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SMART WATER GOVERNANCE AND LEARNING PROCESSES

Introduction

Small-scale communal irrigation schemes in Africa have not realised returns on investment. Critical to this failure is that funders, designers and managers of these schemes have not recognized them as complex socio-ecological systems with a diversity of constraints. These schemes are often under-performing and characterized by a subsistence orientation, which is compounded by poor market integration, low capacity to invest in crop production, low yields, difficulties paying for water, or lack of willingness to participate in system maintenance. The end result is unsustainable utilisation of resources, failed infrastructure, inefficient use of water and land and increased conflict over access to these resources.

Conventional irrigation scheme development has focused on 'hard' technologies to improve the functionality and efficiency of infrastructure and/or irrigation application technologies. However, hard technology improvements on their own have failed to deliver sustainable schemes and improve the livelihoods of irrigation farmers (Inocencio et al., 2007): broken and decaying infrastructure is just one element of an underperforming system. While technologies that are more efficient may help improve yield, they will not necessarily improve profitability. A great many irrigation schemes are trapped in a negative cycle of infrastructure provision, unprofitable farming, lack of investment in maintenance, infrastructure degradation leading to donors subsidizing infrastructure rehabilitation (Pittock & Stirzaker, 2014; Bjornlund et al., 2017).

Transitioning these complex systems into profitable, equitable and economically sustainable schemes requires investment not only in smart technologies but also in the farmers, institutions and building the value-chain network (Figure 1).

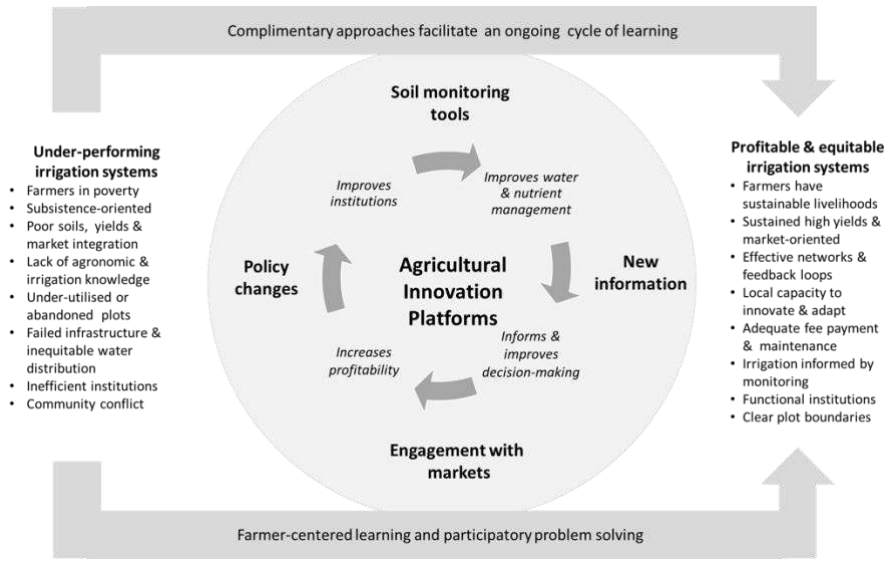


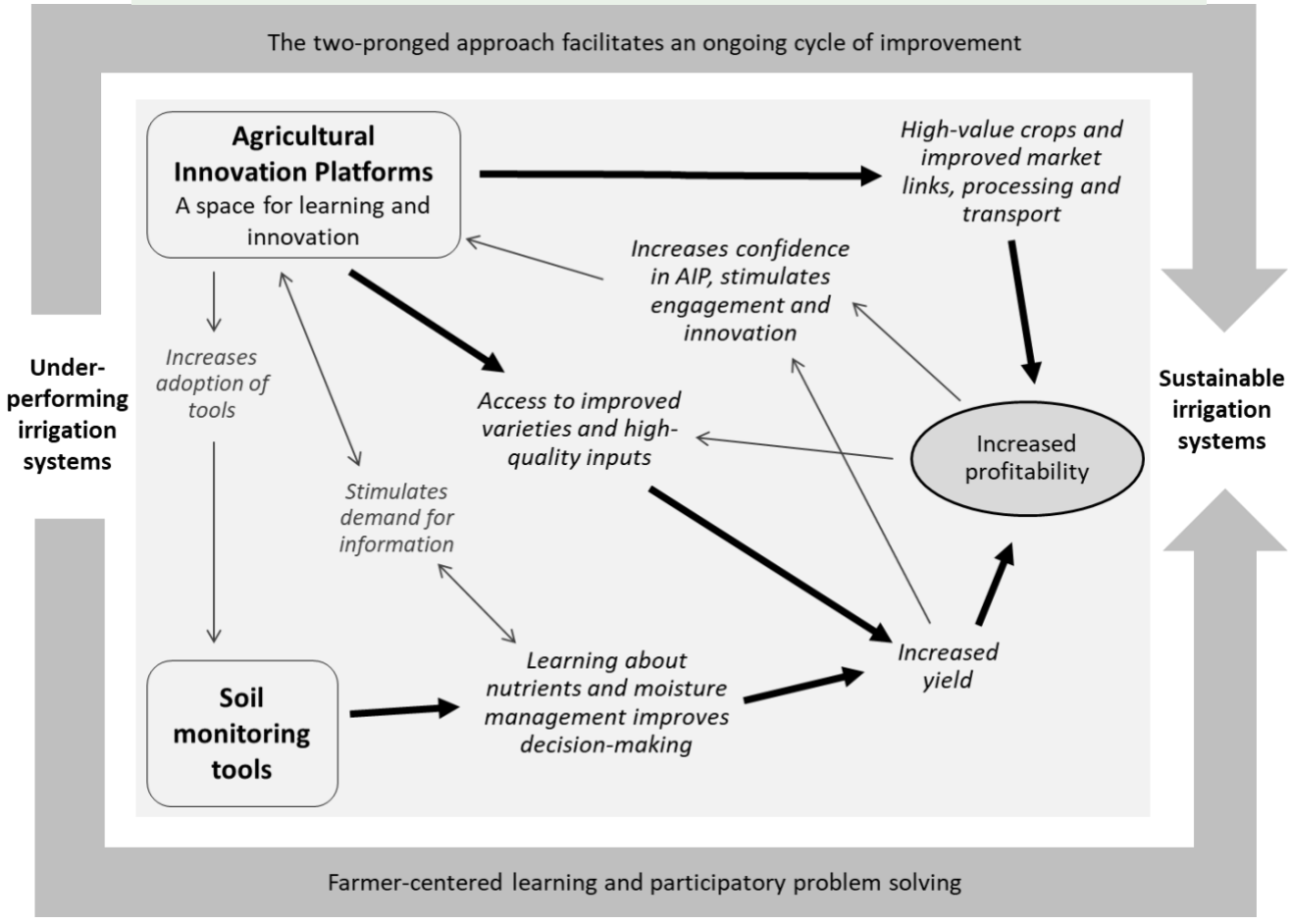
Figure 1 Transitioning under-performing small-scale irrigation schemes in Africa towards profitable and equitable irrigation systems

Project Intervention

A consortium of research partners from Australia and Africa are implementing a project aims was to improve the profitability of small-scale irrigation schemes. It has been developed and implemented in two phases and primarily funded by the Australian Centre for International Agricultural Research (ACIAR). The project features a two-pronged approach consisting of two complementary entry points to transition small-scale irrigation schemes towards long-term sustainability (Figure 2):

- **Smart water management (SWM) technologies** were introduced to monitor soil moisture and nutrients and facilitate farmer learning about irrigation water management to increase yield.
- At the same time, **smart water governance and learning processes,** in the form of Agricultural Innovation Platforms (AIPs), were introduced to bring key stakeholders together to develop solutions to a range of challenges presenting barriers to turn increased yield into increased profitability.

Figure 2 The two-pronged approach and how it influences profitability



Environmental Water Challenges

While irrigation faces considerable challenges to operate sustainably, expansion will take place, regardless of past failures (Stirzaker & Pittock, 2014). Globally, waterlogging and salinity affect 20-30% of irrigated land. This proportion is mirrored in Chokwe, one of Mozambique's largest schemes, where 32% of the irrigated land has been abandoned (Stirzaker & Pittock, 2014). Whilst salinity is not an issue for most of the schemes involved with this project, over-watering is

common in irrigation and salinization is an ever-present threat.

As population and economic growth continues, increased demand will require re-allocation of water among competing uses: such as domestic water supply, sanitation, industry, hydropower and environmental flows (Turral, Svendsen & Faures, 2010). This is particularly problematic where over-extraction is already an issue: for example, the upper Great Ruaha Basin in Tanzania is targeted for irrigation expansion but over extraction is already affecting the environment, tourism and hydropower (Pittock, 2014). Both Kiwere and Magozi are part of this basin, so there are immediate issues of competition for water resources. Climate change will increase the uncertainty of water supply and demand (FAO, 2012). Water productivity has to improve to maintain food production. This will be challenging as farmers: i) believe more water is better than less; ii) often do not pay for water and, therefore, apply it excessively; iii) have a lack of understanding of the consequences of excessive water application; and iv) have no easy way of knowing when a crop has received enough water (Stirzaker et al., 2017). Reducing over-application of water will have positive environmental impacts by lowering transmission losses, which will minimize salinity and waterlogging and increase river flow.

Soil Monitoring Tools

The soil monitoring tools represent sophisticated but simple-to-use technologies designed to support a farmer-centred learning system. These are SWM tools in the traditional sense, but the focus is on resolving the 'soft' component of the irrigation challenge by providing a means for farmers to learn about water and nutrient management, which they can use in their decision-making.

The soil monitoring tools have been developed by the Commonwealth Scientific and Industrial Research Organisation[1] (CSIRO) to stimulate farmers' learning by linking the information from the monitoring to processes that happen when water is delivered to the soil (conceptualizing the processes). The tools provide the results in the form of coloured lights, with the colours representing triggers for action. This way, the results can be easily understood by semi-literate farmers. In receiving and integrating new knowledge about soil moisture and nutrients, farmers can understand the relationships and impacts and, hence, improve crop yields and water use efficiency.

Traditionally, irrigation management has been taught using an engineering paradigm that uses climate, crop and soil data to provide a predicted irrigation volume to farmers. This method suffers from several issues: each variable is prone to error; application of precise volumes may not be practical (e.g. in flood irrigation systems); climate is variable; cropping patterns change; and there is a mismatch in the mental models between scientists and farmers that disrupts the transfer of knowledge (Stirzaker et al, 2017). The theoretical underpinning of the tools is that an irrigation management system for small-scale irrigators in developing countries should:

- provide people-centred and experiential learning;
- facilitate adaptive management by supporting observation, monitoring and feedback; and
- be inexpensive, robust and suitable for farmers with low literacy and numeracy: simple to use and provide the least amount of information needed for irrigation decision-making (Stirzaker et al., 2017).

Farmers received two principle devices:

- **Chameleon**™ Soil Water Sensors (Figure 6 and 7)
- **FullStop**TM Wetting Front Detector (Figure 8) supported by an electrical conductivity meter and nitrate test strips

The Chameleon is an inexpensive resistance-type sensor that measures soil tension. The technique is similar to the well-known 'Gypsum Block', except that the material inside the sensor is a highly absorbent porous media that amplifies the tension signal in the desired range. This material is encased in gypsum to buffer the sensor against variable salt levels in the soil. Three or four Chameleon sensors are included in an array, to measure the top, middle and bottom of the expected root zone. The sensors are buried permanently in the soil and connected to an 8-pin plug. The wires are colour-coded, so the farmer always knows which sensors are at which depth. Each array has a temperature sensor to allow correction of the resistance reading. This sensor includes a unique identification chip.

The Chameleon reader has an LED for each of the sensors, which can show blue, green or red, depending

[1] The development the soil monitoring tools has been supported by the South African Water Research Commission and more recently by ACIAR-funded projects.

on the soil suction at the particular depth. The Chameleon colours are:

- blue, meaning that the soil layer is wet (tension is less than 20 kPa)
- green, meaning that soil is moist (tension is between 20-50 kPa)
- red, meaning that the soil layer is dry (tension is greater than 50 kPa)

A group of farmers share one Chameleon reader. The farmer inserts the sensor array plug into the reader, which displays the soil tension at each depth as blue, green or red. The reader is Wi-Fi enabled and paired with a smartphone. When the reader takes the soil water measurement it picks up the unique ID and stores the results against it. If the hotspot of the phone is on, it uploads the data to a database. If not, the data from many arrays can be stored and uploaded when the reader comes into Wi-Fi contact. In this way, the farmer sees the data in the field when recorded, but at the same time, the process records the entire season's colour pattern online. Farmers can access this pattern through their phone, but they also record the data in their field books.

Colour provides a common language about a plant's ability to extract moisture from the soil. Importantly, because the sensors measure soil tension, calibration is not required, and the 'language' is independent of soil type: however, soil type will influence how quickly the colour changes from blue to green to red. Information on water availability enables farmers to avoid water stress, waterlogging and fertilizer leaching and learn about the value of rainfall. Farmers receive information to make better irrigation decisions and understand the seasonal progression of crop root depth and moisture needs in the soil profile.



Figure 7 Farmer demonstrating the use of the Chameleon reader at Kiwere scheme

Tools to be used in the learning systems

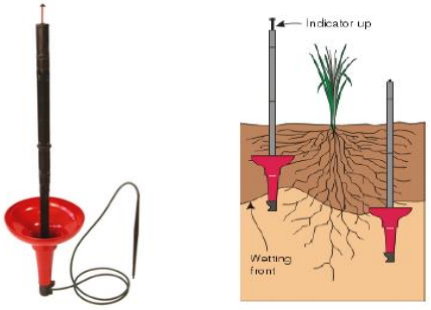
Figure 6 Chameleon™ soil moisture sensors and reader (Photo: VIA Farm website)



The Chameleon reader shows the water stress that plants are experiencing at four depths in the soil. The data are displayed as coloured lights (blue = wet, green = moist and red = dry). The Chameleon helps farmers to see how deep roots are extracting water, how deep irrigation water penetrates, and the optimal time and duration of irrigation.

The reader is Wi-Fi enabled and can hotspot off a phone and deliver the data to the website using the unique ID chip in every sensor array. The data is then collated and displayed in real time to give the 'Chameleon water pattern'. Phone apps are used to collect, store, display and share data so participants can learn together in real time.

The Chameleon is an ACIAR-funded tool in early rollout and is being tested in farmer fields. It is available on https://viashop.csiro.au/



The FullStop Wetting Front Detector is buried in the soil and pops up an indicator when it captures a sample of infiltrating water from irrigation inside the funnel. This water can then be extracted for measurement of salt and nitrate.

The FullStop Wetting Front Detector is a CSIRO-developed tool that is commercially available.

Nitrate colour test strips are used to show farmers the nitrogen status of their soil and help minimise leaching of expensive nutrients. These are commercially available.



Deployment of the Technology

The FullStop was developed in the early 2000s and commercialized in 2004 (Stirzaker, 2003; Stirzaker et al., 2010); it was introduced into Tanzania, Mozambique and Zimbabwe by this project. The Chameleon was first installed on the Kiwere irrigation scheme as part of this project in mid-2014. By 2015, both tools had been provided to five irrigation schemes (not at Magozi as flooded rice production does not require these tools). Tools were deployed on 100 plots across the five schemes (20 on each) with each scheme also receiving two readers.

Field officers were trained in how to install the tools and work with the farmers to take measurements. Each farmer provided with the tools had two FullStop devices and an array of three of four sensors buried at different depths, depending on the crop (Table 6). The number of sensors and depth of deployment varies with the crop. Initially, three or four sensors were used but the final Chameleon model uses three sensors.

Table 6 Irrigation method, crops monitoring and placement depths of FullStop and Chameleon sensors on schemes (Stirzaker, et al, 2017, p. 792)

Scheme	Irrigation method	Crops monitored	Wetting front depths (cm)	Chameleon depths (cm)
Kiwere	Gravity flood	Tomatoes	20, 50	20, 30, 40, 50
Silalatshani	Gravity flood	Maize	20, 40	15, 30, 45, 60
Mkoba	Gravity flood	Maize	20, 40	15, 30, 45, 60
25 de Setembro (Boane)	Pump flood	Maize, cabbage	20, 40	15, 30, 45, 60

The field staff explained to the farmers what the colours meant, when and how to extract water from the FullStop, and how to analyse the water sample for nitrate and salt. It was then the farmer's decision how to act on the monitoring information. The reason for this approach was to remain faithful to the project philosophy—that although there may be an optimum colour pattern from a scientific standpoint, the optimum for a particular farmer may be quite different. Each farmer's management options are context-dependent, they have different appetites for risk and they face a unique set of constraints within which to optimize their business. The colour patterns simply tell the farmers the outcome of their current management and it is up to them to learn their way to a better outcome as their experience and expertise evolves. The output from the tools structures this experiential learning process.

The farmers using the tools maintain a detailed record in their field books of the readings from the tools as well as farm inputs, yield and the prices received for their crops. The installation on the schemes was designed to ensure representation of plots with a different location on the water delivery system: upstream, middle and downstream plots.

Initially, field staff took the readings once or twice a week, and nitrate and salt status were recorded when the FullStop indicator had risen. The farmers recorded the readings directly, if they were present when readings were taken, or the results were communicated to them via mobile phone. Farmers recorded the readings in their field books for their own ongoing record-keeping and learning. The field staff communicated the data to the research team.

Three early issues necessitated a change to this process: i) the cost of employing people to take the readings, record data and enter it into databases; ii) data validity, transcription and quality issues through consolidation of the data across farmers, schemes and countries; and iii) farmers sometimes moved sensors to different crops or plots mixing sensor locations. For these reasons the team abandoned the manual reading system and developed the digital Wi-Fi based version described in the section above. Some additional training was required but it removes human error and facilitates fixing data problems sooner. It also removes the at times lengthy delay from field recording to sharing data with the team. This change did not affect the farmers' access to the data.

In addition to weekly or bi-weekly discussions between the project staff and farmers about the monitoring data, 20 Kiwere farmers were interviewed at the end of the first cropping season in February 2015, about their experience of using the tools. Several months later, ten farmers participated in a focus group to discuss their experiences in more detail and some of these results are summarised in section 4.2.1. The farmers who were

provided with the tools continued to use them throughout Phase 1 and into Phase 2.

Uses and Users of the Data

The key component of the improved monitoring system is the storing, uploading and reporting of data to a platform hosted by the Virtual Water Academy (VIA platform), which was introduced in 2016 (www.via.farm). Field staff upload the FullStop data manually at the time of collection and additional data—such as farm inputs, yield, crop prices and gross margins—are uploaded at the end of each season based on farmers' field books. The VIA platform has been designed for analysis and reporting at various scales, which is being explored further as part of the up- and out-scaling in Phase 2 (section 7.2). Of most relevance to the farmers, is the seasonal, daily or weekly patterns of soil moisture that show the wetting and drying of the soils, rooting depth, and how well irrigation or rainfall refills the soil (Figure 9). Farmers can access this data from their field books, but it is also available graphically on the VIA platform. However, farmers are currently still relying on their field books for learning and sharing with other farmers as reported in section 5.1.

Figure 9 provides an example of a seasonal pattern—showing soil moisture at four depths and nitrate at two depths—available through the VIA platform, and the knowledge that can be gained from its interpretation. The soil is dry at the start of the season and the profile fills with water as irrigation water is applied or rainfall is received. The soil is too wet when all depths show blue and nutrient leaching is likely to occur. The soil is too dry when red is shown. In this example, most root activity is in the 0-30 cm zone, but nitrate is mostly available below 20cm and is leached below 50cm about half way through the season.

The design of the data system should allow different users to access data for different purposes. Farmers need their own copy of all data: so they can increase their knowledge and make their own decisions about their farming practices and conduct end-of-season evaluations. The seasonal patterns across farmers and schemes will be of interest to other stakeholders such as extension officers, local government and irrigation departments. With appropriate placement of tools on the schemes, the results can also be used to evaluate systemic management issues such as over irrigation at the top end of the canal/scheme and water scarcity at the bottom end of the canal/scheme (Pittock & Stirzaker, 2014). The platform can also support benchmarking of performance, identification of better practice and prioritisation of interventions (Stirzaker et al., 2017).

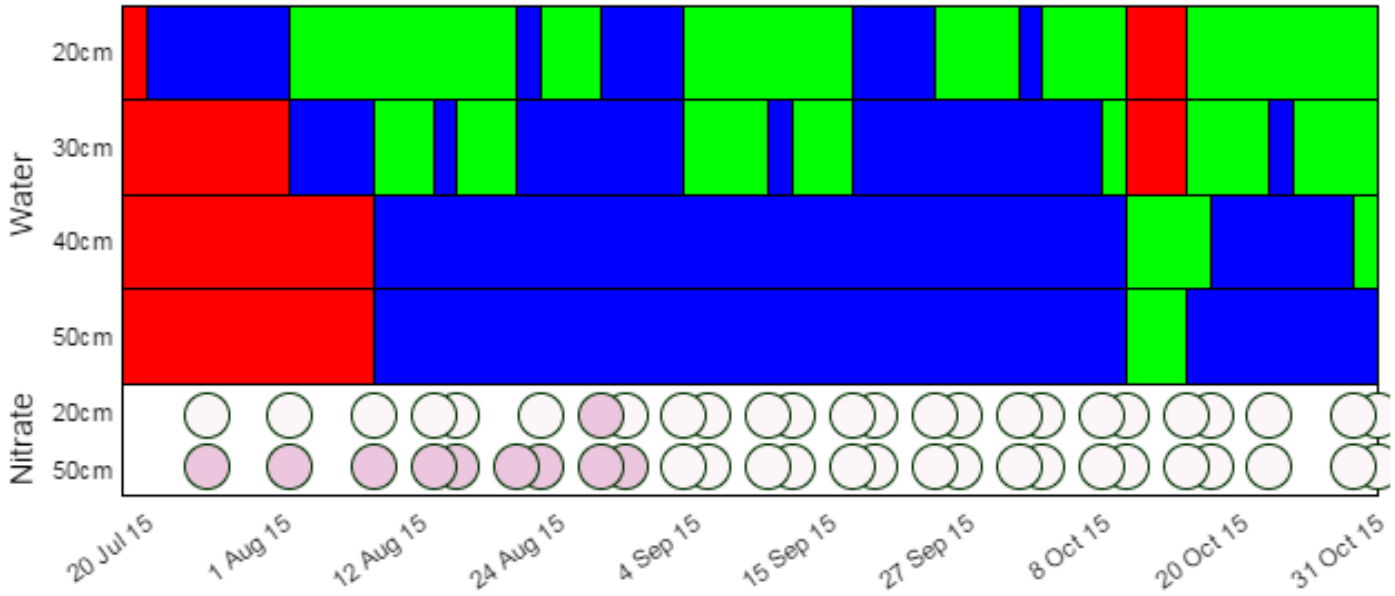


Figure 9 Seasonal pattern of soil moisture and nitrate for a maize crop on Kiwere

Engagement with and Learning from Soil Monitoring Tools

Observations by project staff found that farmers were starting to learn from the tools and were reducing their irrigation within a few months of the tools being deployed. Additionally, farmers requested that the Chameleon reader be kept on the scheme as they wanted to take readings more frequently than the project had initially allowed (Stirzaker et al., 2017). Together with farmers asking for their own reader and other farmers asking for more sensors, this shows that the soil monitoring is valued.

Of the households surveyed, between 24% and 68% had the Chameleon and FullStop devices installed on their plots. Despite the tools not being deployed on all household plots, the level of awareness of the tools is very high, with between 89% and 100% of households surveyed aware that some farmers have the tools. Further, of the households that know about the tools, more than two-thirds know what the tools measure and what this information is used for, and a similar proportion are aware of the changes being made because of the tools. More households report making a change from their use of the Chameleon sensors compared to the FullStop with the changes made varying across the schemes. Where households report that they have made a change based on the tools, the majority report an increase in yield and 43% to 94% report an increase in income. Whilst these figures vary significantly between the tools and across the schemes, they are very positive results.

Farmers have learnt about the complexities of the movement of water and nutrients through the soil profile and examples of this new knowledge are shown in Figure 12. Farmers have been able to correctly interpret the Chameleon colours: for example, by reducing irrigation when blue is recorded at all depths. In some cases, the observations of one farmer—that nitrate strips show white (indicating no nitrate in the Fullstop water sample) when the Chameleon shows blue (moisture is present in the soil)—have led to the learning that overwatering leaches the fertilizer to below the root zone. In response, this farmer reduced their irrigation frequency and found that the crop's new growth was more lush and green. Knowledge about over-irrigation and the relationship to a quick drop in nitrate levels spread quickly throughout one scheme, which then led to a widespread reduction in irrigation

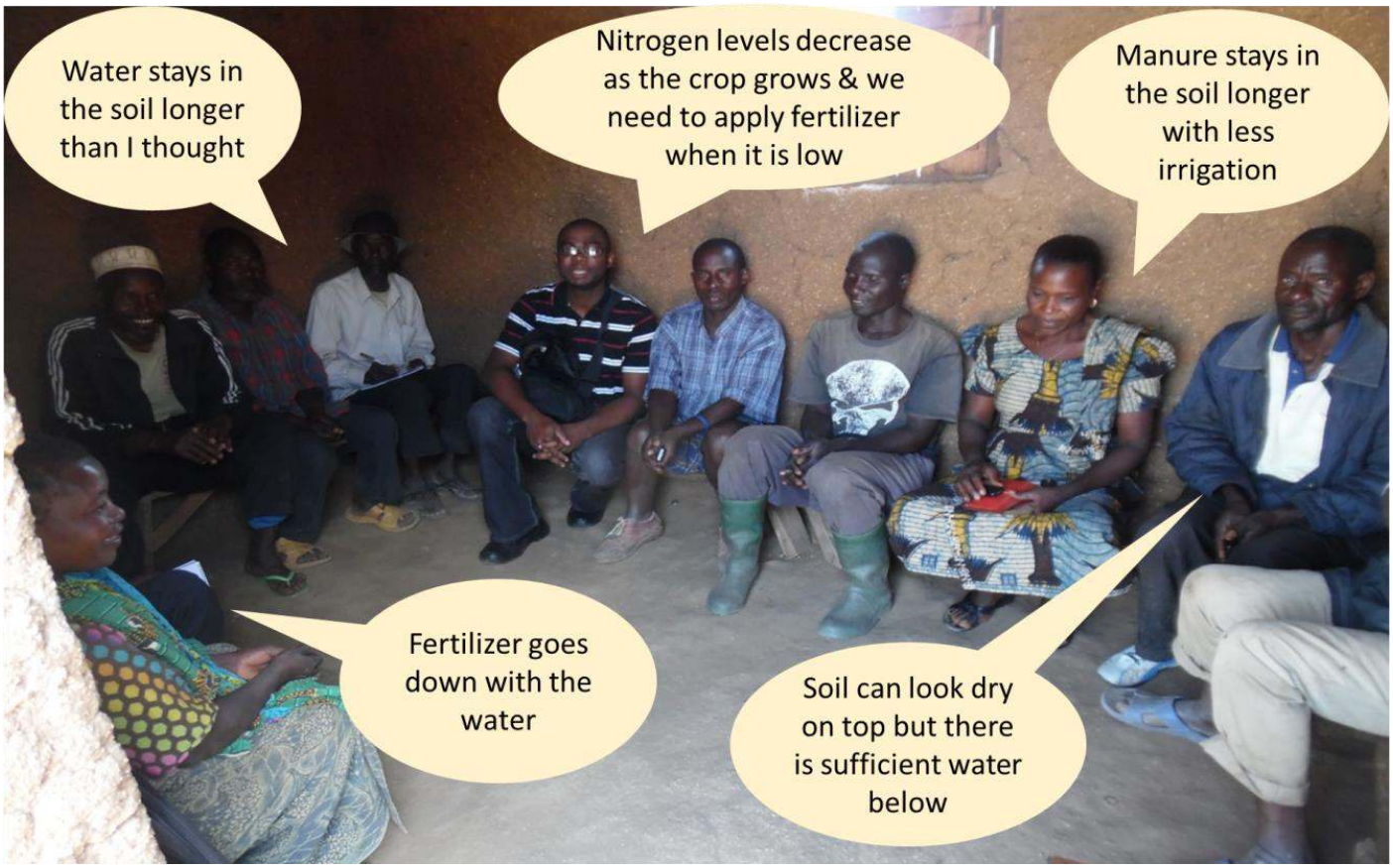


Figure 12 Examples of increased understanding of complex scientific phenomena from Kiwere focus group discussion (Stirzaker, et al., 2017)

Photo courtesy of Ikenna Mbakwe

frequency. This resulted in downstream farmers reporting that more water was available within a short period of time of tool deployment (Stirzaker et al., 2017).

Importantly, it is the combining of data from the two separate monitoring tools that has stimulated understanding and change (Stirzaker et al., 2017). The spread of knowledge and change is also a critical outcome for the project with implications for future tool deployment: for example, on the Zimbabwe schemes, 35% and 24% of farmers had the Chameleon (Table 8) with half or more of households aware of the tools changing their frequency of irrigation (Table 9). As noted earlier, the learning from the tools is ongoing. Farmers using the tools in Phase 1 are continuing to use the tools in Phase 2: they are refining irrigation management and are continuing to learn about the difference between organic and chemical fertilizer management.

Environmental Impacts

A key project impact is reduced irrigation frequency and reduced nitrate leaching into groundwater, benefitting the environment. For instance, the Zimbabwean team measured water use and calculated "water productivity", figure 6. Analysis of the data indicates that water is being saved through skipped scheduled irrigation sessions, leading to a proposal to extend the current seven-day cycle to save more water at the scheme. Salinization is another important environmental issue, for example, on low-lying parts of Kiwere and at the Mkombilenga rice plots in Magozi. By reducing the irrigation frequency at these schemes, we expect that salinity will abate. Further monitoring is required to ascertain the extent of salinity control.
Agrochemicals are poorly handled during the application process and agrochemical containers inappropriately disposed of in the schemes. In Tanzania, for example, the project has addressed these challenges through training and demonstration on best practices for nutrient, pesticide and herbicide management in the irrigated plots. This was organised by the project and delivered by agronomists from Syngenta and Bytrade. Further monitoring is required to ascertain the extent to which farm chemical management improves.

Key Lessons Learnt

When farmers have access to simple tools that they will learn themselves and rapidly change their agronomic practices; The main value of more efficient irrigation water use in situations, where water is not pumped and has an energy cost, is in saving labour that can then be devoted to other livelihood activities;

Lesson 1: Understand the flow-on effect

Learning spread widely within the schemes (evidence of social learning) and practices changed faster than expected, which contrasts with African adoption of soil water monitoring equipment, in general. The number of farmers who changed behaviour and adopted new practices based on learning from the soil monitoring tools far exceeds the number of farmers who had the tools deployed in their plots. For example, 24% of Silalatshani households surveyed had the tools, but up to 73% had changed their irrigation practices. This has important implications for future interventions; as it shows that the flow-on effect within a community can be substantial and this needs to be understood to maximize both the return on investment in the equipment and the anticipated 'reach' of the learning.

Lesson 2: Demonstrate benefits to create willingness to pay for tools (SWM technology)

In the early stages of the project, farmers were reluctant to say how much they were willing to pay for the tools. By the end of Phase 1, the value of the tools had been recognized and most households indicated a willingness to pay.[2] Farmers who currently have the Chameleon arrays want more of them to use in different locations and crops and some would like their own Chameleon reader to take readings more frequently.

Given, the current approximate hardware cost of US$40 for a Chameleon array and US$115 for the reader, the survey results show that 38% to 94% of households would be prepared to pay the amount required for four households to share an array and 78-94% of households would be prepared to pay the cost of 10 households sharing a reader. The flow on effect suggests that such sharing might be the most cost-effective deployment option. Given that some farmers want their own tools, despite the demonstrated flow-on effect, this raises an interesting question around how many farmers actually need the tools. There is more to be learnt about how trust in a technology is developed and spread.

[2] During the Phase 1 EOP survey, at least 80% of households surveyed expressed willingness to make a payment of US$5 or more for a Chameleon array and between 12% and 35% of households are willing to pay US$40. Similarly, 78% to 94% of households are willing to pay US$10 for weekly access to a reader.

Lessons 3: Understand the public and private benefits of the tools and apportion the cost accordingly

The data generated by the Chameleon arrays and readers and uploaded to the Virtual Irrigation Academy has value at several levels: private, scheme, Basin and National as well as for future research. This database collates a wealth of information about water use across different locations and crops (such as crop yield and gross margins), which is currently only available as estimates. For the first time, this system will aggregate data based on plot level data. This raises important questions about how much the farmers, who will only receive the private benefits, should pay for tools that generate data that provides additional public benefits. Hence, Phase 2 aims to develop different business models for how farmers can access the tools and how other institutions such as government and donors can contribute to the cost in exchange for access to the data.

References

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About FANRPAN

The Food, Agriculture and Natural Resources Policy Analysis Network (FANRPAN) is an autonomous regional stakeholder driven policy research, analysis and implementation network that was formally established by Ministers of Agriculture from Eastern and Southern Africa in 1997. FANRPAN was borne out of the need for comprehensive policies and strategies required to resuscitate agriculture. FANRPAN is mandated to work in all African countries and currently has activities in 17 countries namely Angola, Benin, Botswana, Democratic Republic of Congo, Kenya, Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, South Africa, Swaziland, Tanzania, Uganda, Zambia and Zimbabwe.

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