with the National Irrigation Act (2013) and its Regulation (2015), and the National Irrigation Commission in 2012. However, progress towards investment and physical development of irrigation, including attracting the private sector, is trailing below national targets (Makoi & Matekere, 2018). The institutional framework is also not fully operational in all schemes. While these developments are commendable, the critical question of *how* to achieve these goals remains unanswered. This article contributes to answering this 'how' question.

## Study area, interventions and data collection

### *Study area and schemes*

The Kiwere and Magozi irrigation schemes were selected for this study based on their potential to improve agronomic practices, institutional capacity of the IOs, market access, physical accessibility, crop diversity, and the willingness of district authorities to collaborate and offer support to the project (Mdemu et al., 2017). The two schemes are in two different agro-ecological zones of the Iringa District (Figure 1). Kiwere is in the highland agro-ecological zone, which has a mountainous and undulating topography. The scheme's altitude varies from 1292 to 1340 metres above sea level (masl), with mean rainfall and mean temperature of 700 mm and 15 °C, respectively. Magozi is in the lowland agro-ecological zone, with relatively flat landforms at an altitude of 757–766 masl, mean rainfall of 600 mm, and mean temperature of 25 °C (Mziray et al., 2015).

Both schemes were constructed between 2005 and 2007. Kiwere was funded by the Japanese International Cooperation Agency and community efforts, while the Anglican Church, Participatory Agriculture Development Project, District Irrigation Development Fund and community efforts funded Magozi. The estimated direct cost (excluding community labour and local construction materials) of constructing the intakes and the partially lined primary canals was USD334/ha and USD142/ha for Kiwere and Magozi, respectively. The Kiwere and Magozi schemes are managed by the Tupendane and Mkilma IOs, respectively. The former has members from the villages of Kiwere and

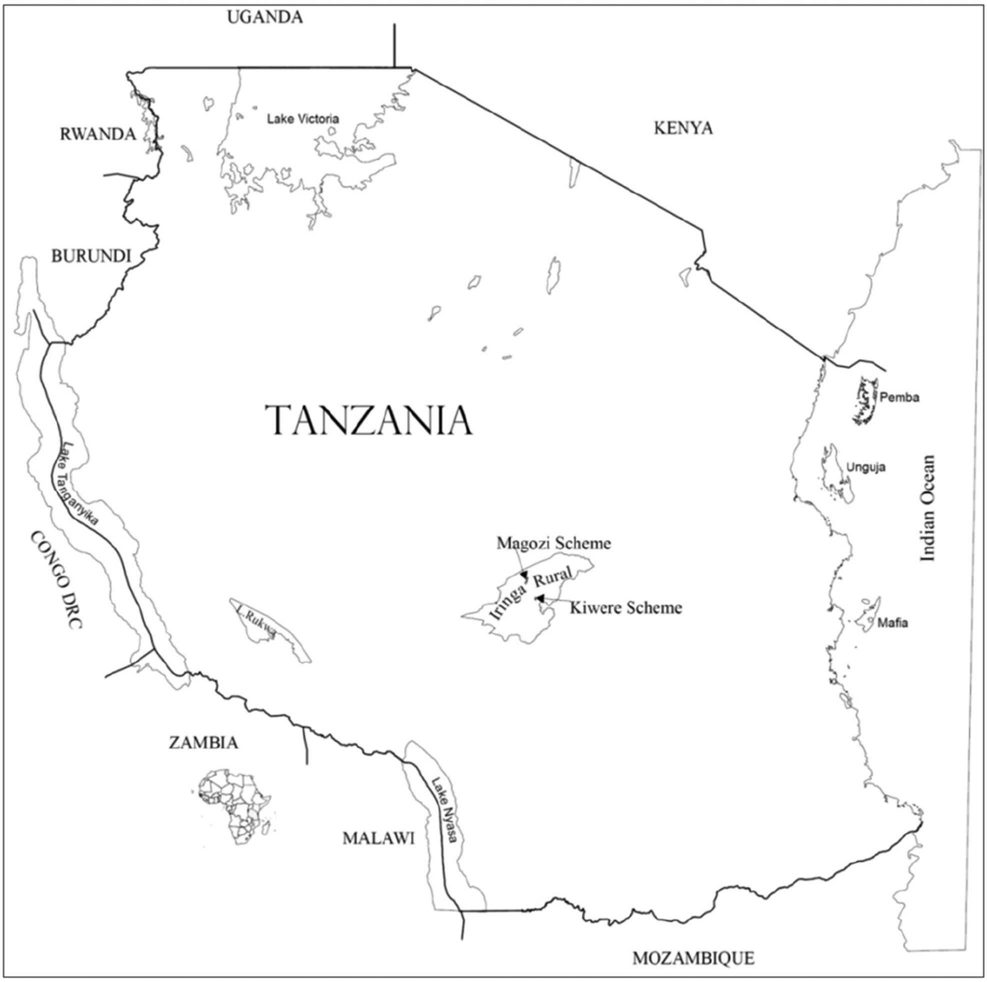


**Figure 1.** Location of Kiwere and Magozi irrigation schemes (Source: Ardhi University, 2015).

Mgela, while the later has members from the villages of Mkombilenga, Ilolo-Mpya and Magozi.

Both schemes derive their water from the Little Ruaha River, which is part of the Great Ruaha River catchment in the Rufiji Basin. In both schemes, water is supplied through a sluice gate and canal system, of which only small sections are lined. IOs are responsible for planning and managing water distribution and scheduling. In Kiwere, water scheduling is organized according to plot location: tail-end users get water from 6:00 am to 12:00 noon, and from noon to 6:00 pm water is used by middle and upstream farmers. In Magozi, where water is supplied through a primary canal, scheduling is mainly used when the flow of water is low: during February to March, when there is no rainfall. Payments for the use of water are calculated per acre: Kiwere farmers are charged TZS30,000 per acre per crop season, while Magozi farmers pay TZS20,000 per acre per year. Magozi farmers have only one crop season in a year.

**Table 1.** Key characteristics of the irrigation schemes (adapted from Mziray et al., 2015).

| Characteristic | Kiwere | Magozi |
|---|---|---|
| Year constructed | 2005–07 | 2005–07 |
| Water source | Little Ruaha River | Little Ruaha River |
| Type of scheme | Small scale | Small scale |
| Number of members in irrigation organization | 168 | 503 |
| Number of farmers | 168 | 512 |
| Irrigated area (ha) | 195 | 939 |
| Mean irrigated area per household (ha) | 0.97 | 1.80 |
| Mean number of cattle | 1.4 | 4.2 |
| Soils | Red loam and clay soils | Expansive clay soils |
| Main crops | Tomato, onion, green maize, leafy vegetables/ beans | Rice |

At the schemes, households are involved in a variety of income-generating activities with engagement in farmwork being dominant (Table 1). Magozi farmers depend on seasonal irrigation of rice between December and May. This is in addition to rainfed farming, in which drought-tolerant crops such as sorghum and millet are cultivated. Irrigated crop income is dominant in Magozi. Kiwere farmers irrigate their main crops, including green maize, tomatoes, onions, green pepper and beans, year-round. Despite the dependence on irrigated farming, the higher altitude and precipitation enable rainfed cultivation to make a significant contribution to total income in Kiwere. In addition, households engage in off-farm work, such as agricultural labour and small businesses.

## The interventions

### Soil moisture and nutrient monitoring tools

Wetting front detectors (WFDs) and Chameleon soil moisture sensors and readers were used in the project. The WFD is a funnel-shaped device which is buried in the soil (Stirzaker et al., 2010; Stirzaker, 2003). As water infiltrates the soil a wetting front is formed, which is the boundary between wet soil above and dry soil below. The speed at which the wetting front moves down the soil profile depends on the initial soil moisture content and the amount of water being applied. When the wetting front reaches the detector, water collects in the funnel, and when sufficient water is collected an above-ground indicator pops up to show that a water sample is ready for extraction using a syringe and rubber hose. This sample is then analyzed for electrical conductivity using a field meter, and nitrate content using a simple colour test. This informs the farmer of the levels of salinity and nitrate in the soil, to monitor them over time, and to observe changes in response to irrigation water management. The tool, thus informs the farmer of the depth to which water has infiltrated into the soil during and after irrigation or rainfall. Two WFDs were installed in each plot, one in the middle of the root zone and another at the bottom of the root zone. This facilitates farmer learning about the dynamics of water and nutrient leaching through the soil profile.

The Chameleon soil moisture sensor uses three sensors that measure soil tension, the force a plant needs to use to extract moisture from the soil (Stirzaker et al., 2017). This negates the need to calibrate the equipment for different soil types. The sensors are permanently buried in the ground at different depths. A portable handheld reader connects to the sensor array and displays the soil moisture as coloured lights (blue for wet, green for moist, red for dry), providing a picture of soil moisture at different depths throughout the root zone. Thus, the Chameleon lets farmers decide whether to irrigate depending on the coloured lights and the condition of the crop. Detailed description of the tools including their technical aspects, can be found at the Virtual Irrigation Academy website (https://via.farm/).

Chameleon sensors and WFDs were installed on 20 farmers' plots at Kiwere from July 2014 and monitored over eight cropping seasons. Not all 20 plots had the tools installed at once, and installation timing was dictated by the start of cropping activities, which depended on access to capital by the individual farmers and other factors, such as types of crops planted. Ten of the 20 farmers consistently monitored their tools during the study period. The scheme's extension officer or the secretary of the IO recorded soil moisture, nitrate levels and electrical conductivity. Initially, data were collected from the tools once a week, and from July 2015 twice a week. The data were communicated directly to the farmers in the field, or by phone if they were away from their plots. The same data were also uploaded to the Virtual Irrigation Academy website, which generates seasonal patterns from the consecutive readings (see Figures 3 and 4 in the Results section). These patterns can be downloaded by the extension officer and provided to the farmers. Consecutive readings show the wetting-drying cycles of the soil at three different depths and the patterns of nitrate and salinity across the season.

### *Agricultural innovation platforms*

AIPs are forums that foster interactions and engagement among a diverse group of stakeholders who share a common interest, and are particularly used to facilitate dialogue that addresses a set of challenges in a system (Makini et al., 2013). In this context, the AIPs were used to address challenges in the irrigation schemes and

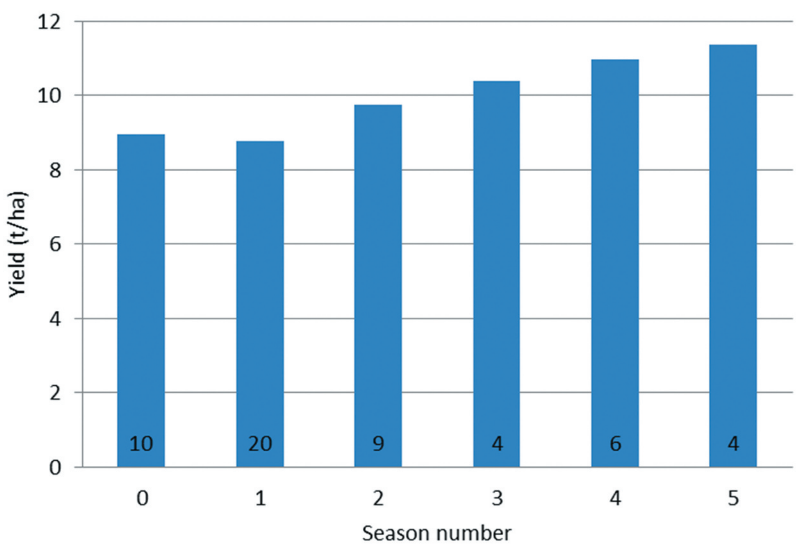


**Figure 2.** Green maize yield in Kiwere Scheme over six seasons. Note: Numbers at the base of the bars are the number of yield observations. Season 0 reflects yield before the interventions.

**Table 2.** Participants in AIP processes in Tanzania.

| | | Farmer participants | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Magozi | | Kiwere | | Non-farmer participants | | |
| AIP meeting | Period | Male | Female | Male | Female | Male | Female | Total |
| 1 | Magozi and Kiwere, 20–21 March 2014 | 15 | 5 | 10 | 4 | 14 | 1 | 49 |
| 2 | Magozi and Kiwere, 21–22 July 2014 | 11 | 4 | 11 | 5 | 15 | – | 46 |
| 3 | Magozi, 14–15 September 2015 | 15 | 5 | – | – | 10 | – | 30 |
| | Kiwere, 16 September 2015 | – | – | 13 | 5 | 8 | | 26 |
| 4 | Magozi, 27 November 2015 | 15 | 5 | – | – | 8 | 1 | 29 |
| 5 | Magozi, 5 March 2016 | 1 | 1 | – | – | 3 | 1 | 6 |
| **Total** | | **57** | **20** | **34** | **14** | **58** | **3** | **186** |

associated value chains. One AIP was established in Kiwere, and one in Magozi, in 2014. Participants in the AIPs included government authorities and agencies (e.g. regional secretariat, district council, agriculture research, river basin management and training institutes), the private sector (e.g. input suppliers, marketers, finance and agro-processors) and NGOs (e.g. Rural-Urban Development Initiative). As described by Van Rooyen et al. (2017), the process involved a visioning exercise to map the current situation and identify specific five-year development targets for the schemes; identification and analysis of the barriers to better productivity and profitability along the crop value chain; solutions to the identified barriers, including a participatory mapping process; and prioritization of the solutions to the barriers and identification of the relevant stakeholders who could implement the solutions. The first AIP meeting, on 20 and 21 March 2014, provided an opportunity to spread awareness of the AIP and the process to the farmers and other AIP stakeholders. Case studies on the use of AIPs for goat production in Zimbabwe by scientists from the International Crops Research Institute for Semi-arid Tropics inspired the stakeholders.

Between March 2014 and 2016, five key AIP sessions were conducted to address specific barriers, with participation of 186 people representing different categories of stakeholders (Table 2). Interactions and networking also took place among stakeholders between the AIP sessions. The AIPs were facilitated by the researchers, and at the end of each AIP session a report was prepared to document the process and the final output. While the initial session involved many participants, subsequent meetings, focusing on finalizing AIP action plans, had fewer participants, as they had a narrower focus and therefore only included the relevant stakeholders.

## *Data collection*

### *Farmer field books*

The 20 farmers with tools were selected so that their plots evenly represented head, middle and tail-end irrigation users and different levels of resource endowment. The farmers with the tools kept a field book and documented important data such as plot area, farm location, types and cost of seeds, fertilizer and agro-chemicals used, planting dates and spacing, amount harvested, and prices for crops sold. This information was then used to compute gross margins for their crops.

### *Household surveys*

The sampling frame for the selection of respondents for the household survey included all farmers who were members of the IOs. From this, a stratified random sampling approach was used based on farmers' socio-economic characteristics, distribution of farm plots (head-end, middle, and tail-end), and gender. This was achieved in collaboration with the scheme IOs. A questionnaire was designed and piloted, and enumerators were trained to ensure consistent application of the questionnaire. The surveys were conducted face to face and took 45 to 60 minutes.

Two rounds of household surveys were conducted: a baseline survey in June and July 2014 and an end-of-project survey in April and May 2017. One hundred farmer households were surveyed, constituting 60% of farmers in Kiwere and 20% in Magozi. The end-of-project survey was intended to be administered to the same households as the baseline survey. However, in Kiwere, 39 new households replaced 37 households that had migrated, one deceased household head and one ailing household head. In Magozi, 21 new households were identified to replace out-migrant households. In these surveys, respondents were mainly household heads, both for male- and female-headed households; if absent, another household member such as a son or a daughter responded. Males dominate households and decision making in Iringa District. Male household heads represented 90% and 87% of the surveyed households in Kiwere and Magozi, respectively. Hence, most respondents were also male.

The 2014 survey captured the baseline situation in terms of household food security, income, and income sources, as well as demographic, socio-economic and farm characteristics and agricultural practices (Mdemu et al., 2017; Mziray et al., 2015). The end-of-project survey captured changes in these parameters which had taken place over the four-year period, as well as changes in irrigation practices as a result of using the tools. The survey also identified who had the tools or where the nearest tool was located. These data provided the foundation for the analysis of the impact of the project's interventions.

### *Focus groups*

In addition to the survey, further qualitative data was collected at three focus groups, conducted in January 2015, July 2015 and May 2016. The purpose was to elicit in-depth discussion and understanding of the changes taking place in the schemes and their linkage to, and implications for, farmers' food security and livelihoods. The focus groups also collected information on the farmers' awareness of the tools, source of knowledge about the tools, interpretation of data provided by the tools, decisions based on the learning from the tools, time saved and its alternative uses, and role of the tools in improving farm management. The focus groups ranged from four to eight participants, with farmers being selected from the list of farmers with and without the tools in the head-end, middle and tail-end of the two schemes.

## Results and discussion

### *Actions taken as a result of the AIP processes*

Through the AIP process, farmers and other stakeholders identified challenges that inhibit productivity and profitability in their schemes. The challenges included issues related to access to and quality of inputs, unreliable markets, knowledge of production, inadequate scheme infrastructure, and management issues (Table 3). Although individual groups of the stakeholders knew these challenges, the AIP process enabled them to be publicly shared and prioritized, and to identify actions to address them and who would undertake them.

The AIP process fostered important links with other value chain stakeholders (Table 4). In Kiwere, farmers had trouble accessing quality farm inputs. Through the AIP, farmers were connected to input suppliers such as Yara, Syngenta and local input suppliers, and gained access to high-quality inputs. Similarly, farmers in Magozi established links with important stakeholders dealing with various value chain activities such as NAFAKA (a staple food value chain project under USAID's Feed the Future initiative) and Dakawa Agricultural Research Institute, which ran demonstration plots using improved rice varieties and trained them in good agronomic practices for rice.

The AIP processes built confidence among farmers for decision making and management of their schemes. For example, a need for scheme maps arose as a result of the discussions in the AIPs and lack of information on the size of the scheme and individual plots. Consequently, a participatory mapping exercise was conducted in both schemes with the support of the district authority and researchers (Table 3). Scheme maps provided a powerful source of information for better planning and decision-making in scheme management (Pittock et al., 2018). The AIP process also initiated study visits to Igomelo scheme in Mbarali District, which created the appetite for better management of the Kiwere and Magozi schemes. As a result, both schemes also revised their constitutions to improve scheme management and fee collection. These changes increased the IO's capacity to plan, supervise maintenance and repair the irrigation infrastructure.

Magozi farmers, through the AIP, convinced the Iringa District Council and the Ministry of Agriculture to construct a storage warehouse, install a rice mill, and expand and improve irrigation infrastructure (Table 3). Farmers funded the construction of the housing for the mill and were part of the committee supervising the contractor engaged to construct the warehouse, expand the irrigation intake and improve the primary canals. These activities represent significant investments, which were made possible through the legitimacy of the AIP process and illustrate the power of collective action through self-organization. The capacity to leverage significant resources beyond the project's budget illustrates the value of the AIP process, and the first steps of self-sustaining irrigation systems. Thus, while Makoi and Matekere (2018) strongly argue for adequate government support to the National Irrigation Commission and IOs as critical for the implementation of irrigation development, it is evident that the strength and potential of collective action by all relevant stakeholders can be realized through processes such as the AIP.

A critical barrier to increased productivity and profitability identified in the literature and through the AIP is lack of information about good agronomic practices and market opportunities, and lack of extension advice (Wheeler et al., 2017). New information was required to achieve the scheme's vision, to increase productivity through improved varieties, to make better use of inputs and water, to reduce post-harvest losses, and to access lucrative markets. Reflecting this, in the end-of-project survey almost all the farmers indicated an increased need for information (Table 5). The inclusive and diverse nature of the AIP facilitated better information flow in several ways (Table 3). This has clearly

**Table 3.** Challenges identified through the AIP process and resulting actions.

| | Actions implemented through the AIP | |
|---|---|---|
| Problem | Magozi | Kiwere |
| Poor seed quality and poor access to farm inputs | Linked farmers with development organizations (e.g. NAFAKA, ARI Dakawa) that facilitate access to high-quality improved rice seeds. | Facilitated local store to supply inputs in the scheme without additional transport and handling costs.<br>Linked farmers to main input suppliers in Iringa (Yara, Syngenta).<br>Facilitated bulk purchase of inputs from input suppliers. |
| Lack of knowledge of production (paddy, tomato, onion) and scheme management | Introduced farmer-managed demonstration plots on System of Rice Intensification using improved rice variety, recommended fertilizer rates and water management practices (2015/2016).<br>Facilitated study visit to Igomelo scheme in Mbarali District to learn effective management of irrigation schemes by IOs. | Facilitated study visit to Igomelo scheme in Mbarali District.<br>Linked farmers to development organization (e.g. BriTEN) providing on-farm training in good agronomic practices. |
| Incomplete irrigation system<br>Insufficient water in the plots | Rufiji Basin Water Board increased the water permit from 0.6 $m^3/s$ to 2.0 $m^3/s$.<br>Iringa District Irrigation Development Fund Magozi provided TZS200 million to expand the intake to accommodate the new water permit.<br>Magozi committed TZS14 million from their own sources to the expansion of the intake and improvement of primary and secondary canals. | Farmers organized repair and maintenance of irrigation system. |
| Low price of rice<br>Poor market for tomatoes | Constructed rice storage warehouse and installed rice mills, which allowed farmers to time their sales for when prices are higher and sell value-added products. | Linked farmers with markets (tomato processor: Darsh Industry & Cheetah Development). |
| Lack of clarity on the size of the scheme and individual farmers' plots | Produced maps of the schemes showing plot boundaries and sizes. | Produced map of the schemes showing plot boundaries and size. |
| Lack of knowledge of soil fertility to inform fertilizer application | Conducted soil sampling, analyzed soil fertility and provided fertilizer recommendations. | Conducted soil sampling, analyzed soil fertility and provided fertilizer recommendations. |
| Inadequate funding to maintain irrigation infrastructures | Revised scheme constitution to raise farmers' annual water use fee. | Revised scheme constitution to raise farmers' annual water use fee. |

**Table 4.** Farmer's linkages with key stakeholders in Kiwere and Magozi schemes.

| | Stakeholders for each link per scheme | |
|---|---|---|
| | Kiwere | Magozi |
| Existing link, | • Government (Iringa District Council, Ward Office, Zonal Irrigation Office) | • Government (Iringa District Council, Ward Office, Zonal Irrigation Office)<br>• Marketing (NAFAKA) |
| Improved link, | • Agro Inputs Suppliers (YARA, SYNGENTA)<br>• Finance providers (Once Acre Fund) | • Agro Inputs Suppliers (YARA, SYNGENTA)<br>• Agricultural Research (DAKAWA) |
| New link | • Processors (DARSH industry)<br>• Finance providers (National Microfinance Bank, Cooperative and Rural Development Bank)<br>• Marketing (FARMSEER) | • Seed Agency/regulator (ASA)<br>• Finance providers (National Microfinance Bank, Cooperative and Rural Development Bank)<br>• Marketing (NFRA) |

**Table 5.** Farmer perception of information needs, access to and quality of information.

| Information access changes | | Magozi ($n$ = 100) | Kiwere ($n$ = 100) |
|---|---|---|---|
| Information needs since last four years | Gone up (%) | 89 | 77 |
| | Stayed the same (%) | 8 | 21 |
| | Decreased (%) | 3 | 2 |
| Access to more and better agricultural advice compared to four years ago | Yes (%) | 96 | 97 |

enhanced farmers' perception of the quality and diversity of information they receive, with more than 95% now accessing more and better agricultural advice from a wider range of relevant sources (Tables 3 and 5). These are very important outcomes and probably also reflect the adoption of new crops, inputs and techniques introduced by the AIP.

### *Changes to irrigation management practices*

During the three years of implementing the tools and AIP initiatives, farmers in Kiwere made significant changes to both the frequency and duration of irrigation (Table 6). The magnitude of change was largest for farmers with tools in their plots. But, importantly, the neighbours of those with the tools also made changes, showing strong evidence of farmer-to-farmer learning (see also Parry et al., 2020). Those with the tools lengthened the irrigation interval by 39%, compared to the 20% increase achieved by their neighbours. And those with the tools reduced irrigation duration by 42%, compared to the 35% decrease of their neighbours. The combined impact was that those with the tools reduced the time spent irrigating by 65%, while their neighbours' time was reduced by 47%. It is anticipated that continued use of the tools may further increase the learning from the tools, resulting in more significant and more widespread changes.

Farmers are now using the time saved through reduced irrigation for other activities, including improving farm management through more weeding (31%), engaging in other income-generating activities (27%), doing family work (19%) and farming other plots that were not previously cultivated (8%) (Bjornlund et al., 2018). These activities improved farm productivity and increased both farm and off-farm income. Saving labour, therefore, represents a huge incentive for the continued use of, and learning from, the tools.

### *The impact of the tools and AIPs on farming practices*

Overall, the use of the tools and AIPs brought about important changes in farming practices in addition to the timing and duration of irrigation events (Table 6). Through the AIP, farmers were introduced to higher-value crops, improved seeds and other farm inputs, and new markets and farming practices. Reflecting this, 23% of farmers in Magozi and and 47% in Kiwere are now growing new crops. With a better understanding of the value of irrigation, 86% and 91%, respectively, are now irrigating land they did not use five years ago (Table 7). The increased availability of water in the system, as result of the reduced frequency and

**Table 6.** Changes in interval and duration of irrigation due to learning from the tools in Kiwere.

| | Farmers who had the tools | Farmers whose neighbours had the tools |
|---|---|---|
| **Irrigation interval (days)** | | |
| 2014 | 2.7 | 2.8 |
| 2017 | 4.4 | 3.5 |
| Reduction | 39% | 20% |
| **Number of irrigations**[a] | | |
| 2014 | 33 | 32 |
| 2017 | 20 | 26 |
| Reduction | 40% | 19% |
| **Duration of irrigation (h)** | | |
| 2014 | 6.2 | 5.1 |
| 2017 | 3.6 | 3.3 |
| Reduction | 42% | 35% |
| **Total time irrigating (h)** | | |
| 2014 | 205 | 163 |
| 2017 | 72 | 86 |
| Reduction | 65% | 47% |

[a]Based on a 13-week crop.

duration of irrigation, is also a contributing factor, especially for downstream users (Manero et al., 2019). This is a critical outcome, considering the serious issues of underutilized infrastructure reported in the literature (Djagba et al., 2014; Moyo et al., 2017). Through using the tools, farmers gained a better understanding of the soil moisture and nutrient dynamics, which resulted in 74% of farmers in Kiwere reporting using less fertilizer. This was probably due to reduced leaching of nutrients. We argue here that the farming of previously unused land is largely attributed to the actions initiated by the AIP (Table 3).

Based on focus group discussions, it is argued that better information access (Table 5) and learning from the tools and the activities initiated by the AIP (Table 3) also resulted in farmers adopting new agronomic practices and technologies and spending more on farm inputs and implements (Table 7). These are all changes that could increase the productivity and profitability of irrigation. In their study of the extrinsic and intrinsic factors that drive uptake of innovations among smallholder farmers, Meijer et al. (2014) stress the importance of knowledge in the adoption of agricultural innovations. Farmers have started to use fertilizer in response to the soil fertility analysis conducted as part of the AIP action plans, as well as training in good agronomic practices (Table 3). The farmers in focus groups told us that based on monitoring of soil water nutrients using the WFD, farmers learned that manure leached more slowly through the soil profile than fertilizer, so more farmers started using manure. In Magozi, for instance, farmers did not use manure or chemical fertilizer before the project's interventions, as one farmer explained: 'We used not to apply fertilizer or manure. However, now that we know the fertility of the soil, we are using manure so that we can increase yields' (male farmer, age 52, Magozi).

The use of fertilizer steadily changed over the project for farmers maintaining field books, with 10% doing so in 2015 and 14% in 2017 (Table 8).

According to Bjornlund et al. (2018), both female and male household members access more information from a wider range of sources, including AIP-initiated activities (Table 3), extension officers, market actors and other farmers, leading to more joint decision making at the household level (Bjornlund et al., 2019). More joint decision making on the use of household resources (such as decisions related to land allocation for different crops,

**Table 7.** Summary of selected changes in farming practices as a result of the interventions.

| | | Magozi | Kiwere |
|---|---|---|---|
| *Changes in farming activities compared to four years ago (% yes)* | | | |
| Reduced amount of chemical fertilizer | | n/a | 74 |
| Farming previously unfarmed irrigated land | | 86 | 91 |
| Added new crops not grown four years ago | | 23 | 47 |
| *Changes in spending compared to four years ago* | | | |
| Spending on irrigation/farm inputs (%) | Less | 14 | 7 |
| | About the same | 21 | 20 |
| | More | 65 | 73 |
| Spending on farm implements (%) | Less | 13 | 5 |
| | About the same | 22 | 29 |
| | More | 65 | 66 |

N/a = not applicable. The tools were not part of the interventions at Magozi.

**Table 8.** Increase in rice yield for farmers maintaining field books in Magozi scheme.

| | 2015 | 2016 | 2017 |
|---|---|---|---|
| Number of farmers with field books | 20 | 20 | 20 |
| Female farmers | 25% | 20% | 57% |
| Average area (ha) | 1.6 | 1.7 | 2.98 |
| *Agronomic data* | | | |
| Farmers that applied fertilizer | 10% | 13% | 14% |
| Average rice yield (t/ha) | 2.9 | 3.6 | 3.7 |

purchase of inputs, time allocation, irrigation, and use of household income) may play a significant role in contributing to better decisions and welfare outcomes at the household level, such as improved welfare and food security of households (Amugsi et al., 2016). Reflecting these factors, 65% of farmers have increased their spending on farm inputs and implements over the last four years (Table 7), which has also contributed to increased yield.

## *Impact on yield*

By using the tools and implementing other changes introduced by the AIP, farmers in Kiwere reported large increases in yields of green maize. While yields did not increase during the first season, farmers' field book data show they increased steadily in subsequent seasons (Figure 2). This could indicate that during the first season farmers were getting used to the tools, with the changes introduced in response to the AIP process emerging in year 2. Thereafter, farmers started to apply their new knowledge to change their irrigation and soil fertility management practices.

In part, the yield increase could be attributed to a lower irrigation frequency, which reduces leaching of nutrients and enhances plants' use of nutrients. However, the increases might also be through improved supply of better-quality inputs and improved agricultural practices introduced through the AIP. Observations and yield information obtained during focus groups in 2016 suggest that the yield of tomatoes, onions and green maize, for farmers deemed 'good' performers, almost doubled from 2014 to 2015. However, farmers' field book data for maize suggests an average increase of 28% between the first and fifth season, and there is no evidence to support these statements for tomatoes and onions. Further, the reduced nutrient losses and decreased labour demand for irrigation should increase farming profitability.

The effects of reduced irrigation on soil moisture are illustrated in Figures 3 and 4, which show the seasonal pattern of Chameleon data for two consecutive maize crops grown by the same farmer. The Chameleon data are displayed for four depths (20, 30, 40 and 50 cm). The soil moisture sensors for the first crop show that the soil is wet (blue) throughout the profile for the duration of the season (Figure 3), which indicates that the farmer was irrigating very frequently. The following season, the farmer reduced the number of irrigation events, as can be seen by the increase in green readings, indicating reasonably moist soil (Figure 4). This reflects focus group discussions involving this farmer. He had observed that if the Chameleon is always blue, then when testing the soil water in the WFD, the nitrate strip will rapidly change from purple (high N) to white (low N), indicating that his fertilizer is now below the root zone. This suggested to him that he was over irrigating. The farmer also observed that his tomato crop was greener after skipping irrigation (Stirzaker et al., 2017). Skipping irrigation quickly spread to other farmers as yields started to increase (Figure 2).

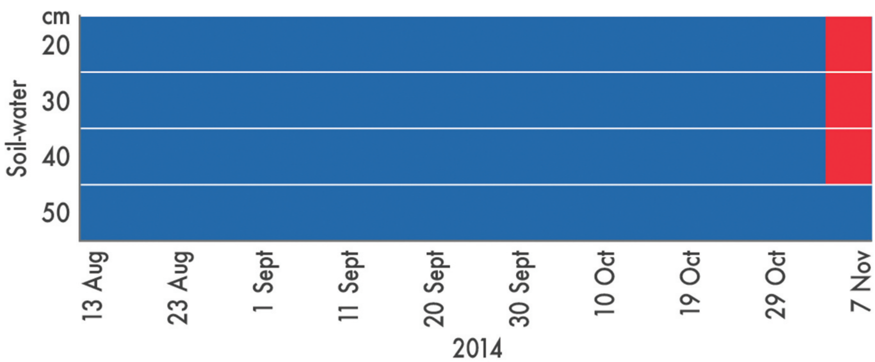


**Figure 3.** Soil moisture data for maize crop from 1 July to 11 November 2014. Source: https://via.farm/

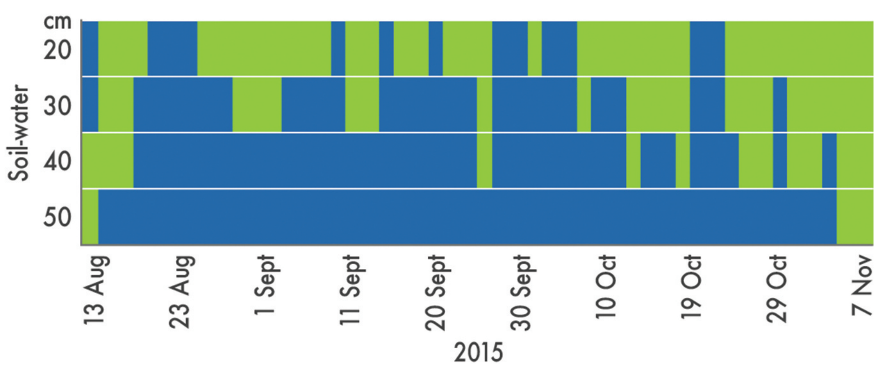


**Figure 4.** Soil moisture data for maize crop from 8 August to 23 November 2015. Source: https://via.farm/

In Magozi, following the AIP-initiated actions (Table 3), the average rice yield for those maintaining a field book increased by 29% (Table 8). However, these yields are still low; even the best yield is below the potential yield of 8 t/ha for this region (Trevor Wilson and Lewis, 2015). The increase in average yields is largely due to increases in the middle and tail-end sections of the scheme. The head-end yields barely changed, only increasing 5% over the three years. However, the middle and tail-end yields increased by 31% and 68%, respectively, and their yields now exceed those of the head-enders (Figure 5). Using an independent data set, Manero et al. (2019) found that, before the interventions, the middle farmers had better yields than the head-enders. The authors argued that the head-enders were over-irrigating while the middle farmers, by default, received a more appropriate volume, and the tail-enders had the lowest yield. Flooding in 2016 might have contributed to availability of water and nutrients in the soils, and thus raised productivity in the middle and tail-end. Importantly, security of water access for the middle and tail-end farmers was further improved following the expansion of the scheme's water intake in 2016. These findings suggest that farmers in the middle and tail-end of the system have benefited most from the irrigation system intake upgrade.

### *Impact on perception on water supply and conflicts*

In Kiwere, the baseline data show that before the interventions 29% of tail-end farmers rarely got the water they needed, compared to 3% and 9% in the head-end and middle, respectively (Table 9). This indicates that water supply at the tail-end was much less reliable than in the other parts of the scheme. This leads to lower satisfaction with the water supply and hence greater conflict over water access compared to the head-end and middle farmers. Such conflicts reduce farmers' willingness to engage in collective actions, such as scheme maintenance and paying water fees, which reduces the productivity of irrigated land.

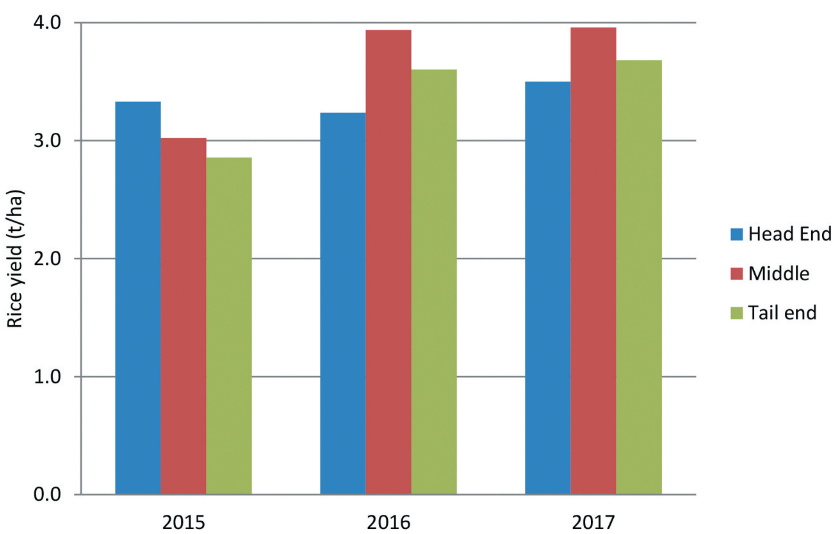


**Figure 5.** Average rice yields for Magozi.

**Table 9.** Plot location on the canal and initial satisfaction over irrigation water supply at baseline situation.

| | Magozi | | | Kiwere | | |
|---|---|---|---|---|---|---|
| | Head-end | Middle | Tail-end | Head-end | Middle | Tail-end |
| **How often did the farmer get the water they need(%)?** | | | | | | |
| Never | 0 | 0 | 3 | 0 | 0 | 0 |
| Rarely | 16 | 16 | 23 | 3 | 9 | 29 |
| Mostly | 53 | 50 | 57 | 22 | 30 | 43 |
| Always | 31 | 34 | 17 | 76 | 61 | 29 |
| **Overall satisfaction with supply of irrigation water(%)** | | | | | | |
| Dissatisfied | 31 | 36 | 50 | 11 | 11 | 14 |
| Neutral | 11 | 2 | 47 | 3 | 2 | 14 |
| Satisfied | 58 | 62 | 3 | 79 | 87 | 71 |

The initial scheme assessments and interactions with farmers and focus groups showed that conflicts over access to water due to plot location within the scheme (head-end/tail-end) was a serious issue in Kiwere. The water scheduling allocated water to tail-end users in the morning and to the head-end after midday. However, farmers at the head-end and middle took water out of turn. This led to water use conflicts between the head-end and tail-end farmers. It was common that when one farmer was irrigating, another farmer would come and block that farmer's water, to get water to their own plot. The conflicts reduced production, and some farmers were irrigating at night to avoid conflicts. At the beginning of the project, this issue was repeatedly raised at the AIP meeting, and it was agreed that head-end users should respect downstream users' rights.

Over the four years of the project, 39% of tail-end users still perceived that their location influenced their water supply, with 91% reporting that they receive too little water; however, 75% acknowledged that conditions had improved over the four-year period (Table 10), and 79% of all farmers perceived the allocation process as fairer (Table 11). Farmers no longer irrigate at night, as farmers are now respecting their allotted time. This is probably an outcome of the increased water supply due to the lower frequency and shorter time of irrigation. This has reduced the overall conflict over water (Table 12).

**Table 10.** Plot location within the scheme and changes in water supply over the last four years.

| | Magozi | | | Kiwere | | |
|---|---|---|---|---|---|---|
| | Head | Middle | Tail | Head | Middle | Tail |
| **Does this location affect access to water?** | 20 | 19 | 35 | 16 | 6 | 39 |
| **How does this influence water supply? (% of those affected)** | | | | | | |
| Too much | 33 | 0 | 8 | 33 | 50 | 9 |
| Too little | 33 | 100 | 92 | 33 | 50 | 91 |
| Right amount | 33 | 0 | 0 | 33 | 0 | 0 |
| **Has access to water positively changed over the last four years?** | 73 | 92 | 92 | 66 | 100 | 75 |

**Table 11.** Changes in the willingness to participate in collective action and perception of fairness of water allocation.

| | Magozi | Kiwere |
|---|---|---|
| Participate more in scheme maintenance than four years ago? (% yes) | 99 | 100 |
| More willing/prepared to pay for water than four years ago? (% yes) | 100 | 100 |
| More able to pay for water than four years ago? (% yes) | 99 | 98 |
| The process of water allocation and use is fairer than four years ago? (% yes) | 87 | 79 |

**Table 12.** Changes in conflict over water (% of households).

| | Magozi | Kiwere |
|---|---|---|
| **Within the household** | | |
| Decreased | 88 | 89 |
| Same | 3 | 9 |
| Increased | 9 | 1 |
| **Between farmers on the same canal** | | |
| Decreased | 82 | 82 |
| Same | 3 | 13 |
| Increased | 15 | 5 |
| **Between head-end and tail-end users** | | |
| Decreased | 83 | 83 |
| Same | 3 | 11 |
| Increased | 14 | 6 |
| **Between the scheme and other water use** | | |
| Decreased | 82 | 89 |
| Same | 12 | 8 |
| Increase | 6 | 3 |

A similar situation was observed in Magozi. The initial scheme assessments, interactions with farmers and focus groups point to serious conflicts between farmers at head-end and tail-end before the project. Only 17% of farmers always received the water they needed, and only 3% were satisfied with their supply (Table 9). The tail-end users were severely affected, with some complete crop failures when there was not enough water at rice flowering stage, and some farmers did not harvest their fields at all. The main reason for the water problems was that the scheme had an inadequate water permit and water intake from the river for the area of rice being grown. The water supply issue was resolved through the AIP process (Table 3). This led to a greater intake from the river and a larger water use permit (from 0.6 to 2 $m^3/s$). At the end of the project, 35% of tail-enders and 19% of middle irrigators still said that their location in their scheme affected their supply. Of those affected, 92% and 100% of the tail-end and middle thought that they received too little water. However, 92% of both middle and tail-end users said that their supply had improved (Table 9), and 87% of all irrigators perceived that the allocation process was now fairer (Table 11). Now that there is more water available, the level of conflict over water has decreased (Table 12).

Less conflict has brought greater willingness to participate in collective action, such as paying water fees and helping with maintenance (Table 11), which in turn has improved the conditions of the infrastructure and contributed to improving the reliability of water supply.

## *Impact of changes in farming practices on income and food security*

### *Impact on income*

More than 60% of farmers in both schemes report changes in their sources of income over the last four years and an increase in both farm and off-farm income, more so at Kiwere than Magozi (Table 13). Farm income increases can be linked to increased yields as well as the introduction of higher-value crops and improved market access. Small businesses are cited as a major source of off-farm income for 58% of households in Magozi and 67% in Kiwere. At Kiwere, this reflects that farmers have

**Table 13.** Perceptions of improvements in income.

| Variable | | Magozi (*n* = 100) | Kiwere (*n* = 100) |
|---|---|---|---|
| Changes in income sources in the last four years (% yes) | | 63 | 66 |
| Off-farm income compared to four years ago (% of respondents) | Worse | 22 | 22 |
| | Same | 334 | 23 |
| | Better | 43 | 55 |
| Farm income compared to four years ago (% of respondents) | Worse | 23 | 15 |
| | Same | 23 | 18 |
| | Better | 54 | 67 |

invested at least part of the time saved by reduced irrigation in small businesses and other off-farm work activities (Bjornlund et al., 2018).

Understanding gross margins allowed farmers to select new and more profitable crops that they were not cultivating before; hence, 23% of farmers at Magozi and 47% at Kiwere now grow crops they did not grow four years ago (Table 7). Information on profitable crops was disseminated to the farmers through the AIP meetings, and through networking with input suppliers they gained access to high-quality seeds and improved varieties. This was particularly the case at Kiwere, where farmers produce various horticultural crops and can irrigate year-round. However, at Magozi the introduction of an improved rice variety resulted in increased yield. One farmer, who harvested about 990 kg in a plot of about 0.08 ha (equivalent to a yield of 12.8 t/ha), said, 'After adopting SARO5 as a result of AIP interventions, my production has been high and even income has increased' (male farmer, age 35, Magozi).

Consistently, more farmers perceive higher off-farm and farm income in Kiwere than in Magozi. For Magozi, this could be attributed to the nature of labour requirements in rice farming, as well as the scant opportunities for off-farm activities as compared to Kiwere, with its proximity to Iringa Town. Further, since Kiwere farmers had both the tools and the AIP, the difference could be an indication of the added and interactive impact of the two interventions, especially considering the time saved due to reduced irrigation that could be used for off-farm income-earning activities.

Improvements in farm incomes can largely be linked to higher gross margins (Table 14). For example, average gross margins (in million TZS/ha) in Magozi increased from 1.43 in 2015 to 1.75 in 2017, although the highest were in 2016. Similarly, in Kiwere, gross margin for green maize show a considerable increase from 2014 to 2018. The low gross margins for 2015 could be attributed to the much higher production costs in that season.

## *Influence on food security*

Before the project's interventions, 29% of farmers in Magozi and 37% in Kiwere had experienced food shortages over the preceding five years (Mziray et al., 2015). However, following the interventions, most households perceived that their food security situation had improved (Table 15). In Kiwere, farmers had the advantage of being able to irrigate year-round and produce a more diverse selection of crops, integral to a more varied and nutritious diet. In this scheme, over 50% of farming households indicate that they have

**Table 14.** Gross margins in Magozi and Kiwere for farmers with field books.

| Scheme and type of gross margin | Year | | | | | Change |
|---|---|---|---|---|---|---|
| | 2014 | 2015 | 2016 | 2017 | 2018 | |
| **Magozi** | | | | | | |
| Average area (ha) | – | 1.6 | 1.7 | 2.98 | – | |
| Production cost (million TZS/ha) | – | 0.79 | 1.63 | 0.91 | – | 15% |
| Sale price (million TZS/t) | – | 0.75 | 0.97 | 0.73 | – | −2% |
| Gross margin (million TZS/ha) | – | 1.43 | 1.9 | 1.75 | – | 22% |
| Best gross margin (million TZS/ha) | – | 2.64 | 4.8 | 3.34 | – | 26% |
| Gross margin male (million TZS/ha) | – | 1.51 | 2.02 | 1.62 | – | 7% |
| Gross margin female (million TZS/ha) | – | 1.22 | 1.41 | 1.63 | – | 34% |
| **Kiwere** | | | | | | |
| Average area (ha) | 1.40 | 1.49 | 1.14 | 1.29 | 1.19 | |
| Production cost (million TZS/ha) | 1.14 | 1.81 | 1.51 | 1.74 | 1.55 | 36% |
| Sale price (million TZS/t) | 0.28 | 0.28 | 0.33 | 0.35 | 0.31 | 11% |
| Gross margin green maize (million TZS/ha) | 1.38 | 0.68 | 1.87 | 2.06 | 2.01 | 46% |
| Best gross margin (million TZS/ha) | 2.85 | 1.15 | 2.74 | 2.58 | 2.48 | −12% |
| Gross margin male (million TZS/ha) | 1.49 | 0.77 | 2.22 | 2.24 | 1.81 | 21% |
| Gross margin female (million TZS/ha) | 1.2 | 0.62 | 1.3 | 1.69 | 1.7 | 42% |

**Table 15.** Improvement in food situation and spending of extra income.

| | | Magozi ($n$ = 100) | Kiwere ($n$ = 100) |
|---|---|---|---|
| Perception of improvement in food security compared to five years ago (%) | Worse | 23 | 16 |
| | Same | 19 | 14 |
| | Better | 58 | 70 |
| Perception of whether it is cheaper now to grow own staple food (%) | Cheaper | 79 | 76 |
| | More or less the same | 6 | 2 |
| | More expensive | 15 | 22 |
| Spending of extra income | Food | 25 | 16 |
| | Education | 19 | 20 |
| | Health | 18 | 14 |
| | Farm input | 10 | 19 |
| | Investment in farm | 15 | 14 |
| | Investment in home | 13 | 1 |
| Spending on food now compared to four years ago | Less | 12 | 15 |
| | About the same | 34 | 23 |
| | More | 54 | 62 |

increased their production of green and grain maize, tomatoes, onions, soybeans and other vegetables. Proper water and nutrient use resulting from the learning from the tools and the AIP were the main reasons for the observed increase in yield, but the increased production also reflects the activation of previously unused land. All farmers in Magozi produce rice, and 43% reported an increase in yield, mainly due to better agronomic practices such as improved seed varieties, planting density and fertilizer application. Overall, analysis from the end-of-project survey shows that the production of most crops has increased compared to four years ago (Mdemu et al., 2018).

The impact of higher income on food security is reflected in the proportion of extra income spent on food (Table 15), with 25% and 16% of farmers in Kiwere and Magozi, respectively, spending extra income on food, and 54% and 62%, respectively, spending more on food than they did four years ago. This reflects that twice as many farmers report selling irrigated crops to be food secure (Table 16). This is likely to reflect that farmers are now focusing more on growing new and higher-value crops following computation and better understanding of gross margins.

**Table 16.** Percentage of households selling irrigated produce to be food secure.

| | Magozi | Kiwere |
|---|---|---|
| Baseline | 49 | 41 |
| End of project | 94 | 85 |

Further, higher income is not spent only on food but also on other needs such as education and health, farm inputs, and home improvements (Table 15). These are critical findings, as increased spending on farm inputs will result in future production increases. Further, increased spending on food, health and education will increase household members' ability to work and children's ability to learn. More education will result in more knowledgeable future farmers and better ability to make a transition to other livelihood options.

## Conclusion

This article has considered the effect of farmer-friendly and simple-to-use soil moisture and nutrient monitoring tools and agricultural innovation platforms on the income and food security of smallholders in small-scale irrigation schemes in Tanzania. Introducing the tools and the AIP improved smallholders' income and food security. In both schemes, AIPs linked farmers to input and output markets, promoted higher-value crops, contributed to value-adding actions (such as the establishment of a rice storage and milling facilities) and strengthened the IOs. Using the soil moisture and nutrient monitoring tools, farmers at Kiwere have gained a better understanding of the soil moisture and fertilizer dynamics and how these variables are affected by irrigation timing. Farmers learned that over-irrigation leads to the leaching of nutrients below the root zone, where they become inaccessible for the plants. In response, farmers reduced their irrigation frequency and duration and thereby significantly increased their yields. During the AIP process poor nutrient management and lack of information on soil fertility status were identified as a major barrier to improving productivity. Soil analysis of the irrigated plots was therefore proposed, to provide appropriate recommendations on type and quantity of fertilizer application. Demonstration plots were established to show new crop varieties and agricultural management practices, improving farmer understanding.

The interventions increased yields and reduced resource use, including labour for irrigation and fertilizer use, raising gross margins and farm income. Labour saved by reducing irrigation has been invested in off-farm income-earning activities and better farm management, which further increased yields. The result is that both farm and off-farm income have increased, improving households' access to food, health and education. These are all factors that increase food security and the general well-being of household members.

The results suggest that the combination of tools and AIP has had many positive outcomes. 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.

These findings have significant implications for policy makers and water managers planning to revive existing irrigation schemes or invest in new schemes. When doing so, they need to acknowledge that these schemes are complex systems. In comparison to dryland farming, irrigation schemes have a very high cost structure and therefore much higher financial risk. It is critical that any investment in small-scale irrigation schemes be associated with the introduction of both technical and institutional mechanisms (for example, the tools and the AIP) to increase water use efficiency and productivity. Higher productivity must be converted to higher profitability to enable farmers to pay for water and inputs and self-organize to engage in collective action, such as irrigation scheme maintenance. Self-sustaining irrigation systems are needed to achieve food security and improve viability for rural households and schemes, and simultaneously achieve the development goals of governments and investors.

## Acknowledgments

This research was part of the projects Increasing Irrigation Water Productivity in Mozambique, Tanzania and Zimbabwe through on-Farm Monitoring, Adaptive Management and Agricultural Innovation Platforms (FSC-2013-006) and Transforming Smallholder Irrigation into Profitable and Self-Sustaining Systems in Southern Africa (LWR/2016/137), both funded by the Australian Centre for International Agricultural Research and participating organizations. We thank the two reviewers for constructive comments, which improved the final manuscript considerably. We also thank Ms. Karen Parry for her assistance in editing and structuring the article.

## Disclosure statement

No potential conflict of interest was reported by the authors.

## ORCID

M. Mdemu http://orcid.org/0000-0002-8110-8456
L. Kissoly http://orcid.org/0000-0003-2762-2339
H. Bjornlund http://orcid.org/0000-0003-3341-5635
E. W. Christen http://orcid.org/0000-0002-6009-3689
A. van Rooyen http://orcid.org/0000-0003-2035-049X
R. Stirzaker http://orcid.org/0000-0001-6956-4179

## References

Amugsi, D. A., Lartey, A., Kimani, E., & Mberu, B. U. (2016). Women's participation in household decision-making and higher dietary diversity: Findings from nationally representative data from Ghana. *Journal of Health, Population and Nutrition*, *35*(1), 16. https://doi.org/10.1186/s41043-016-0053-1

Bjornlund, H., Parry, K., Pittock, J., Stirzaker, R., van Rooyen, A., Moyo, M., & Ramshaw, P. (2018). Transforming smallholder irrigation into profitable and self-sustaining systems in southern Africa. In K-water & IWRA (Eds.), *Smart water management: Case study report* (pp. 330–381). https://www.iwra.org/swmreport/

Bjornlund, H., Zuo, A., Wheeler, S. A., 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

Burney, J. A., & Naylor, R. L. (2012). Smallholder irrigation as a poverty alleviation tool in sub-Saharan Africa. *World Development*, *40*(1), 110–123. https://doi.org/10.1016/j.worlddev.2011.05.007

De Fraiture, C., & Giordano, M. (2014). Small private irrigation: A thriving but overlooked sector. *Agricultural Water Management*, *131*, 167–174. https://doi.org/10.1016/j.agwat.2013.07.005

Denison, J., & Manona, S. (2007). *Principles, approaches and guidelines for the participatory revitalisation of smallholder irrigation schemes, Volume 1: A rough guide for irrigation development practitioners* (WRC Report No. TT 308/07). Water Research Commission.

Djagba, J. F., Rodenburg, J., Zwart, S. Z., Houndagba, C. J., & Kiepe, P. (2014). Failure and success factors of irrigation system developments: A case study from the Ouémé and Zou valleys in Benin. *Irrigation and Drainage*, *63*(3), 328–339. https://doi.org/10.1002/ird.1794

Inocencio, A., Kikuchi, M., Tonosaki, M., Maruyama, A., Merrey, D., Sally, H., & de Jong, I. (2007). *Costs and performance of irrigation projects: A comparison of sub-Saharan Africa and other developing regions* (Research Report 109). International Water Management Institute.

Japan International Cooperation Agency & Ministry of Agriculture, Food Security and Cooperatives. (2002). *The study on the national irrigation master plan in the United Republic of Tanzania*. JICA and MAFC.

Kadigi, R. M. J., Tesfay, G., Bizoza, A., & Zanabou, G. (2012). *Irrigation and water use efficiency in Sub-Saharan Africa* (Policy Research Paper 4). Global Development Network.

Makini, F. W., Kamau, G. M., Makelo, M. N., & Mburathi, G. K. (2013). *A guide for developing and managing agricultural innovation platforms*. Agricultural Research Institute and Australian Centre for International Agricultural Research.

Makoi, H. J., & Matekere, E. (2018). Current policy priorities and regulatory approaches for irrigation and associated challenges of 'farmer-led' irrigation development in Tanzania. *Forest Research and Engineering International Journal*, *2*(3), 152–161. https://doi.org/10.15406/freij.2018.02.00041

Manero, A., Wheeler, S. A., Zuo, A., & Mdemu, M. (2019). Exploring the head versus tail-end dichotomy on yield and farm incomes in smallholder irrigation schemes in Tanzania. Water Resources Research, 55 (5). https://doi.org/10.1029/2018WR023483.

Mdemu, M. V., Kissoly, L., Kimaro, E., Bjornlund, H., & Parry, K. (2018). Increasing irrigation productivity in Mozambique, Zimbabwe and Tanzania through on farm monitoring, adaptive management and agriculture innovation platforms. End-of-project survey report – Tanzania (Project no. FSC-2013-006). Ardhi University.

Mdemu, M. V., Mziray, N., Bjornlund, H., & Kashaigili, J. J. (2017). Barriers to and opportunities for improving productivity and profitability of 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

Meijer, S. S., Catacutan, D., Ajayi, C. O., Sileshi, G. W., & Nieuwenhuis, M. (2014). The role of knowledge, attitudes and perceptions in the uptake of agricultural and agroforestry innovations among smallholder farmers in sub-Saharan Africa. *International Journal of Agricultural Sustainability*, *13*(1), 1–15. https://doi.org/10.1080/14735903.2014.912493

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

Mziray, N., Mdemu, M. V., & Bjornlund, H. (2015). *Baseline report, Kiwere and Magozi irrigation schemes in Tanzania* (Project no. FSC-2013-006). Ardhi University.

Nkhoma, B. G. (2011). The politics, development and problems of small irrigation dams in Malawi: Experiences from Mzuzu ADD. *Water Alternatives*, *4*(3), 383–398. http://www.water-alternatives.org/index.php/volume4/v4issue3/148-a4-3-7/file

Oates, N., Mosello, B., & Jobbins, G. (2017). *Pathways for irrigation development: Policies and irrigation performance in Tanzania* (Working Paper, Pathways to resilience in semi-arid economies). Overseas Development Institute.

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*. 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., … 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, Australian Centre for International Agricultural Research.

Reincke, K., Vilvert, V., Fasse, A., Graef, F., Sieber, S., & Lana, M. (2018). Key factors influencing food security of smallholder farmers in Tanzania and the role of cassava as a strategic crop. *Food Security*, *10*(4), 911–924. https://doi.org/10.1007/s12571-018-0814-3

Rosegrant, M. W., & Perez, N. D. (1997). *Water resources development in Africa: A review and synthesis of issues, potentials and strategies for the future* (EPTD Discussion Paper No. 28). Environmental and Production Technology Division, IFPRI.

Stirzaker, R., Mbakwe, I., & Mziray, N. (2017). A soil and water 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. J. (2003). When to turn the water off: Scheduling micro-irrigation with a wetting front detector. *Irrigation Science*, *22*(3–4), 177–185. https://doi.org/10.1007/s00271-003-0083-5

Stirzaker, R. J., Stevens, J. B., Annandale, J. G., & Steyn, J. M. (2010). Stages in the adoption of a wetting front detector. *Irrigation and Drainage*, *59*(4), 367–376. https://doi.org/10.1002/ird.472

Trevor Wilson, R., & Lewis, I. (2015). The rice value chain in Tanzania. A report from the Southern Highlands Food Systems Programme. FAO, Rome, Italy. http://www.fao.org/fileadmin/user_upload/ivc/PDF/SFVC/Tanzania_rice.pdf

United Republic of Tanzania. (2010). *National irrigation policy*. Ministry of Agriculture Food Security and Cooperative.

United Republic of Tanzania. (2014). *Agriculture climate resilience plan*. Ministry of Agriculture Food Security and Cooperative.

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*. https://doi.org/10.1080/07900627.2020.1747409

van Rooyen, A., 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

Wheeler, S., Zuo, A., Bjornlund, H., Mdemu, M., & van Rooyen, A. (2017). An overview of extension use in irrigated agriculture and case studies in south-eastern Africa. *International Journal of Water Resources Development*, *33*(5), 755–769. https://doi.org/10.1080/07900627.2016.1225570

Wichelns, D. (2014). Investing in small, private irrigation to increase production and enhance livelihoods. *Agricultural Water Management*, *131*, 163–166. https://doi.org/10.1016/j.agwat.2013.09.003

World Bank. (1996) . *Staff appraisal report for Tanzania: River basin management and smallholder irrigation improvement project, agriculture and environment operation*. Eastern Africa Department, Africa Region.

You, L., Ringler, C., Nelson, G., Wood-Sichra, U., Robertson, R., Wood, S., & Sun, Y. (2010). *What is the irrigation potential for Africa? A combined biophysical and socioeconomic approach*. International Food Policy Research Institute.