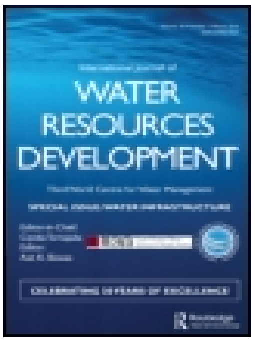

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The importance of learning processes in transitioning small-scale irrigation schemes

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ABSTRACT

Many small-scale irrigation schemes are dysfunctional, and learning, innovation and evaluation are required to facilitate sustainable transitions. Using quantitative and qualitative data from five irrigation schemes in sub-Saharan Africa, we analyze how learning and change arose in response to: soil monitoring tools, which triggered a deep learning cycle; and agricultural innovation platforms, which helped develop a social learning system. Knowledge generation and innovation were driven by the incentives of more profitable farming. Learning and change spread to farmers without the tools, and learning at different levels resulted in extension and governance stakeholders facilitating profound institutional change.

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Government-owned small-scale irrigation schemes; learning system; innovation; Mozambique; Tanzania; Zimbabwe

Introduction

Irrigation is promoted by many governments and donors to reduce poverty and improve food security in the world's poorest regions (Burney & Naylor, 2012). However, 40% of irrigation systems in southern Africa are classified as unsuccessful, with specific concern about government-managed schemes (Mutiro & Lautze, 2015). Many factors contribute to this high failure rate, including the subsistence orientation of some small-scale irrigation schemes (SSISs) (Bjornlund et al., 2017). Poor interaction between the actors – irrigators, input suppliers, markets, extension staff and governance systems – results in system dysfunctionality and lack of profitability (van Rooyen et al., 2017). Irrigation requires significant infrastructure and expertise to access, store, and convey water to the schemes; distribute water equitably to farmers' fields; and consider the needs of the environment and other users beyond the scheme. In comparison to dryland farming, irrigators require extra skills to manage water within their plots.

Agricultural research for development (AR4D) is the application of research activities to achieve development goals through changes in knowledge and practices of a broad range of actors: farmers, extension services, development practitioners and policy makers (Thornton et al., 2017). AR4D has much to offer in improving the profitability of SSISs, but impacts have been limited by linear approaches and a failure to understand how change

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happens (Spielman et al., 2009). The formal knowledge system triangle of research, education and extension provided a good foundation for agricultural development, but has not been sufficient to bring about coherence and innovation (as change) in socio-technical systems (Brunori et al., 2013). Consequently, there has been a shift towards systemic thinking and the use of multi-actor processes in the co-development of innovation through interaction, knowledge sharing and social learning (Klerkx et al., 2012; Knickel et al., 2008; Moschitz et al., 2014). More reflection is needed on what is working in AR4D, in association with agricultural innovation systems, and how current approaches can be improved (Maru, 2018).

This article reports on the learning arising from the project Increasing Irrigation Water Productivity in Mozambique, Tanzania and Zimbabwe through On-Farm Monitoring, Adaptive Management and Agricultural Innovation Platforms, subsequently renamed Transforming Small-Scale Irrigation in Southern Africa or TISA. This project aimed to stimulate change and improve profitability in five government-owned SSISs in Tanzania, Mozambique and Zimbabwe. The project used two synergistic interventions: Agricultural innovation platforms (AIPs) and soil monitoring tools. AIPs are valued as an R&D approach in Africa (Fantubi et al., 2016), where learning and network building are core features. The soil monitoring tools depart from the traditional technology transfer paradigm, having been purposefully developed to create a farmer-centred learning system (Stirzaker et al., 2017). The article addresses two questions: what role has learning played in transitioning irrigation schemes towards being adaptive systems with improved functionality; and how far has the learning spread?

Literature

Adaptive management requires that the system's actors learn to do things differently (Stirzaker et al., 2011). Within SSISs, the actors are diverse, and constraints span irrigation and agronomic knowledge, market linkages and institutional arrangements (Bjornlund et al., 2017; Pittock & Stirzaker, 2014). Put differently, much learning and innovation is required to transition a dysfunctional SSIS to an adaptive system. AR4D has traditionally given primacy to research organizations, as a key source of innovation, and education and extension staff as dissemination processes (Hermans et al., 2015; Maru, 2018). AR4D is now more closely linked with approaches that enable collaboration for innovation across a range of knowledge producers (Maru, 2018). Technology is still important, with the terms 'translation', 'co-construction', and 're-innovation' used to emphasize the deep coupling between a technology and the socio-economic context where it is introduced (Garb & Friedlander, 2014).

Farmers need irrigation management skills and working knowledge of the plant-soil-atmosphere continuum (Stevens, 2006). While soil monitoring has the potential to improve irrigation management, adoption has been low worldwide (Stevens, 2006; Stirzaker, 2006). Adoption is influenced by many factors, including socio-economic, cultural and institutional factors, and the cost and complexity of technologies (Stevens, 2006). While formal training may impart knowledge regarding irrigation scheduling, farmers are often unable to act alone: for example, the rigid irrigation schedules often enforced by irrigation management committees mean irrigation happens at fixed frequencies, regardless of a crop's water requirements (Moyo et al., 2020). Hence, inflexible scheduling prevents farmers from practising with the knowledge gained from monitoring.

Extension staff are a typical source of advice in SSISs, with more than 70% of irrigators on six sub-Saharan African schemes using advice from extension staff in managing irrigated crops (Wheeler et al., 2017). However, this proportion varies, as extension staff may lack irrigation skills, or be absent from the schemes, or expensive to access; hence, farmers often use their own knowledge and that of other farmers for irrigation scheduling (Stevens, 2006; Wheeler et al., 2017). More broadly, the technology-supply-push approach has failed to interconnect the different services farmers need, such that training and extension systems have not improved productivity (Hounkonnou et al., 2012). Further, participatory approaches that seek to make technologies context-specific can still fail if opportunities are lacking and institutional barriers are not addressed (Hounkonnou et al., 2012). Training is an accepted part of the learning tool kit in the context of successful learning organizations (Garvin et al., 2008). However, Garvin et al. (2008) explicitly note that learning arises from a concrete series of learning processes that work together to efficiently move information to those who need it: education and training, information collection and transfer, analysis, and experimentation. Skills in creating, acquiring and sharing knowledge underpin the ability to adapt to unpredictable and changed circumstances. This article proposes that training in the use of soil monitoring tools and putting the tools in the hands of farmers enabled experimentation and knowledge sharing, and triggered a very deep learning cycle, as intended by Stirzaker et al. (2017).

AIPs are a form of multi-stakeholder platform, which focus on identifying and dealing with system constraints and immediate concerns (Independent Science and Partnership Council [ISPC], 2015). Their rationale and role has been described variously as partnerships for inclusiveness, dealing with complex problems, and increasing economic efficiency (ISPC, 2015, citing Echeverría & Byerlee, 2002); and, of increasing interest, networks for learning and innovation (Moschitz et al., 2015). For some, an AIP's main role should be to enhance and perpetuate demand for innovation and remove system bottlenecks (Ngwenya & Hagmann, 2011). Communities with an innovation platform have been shown to have more connections to actors beyond their community (Hounkonnou et al., 2012), and the networks formed should become self-sustaining if the right feedback mechanisms develop (van Rooyen et al., 2017). Where AIPs are appropriately facilitated and achieve good interaction and integration of different knowledge types, the resulting innovation capacity should outlive the AIP (Boogaard et al., 2013). In these circumstances, social learning should become a natural part of knowledge generation and sharing processes. Ison et al. (2004) observe further advantages of social learning – gaining a wider ownership of problems, reallocation of responsibilities, and supporting decision making in complex situations – such that this approach should be part of policy conception and implementation.

Information flows, knowledge, learning and innovation

This article explores how learning has been stimulated, rather than seeking to advance the debate on theoretical framings of knowledge or learning processes. While knowledge processes are integral to learning, knowledge in the agricultural context is often approached as a homogeneous concept (Kuehne & Llewellyn, 2017). For this reason it is advantageous to draw on the DIKW model, which distinguishes between data, information, knowledge and wisdom (Figure 1, *left*). The hierarchy is commonly attributed to

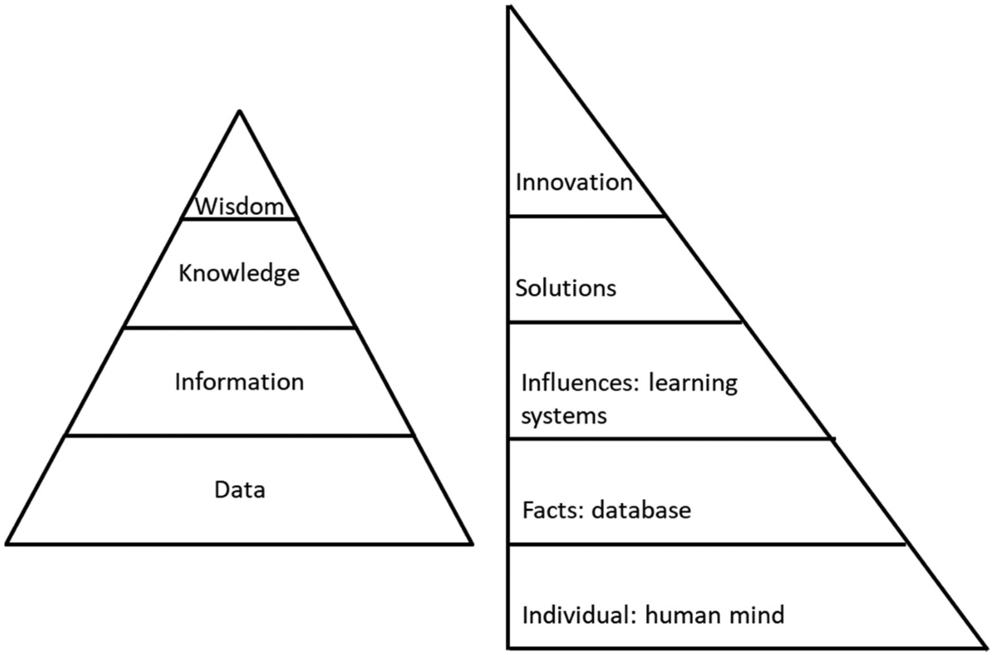

Figure 1. The data-information-knowledge-wisdom hierarchy, aligned with Hicks, Dattero, and Galup's (2006) five-tier knowledge process model (adapted from Evely et al., 2012).

Ackoff, though its origins are linked to a poem by T. S. Eliot (Rowley, 2007). Inherent in the hierarchy is the concept that each higher level is based on and includes the level(s) below (Kuehne & Llewellyn, 2017); that is, wisdom builds on knowledge, which builds on data and information.

The DIKW model, often accredited as the basis of many conceptions of knowledge, enables an understanding that: data (as objective facts, e.g. soil monitoring data) need to be processed to become useful; information provides the capacity for action and creates knowledge when linked to context; and wisdom is associated with the creation of new ideas (Evely et al., 2012). While we acknowledge that there are other framings of knowledge, understanding and action (e.g. Wagenaar & Cook, 2003), the DIKW model has value in the context of this article, especially where the participant in the process is conceived as the farmer leading their knowledge process.

Hicks, Dattero, and Galup's (2006) five-tier model emphasizes knowledge processes (Figure 1, *right*). Integrating the two models (Figure 2) offers a way to combine conceptions of knowledge (DIKW) with knowledge processes (adding meaning, learning and innovation). A noted weakness of these models is their linear approach to knowledge processes, with systems and complexity thinking introducing the notion of cyclic processes (Evely et al., 2012). Hence, an arrow is added on the left in Figure 2 to acknowledge the need for new data as an ongoing process of adaptation and experiential learning. Data requirements will change over time, as new data are constantly needed to deepen understanding and inform the development of more complex mental models.

This integrated model has value in association with the systems view of learning explored in this article. The model helps explain the relationship between the learning

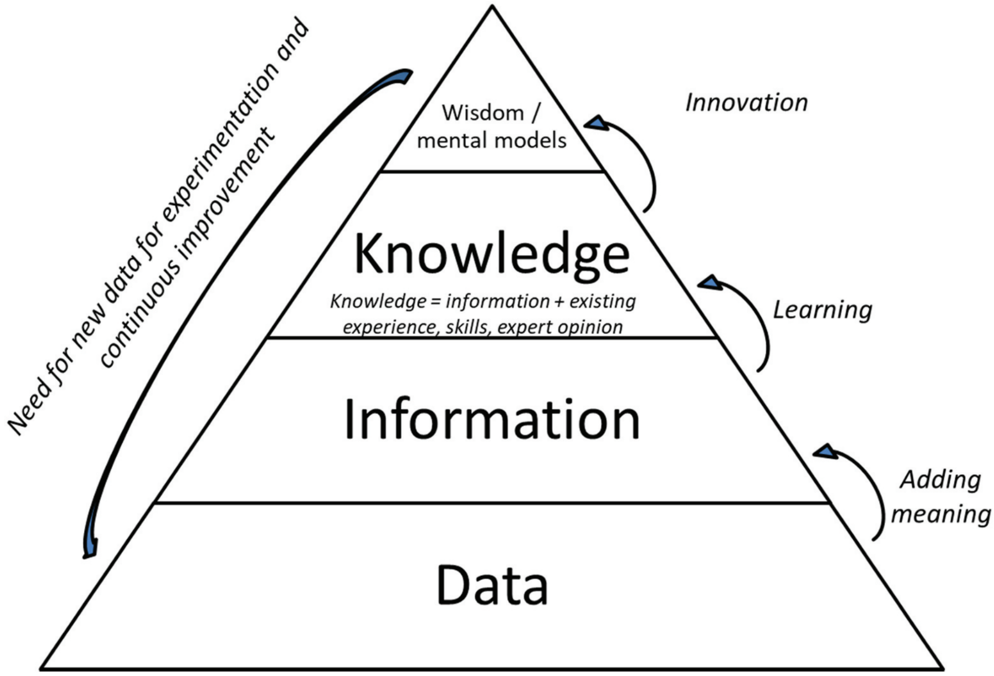

Figure 2. Integration of the data-information-knowledge-wisdom hierarchy with knowledge processes.

and innovation that result from the use of the project's monitoring tools, and makes the distinction between activities that only provide information versus those that foster learning, new behaviour and practices (innovation) and ongoing experimentation. A better understanding of local knowledge processes should improve researchers' understanding of the system.

Information flows are critical in complex systems. Lack of feedback, or information that 'locks in' poor behaviour, will result in system dysfunction and prevent system improvement. Improved information flows help with self-organization, such that the system can learn, diversify and generate new structure (Meadows, 2009). However, it is learning through the evaluation of information that creates the capacity for action and changes in perception, knowledge and behaviour (Brunori et al., 2013). Therefore, learning in this article is evidenced by change in decision making and action. The incentive to learn is important, with experimentation often motivated by opportunity (Garvin, 1993), and benefits and costs creating either an incentive for, or a deterrent to, action (Ostrom, 2011): learning leads to action and change when the right incentives are in place. Learning, as change in perceptions, knowledge and behaviour, can be applied to individuals, groups or organizations (Sol et al., 2013).

Social learning is of particular interest with respect to innovation in a system and has been defined as 'a change in understanding that goes beyond the individual to become situated within wider social units or communities of practice through social interactions between actors within social networks' (Reed et al., 2010, p. 10). The understanding gained through social learning processes engenders more sustainable changes in practice

(Ison et al., 2004). Innovation can be conceived as 'the successful exploitation of creative ideas' (Knickel et al., 2008, p. 883), and encompasses institutional change as well as new technologies (Brunori et al., 2013). The scale of innovation required ranges from incremental to radical and is commensurate with the level of the constraint (Brunori et al., 2013). Innovation is the key to transition, and in most circumstances it arises from collaborative networks and recurrent social processes (Moschitz et al., 2014). It is underpinned by the co-production of knowledge through the constant interaction of a diversity of actors: the stronger the interactions and information flows, the stronger and faster the innovation (Brunori et al., 2013). In agriculture, knowledge construction has been segmented and disconnected from practice (Knickel et al., 2008), but it should be embedded in social settings so that farmers become knowledge creators (Ngwenya & Hagmann, 2011). Differences in knowledge cultures, practices and approaches to innovation need to be bridged (Tisenkopfs et al., 2015), which can be mediated through facilitation to create a space of trust and security (Ostrom, 1998).

In complex adaptive systems, trust, reciprocity and reputation are a mutually reinforcing core that develops through recurring face-to-face communication and leads to greater cooperation and benefit (Ostrom, 1998, p. 12). A core attribute of a complex adaptive system is decentralized coordination and self-organization, such that the system can anticipate and respond to change. Agricultural knowledge systems should be adaptive and focussed on creating the capacity for self-organization (Brunori et al., 2013). Systemic change requires learning, experimental processes and changed behaviour to reach all stakeholders in the system (ISPC, 2015).

Method

Scheme background and intervention

This article reports on an AR4D project which aims to increase the profitability of irrigation in government-owned SSISs through two interventions: soil monitoring tools and AIPs, which reflect the systemic nature of an SSIS's constraints (Pittock & Stirzaker, 2014). Five irrigation schemes were part of the project from mid-2013 onwards: Kiwere and Magozi in Iringa, Tanzania; 25 de Setembro in Boane District, Mozambique; and Mkoba and Silalatshani in Gweru Rural and Insiza Districts, Zimbabwe. For more details about the schemes and irrigation in these countries, see Mdemu et al. (2017) for Tanzania, Moyo et al. (2017) for Zimbabwe, and de Sousa et al. (2017) for Mozambique.

The soil monitoring tools comprise two devices: (1) a Chameleon, which is an array of three or four soil moisture sensors permanently buried at different depths and a handheld device to read the data; and (2) Wetting Front Detectors (WFD), which are buried at two depths (in the upper and lower root zones) to collect water samples for nitrate and electrical conductivity testing. The Chameleon has an intuitive interface: soil moisture is measured by soil tension (so calibration for soil type is not required), adjusted for temperature, and communicated by blue, green or red lights, indicating that the soil is wet, moist or dry, respectively. Together, the tools support irrigation management, allowing irrigators to 'see' the soil moisture at depth and to understand how quickly moisture and solutes move through the profile. From a learning perspective, an important feature of these tools is that the data are immediately available to farmers, so the design enables experimental learning and improved decision making (Stirzaker et al., 2017). Soil monitoring tools were supplied to 20 irrigators in all schemes except Magozi (they are unsuitable for flooded rice production); hence, Tables 1 and 2 only report findings from four schemes.

Selection of the irrigators was based on the following criteria: they were respected and trusted; they represented different locations along the water delivery system; and they could communicate their learning to others (Bjornlund et al., 2020). The farmers and extension staff installed the tools after receiving training on their installation and use from the project team. Farmers recorded the monitoring results in a field book along with data on type and cost of inputs, crop volume harvested, prices received, rainfall, and irrigation events. Importantly, farmers were only trained in the meaning of the coloured lights in

Table 1. Household engagement, awareness and changes made (between 2013/14 and 2016/17) from use of monitoring tools.

	Tanzania	Mozambique	Zimbabwe	
	Kiwere	25 de Setembro	Mkoba	Silalatshani
Number of farmers on scheme, 2016/17	168	38	75	845
Households with soil monitoring tools (%)	42	68	35	24
Households aware of the tools (%)	92	100	96	89
Households that have changed how often or for how long they irrigate (%)	59	86	46	73
Have changed irrigation frequency (%)	63	88	50	54
Households that know about the tools:				
Are aware of changes farmers have made because of the tools (%)	73	96	87	73
Know what the tools measure and what they are used for (%)	72	93	86	70
Households that have made changes because of their learning from				
Chameleon sensors (%)	50	93	54	55
Wetting Front Detectors (%)	48	68	37	26
Households that changed practice from using the tools and also increased yields (%)	93	83	86	77
Households that changed practice from using the tools and also increased income (%)	94	80	43	55

Note: As Magozi uses flood irrigation to produce rice, the tools were not deployed there.
Sources: Cheveia, et al. (2018), Chilundo et al. (2020), Mdemu et al. (2018), Moyo et al. (2020).

Table 2. Changes to irrigation practices from using the tools for farmers with and without the tools.

	Tanzania		Mozambique		Zimbabwe			
	Kiwere		25 de Setembro		Mkoba		Silalatshani	
Variable	2013/14	2016/17	2013/14	2016/17	2013/14	2016/17	2013/14	2016/17
Farmers with tools								
Number of irrigation events per season	26	20	14	7.5	20	8.1	18	8.5
Number of siphons used	n/a	n/a	n/a	n/a	7	5	9	8
Time taken to irrigate plot (mean hours)	4	2	4.5	2.5	2	1	4	2
Farmers without tools								
Number of irrigation events per season	26	20	14	9	20	10.5	18	7.7
Number of pipes/siphons used	n/a	n/a	n/a	n/a	7	5	9	8
Time taken to irrigate plot (mean hours)	4	3	4.5	3	2	1	4	2

Notes: As Magozi uses flood irrigation to produce rice, the tools were not deployed there. Siphons are only used in the Zimbabwe schemes.
Sources: based on Cheveia et al. (2018), Mdemu et al. (2018), and Moyo et al. (2020).

relation to soil moisture; they they were not trained or guided in how to change their irrigation practices. Experimentation needed to emanate from their own learning.

AIP processes were implemented in each of the irrigation schemes involved with the project. First, workshops on the AIP process were conducted by an experienced AIP practitioner (a member of the project's research team), and information was collected on each scheme to understand the local context and identify key stakeholders to be involved in the AIP, e.g. from the farming, governance and value chain sectors (Bjornlund et al., 2020; van Rooyen et al., 2017). Local facilitators were trained to implement the four main steps of an AIP process: introducing the AIP to gain stakeholder commitment, initiate networking and clarify roles; identifying system constraints and a deep understanding of root causes; a visioning exercise to develop a picture and narrative that expresses stakeholders' vision for the scheme; and an innovation process to prioritize constraints, develop and implement solutions, and identify which stakeholders will be involved (van Rooyen et al., 2017). The first three steps were undertaken in a two-day workshop, with innovation processes following as required outside the AIP meetings (Bjornlund et al., 2020). Activities to address issues take place outside the AIP meetings; thus, activities are stimulated by the AIP rather than being part of the actual AIP meetings. The typical role of AIPs is to overcome barriers such as access to markets, realizing profit from improved yields, and building social networks and capital, for example, through training (van Rooyen et al., 2017). However, it was anticipated that the AIP would form the basis for social learning and capacity to change by bringing together farmers, irrigation associations, extension staff, the private sector and governance systems. For a more detailed description of the processes involved in initiating and implementing an AIP, see van Rooyen et al. (2017), Bjornlund et al. (2020) and Pittock et al. (2018).

Data on learning

This article endeavours to present an account of the learning and innovation processes associated with the key changes that took place on the schemes. First, we report on quantitative data from household surveys in the project's five schemes in 2014 and 2017. Trained enumerators collected data including demographics, area farmed and crops grown, food security, and how a household's situation and practices had changed between the two survey periods. Where possible, the same households were interviewed for the two surveys. Of particular relevance for this article is the data on engagement, awareness of changes in response to using the monitoring tools, and changes to irrigation practices (reported for all schemes except Magozi, where the tools are not used). Changes relating to information sources and advice are reported for all five schemes. The survey data were rigorously validated and analyzed and have been previously published (see Tables 1, 2 and 3 and accompanying citations). In this article this data are reapplied to provide context and insight on the learning that resulted in specific changes across all schemes.

Second, this article presents qualitative data as a detailed written account of the history of how learning took place: that is, learning as evidenced by change in decision making and action. The approach draws from Douthwaite and Ashby's (2005) 'innovation histories' as a method of learning from the collective experiences of people who have been involved with a project. An underpinning concept of this method is the notion that learning histories of innovation, and (we would contend) of the learning process itself, are rarely written down and that the process of developing a shared history stimulates reflection and can contribute to future planning. The approach broadly includes identifying introductory text and drawing on the collective knowledge of a core group of people connected to an innovation and, in this case, a project.

Qualitative data on learning and change were initially collated from project documentation as the introductory text. The lead author drafted Tables 4, 6 and 6 and populated the tables with data gleaned from a special issue of the *International Journal of Water Resources Development* (vol. 13, no. 5, 2017); project reporting in Pittock and Ramshaw (2018); and project documentation such as team reports of AIP meetings, workshops, focus groups and field observations. The data on learning drawn from these sources broadly fell into individual and group learning by farmers and learning by stakeholders in the wider system. At this stage, the columns in the tables were not all completed, as often there were data on the information and the changes made but not the interim detail. A core group of three people then refined the columns in the table and added personal knowledge prior to circulation to three other contributors to the article and TISA team members (one each from Tanzania, Mozambique and Zimbabwe). Collectively, these contributors (all authors of the present article) represent experts on the changes that have taken place on the schemes.

The tables were circulated as a way to stimulate thinking on learning and changes. Contributors were asked to add additional examples of learning and carefully delineate between the information that was the impetus for learning, the actual learning that took place, the factors that enabled learning, the incentives to apply the learning, and the resulting decision(s) taken and/or behavioural change(s). In lieu of a face-to-face meeting, one member of the core group then discussed the tables with the other contributors during visits to each country to help stimulate thinking. All contributors then critiqued and refined the data through several iterations using the 'track changes' and 'comment' features of Microsoft Word. While Douthwaite and Ashby (2005) used participatory workshops to generate and refine data, this was not practical for a team that is dispersed across four countries.

The data in Tables 4, 5 and 6 represent the collective and deep understanding of the history of how learning and change has taken place in the schemes in response to TISA's two interventions.

Results

Reported behavioural changes

The proportion of households receiving the tools varied across the schemes, from 24% in Silalatshani to 68% in 25 de Setembro (Table 1). Across all schemes, most households were aware of the tools, what they measure and the changes being made by farmers. In general, the proportion of households making changes to their irrigation practice (frequency and duration) between 2013/14 and 2016/17 ranged between 46% (Mkoba) and 86% (25 de Setembro), with 54% or more making changes based on learning from the Chameleon and 26–68% based on learning from the WFD.

The proportion of farmers changing their irrigation practice (and improving yields and income) is higher than the proportion receiving the tools. While the exact social processes and interactions may never be fully known, we contend that the spread of change in

Table 3. Examples of individual learning.

Information	Learning	Enabling factors	Incentive to apply learning	Decision / behavioural change
Introduction, training and installation of the tools				
The tools: type, function, how to use, and understanding the colours	Root systems of crops are different. There *could be* a better way to manage water and nutrients. *Probably* I am using too much water and wasting fertilizer.	Insights from researchers, extension officers and AIP meetings	That better water management will reduce input spending and increase yield	Accepting opportunity to use the tools; farmers start to understand that even with minimum irrigation, the soil retained moisture and showed blue in the root zone
Establishing baseline soil conditions				
Results of individual plot soil analysis: soil type, fertility and fertilizer recommendations	Farmers understand that their soil fertility is low, that this causes low yield, and which fertilizer they need to apply to improve yields. Established need for demonstration plots to compare fertility management practices (Table 5).	Financing of soil analysis, trust in research team, and farmers being able to make own observations on demonstration plots	To increase yields	Adoption of fertilizers and making of thermal composts for soil fertility amendment
Chameleon monitoring				
Soil moisture at different depths	Although topsoil is dry, water is still available at lower levels. Understand/verify the contribution of rainfall to soil moisture. Can skip irrigation.	Information available instantly in the farmers' fields while simultaneously observing plant condition; trust in tools as plants still grow well; training / capacity development from researchers	To save time, make better use of rainfall and increase yield; project anticipated that reduced water use would be the incentive	Not to irrigate until needed (increasing the time between irrigation events, irrigating for shorter periods and using fewer siphons)
Wetting Front Detector (WFD) monitoring				
Water has reached where the WFD is installed; nitrate and salt levels at WFD depths	Can stop irrigating when WFD flag pops up. Dark purple colour (high nitrate) is needed in the root zone, not at the deeper zone. If it is darker purple deeper and lighter above, then fertilizer is used or lost through leaching. Application of chemical fertilizer increases nitrate levels in the soil, but with manure the nitrate stays in the soil longer.	Discussions and insights from extension staff and researchers and trust in the tools; farmer observations of plant condition and whether it improves with fertilizer application	To reduce fertilizer use (amount and frequency of application), save money (hired labour for irrigation) and increase yield	Change the mode of fertilizer application: precision application of fertilizer or micro-dosing (Silalatshani); thermal composts as fertility amendments (Mkoba); reduced frequency of application and increased use of manure (Tanzania); and starting to apply after irrigation (Mozambique)

(*Continued*)

Table 3. (Continued).

Information	Learning	Enabling factors	Incentive to apply learning	Decision / behavioural change
Chameleon and Wetting Front Detector in combination				
Chameleon reader colours and nitrate levels	Integrating information from Chameleon and WFD to balance irrigation frequencies and nutrient retention in the root zone	Installation of both tools in the plots; discussions with other farmers, and extension and project staff	To save water and labour and increase yield and income	As above; understanding the need for improved irrigation scheduling to link with crop type and stage of development; reduced conflict
Farmer field books and gross margin analysis				
Record of activities and resources used across the season	Better timing of farming activities (e.g. fertilizer application); level of profit or loss at the end of the season; and how spending on inputs and profitability differs across crops	Training given in use of field books; discussions with other farmers, extension and project officers	To improve understanding of resource use (e.g. inputs) and the farming enterprise; potential to access credit facilities	Changes in inputs used (by comparing farmers' records) and crop portfolio
Gross margin training (M)	Business plan development and irrigation scheme management; maize can be more profitable when proper agricultural practices are followed	Supported by Instituto Nacional de Irrigação, the research team and District Services for Economic Activities	To improve understanding of the investment required per crop and seasonal price forecasting	Farmers have individual crop business plans and are selecting more profitable crops.

Source: project team observations and reflections.

Table 4. Examples of group activities for learning (as stimulated by farmers' use of the tools or AIP interaction).

What initiated the social learning	Learning process	What was learned	Spread of learning	Enabling factors	Incentive to apply learning	Decision / behavioural change
Farmers observing other farmers making improvement from tools	Tools become the reference point for decisions	Integrating information from chameleon and WFD to balance irrigation frequencies and nutrient retention in the root zone	Mainly through farmer–farmer observations, extension staff and scheme meetings	Demonstration on others' plots (i.e. word of extension staff not enough on its own)	To save time and fertilizer and improve production	Changes in water use at block scale; reduced labour and less conflict
Demonstration plots (Z)	20 paired maize plots showcasing improved practices and use of monitoring tools	Optimum fertilizer application, manure use and timely management	Farmer–farmer within scheme and other schemes through field days	Farmers learn by seeing and doing	To improve productivity and profitability	Judicious use of fertilizers, introduction of thermal compost and improved agronomic practices (e.g. plant spacing and land levelling)
Demonstration plots (T)	20 plots (project's initial 20 farmers) for specific crops	Over-irrigation, the level of leaching and requisite levels of fertilizer to apply (K); improved rice varieties and correct fertilizer and application (Ma)	Farmer–farmer within the scheme; visits to demonstration plots and scheme/village meetings (K, Ma)	Farmers' observation; extension staff influence (K, Ma)	To potentially save money on inputs (e.g. fertilizer) and improve productivity (K, Ma)	Start to use fertilizers and manure (K); use of improved varieties (Ma)
Exchange and study visits	Farming operations on other schemes (Z, Mo)	Water and soil management, marketing produce, and crop profitability Best practices for tomato and maize production (Mo)	Farmers implementing new ideas spread to other farmers (normal interactions, scheme meetings)	Farmers requested visits; farmers learn by seeing and doing themselves	To improve productivity and profitability	Adoption of new more profitable crops (e.g. garlic on Silalatshani); reduced number of rice varieties, adopted improved varieties (Magozi) Implementation of best practices (e.g. staking of tomatoes and improved spacing for maize crops); tutoring of other farmers by those who went on the visit
	Comparing fertilizer management for specific crops (T)	Nutrient requirements for specific crops				Use of manure
	Observation of scheme infrastructure and operations (T)	Better collection of fees, a stronger constitution and better leadership (education and experience)			The potential to improve farming activities and scheme management and operations	Revision of scheme constitution and bylaws and doubling or tripling of farmer contributions to meet costs; change of leadership of the scheme. understand the value of scheme mapping

(*Continued*)

Table 4. (Continued).

What initiated the social learning	Learning process	What was learned	Spread of learning	Enabling factors	Incentive to apply learning	Decision / behavioural change
Absence of actual data/ information on the size of the irrigation schemes (T)	Mapping of the schemes	Size of the scheme; accurate data/information assists effective collection of water use fees; how to improve scheme accessibility	All farmers and scheme leaders; information shared with AIP members and local meetings; maps shared with IMC, zonal irrigation commission, village, district and regional authorities	Trust in the process and project team; expertise from the project team; readiness of the farmers; support from scheme and irrigator organizations	The potential for improved spatial understanding of schemes and scheme management	Clarity on fee payments relative to plot size; increased willingness to pay operation and maintenance fees; further potential to obtain Certificates of Customary Rights of Occupancy (T)
Farmers from Magozi visit Igurusi Market (T)	Observation of market operations	Value adding	Meetings with irrigation committee; AIP scheme meetings	Meetings facilitated government co-funding for a warehouse	To increase prices received	Build warehouse near the schemes to house milling machine (to sell processed instead of unprocessed rice) and store rice until market prices are higher

Note: Mo = Mozambique; T = Tanzania; Z = Zimbabwe; K = Kiwere; Ma = Magozi; IMC = irrigation management committee.

behaviour is a result of social learning (Table 1). The changes in irrigation practices include a reduction in the frequency and duration of irrigation events, a reduction in the number of siphons used (where relevant), and a reduction in number of irrigation events per season (Table 2). This has resulted in time savings of 11.9–19 and 6–20.6 hours per season for farmers with and without the tools, respectively. While not identical, improvements are apparent for all farmers, which further reinforces that social learning has taken place: that is, the understanding of the benefits of changing practice and the actual practice changes required to achieve these benefits has been shared and adopted by most farmers. Further, this change in practice appears to have occurred without a formal facilitation forum, though the AIP as a networking opportunity may have helped.

Individual and social learning leading to these changes

The learning arising from individual and group learning activities is presented separately. Individual learning activities include the use of the tools, soil analysis, field books and gross margin analysis for individual plots (Table 3). Farmers learnt, for example, the relationship of fertility and yield, that water could be available at lower depths when the surface is dry, and which crops are more profitable. The learning from using the tools and field books spread beyond those initially trained in their use. Extension staff and the farmers with field books talked to other farmers, who then bought their own books to record data (Kiwere, 25 de Setembro). Focus groups and other group activities initiated a diversity of learning within and between schemes (Table 4). Demonstration plots, established in response to the baseline soil analysis to showcase better practices, were also instrumental in spreading learning across the schemes and to farmers further afield (Silalatshani).

Importantly, most households report that their information needs have increased; consequently, through the AIP and associated activities, they have better access to a wider range of information sources, and they are acquiring better agricultural advice (Table 5). Government extension staff were integral to the project in all countries and (in addition to their scheduled visits) assisted with the collection of data from the tools, completion of field books, and interpretation of monitoring data; supervision of demonstration plots; participation in scheme meetings and AIPs; and discussions with farmers during exchange visits, visits by other schemes and other informal visits to the schemes. Farmers capitalized on these opportunities to consult further, and there is evidence that the quality and regularity of extension staff–farmer interactions have improved, which has been highly beneficial for farmers. Extension staff also appear to have gained from their increased contribution and farmers' appreciation of it, leading to more motivated and engaged extension officers.

Table 5. Changes in information needs, sources and advice (percentage of households).

	Tanzania		Mozambique		Zimbabwe
	Kiwere	Magozi	25 de Setembro	Mkoba	Silalatshani
Information needs have increased	77	89	74	74	81
Range of information sources has increased	77	89	76	83	89
Getting better agricultural advice	97	96	96	91	95

Sources: Chilundo et al. (2020), Mdemu et al. (2018), Mdemu et al. (2020), Moyo et al. (2018).

Learning in the system beyond the scheme

Table 6 shows where learning has taken place in the wider system, fostered by the AIP, a combination of the tools and AIP, and in some cases directly by TISA's research teams. There are examples of learning by extension staff, the private sector and the governance systems. In the latter, learning has taken place at several scales: for example, district authorities have understood the implications of poor-quality inputs and have taken on the role of inspecting products in supply chains (Tanzania); or they realized their role to fill a gap in information (e.g. supporting a land audit to understand the relationship of vacant land and absentee landholders in Zimbabwe).

Discussion

The farmers received training in the installation and use of the tools, but no guidance was provided on how to change irrigation practices in response to the Chameleon's coloured lights. By monitoring, typically at weekly intervals, farmers gradually learnt about the relationship between rainfall and irrigation and soil moisture status, and the changing water requirements of crops at different stages of maturity. The importance of this initial learning should not be underestimated: as farmers developed trust in the tools, they began to skip irrigation events, and gained confidence and experience in managing the system. They also maximized the contribution of rainwater to minimize the use of irrigation water (see Moyo et al., 2020, for a discussion). When discussing reductions in irrigation frequency with farmers, they were adamant that such changes would never have been accepted if they were externally enforced: 'a big no!' said Senzeleni Mpofu of Silalatshani (van Rooyen, personal communication). Similarly, farmers learnt about nutrient leaching from their use of the tools and integrated this knowledge with irrigation frequency and rainfall events to determine the required frequency and amount of irrigation (Moyo et al., 2020). Farmers experimented by reducing the frequency of irrigation, which was expected but not advocated by TISA, and when they continued to see high moisture levels, they reduced the number of siphons and eventually irrigation duration.

Importantly, the tools are creating feedback loops, a cyclic learning process has ensued, and a functional knowledge system has developed that integrates the tools' data and information (Figure 3). Continuous experimentation and evaluation (discussions between farmers) has enhanced learning, enabling farmers to build new mental models of the soil-water-nutrient dynamics, and improving their confidence and skills to innovate. The three strategies to change irrigation represent a striking example of ongoing farmer innovation, correlating with Holland's (1995) analogy of building blocks and adaptation in complex adaptive systems. That is, actors create new rules for the reuse of building blocks – rainfall, frequency and duration of irrigation, and number of siphons – and innovation occurs when these are put together in new ways. Actors 'adapt by changing their rules as experience accumulates' (p. 11). As noted earlier, this exemplifies the process of evaluating innovation, resulting in further adaptation.

A highly adaptive knowledge system has emerged, in which farmers their adapt water use in response to crop type, growth stage and rainfall. Mental models have shifted, with many farmers and extension staff in Silalatshani now managing irrigation as supplementary to rainfall, which was the original intended role of the schemes (Moyo et al., 2020).

Table 6. Examples of training and learning and change by actors in the wider system.

Actor	Training/learning forum	Information/learning	Application and impact
Support services			
Extension staff	Gross margin training initiated by International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and Department of Agricultural Extension & Technical Services (AGRITEX) (Z).	Crops stipulated in cropping calendars are not profitable and calendar restricts farmer profitability.	Learning from applying the gross-margin figures to influence farmers' crop choices, convinced staff and their managers to introduce high value crops. Training cascaded down to farmers with ongoing use of gross margin analysis. Farmers growing more viable crops and have improved income.
	ICRISAT, AGRITEX and farmers monitoring moisture through the tools (mainly Chameleon) (Z).	Inflexible water scheduling prevents farmers from matching water supply to crop needs and restricts farmers' innovative capacities/experimentation and their ability to improve productivity.	IMC introduced more flexible water scheduling, which helped in reducing scheme-level water use and, in turn, saved time, labour, water and reduced conflicts. Better utilization of rainfall, and change in mindset about the role of irrigation (i.e. supplementary).
	AIP (Z).	Learn new facilitation skills.	Extension staff now facilitate the AIP and takes expertise and learning to other irrigation schemes, including linking these to markets and financial services.
Private sector			
Markets	AIP (T, Z).	Understanding of farmers' information needs and how to better address their marketing problems.	Farmers provided with an e-marketing platform. Farmers linked to markets in and outside the region (e.g. East African Grain Council). Farmers provided with ongoing information on prices, quality grades and standards. Improved understanding of market-oriented production increases farmers' confidence to invest. Farmers growing more viable crops and have improved income.
Input suppliers	Scheme and district AIPs (T, M).	Importance of 'reaching down' to farmers. Enhanced understanding of farmers' challenges and how to improve input supply systems.	Suppliers established demonstration plots. The network of registered agro-dealers has expanded. Most farmers now buy better and certified inputs (seeds and agro-chemicals) from registered dealers rather than local markets. Farm losses were reduced and yields increased due to improved delivery and access to inputs.

(*Continued*)

Table 6. (Continued).

Actor	Training/learning forum	Information/learning	Application and impact
Governance			
Engineers	ICRISAT workshop with Zimbabwe Irrigation Technology Centre (ZITC), AGRITEX and DoIRR (Z)	Value of the tools and impacts from TISA on the schemes. Flexible water supply is needed to meet different crops' needs.	Request to test the tools and to out-scale the tools in Matabeleland North and at ZITC to help nationwide cascading of the tools. Supported tools being embraced at the national level. Tools have been installed in other blocks of Silalatshani.
	District AIP with engineers from the District, Regional Office, Zonal and National Irrigation Commission (NIC), Rufiji River Basin Development Authority (RUBADA) (T).	Value of and potential of the tools.	Willingness to disseminate the tools to other schemes. Participation in project activities: supported Magozi scheme in the process of acquiring permit to expand the intake (e.g. technical documents); and supported training of IMC on the operation and maintenance of the irrigation infrastructure.
Water management organization	AIP meetings and discussions between Zimbabwe National Water Authority (ZINWA), District Administrator (DA) and IMC (Z).	Farmers were unable to pay ZINWA's water bill, which has become excessive when the debt was transferred from the devalued Zimbabwe dollar to US$. This debt was blocking progress, stopping water delivery at critical stages of crop growth, and was essential to address. Understanding of the mismatch between water pricing business models and the proportion of scheme land usage and implications for farmers and scheme's ability to pay.	Recalculation of water bill. Farmers more confident to farm plots and make changes. Monitoring of land usage and farmers' ability to pay.
	Involvement of irrigator organizations, RUBADA, Zonal and NIC in district AIP (T).	Water savings using the tools. Helped convince basin authority that overall river flow would not be impacted by further extraction.	Allowed expansion of intake for Magozi scheme.
District Government	Iringa District Authority involvement in AIP (T).	Challenges and opportunities along value chain and water shortages.	Allocation of funding to expand Magozi irrigation intake. Regulation of input businesses (inspect, enforce quality and standards, safety), including regular visits to input supply chains (centres, warehouses, agro-dealers etc.). Reduced incidences of sub-standard inputs.
	Regional District Council involvement in AIP (Z).	Land audit was conducted and showed vacant land is related to absentee plot holders.	Farmers with unfarmed plots encouraged to farm plots. Unused plots reallocated to people present on the scheme. Improved land use.
Director of Irrigation	Meeting with ICRISAT and TISA to discuss project outcomes (Z).	Value of tools and AIP approach.	Commitment to use extension staff to support TISA's out-scaling phase. Agreement for training of AGRITEX, DoIRR and ZITC staff, including irrigation training for extension staff.

Note: M = Mozambique; T = Tanzania; Z = Zimbabwe; IMC = irrigation management committee.

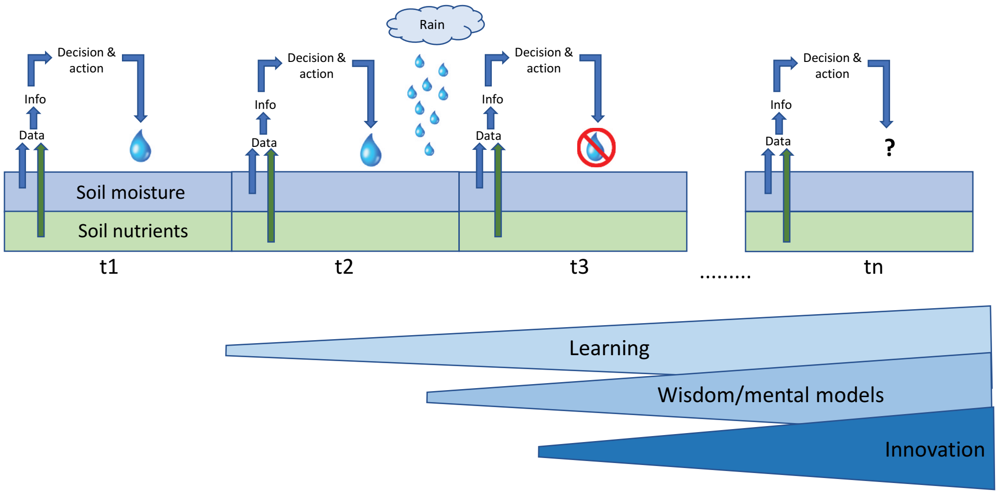

Figure 3. Knowledge system developed from Chameleon and Wetting Front Detectors.

Importantly, there was no financial incentive for Silalatshani farmers to reduce their water use, as the price remained the same. It became apparent that nutrient management and labour saving encouraged farmers to adopt the learnings from the tools, rather than the intended incentive of saving water.

The change in behaviour of farmers without the tools represents significant social learning. We speculate that social networks have been important for this. Farmers comparing field book data also initiated changes in the inputs used, and use of the books spread to other farmers (Table 3). The AIP-initiated training activities – gross margin analysis, demonstration plots, soil analysis, and exchange and study visits (Table 4) – have also culminated in social learning within and across schemes, and resulted in a variety of agronomic improvements (e.g. better fertilizer use and new, more profitable crops) as well as institutional changes (e.g. changes in schemes' constitutions to enable irrigation organizations to enforce rules on fee payment and participation in system maintenance). Reduced nutrient leaching is important to increase yields, but given the high cost of fertilizer, it is essential to match the crops grown with market demand. Hence, the AIP focussed on linking farmers to the private sector so they could learn directly from buyers about quality grades, price standards, timing and market-oriented production (Tables 4 and 5; Bjornlund et al., 2020). It is likely that researchers, extension staff and farmers have constituted a 'tight' learning network in supporting the successful integration of a new technology alongside a mix of other training and learning activities (Garb & Friedlander, 2014).

Large-scale changes in behaviour and significant water savings have taken place at the scheme or sub-scheme scale. The reduction in labour requirements for irrigation allowed more time for farm and off-farm activities and diversification of income streams; improved yields and incomes; improved food security; increased capacity to pay for health, education and irrigation fees; reduced water use, making more water available for downstream users; and reduced conflict (Bjornlund et al., 2018; see also Moyo et al., 2020 for contribution to Global Multi-dimensional Poverty Index). Incentives for action are important, and we propose that the reduced need for irrigation labour and improved yields and income were critical in driving individual learning and the spread of change beyond those who had the tools. The emergence of improved collective action (preparedness to participate in scheme maintenance and pay for water) represents another outcome of aggregate change in behaviour (Chilundo et al., 2020; Mdemu et al., 2020; Moyo et al., 2020). These findings align with another characteristic of complex adaptive systems, whereby the aggregation of changes in the strategies of adaptive actors leads to the emergence of large-scale behaviour (Holland, 1995).

Putting the tools in farmers' hands has clearly played a significant role; the AIP has stimulated changes that Brunori et al. (2013) describe as radical innovation in higher levels of the system. Through governance, private-sector and extension staff connecting with the farmers through the AIP, they have recognized their role in unblocking institutional constraints (Table 6). This accords with the role of the AIP as 'creating discomfort and breaking silos', such that stakeholders recognize their role in system failure and reposition themselves in terms of how they can make the system work rather than addressing their mandates (Ngwenya & Hagmann, 2011). The inspection of input quality by district authorities is one example (Tanzania). Another is the resolution of a significant bill with the Zimbabwe National Water Authority, which gave farmers the confidence to invest in their plots (Table 6).

In some cases, specific additional activities have stimulated system change and embedded the learning into new institutional arrangements for the longer term. The cropping calendar at Silalatshani was accepted as official policy for 50 years, requiring the production of staple crops that were unprofitable for farmers. As the policy could not be opposed, a training session was organized to refresh government support services in the use of gross margin analysis (van Rooyen et al., 2020). This revealed the small gross margins associated with staple crops and provided the basis for extension staff and their superiors to abandon the cropping calendar. And this led to the introduction of new, profitable crops, such as garlic, as farmers could now decide which crops to grow. The findings illustrate how learning can initiate the removal of significant system constraints, and how learning by influential individuals (directors of irrigation agencies) can then spread the impact more widely (Table 6). For a comprehensive discussion, see van Rooyen et al. (2020). This change is supportive of social learning as an approach that leads to sustainable change through shared understanding and wider ownership of problems and solutions (Ison et al., 2004).

In the government-owned SSISs that are part of this project, the tools provided a catalytic entry point at the individual farmer level (Level 1), whereas the AIP worked with farmer groups through to policy (Levels 2 to 4) (Figure 4). Interactions and learning have taken place within and between the actors at different levels of the system: from farmers though to policy makers. In this way, farmers' physical use of the tools and the AIP processes have allowed learning to reach the highest levels of governance – an important starting point for effective out-scaling. In theory, there may be other approaches or combinations, which can provide suitable entry points at different levels of the system.

Figure 4 also shows where traditional extension operates in a system. The findings clearly show that extension–farmer interactions have been beneficial and that extension staff learning has had positive impacts. Initially, no extension staff were allocated to 25 de Setembro, but the increased demand for information from farmers resulted in an officer being assigned to the scheme. In Zimbabwe, extension staff are now facilitating the AIP

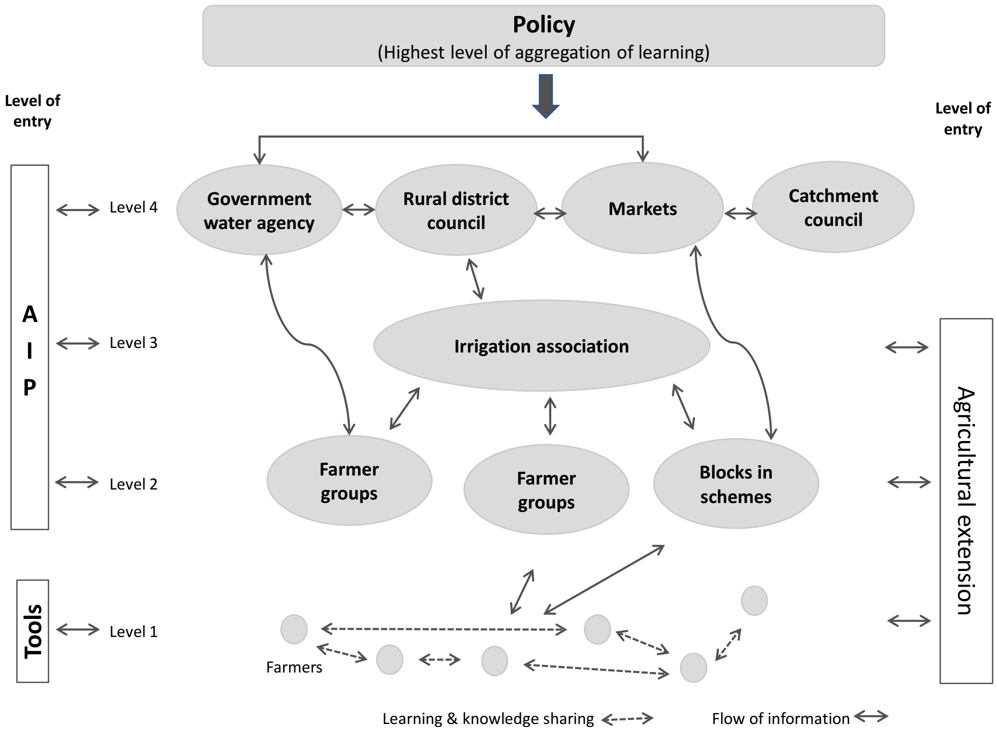

Figure 4. Hierarchical structure of actors in government-owned small-scale irrigation schemes, level of entry of monitoring tools, agricultural innovation platforms and traditional agricultural extension, and spread of learning in and between actors. Note: this is a simplified arrangement of interactions between actors.

and sharing learning across schemes and other parts of the system. Kuehne and Llewellyn (2017) observe several benefits of the agronomist–farmer relationship that are pertinent to extension–farmer interactions and supported by this article: there is a benefit for both parties from co-learning, as each may have knowledge that is not known by the other; a more equal relationship is less threatening and more empowering for farmers; and depending on their level of experience, farmers may need others' knowledge for confidence, or reassurance, when evaluating a barrage of new information. Extension is being reinvented, with new tasks being ascribed to the role: 'communication and innovation, network building, learning, co-design and negotiation' (Leeuwis, 2004, cited in Garb & Friedlander, 2014, p. 14). In other settings, specialist innovation brokers are emerging, focussing on facilitation and acting as intermediaries to build links for interaction (Klerkx et al., 2012). In an innovation system, farmers need to be at the centre of knowledge generation, meaning that extension staff must be prepared to relinquish their power and change their behaviour (Ngwenya & Hagmann, 2011). There is some evidence that this shift has been made by extension staff.

The spread of learning is encouraging not only for the flow-on impacts but because social learning across the system is such an integral part of self-organization and adaptability, and systemic change requires all actors to make changes. Within the emerging system behaviour, complex individual adaptation is taking place as farmers integrate different types of knowledge to improve production and market strategies, providing new incentives to use and acquire information (Table 6). Farmers' autonomous learning has taken place in a relatively short period – particularly considering that the Silalatshani scheme, for example, has most probably been unprofitable since the scheme was initially developed in the 1960s – and we contend that the speed of learning and change has been driven by farmers directly accessing actionable data, the right incentives, and the relaxation of restrictive rules. Consistent with Brunori et al.'s (2013) observation on the intensity of innovation, we also speculate that the fast pace of change is evidence of increased intensity of interaction and information flows.

Conclusion

A healthy mix of training and subsequent experiential learning has led to significant change. Training enabled farmers to instal and use the tools, but it was the interpretation and use of the information in a practical setting that fostered experiential learning and behavioural change. Experimentation and generation of new knowledge continued, resulting in innovation in irrigation practices and new mental models of the role of irrigation. The tools have established new feedback loops, which are trusted and have become a reference point for irrigation decision making (van Rooyen et al., 2020). While most farmers might like to have the tools, change has spread (facilitated by social learning), and more farmers have made changes than received the tools. Therefore, this study suggests that having 20–35% of irrigators with the tools can have a significant impact within three to four years with limited resource deployment. We speculate that if there is time for change to be gradual, then fewer tools are required; faster change requires more tools.

While the AIP was primarily introduced to implement improvement in the system, it is clear that it has facilitated an environment where a learning system has developed in which knowledge has been generated and shared among stakeholders at various levels. Farmers' adaptation has led to many positive impacts for households and the emergence of scheme-scale benefits: reductions in water use; more nutrients retained in the root zone; greater yields; and produce being sold into more profitable markets (Chilundo et al., 2020; Mdemu et al., 2020; Moyo et al., 2020). The result is higher farmer profitability and better functionality of schemes.

Social learning has enabled innovation to spread across the schemes. Furthermore, learning has taken place in a relatively short time, driven by the incentives of saving time and money and increasing yield (rather than by saving water). The translation of higher yields into higher income, through AIP activities, has strengthened the incentive to innovate. Real and systemic change occurs when all actors in the system learn and change their behaviour, and there is evidence of profound institutional change in higher levels of the system's governance, which has unblocked constraints and stimulated innovation.

Learning and the integration of different types of knowledge are cornerstones of resilience (Folke et al., 2003). The ability to adapt to change, the combined learning by many actors at various levels of the systems, and the consequent changes in behaviour should allow the government-owned SSISs involved with this project to continue transitioning towards more profitable and resilient systems. Further, this work clearly illustrates the nuanced differences between training and learning.

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