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Institutional and technological innovations for sustained change in smallholder irrigation schemes in southern and Eastern Africa

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ABSTRACT

Water management systems must become more adaptable to alleviate projected shortfalls. Integrated socio-institutional and technological interventions are required to generate sustained change in irrigation water management and the profitability for smallholders and their schemes. We illustrate this by conducting an ex-post analysis of the 'Transforming Irrigation in Southern Africa' (TISA) project, which was implemented in two phases from 2013 to 17 and 2017–2023. The project introduced institutional and technological innovations to smallholder irrigation schemes in Tanzania, Mozambique and Zimbabwe: Agricultural Innovation Platforms as a participatory approach to engage farmers and stakeholders; and soil moisture monitoring tools to support farmer learning. We hypothesised that these innovations, despite differing socioeconomic and biophysical conditions in the three countries, would work synergistically to improve farmers' adaptive capacity and generate sustained change. In this paper, we test our hypotheses through a synthesis of peer-reviewed TISA literature, focussing on four smallholder irrigation schemes and five factors identified in the literature as critical for increasing farmers' adaptive capacity. Drawing predominantly on household surveys administered at the beginning, middle and end of the TISA project, we analyse a set of relevant indicators linked to the five factors. In addition to many changes, we found changes in irrigation management, including a reduction in total water use to less than half pre-TISA levels. Further, the changes were sustained when the schemes transitioned from an intensive research-for-development phase into a more operational phase. This research also shows that when governments listen to farming communities and revise institutional arrangements, such as water scheduling and scheme constitutions, this fosters more sustainable irrigated agriculture. We conclude that when initiating development projects for sustained change within smallholder irrigation schemes policy makers and donors must commit sufficient project time and funding for both a development phase and a transition to an operational phase. Programs must take a participatory approach and support multiple interventions including both socio-institutional and technological interventions.

1. Introduction

Globally, it has been predicted that the shortfall between water supply and demand will increase to around 40 % by 2030, unless current water management practices are changed (UN-Water, 2023). Considering that agriculture accounts for 80 % of consumptive use in most water scarce catchments, and demand will increase with predicted population growth, there will be increased demand to transfer water to other uses. Hence, agricultural production systems need to become resilient and adaptive to climate change and increased competition for water.

Climate change will continue to adversely affect agricultural production in sub-Saharan Africa (SSA) (IPCC, 2022). For example, in Tanzania it has been estimated that maize, sorghum and rice yields will decline by 3.6 %, 8.9 % and 28.6 %, respectively, by 2050 (Rowhani et al., 2011). This is largely because of shorter growing periods due to the unpredictable beginning and end of the rainy season (Mkonda et al., 2018; Zougmoré et al., 2018; Haile et al., 2019). These changes will result in detrimental economic, nutritional and health implications (IPCC, 2021; IPCC, 2022). The frequency and severity of extreme events,

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such as floods and droughts, are also predicted to increase (e.g. see Mubaya et al., 2012).

The IPCC (2022) argues that Africa is particularly vulnerable to climate change due to poverty, governance challenges, limited access to basic services and resources, violent conflicts and high levels of climate-sensitive livelihoods, namely smallholder farming, pastoralism, and fishing.

One fifth of SSA's economic output and 60 % of its labour force depends on agriculture (IPCC, 2022; Staatz and Dembele, 2008; Woetzel et al., 2020). However, 97 % of agricultural production systems are rain-fed, making the sector highly sensitive to climate change (Mafongoya and Ajayi, 2017). Irrigation development has been proposed as a solution to the dependence on rainfall and to increase food production, with governments and donors investing in irrigation schemes: for example, the Government of Zimbabwe, with support from development agencies, is investing in new irrigation development and measures to improve existing irrigation facilities (Mwadzingeni et al., 2022). However, large and small irrigation developments in SSA have a long history of underperforming or failing, due to poor irrigation water management leading to salinity, water logging and fertilizer leaching, production of low-value crops, lack of access to inputs, poor quality inputs, which results in low profitability and inability and unwillingness to pay water fees and participate in scheme maintenance. This has resulted in an ongoing cycle of repair-decay-repair (Bjornlund, et al., 2017; Bjornlund et al., 2020a).

We argue that this cycle arises from linear approaches to development and the use of single interventions—for example, rehabilitating infrastructure—rather than treating irrigation schemes as complex socio-ecological systems. The literature reflects this complexity, with numerous factors identified to enhance farmers' capacity to adapt to climate change (Abdul-Razak and Kruse, 2017; Shikuku et al., 2017). These can be grouped into five critical factors. First, smallholders' adoption of new farming practices requires an enabling institutional environment: such as supportive and functional land tenure arrangements, irrigator organizations and local government and non-government institutions (Clay and King, 2019). Second, appropriate and context-relevant agricultural technologies enable farmers to address agricultural challenges (Abdul-Razak and Kruse, 2017). Third, functional agriculture-related infrastructure (e.g. roads) enables access to input and output markets, and irrigation infrastructure provides reliable supply of water (Abdul-Razak and Kruse, 2017; Mango et al., 2018; Pörtner et al., 2022; Rosa et al., 2020). Fourth, economic resources enable farmers to access inputs, information, and services. Economic resources encompass farm and non-farm incomes, physical assets, such as land and livestock, and credit (Defiesta and Rapera, 2014). Further, diversification of income streams increases total household income (Manero et al., 2020). Fifth, social capital enables farmers to learn and access information, knowledge and support from established social networks (Agrawal, 2010). These factors have been identified in various isolated studies in different parts of the world and different contexts. However, we have not identified any studies exploring how a particular theory of change and two-pronged approach, applied across several schemes and jurisdictions, can facilitate similar sustained changes in the adaptive capacities of farmers and their schemes. This study fills this gap in the literature.

Managing and stimulating change in irrigation and associated food production systems is complex under normal conditions, with complexity intensified by the need to increase food production and manage water shortfalls. Multiple interventions across different scales are needed to facilitate learning opportunities, build resilience and capacity to adapt to climate change, and achieve sustained change of the agricultural systems (Parry et al., 2020; van Rooyen et al., 2020). This paper reports on ten years of agricultural research for development as part of the 'Transforming Irrigation in Southern Africa' (TISA) project operating from 2013 to 23 and implemented in a Phase I (2013–17) and Phase II (2018–2023) within smallholder irrigation schemes in Tanzania, Mozambique, and Zimbabwe. TISA introduced two major interventions—Agricultural Innovation Platforms (AIPs) as a social institution, and simple-to-use soil moisture and nutrient monitoring tools as a technology—as a two-pronged approach to build capacity.

This paper provides an ex-post analysis synthesising TISA's outcomes and drawing on published and peer reviewed papers. It adds values to these papers by exploring outcomes from TISA's two pronged approach, which was consistently introduced across four schemes located in three countries with differing political, economic, climatic, agricultural and cultural systems. There are several hypotheses implicit within TISA's theory of change and the approach taken: i) that despite the differences in schemes, the approach can generate similar changes in irrigation water management, farmers' profitability and schemes viability, and that change can be sustained as the project transitions from a research to a more operational phase; ii) that the TISA approach will influence farmers' adaptive capacity across the five factors identified in the literature, and thereby transition schemes from dysfunctional to functional and sustainable schemes; and iii) that the interventions will operate synergistically to increase farmers' adaptive capacity. The synthesis presented regarding these hypotheses fills the identified gap in the literature and provides a significant contribution to the existing adaptation literature.

The paper is structured as follows. Section 2 provides brief background on TISA: the theory of change and the rationale behind the two-pronged approach. Section 3 overviews the methodology, including summarising the study regions, data sources and their limitations and the indicators analysed and their linkage to the five critical factors for adaptive capacity. Section 4 synthesises key TISA evidence from existing peer reviewed publications, and is structured by the five factors posited to improve adaptive capacity. Section 5 discusses how the TISA approach has improved farmers' adaptive capacity with respect to the five factors, and how the interventions worked synergistically to stimulate innovation, build capacity and link to various Sustainable Development Goals (SDGs). The discussion also provides key lessons for politicians, practitioners, NGO's and funding agencies engaging with smallholder communities to generate sustained change. The paper concludes with some policy implications and future research needs.

2. The TISA approach

In this section we briefly describe the TISA approach to provide background on the project as context for the results synthesised from TISA's published peer-reviewed papers. The first sub-section describes the Theory of Change while the second sub-section describes the two-pronged approach that illustrates the synergies between the project interventions.

2.1. Theory of change

A theory of change is a sequence of changes that are anticipated to lead to an outcome, forming a pathway towards impact (Vogel, 2012). The theory underlying the TISA approach is discussed in detail in Pittock et al. (2020). In discussions with key local and national stakeholder, poor irrigation management was identified as the major issue affecting scheme performance. Hence, TISA's theory of change considers higher physical and economic water productivity as the entry point for stimulating change. TISA provided farmers with simple-to-use monitoring tools to enhance their irrigation management, and AIPs were introduced to identify and overcome productivity barriers (more detail in Section 2.2).

The hypotheses implicit within the TISA approach are listed in the introduction. It was anticipated that these interventions would work synergistically to create positive outcomes (Fig. 1) and heighten social capacity, triggering a virtuous cycle of improvement. It was anticipated that two self-reinforcing feedback loops would be established: (1) the individual farmers and their organizations would gain confidence and

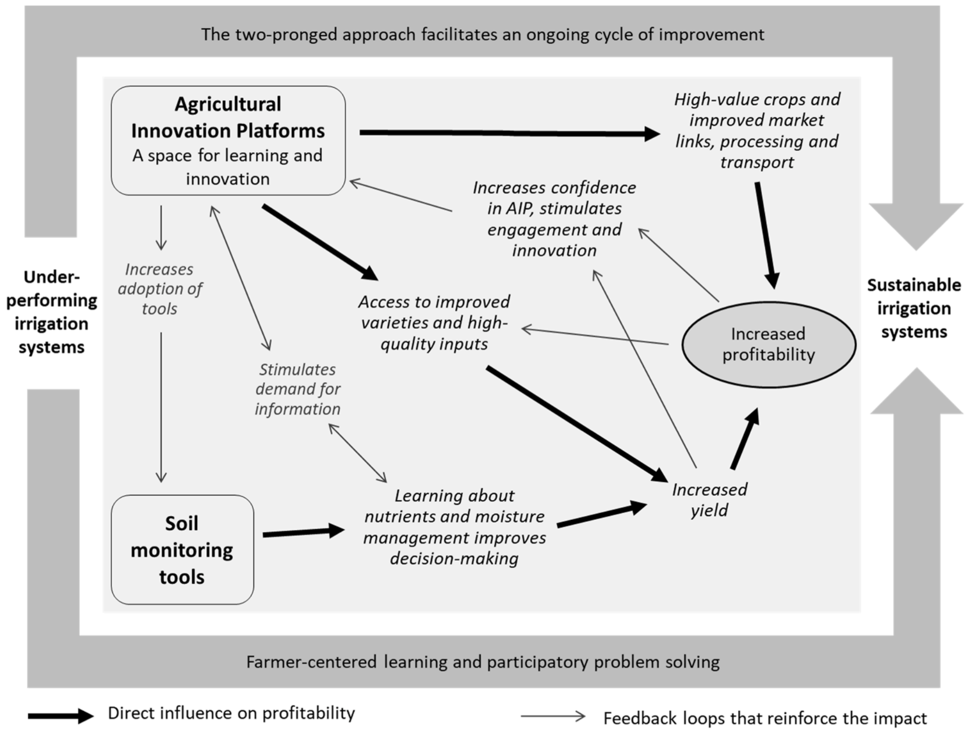

Fig. 1. TISA's two-pronged approach (Source: Bjornlund et al., 2021).
Fig. 1 shows how the TISA project facilitated change through Agricultural Innovation Platforms and soil monitoring tools and how these changes interacted.

skills to innovate further; and (2) farmers would demand more appropriate policies and support services from government agencies. Long-term outcomes should emerge: more sustainable water use, greater food security and higher farm incomes, resulting in increased resilience and adaptive capacity.

2.2. The two-pronged approach: the AIP and tools

We anticipated that the two interventions would create synergies and feedback loops to kick start a process of change within smallholder irrigation schemes, transitioning them from dysfunctional to functional and sustainable schemes (Fig. 1). The AIPs acted as facilitators of social interactions and institutional change—and in this way were socio-institutional interventions—and the monitoring tools were technological interventions.

AIPs are multi-stakeholder forums that facilitate communication and coordination between a diversity of actors to identify and deal with system constraints of immediate concern, enhance networks for learning and innovation, and identify feasible and practical innovations (Pittock et al., 2020; van Rooyen et al., 2017). In the TISA project, local facilitators were trained and mentored to run AIPs and move through a multi-step process: i) key stakeholders of an irrigation scheme were brought together such as farmer representatives, extension services, local development authorities, input suppliers and output buyers; ii) maps of the present state and future aspirations for the scheme were drawn as part of a visioning exercise; iii) stakeholders identified barriers to improved productivity, potential solutions and other opportunities; and iv) the stakeholders capable of progressing the solutions were identified and solutions were implemented (van Rooyen et al., 2017). The last step sometimes required the involvement of additional stakeholders such as finance institutions or NGOs.

While the AIP approach was introduced across all the schemes, the collaborative and inclusive nature of the AIP process allowed constraints to emerge that were unique to each scheme and its socio-economic and biophysical context so that the interventions could be designed to accommodate this context. The solutions identified by the AIP led to a diversity of supplementary interventions in the schemes (see evidence in Section 4.1.1).

The soil moisture and nutrient monitoring tools were developed by CSIRO in Australia and were designed to be simple to use. They were given to 20 farmers in each scheme at the beginning of Phase I. For a technical discussion of the tools and their reliability see Stirzaker et al. (2017) and Stirzaker and Driver (2024). The farmers were selected in collaboration with local stakeholders, according to two criteria: the tools should be distributed across the irrigation scheme, and the selected farmers should be trusted by other farmers to facilitate farmer-to-farmer learning.

The Chameleon reader and sensor arrays provide information about soil moisture, and the Full Stop Wetting Front Detector and nitrate strips were used to measure the nutrient and salinity content of soil moisture. Each farmer received a sensor array and two Full Stop devices, and each scheme received two Chameleon readers to share among the 20 farmers.

The sensor arrays comprise three sensors that are buried in the top, middle and bottom of the root zone with a cable reaching above ground level. This cable connects to the Chameleon reader, which provides the soil moisture level at each depth by a coloured light: blue = too wet, green = about right, and red = too dry. The Full Stops are buried to collect a soil moisture sample in the middle of and below the root zone. Each device is connected to the surface by a tube, and an indicator pops up when a sample is ready for collection. The sample is then extracted using a syringe and analysed for nutrients and salinity. Over time, and by recording readings from both tools, the two tools provided a good understanding of soil water moisture and nutrient dynamics. The farmers learnt that fertilizer leaches below the root zone and is lost to the plants when the Chameleon's lights are consistently blue.

3. Ex-post analysis of adaptive capacity and whether change has been sustained

We undertake an ex-post analysis and synthesis of TISA evidence by re-applying results from peer-reviewed TISA papers to test the three hypotheses listed in the introduction. This section describes the study regions and schemes, provides a brief overview of data sources underlying the TISA results and introduces the indicators and their linkage to the five factors of adaptive capacity from the literature.

3.1. Study regions and schemes

In 2012–13 the Australian Centre for International Agricultural Research commissioned a scoping assessment covering nine countries in eastern and southern Africa to identify where to undertake this research (Pittock et al., 2013). Criteria for selecting priority countries included the following: potential to enhance food production and reduce poverty from existing and proposed irrigated agriculture; favourable policies and government support; stable governance structures; local research expertise; and capacity to inform regional inter-governmental organisations. Based on these criteria Zimbabwe, Mozambique and Tanzania were selected. The irrigation schemes within each country were selected based on: recommendations from our African partners; the national government approving our research; water infrastructure having at least a minimum level of functionality; and community leaders being willing to be partners in the research.

Phase I engaged five schemes and Phase II was out-scaled to 41 schemes with approximately the same project staff and financial resources. This paper focuses on three schemes that were part of both phases: Kiwere in Tanzania, 25 de Setembro in Mozambique and Silalatshani in Zimbabwe (Table 1, Fig. 2). Qualitative findings from the Magozi rice growing scheme in Tanzania are included when particularly illustrative. The impacts of the TISA approach during Phase I (TISA I) and Phase II (TISA II) are analysed based on existing peer reviewed studies. TISA I and II represent periods of intensive and significantly reduced project involvement, respectively. During TISA II many of the functions carried out by project staff during TISA 1, were transferred to local stakeholders and TISA I farmers were used to train TISA II farmers in the use of the tools. This allows us to assess whether the TISA approach has generated change and impacts that were sustained as the schemes transitioned from a project to a more operational stage.

We acknowledge that the way the schemes were selected could potentially introduce some bias. As this was a research-for-development project, we had to ensure that the schemes showed willingness and the potential to engage in the intended project activities. However, bias can impact in different ways: for example, the director of irrigation in Zimbabwe later revealed that Silalatshani had been suggested as it was the least functional scheme in Zimbabwe and, hence, surely in need of improvement.

Table 1
Key characteristics of the schemes.

	Tanzania Kiwere	Mozambique 25 de Setembro	Zimbabwe Silalatshani[1]
Year constructed	2004–07	1975	1968–69
Location	Iringa District	Boane District	Insiza District
Farmers	168	40	212
Irrigated (ha)	195	38	110
Main crops	Tomatoes, onions, green maize	Cabbages, tomatoes, green beans	Maize, wheat, sugar beans
Management / Administration	Irrigators' Organization	Farmers' Association	Government with Irrigator Organization
Land tenure	Customary	Historical right by occupation	Statutory land tenure
Soils	Sand & clay of varying fertility	Mostly fertile clay soils	Mostly loamy sandy soils
Rainfall (mm)	700	650–900	450–650
Water source and conveyance method	River, gravity canal	River, motor pump	Dam, gravity canal
Irrigation method	Gravity furrow	Gravity furrow	Gravity flood

Notes: [1]Silalatshani has 845 farmers on 442 ha, the project was within the Landela Block with 212 farmers. Reference made to Silalatshani refers to the Landela Block.
Sources: Project data.

Fig. 2. Study sites in the three countries. (Source, Clive Hilliker, ANU). Its caption: It shows map of the location of the irrigation schemes that were part of the project in Tanzania, Mozambique and Zimbabwe.

3.2. Data sources underlying the results used for the ex-post analysis

The evidence presented in this paper is based on data collected as part of a research-for-development project, with specific objectives and purposes for data collection. In this paper, we re-apply these results to analyse the impact of the TISA approach on farmers' adaptive capacity and whether change was sustained. The results and our analysis are primarily based on quantitative data supported by qualitative data collected from the schemes, using four methods. First, three household surveys: a baseline survey in 2014; an end of Phase I survey in 2017; and an end of Phase II survey in 2021. In Tanzania and Zimbabwe, the aim was to interview 100 households in each survey, which represented a substantial proportion of the population in each of the two schemes. In Mozambique, the aim was to survey the population, as the scheme was much smaller. In Tanzania and Zimbabwe, households were selected to represent farmers at the head, middle and tail end of the scheme, households with different resource availability and with both female- and male-headed households. Survey development and administration included ensuring consistency of questions across countries, enumerator training and pre-testing, rigorous checking of data validation processes, and the use of tablets for data collection (second and third surveys) to further improve data accuracy. The survey data was analysed using descriptive statistics.

Second, all farmers were encouraged to keep a field book with records of their farming practices, with those who accepted to use the monitoring tools committing to maintain the field book and those without the tools encouraged to do so. Farmers kept ongoing records of farm operations (e.g. fertiliser practices), inputs purchased (e.g. seeds and fertiliser) and their prices, volume harvested, and prices received. The field books were maintained in collaboration with extension officers and project staff, which improved their accuracy and consistency. This data was used to calculate yields and gross margins during end-of season workshops with extension officers and all farmers who had kept a field book. Third, qualitative data was collected from focus groups with farmers discussing various issues, as well as at the end-of-season gross margin workshops. Fourth, observations were collected by project staff when visiting the schemes. The qualitative data has been drawn on to a lesser extent than the quantitative data and is predominantly used to provide further insight or interpretation of quantitative findings. This extensive and rich combination of quantitative and qualitative data provided the ability to triangulate results to substantiate outcomes.

The data collection processes and the analyses are extensively reported in the country specific peer reviewed papers. For Tanzania see Mdemu et al. (2017), (2020), (2024); for Zimbabwe see Moyo et al. (2017), (2020), (2024) and for Mozambique see de Sousa et al. (2017), Chilundo et al. (2020) and Tafula et al. (2025).

3.3. Indicators of adaptive capacity and sustained change

The indicators used to demonstrate change in farmers' adaptive capacity and whether these changes were sustained when the TISA I schemes transitioned from the research-intensive phase to a more operational phase in TISA II are set out in Table 2. The term 'sustained change' is used to mean change that arises and is maintained during the TISA project.

The data collected was designed to report on TISA's specific objectives and as such did not require the use of a control sample; hence, in reapplying TISA evidence we cannot validate our analysis by comparing changes in the TISA schemes against data from schemes that were not part of TISA. We acknowledge that this is a shortcoming. However, a survey of a control group of schemes was conducted in 2021 to measure whether the TISA approach enabled farmers to manage and cope with COVID-19 restrictions. The results of this study are published in Bjornlund et al. (2024) and we make brief reference to the findings in the conclusion.

4. Synthesis of evidence of change and outcomes through TISA project

In this section we synthesise TISA evidence of change structured by the five factors from the literature posited to improve adaptive capacity to substantiate our hypotheses. The enabling institutional changes, and

Table 2
Assessment framework of improved adaptive capacity and sustained change.

Adaptive capacity factors	Indicators of changes in capacity
Enabling institutional environment (Section 4.1)	Examples of institutional change through supplementary interventions Institutional change in water fees and land audits Links to financial institutions Changes to water scheduling and cropping calendar
Appropriate and context-relevant agricultural technologies (Section 4.2)	Uptake and changes in irrigation practices from using soil monitoring tools irrigation practices; yield; contribution of water from rainfall and irrigation to water productivity Uptake for farmers field books and changes in agronomic practices: use of field books; gross margins; area irrigated; crop selection
Functional agriculture-related (e.g. roads) and irrigation infrastructure (Section 4.3)	Infrastructure upgrades through supplementary interventions
Economic resources (Section 4.4)	Improved economic resources: yields; gross margins; perceptions of change in income Improved wellbeing: perceptions of change in children's education, food security and health
Social capital (Section 4.5)	Changes related to conflict; participatory mapping and conflict; willingness to engage in collective action*

technologies and infrastructure are presented first as these changes underpinned household-level changes to economic resources and social capital. While evidence is grouped into the five factors related to adaptive capacity, there are numerous interactions between the factors.

4.1. Enabling institutional environment

4.1.1. Supplementary interventions actioned by the AIP

Through the process of identifying constraints to profitability, actions were taken by the AIP stakeholders leading to numerous supplementary interventions, which are listed in Table 3. These examples all have elements that reflect institutional changes made at various governance levels. In Section 4.1.2 to Section 4.1.4, we discuss selected institutional changes in more detail.

4.1.2. Land utilization, water fee changes and land audits

In Zimbabwe, three major issues caused low productivity and underutilization of land: a conflict with the national water authority (ZINWA) over payment of an old debt, absentee landholders, and low willingness to pay water fees and participate in system maintenance. ZINWA often cut off water supply at critical times during the growing season to force farmers to pay their debt. As a result, famers failed to recoup their investment in the crop, and many gave up farming their irrigation plot to pursue other livelihood opportunities. The AIP invited senior ZINWA staff from Harare to attend an AIP meeting to resolve the water debt issue. In response, the debt was renegotiated, and farmers started to repay the adjusted debt and resumed farming (Moyo et al., 2017; van Rooyen et al., 2017). In relation to the many absentee landowners, the district leadership and the members of the Agricultural Technical and Extension Services, agreed to undertake a land audit and took steps to encourage these landowners to ensure their land was farmed (van Rooyen et al., 2017).

In Mozambique, the participatory mapping identified unused plots, with absentee landowners advised they would lose their plot if it remained unused (Mdemu et al., 2023). As a result, unfarmed land was used by other family members or reallocated to young farmers, with elderly farmers also renting their plots to other farmers. The mapping process also identified some previously unallocated land connected to the current infrastructure, and some vacant land that could be irrigated from the river if a pump was installed. Finance was negotiated through the AIP process to buy the pump. This land was allocated to young farmers who were each provided with an experienced farmer as a mentor (Chilundo et al., 2020; Mdemu et al., 2023).

4.1.3. Links to financial institutions

In Tanzania, AIP participants negotiated with financial institutions to educate farmers about credits and loans. As a result, 615 farmers in four schemes under TISA interventions and two non-TISA schemes received loans from the Cooperative Rural Development Bank (CRDB) by December 2021. Similar negotiations were undertaken with financial institutions such as the National Microfinance Bank and the Mufindi Community Bank. Farmers' registration in the database, created as part of the participatory mapping process, and membership of the irrigator organization, were conditions for being granted a loan (Mdemu et al., 2023). According to the credit officer of the CRDB in Iringa Town, the main reason for now granting credit was that farming was now profitable; hence, the CRDB was now confident that farmers could pay back the loans (statement made at Kiwere, 17 October. 2023).

In Mozambique, arrangements were made through the AIP for Tecnologia E Consultoria Agro-Pecuaria to provide technical assistance to develop production plans, which are essential for obtaining finance from the private-public development bank Gabinete de Apoio e Consultoria a Pequenas Indústrias. As a result, 15 farmers accessed credit to invest in high-quality inputs, such as certified seeds, pesticides and fertilizers (Tafula et al., 2025).

Table 3
Examples of identified constraints and actions taken by AIP stakeholders.

Constraint	Action taken by the AIP stakeholders and supplementary interventions
Ageing tractor and truck (de S)	Contacted a Japanese NGO, which had previously assisted, and a new tractor was purchased.
Water debt of US$286,000 owed to ZINWA (S)	Brought the issue to the surface, ZINWA recognized its importance, and engaged with the IMC to discuss its resolution, and the debt was restructured.
Insufficient irrigation water (M, deS) and high irrigation costs (deS)	Supported farmers to design an irrigation rehabilitation strategy, which was funded and implemented by the government (deS). Negotiated with the Rufiji Basin Water Board to increase the water permit and with Irrigation District Development Fund to expand the intake (M)
Poor integration into input and output markets (S)	Linked farmers to an existing produce buyers' forum in Bulawayo
Bogus suppliers selling poor quality seed and fertilizer (K)	Negotiated linkages to credible suppliers and organized bulk purchases. Main input suppliers provided farm input demonstrations.
Low farm income (de S, S, M)	Installed tools, and farmers were connected to markets (S). Held workshops with farmers to compute gross-margins for key crops (deS). Negotiated with government department to co-fund the construction of rice mill and warehouse (M)
Absentee landowners and unfarmed plots. (S, de S)	Initiated participatory mapping and a plot audit. Unfarmed plot owners encouraged to use their plots (S). Initiated discussions on how to use unoccupied plots and engage young farmers. Absentee landowners told they would lose their plot if not used (de S).
Conflicts over boundaries, plot sizes and water fees (K)	Initiated participatory mapping to show agreed boundaries and plot sizes. Mapping also used as an information system.
Inefficient management of irrigation water and high in-field water losses (S, K)	Introduced soil moisture and nutrient monitoring tools and training on their use (S, K).
Inadequate funding for system maintenance (K, M)	Arranged a visit to a well-functioning scheme for the scheme committee to learn how they were organized. Schemes subsequently made changes to their constitutions.
Lack of agronomic knowledge and low productivity (S, K, de S)	Arranged a field trip and training of farmers and extension officers (de S). Initiated: i) paired demonstration plots; ii) training workshops on improved agronomic practices; iii) exchange visits to other schemes; and iv) on the spot training on specific issues (S). Arranged a visit to others schemes by farmers and extension, agricultural and project officers. Made linkages to development organization providing training on agronomic practices (K).
Unknown fertilizer application rates (K, S, deS)	Provided soil fertility analysis and fertilizer recommendations for different crops on different soils.
Poor crop selection (S)	Organized training of support services in gross margin analysis and linked farmers to better markets.
Invasion of cultivated fields by cattle (de S, S)	Organized a meeting with livestock farmers to discuss the issue of cattle invading the scheme. New pathway identified for cattle to access water and ways for farmers to raise funds to build fence around the fields.
Lack of irrigation maintenance program (d eS)	Held workshop with farmers and extension officers to develop a business plan for scheme to assess the cost of system and building maintenance. Crop preferences, agronomic practices and yields were discussed.
Access to finance (K, de S)	Contacted local credit providers (K, de S) and organized training for farmers in preparing funding applications (de S)

Note: de S, K, M and S denote 25 de Setembro, Kiwere, Magozi and Silalatshani smallholder schemes, respectively. Adapted from Bjornlund et al. (2020b)

4.1.4. Scheme institutions: water schedules and cropping calendars

Several fundamental institutional changes were catalysed through the AIP processes. In Zimbabwe, water had been delivered according to a fixed schedule, meaning applications could not be adjusted to meet plants' needs. When farmers learnt that weekly irrigation was not required, they successfully negotiated with the irrigator organization for water to be delivered when needed. This provided farmers with improved management flexibility and better irrigation decision making (Moyo et al., 2020, van Rooyen et al., 2020).

Also in Zimbabwe, a seasonal cropping calendar, that had prescribed what the farmers could grow since 1972, had restricted production to low value staple crops like maize. When farmers insisted on growing higher value crops it created conflict with the Irrigator Organization. A gross margin workshop with extension officers and irrigation department staff demonstrated that growing maize resulted in negative gross-margins. In response, the cropping calendar was abandoned, enabling farmers to introduce new crops (van Rooyen et al., 2020).

In Tanzania, the AIP arranged a visit to a well-functioning scheme to learn how they were organized. As a result, both schemes revised their constitution to improve clarity over responsibilities and increase water fees. This improved the irrigator organizations' ability to plan, maintain and repair the irrigation infrastructure (Mdemu et al., 2020)

4.2. Appropriate and context-relevant agricultural technologies

4.2.1. Uptake and changes in irrigation practices from using soil monitoring tools

There is strong evidence of farmers' willingness to change their irrigation practices in response to learning from the use of the tools, with farmers responding relatively quickly to their increased understanding that they were over irrigating and leaching fertilizer below the root zone (Fig. 3, Table 4).

Considering that the tools were only given to 20 farmers in each scheme, there is strong evidence of ongoing farmer-to-farmer learning and sustained change. Almost all those changing their practice prior to July 2017 maintained this until 2021, with many of the early adopters making further changes and a third to half of those not making changes prior to July 2017 doing so before the end of 2021 (Table 4). This is evidence that change was sustained and further built on as the project transitioned into a more operational phase. Farmers made two changes: they reduced the number and duration of irrigation events. This reduced total water-use to less than half pre-TISA levels in all three countries and had a corresponding reduction in farm labour.

4.2.2. Uptake of farmers field books and changes in agronomic practices

TISA introduced farmer field books to record farm activities. Almost half the farmers accepted the field books, and the majority maintained them (Table 5). At the end of each season the extension officers and project staff held workshops and discussions where farmers computed their gross margins and yields and compared their results. Through this process it became evident that some farmers increased their yield and gross margins more than others by using more or different fertilizers, seeds with improved quality or different agricultural practices such as manuring and fertilizer application rates. We argue that this learning process helped farmers understand why some had higher yields and

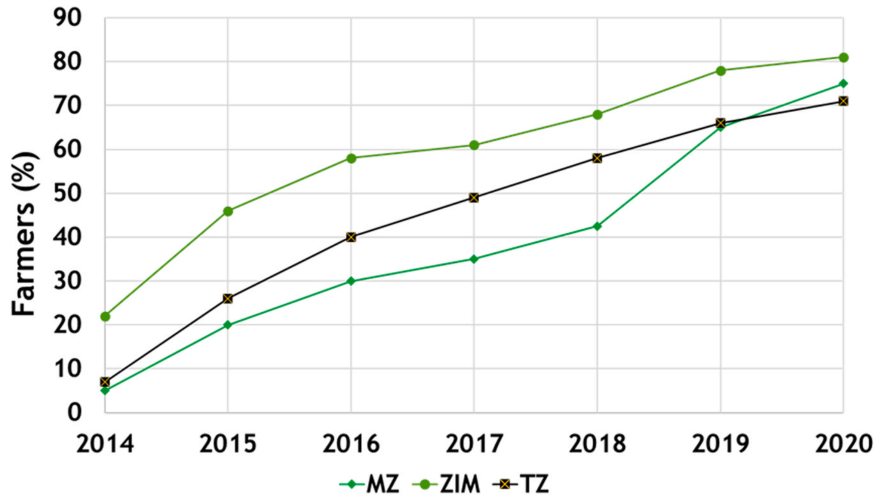

Fig. 3. Changes to irrigation practices 2014–2020/21. Note: MZ=Mozambique; ZIM=Zimbabwe; TZ=Tanzania. It caption: It is a graph of the year (2014–2020 along x axis) the proportion of farmers changing irrigation practices (y axis). Three lines (one for each country) show an increasing trend of adoption of new practices.

Table 4
Changes in irrigation practices.

	Zimbabwe		Tanzania		Mozambique	
	2013–17	2017–21	2013–17	2017–21	2013–17	2017–21
% made changes prior to July 2017	60	NA	50	NA	86	NA
% of those still use the new practice	NA	94	NA	93	NA	80
% made first change after July 2017	NA	31	NA	53	NA	50
% reducing number of events	88	100	71	62	85	86
Number of days between event before	7	7	2	2	8	5
Number of days between events after	15	16	5	4.2	12	12
% of those reduced duration of event	52	66	29	78	56	23
Duration before (hours)	4.0	2.9	5.0	5.0	5.0	4.8
Duration after (hours)	2.0	1.4	3.0	3.5	3.0	3.2
% of those that changed 2013–17 that continued to learn and make changes	NA	78	NA	48	NA	77

Sources: Mdemu et al. (2020), (2024), Chilundo et al. (2020), Tafula et al. (2025), Moyo et al. (2024) and project data

Table 5
Use of farmers' field books.

	Zimbabwe	Tanzania	Mozambique
% of farmers received field book	44	47	38
Of those, % maintained it	74	66	87
% used it to compute gross margins	83	100	92
% used it to plan the next season's crop	89	90	62

Source: Project data.

farm income than others and facilitated farmer-to-farmer learning. More than 80 % of those keeping a field book used them to compute gross-margins, and nearly all farmers in Tanzania and Zimbabwe used them to plan cropping for the next season (Table 5).

AIP interventions included soil testing and associated fertilizer recommendations, demonstration plots, new crop varieties, higher value crops, access to quality inputs, improved agricultural practices, and improved market linkages. We argue that combined with data on gross margins, this improved farmers' ability to react to market signals. In response, extension officers reported increased demand for knowledge, which challenged and encouraged them to source new information. During field visits, extension officers reported that they felt more valued by the communities.

A large proportion of farmers in Tanzania and Zimbabwe adjusted their access to land by either reducing or expanding their area under irrigation (Table 6). They made the adjustment by farming more or less of the land they controlled or by temporarily leasing/renting land to or

Table 6
Changes in farmers' irrigated area and crop selection.

	Zimbabwe	Tanzania	Mozambique
Change in area irrigated during the last four years			
% of farmers finding that their area has:			
Decreased	29	45	0
Unchanged	39	11	100
Increased	32	24	0
% of farmers who introduced new crops	–	42	87
Of these			
% green Maize	0	18	65
% cereals/grain maize	13	2	5
% vegetables	13	63	158[1]
% legumes	2	14	38
Reasons for growing new crops			
% demand was good	51	33	53
% prices were good	79	40	47
% new market access	NA	23	6

Notes: [1]At the Mozambique scheme many farmers tried out new vegetable crops.
Source: Mdemu et al. (2024), Tafula et al. (2025), Moyo et al. (2024).

from other farmers. Farmers in Tanzania and Mozambique, in particular, grew new crops. We argue that the improved market linkages and other AIP interventions led to the increased demand for new knowledge and was in response to market signals.

Several market-related barriers impacted profitability for Magozi's rice farmers. Farmers individually produced and sold many different varieties of rice either to buyers coming to the scheme or by taking the rice on the bus to Iringa town. Both practices resulted in low prices. Further, farmers were selling unprocessed paddy rice immediately after harvest when prices were at their lowest. The AIP firstly facilitated negotiations for co-financing between the government and farmers for the building of a rice mill to process the paddy and a central storage warehouse. Second, the AIP initiated a discussion among the farmers that resulted in them growing only two rice varieties. These changes allowed farmers to store their rice until prices had increased and collectively negotiate bulk sales of the processed rice, which could be sold by the truck load. This significantly increased the price farmers were paid and reduced transport costs (Mdemu et al., 2024).

4.3. Functional agriculture-related and irrigation infrastructure

The AIP facilitated improvements to existing infrastructure. In Mozambique, most of the channels supplying farmers' fields were unlined, which resulted in large water losses, slow supply to tail-end users, and high pumping cost. Infrastructure upgrades were negotiated with the National Irrigation Institute, and funded by the government with farmers providing some of the labour (Chilundo et al., 2020). The infrastructure upgrades have significantly improved the speed of water delivery for all irrigators, increased the volume received by tail-end users, and reduced farmers' pumping costs.

At the Magozi scheme, the extraction allocation and intake from the river were too small, restricting the flow of water into the scheme, which especially affected tail-end users. An increased allocation and construction of a larger intake were negotiated with the Rufiji Basin Water Board. This was jointly funded by farmers and the Iringa District Irrigation Development Fund (Mdemu et al., 2020).

In Zimbabwe, cattle invasion into the fields and canals caused damage to crops and canal banks. In the visioning process the farmers proposed fencing to keep cattle out. The farmers then discussed the problem outside the AIP meeting and agreed to pay an additional monthly fee to fund fencing material and labour (Bjornlund et al., 2020a).

4.4. Economic resources

4.4.1. Improved economic resources

Fig. 4 shows increased green maize yields for farmers with and without the tools in Mozambique. This reflects the impact of synergistic interventions (Fig. 1, Table 3), such as

- reduced fertilizer leaching due to learning from the tools, resulting in reduced irrigation,
- improved input market linkages, and improved quality of inputs (e.g. seeds),
- demonstration plots which facilitated learning about how to grow new crop varieties, and use new farm inputs and better farm management practices, and
- soil tests to inform effective fertilizer application plans.

Farmers clearly experienced rapid results with yields increasing fourfold over the first four years and then stabilizing until they fell slightly due to COVID-19 restrictions in 2020 (Tafula et al., 2025). While farmers with the tools quickly increased their yields, farmers without the tools followed the same trend albeit at a slower rate, suggesting that farmer-to-farmer learning took place. The average yield increases were just over 200 % in Tanzania (Mdemu et al., 2020). In Zimbabwe, water productivity in maize production increased from 0.2 kg/ m^3 in 2013/14 to 1.28 kg/ m^3 in 2016/17 (Moyo et al., 2020).

The increased yields were successfully translated into increased gross margins due to other AIP initiatives such as: improved market information; new high-value crops; improved quality of inputs; and farmers' greater willingness to engage in collective bargaining opportunities as an outcome of reduced levels of conflict (see Mdemu et al., 2020, 2024 for Tanzania and Moyo et al., 2024 for Zimbabwe). For example, the increase in gross margins for green maize in Mozambique (Fig. 5) follow a similar pattern to yield increases (Fig. 4). Both yields and gross margins continued to grow in the more operational phase, inferring sustained impact.

Further, as farmers reduced the time spent irrigating by more than half (Table 4) this time was mostly invested in increased farm work or off-farm income earning activities. Combined with increased gross margins, this resulted in increases in both farm and off farm income, which continued into the more operational phase (Table 7).

As Zimbabwe's farmers began to factor rainfall into their irrigation decisions, they reduced their irrigation frequency and intensity (Table 4), which resulted in rainfall as a proportion of total water use increasing from 20 % to close to 80 % (Fig. 6). Consequently, the scheme reverted to providing supplementary irrigation as originally intended (Moyo et al., 2024).

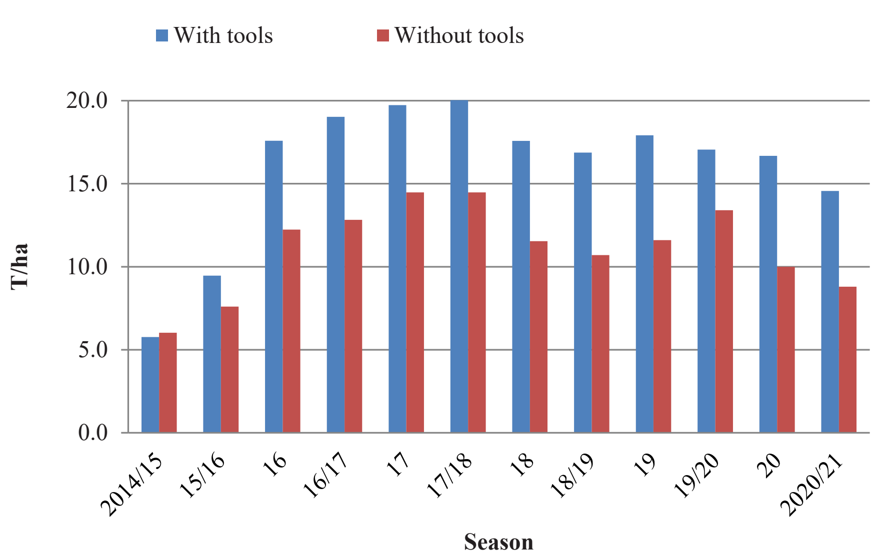

Fig. 4. Green maize yield (tonnes/ha) in Mozambique 2014 to 2021 (Source: Tafula et al., 2025). It caption: It is a bar chart with the season along the x axis and green maize yield in tonnes/ha (y axis) for farmers with and without the tools.

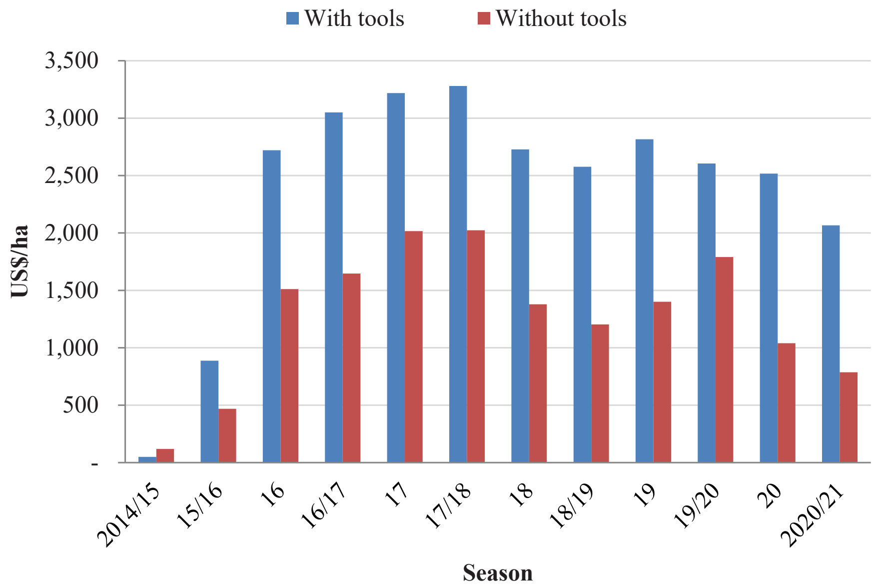

Fig. 5. Gross margins from green maize in Mozambique 2014 to 2021 (Source: Tafula et al., 2025). It caption: It is a bar chart with the season along the x axis and gross margin for green maize in USD/ha (y axis) for farmers with and without the tools.

Table 7
Farmers' perception of changes in farm and off-farm income over the 2014–17 and 2017–20 periods (%).

	Zimbabwe		Tanzania		Mozambique	
Change in farm income	2013–17	2017–20	2013–17	2017–20	2013–17	2017–20
Worse	38	10	24	6	11	35
Unchanged	13	28	23	13	7	30
Improved	49	62	53	81	83	35
Change in off-farm income						
Worse	26	7	21	6	25	8
Unchanged	33	40.	23	27	15	77
Improved	41	48	56	67	60	5

Source Mdemu et al. (2024), Tafula et al. (2025), Moyo et al. (2024)

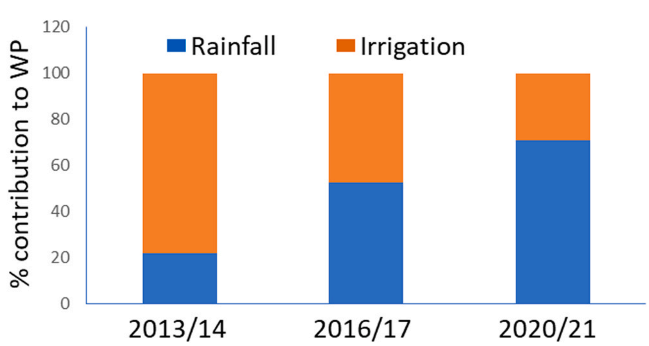

Fig. 6. Contribution of water from rainfall and irrigation to water productivity, Zimbabwe (Source: Moyo et al., forthcoming). It caption: It is a bar chart with the season along the x axis and the percentage contribution water from rainfall and irrigation to water productivity (y axis). Chart shows contribution of rainfall increasing.

4.4.2. Improved wellbeing

The increase in household income improved farmers' ability to purchase farm inputs, which contributed to the increased yield. It also improved households' ability to pay for food, their family's health and their children's education (Table 8). The findings also show that the process of improvement that commenced during Phase I was sustained into the more operational phase, until the onset of COVID-19 in 2020. Critically, these outcomes improved the mental and physical capacity of household members, which will positively influence the future productivity and work prospects of households and children's capacity to learn.

4.5. Improved social capital

The tools and many AIP interventions (Table 3) improved social capital. Reduced water use, through improved irrigation practices (Table 4), improved tail-end users' supply and the supply reliability for other water users dependent on the same water source. This reduced conflicts between farmers within the scheme and between scheme farmers and other users. With increased household income, conflicts between husbands and wives over allocation of scarce financial resources reduced (Mdemu et al., 2020; Moyo et al., 2020).

The participatory mapping process clarified plot boundaries and established plot ownership and relative plot sizes, which reduced conflict among neighbouring farmers in all schemes. In Zimbabwe, the mapping clarified which block reserved land belonged to. This land is critical for farm households to access resources such as firewood and thatching materials for roofing and is often an income source for the scheme. In all countries, the scheme maps reduced the conflict over payment of water fees and increased the willingness to pay water fees and participate in scheme maintenance. (Mdemu et al., 2023).

These developments have increased community coherence and trust and built farmers' agency. As a result, the willingness to engage in collective action has increased such as: collective marketing and purchase of inputs; voluntary payments to build a fence in Zimbabwe; agreeing to grow only two rice varieties in Tanzania; and setting plot

Table 8
Changes in households' perceptions of their wellbeing (%).

	Zimbabwe		Tanzania		Mozambique	
Perception of	2013–17	2017–20	2013–17	2017–20	2013–17	2017–20
Capacity to pay for children's education						
Worse	46	15	13	5	11	28
About the same	23	30	26	28	18	47
Better	31	50	61	67	61	25
Household's food security						
Worse	11	6	16	5	11	15
About the same	25	51	14	44	22	50
7Better	64	45	70	51	67	35
Health of your family						
Worse	2	9	5	6	14	2
About the same	56	81	20	54	25	75
Better	42	10	75	40	61	23

Source: Moyo et al. (2024); Mdemu et al. (2024); Tafula et al. (2025).

land aside to create access roads for farm machinery (Mdemu et al., 2020, 2023 and 2024; Moyo et al., 2020).

5. Discussion

TISA's theory of change theorised that sustained changes in irrigation water management, and flow-on improvements to yield, household income and wellbeing, could be facilitated where there was a community of interest in a commonly shared resource, such as a smallholder irrigation scheme. Changes were expected to arise by creating learning experiences, which would increase farmers' adaptive capacity across schemes with different socioeconomic and biophysical conditions and, hence, their capacity to sustain the improvements achieved. Overall, we have provided evidence to substantiate all three hypotheses underlying TISA's theory of change and its two-pronged approach. TISA initiated a participatory and adaptive management approach with continuous improvements. This analysis confirms that the changes and their impacts—in the form of increased yield, gross margins, farm and off farm income and improved ability to pay for health, education and food security—were similar across the schemes and were sustained after the schemes transitioned from the project to a more operational phase (hypothesis i).

We found clear evidence that the TISA approach addressed most of the key issues associated with the failure of smallholder irrigation and thereby improved the conditions for farmers and their schemes on all five factors posited in the literature to increase farmers' adaptive capacity (hypothesis ii).

First, the institutional environment influences smallholders' ability to change their practices and, hence, to adapt to changing conditions. These institutions include land tenure, irrigator organizations and local government and non-government institutions. The participatory mapping process increased tenure security, which facilitated access to credit. In Zimbabwe, AIP processes changed water allocation rules, providing more flexible irrigation water delivery. Further, the irrigation department abandoned the long-standing cropping calendar, which enabled farmers to grow higher value crops in response to market signals. In Tanzania, farmers agreed to revise the irrigator organization's constitution to clarify responsibilities and increase water fees. Consistent with Clay and King (2019), we argue that these changes increased farmers' profitability and ability to change, resulting in improved adaptive capacity. The institutional changes have directly contributed to promoting economic growth, reducing poverty and ability to adapt to climate change (SDGs 1, 8 and 13), but also more sustainable management and consumption of natural resources (SDGs 6 and 12).

Second, appropriate and context-relevant agricultural technologies. The soil moisture and nutrient monitoring tools were the most important technologies introduced by TISA, and stimulated many changes as noted earlier. Considering that poor irrigation management was identified as a key productivity barrier during preliminary discussions with key stakeholders, the tools were context relevant. Further, the simplicity of using the tools made them appropriate in the local context and provided farmers with site specific data, increasing their agency. Other critical technologies included the introduction of new crop varieties and agronomic practices such as crop spacing, fertilizer application methods, and soil tests for better informed fertilization. Consistent with Abdul-Razak and Kruse (2017), we argue that these technologies have improved farmers' capacity to adopt new farming practices and hence increased their adaptive capacity; thereby, also contributing to improved water use and economic growth (SDGs 6 and 8).

Third, agriculture-related infrastructure. The AIPs facilitated several critical infrastructure improvements such as lining of the canals in Mozambique, and the extension of the intake, and the new rice warehouse and mill in Tanzania. The new warehouse and rice mill have added value to farmers' crops, reduced post-harvest losses and allowed farmers to store rice until prices increase, which has increased farmers' income and adaptive capacity. Consistent with Egyir et al. (2015) and Abdul-Razak and Kruse (2017), we argue that this has increased farmers' adaptive capacity. The introduction of locally-appropriate infrastructure in tandem with improved socio-economic conditions, that helps sustain infrastructure use and maintenance, contributes to building more resilient infrastructure (SDG 9).

Fourth, economic resources. The time saved by reduced irrigation has significantly diversified farm households' income stream, which Manero et al. (2020) found to increase total household income. Further, farmers have increased their gross-margins and farm and off-farm income, which Defiesta and Rapera (2014) also found increased adaptive capacity. These improvements help reduce poverty, enhance health and well-being, promote economic growth and, overall, leave the community's with improved ability to adapt to climate change (SDGs 1, 3, 8 and 13).

Fifth, the AIPs facilitated several interventions which increased social capital. Significant awareness was created among the schemes' broader stakeholder groups about the barriers to farmers' profitability. The participatory mapping process further engaged farmers, extension officers and scheme management. This process identified critical issues affecting individual farmers and their scheme as well as their root causes, several of which were known by many but not collectively acknowledged. Hence, the participatory mapping fostered multi-scale learning and created a collective responsibility to address the issues (Mdemu et al., 2023). Further, the mapping process created clarity and certainty over plot sizes, which has reduced conflict over fee payment and participation in scheme maintenance. The monitoring tools enabled learning opportunities. This resulted in increased water supply for tail-end users, which has significantly decreased the level of conflict between farmers within the scheme and with other water users dependent on the same resource. The reduction in conflict has increased farmers' willingness to engage in collective action, such as collective sale of outputs and purchase of inputs, voluntary payment for fencing, and agreement to only grow two rice varieties. The establishment of demonstration plots and market linkages increased farmers' access to reliable information and market feedback about demand and market prices. Consistent with Agrawal (2010), we argue that these changes increased farmers' social capital and, hence, their adaptive capacity. Improved social capital is not explicitly reflected in the SDGs, yet it underpins individuals' well-being and economic means and ensures that water use and infrastructure innovations are more likely to be sustained (SDGs 1, 3, 6, 8 and 9).

We further hypothesised, that a combination of a socio-institutional and technological interventions would create learning opportunities and stimulate iterative innovations, and thereby work synergistically to improve adaptive capacity (hypothesis iii). The anticipated synergies to increase profitability were realised. Learning from the tools improved irrigation management and contributed to increased yields. AIP interventions improved access to quality inputs, and test plots demonstrated the use of inputs and improved farming practices and provided knowledge on growing improved varieties and higher value crops. The synergies between these interventions further increased yield and translated yield increases to increased gross margins, as hypothesised by the two-pronged approach (Fig. 1). The AIPs also provided a forum that empowered stakeholders to address additional locally-specific barriers to increased profitability through significant institutional innovation: for example, changes to water scheduling; removal of restrictive cropping calendars; adoption and use of field books and workshops to calculate gross margins and share learning; and agreement for farmers to collaborate on crops grown.

Analysis of the impact of COVID-19 restrictions on TISA farmers, compared to farmers from schemes not benefitting from the TISA interventions, has provided further clear evidence that the TISA interventions have allowed farmers to manage the restrictions and adapt to the new production conditions (Bjornlund et al., 2024). TISA farmers reported far less impact of the restrictions on their farm, household and scheme. This further confirms our findings that the TISA interventions have improved farmers' adaptive capacity.

The supplementary interventions stimulated through the AIP are examples of iterative innovation: participatory mapping; demonstration plots; co-funding between farmers and other governance scales for infrastructure development; and the use of mapping databases to support access to finance. TISA research illustrates how multi-scale learning and innovations were stimulated through the two-pronged approach: extension staff transferring learning to other schemes; output markets providing e-marketing platforms for farmers; irrigation engineers and the highest levels of irrigation governance being willing to disseminate the monitoring tools; and the use of participatory processes to simultaneously address barriers (e.g. incorrect or unknown plot boundaries) and engender collective and multi-scale responsibility for implementing solutions, with the participatory mapping process a documented supplementary and successful intervention (Mdemu et al., 2023; Parry et al., 2020). AIPs provide transparency and credibility for 'bottom-up' arguments, which underpins negotiation with key stakeholders that are traditionally difficult for farmers to influence (van Rooyen et al., 2020). Thus extending farmers' influence across the management system and helping secure appropriate investments in infrastructure, equipment and learning opportunities, which would not have been feasible with limited human and financial project resources.

There are multiple key lessons emerging from TISA for politicians, practitioners, NGO's and funding agencies engaging with smallholder communities to generate sustained change. First, any approach must be participatory and involve all affected stakeholders in processes of identifying barriers and implementing solutions. Second, learning opportunities must be created that enable farmers to learn new production systems and practices, these must include learning between farmers, between farmers and extension officers, and between farmers and managers from different schemes and communities. Third, interventions to facilitate change must be of sufficient duration; hence, adequate funding is required for change to be embedded and to allow for both an implementation/project phase and a transition from this phase to an operational phase. The duration required will depend on specific conditions of the individual project: such as, the current conditions of infrastructure, agronomic practices, and functionality of governance structures. In the TISA context, ten years was sufficient.

Fourth, it is critical to carefully consider how to out-scale the approach taken. Ncube et al. (2025) argue that scaling approaches should be designed to fit a specific context and integrated into a project's theory of change and require the right mix of AIP stakeholders with a collective capability to first create and anchor innovations at the micro (niche) level and then institutionalise them in other levels of the system. Fifth, projects should ensure that their intervention has quick and significant impacts on farmers' livelihoods as a strong incentive to continue their new practices. In TISA, learning from the tools made farmers start to change their irrigation practices with immediate impact on yields and time spend irrigating. Sixth, projects need to actively and purposefully explore how other development activities in the region can be integrated into the project for training and funding purposes to increase the impact of all projects and reduce costs.

While these lessons are based on experiences from smallholder irrigation schemes in southern and eastern Africa, we argue that there is no reason why similar approaches would not work in other parts of the world and within larger irrigation schemes, particularly where there is a diversity of actors comprising several levels of governance. The intent of an AIP approach is to involve local stakeholders in identifying barriers and solutions, and the process is inherently responsive to different contexts. However, further research is needed to explore which large-scale irrigation contexts the approach is suitable for and if and how the lessons can be amended to suit other parts of the world.

6. Conclusion

Small-scale irrigation systems are complex socio-ecological systems. The underlying rationale for the two-pronged approach was that sustained change could be facilitated where there is a community of interest in a commonly shared resource, such as a smallholder irrigation scheme. Further, that sustained change could be facilitated through resource and crop monitoring, social learning, and building an adaptive and participatory management culture. Beneficial synergies between socio-institutional and technological interventions were anticipated.

The analysis clearly substantiates our hypotheses with significant implications for government and development agencies investing in new and existing irrigation infrastructure. We documented significant improvements across three countries with different socioeconomic and biophysical conditions and on the five factors identified in the literature as increasing farmers' adaptive capacity. Further, improvements were sustained and built on as the project transitioned into a more operational phase. The interventions made throughout the system helped farmers to overcome barriers and created an incentive to learn and improve farmers' livelihoods and system functionality. Working synergistically, the two-pronged approach facilitated multi-scale learning and iterative innovations, with bottom-up pressure and evidence generating change at higher governance scales that are harder to influence.

TISA's research was not structured to determine whether multiple interventions were more effective than single interventions or whether some bundles of interventions are more or less effective than other bundles. However, findings lend significant weight to the argument that multiple interventions do increase adaptive capacity and profitability and improve the functionality of small-scale irrigation schemes, and that two initial complimentary interventions can stimulate multi-scale change. Single interventions—such as fixing infrastructure or creating irrigator associations without supplementary capacity building—neglect the complex social-ecological interactions that are influenced by context-dependent institutional barriers. These dynamics are understood best by the actors; hence, the importance of participatory processes that harness local knowledge, empower stakeholders and extend their sphere of influence, and facilitate iterative innovation.

We argue that the irrigation schemes have gained improvements during a development phase, have sustained these improvements in a more operational phase, and have transitioned from dysfunctional to functional and more sustainable systems. Thus, a critical learning of relevance for governments, NGOs and other organizations working for sustained change within smallholder irrigation schemes is that sufficient project time and funding should be committed and the importance of having both a development phase and a transition to an operational phase. Hence, long-term commitment to projects is essential for success. For TISA, the funding agency committed to ten years of continued funding, which we argue has had a significant influence on the sustained outcomes of the TISA approach.

Future research is needed to identify how these functional systems can stimulate economic development and growth more broadly in their local communities. In this regard, the Australian Centre for International Agricultural Research, which funded the TISA project, has been convinced to fund the first stage of a new project aiming to research how irrigation schemes can become engines of local economic development using the concepts of circular food systems and agroecology.

Irrigation policies and development should recognise new and existing schemes as socio-ecological systems with complex interactions between components. Failing to do so will inevitably result in continuing intervention approaches that reinforce the well-established build/decay/refurbish/decay cycle. Technological innovations—such as monitoring tools to improve water productivity—should be introduced alongside participatory processes that facilitate multi-scale learning and iterative innovation to identify and resolve barriers to profitability and scheme functionality. As demonstrated in this paper, it is essential to combine technological and social processes and initiate multiple locally-appropriate interventions through participatory processes in order to stimulate effective change and ensure the global community can address the SDGs and sustainably feed a population of 10 billion people.

Author contributions

Withheld for review

CRediT authorship contribution statement

Bjornlund Henning: Writing – review & editing, Writing – original draft, Methodology, Conceptualization. **Parry Karen:** Writing – review & editing. **van Rooyen Andre Frances:** Writing – review & editing. **Pittock Jamie:** Writing – review & editing.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: All authors report financial support was provided by Australian Centre for International Agricultural Research.

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Data availability

The data that has been used is confidential.

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