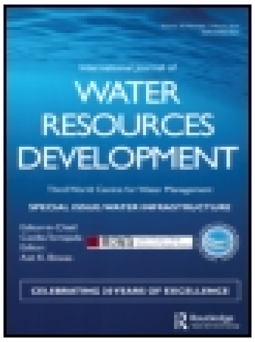

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# Do agricultural innovation platforms and soil moisture and nutrient monitoring tools improve the production and livelihood of smallholder irrigators in Mozambique?

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**ABSTRACT**
Over four years, a research-for-development project was implemented at the 25 de Setembro irrigation scheme in Mozambique. The project introduced agricultural innovation platforms to overcome barriers to production such as input and output supply chains and poorly maintained irrigation canals. Soil moisture and nutrient monitoring tools were provided so that farmers could improve their irrigation and fertilizer management. The farmers increased their crop production through the use of the tools and better irrigation infrastructure, and increased their income and overall well-being through better links to markets and new information sources facilitated by the agricultural innovation platforms.

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**KEYWORDS**
Irrigation management; green maize; markets; Mozambique

## Introduction

In sub-Saharan Africa there are sufficient land and water resources for expanded irrigation, but only if water is managed effectively (De Fraiture & Wichelns, 2010). It has also been well documented that small-scale irrigation has significant potential to increase productivity, food security and income in the rural areas of developing countries (Peter, 2011). However, the track record of small-scale irrigation schemes has been very poor for a multitude of reasons (Bjornlund et al., 2017). As a result, farmers are unable or unwilling to pay water fees and participate in maintenance, resulting in dilapidated infrastructure (De Fraiture et al., 2014).

In the past, the focus has been on more efficient irrigation infrastructure, to increase crop yield and improve the productivity of small-scale irrigation (Mabhaudhi et al., 2018). But it has been argued that this does not always result in more profitable farming and better food security, as other factors, such as lack of market integration and transportation, prevent the translation of higher yields into higher profits (Beddow et al., 2015; Bjornlund et al., 2017). To ensure that the new willingness to invest in irrigation will not again result in unproductive assets, it is critical to take a different approach to developing

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new irrigation schemes or refurbishing old ones. There are also opportunities to improve the performance of existing irrigation schemes (De Fraiture & Wichelns, 2010).

Other studies also provide insights into the barriers to productivity and profitability of small-scale irrigation schemes, and possible ways of overcoming them. For example, Mdemu et al. (2017) argued that limited access to finance hindered farmers from attaining higher agriculture productivity and profitability in Tanzania, because they could not afford high-quality agricultural inputs, transport or storage facilities to sell produce at good prices when supply was low. But while farmers do not have secure access to markets, they are reluctant to take out loans to purchase inputs due to the risk of not selling their produce at a price that allows them to repay the loan and interest. Further, banks are unwilling to lend when tenure is not secure and the risk of non-performance is high. Wheeler et al. (2017) report that farmers in Mozambique are rarely assisted by extension agents due to a lack of human and financial resources, which often results in lack of knowledge and low productivity. Reflecting these issues, Van Rooyen et al. (2017) highlight the need for multi-stakeholder engagement throughout the entire agricultural value chain to make small-scale irrigation viable and sustainable. Therefore, there are clearly opportunities to improve the performance of existing irrigation schemes, as suggested by De Fraiture and Wichelns (2010).

Thus, investment in hardware and technology needs to be combined with the introduction of multi-stakeholder processes to identify and resolve barriers to farmers' increasing their yields and converting these to higher profitability.

The agriculture sector is critical for Mozambique and its people, as it employs about 80% of the population and accounts for about a quarter of GDP (INE, 2018). Despite the potential for 36 million hectares of arable land to be brought into production, of which 3 million hectares are irrigable, agricultural production and productivity remain very low (MINAG, 2013; World Bank, 2016). Recent government plans acknowledge the need to focus on smallholder farmers to foster agricultural development through technology transfer and adoption, infrastructure development, improved agricultural practices, access to markets and agricultural inputs, strengthening of institutions and organizations, and adequate policy and legislation (MINAG, 2011). Nevertheless, the irrigation sector has several challenges: a relatively small area is currently developed in comparison to the potential area; the land that has been developed to date is underutilized; poor maintenance; irrigation infrastructure is rapidly deteriorating; water use efficiency is poor; and there is conflict among water users (Beekman & Veldwisch, 2016; MINAG, 2013). For instance, INIR (2017) states that of the 181,000 ha of land developed with irrigation infrastructure, only 50% is currently operational. This is mainly due to inadequate public funds allocated to irrigation maintenance, lack of technical resources, and farmers not being linked to markets.

Recently, the government has focused on revitalizing and expanding irrigation schemes to increase food production (INIR, 2017). This article helps inform this investment in Mozambique by providing clear strategies to help both new and existing irrigation schemes be both financially and environmentally sustainable and able to retain youth in farming.

To improve approaches to revitalizing government-funded smallholder irrigation in Mozambique, we evaluated two interventions introduced to one irrigation scheme over a four-year period. The first was the establishment of an agricultural innovation platform

(AIP), a forum for stakeholders, as an approach to address market and other institutional issues. The second was the deployment of soil water and nutrient monitoring tools, which enabled farmers to learn and adapt their management practices. The overall aim of the research was to assess the combined effects of the AIP and monitoring tools on the productivity and profitability of the small-scale farmers and their irrigation scheme.

## Background information about the study

### *Study area*

This study was undertaken at the 25 de Setembro irrigation scheme, in Boane District in Mozambique. This is a government-built and government-supported smallholder scheme about 30 km south of Maputo City. It was chosen as it was close to Maputo, where the researchers were based, it was a scheme that was being actively used by farmers (although facing challenges), and it was small enough for the researchers to understand and meet with all the farmers. The irrigation scheme, with an area of 38 ha, was constructed in 1975 and legally established as a registered association in 1981. Like most small irrigation schemes in the country, farmers mainly produce maize, tomatoes and beans, for sale in nearby markets and for home consumption.

The scheme had 56 farmers when established, but when the study commenced in 2013 there were only 38 (22 male and 16 female). In 2013, the average age of a household head was 57, and the average household had 6.8 persons (De Sousa et al., 2017). In the households, 32% had no formal education, 37% had attended or completed primary school and 31% had attended or completed secondary school. The average farm area was 1.1 ha, and the main crops grown were green maize (71%) and cabbage/tomatoes/cowpea (29%) (De Sousa et al., 2017). According to soil tests conducted at the scheme, the soil texture ranged from sandy clay (86%) to clay (14%).

The irrigation scheme extracted water from the Umbelúzi River using a 40 HP diesel pump that could deliver 125 l/s. The pumped water was then distributed by gravity through a canal system, and applied to the fields using furrow irrigation. Each individual irrigator bought fuel to run the pump when they wanted to irrigate. The association's office maintained an irrigation scheduling book, where members booked a time when they wanted to irrigate. However, the irrigation scheduling was subject to constant negotiation, and at times the association constrained supply to once every six or seven days.

Both men and women participated in most farm work. However, men were responsible for building, and for supplementing household income by off-farm work, while women were responsible for most domestic work (De Sousa et al., 2017).

In 2013, irrigators had poor access to market information, with only 27% aware of buyers who would pay a higher price than they were currently getting. Even though farmers could receive higher prices at the Maputo City market (35 km away), they mainly sold their produce immediately after harvest, with buyers often harvesting the crops. This has both benefits and costs. Farmers do not need to pay harvest and transport costs, and the risk of post-harvest losses is transferred to the buyer. However, when the buyers do the harvesting, they tend to pick only the best (De Sousa et al., 2017).

Before the project, there was no assessment of how irrigators made their irrigation management decisions. However, observations and conversations with irrigators at project inception suggested that they based their decisions on the plant's appearance and the dryness of the soil surface. As a result, most farmers were likely to have been over-irrigating, leading to potential nutrient leaching and lower productivity. However, some may have been under-irrigating due to the high cost of fuel.

Extension services are critical to provide crop management advice, and its provision is the responsibility of the government. However, extension officers had little influence in the scheme: only 28% of farmers had talked to an extension officer in the two years before the study (Wheeler et al., 2017).

At the beginning of the project, the main constraints faced by irrigators were: 84% of farmers reported low use of inputs (certified or good-quality seeds and fertilizer); 64% reported lack of implements and tools; and 36% reported limited access to markets. Moreover, the farmers association was facing many difficulties, such as breakdown of the irrigation pump, management issues, members leaving the scheme, non-payment of fees, and distrust among members (De Sousa et al., 2017). Also, unlined canals resulted in water losses, long delays in conveying the water to fields, and high pumping costs. On some occasions, these inefficiencies also contributed to further limiting water scheduling to once every 15 days. However, De Sousa et al. (2017) suggested that these water distribution issues were less constraining than access to inputs, transport, markets and extension services.

## *Project interventions at the irrigation scheme*

The project introduced two complementary interventions: an AIP to resolve market and other challenges limiting productivity and profitability; and soil monitoring tools to increase farmer learning about soil moisture and nutrient dynamics for better irrigation and nutrient management. We hypothesized that this two-pronged approach would increase economic development by improving productivity and profitability and transition the scheme into a prosperous and sustainable irrigation community. Fieldwork for the project ran from 2013 to 2018.

### *The agricultural innovation platform*

An AIP is a forum that brings together all the stakeholders with an interest in the irrigation scheme, creating an environment in which their roles within the larger system become self-evident and everyone understands their role in the network (Van Rooyen et al., 2017). AIPs have been acknowledged as drivers of change by numerous development organizations in sub-Saharan Africa. They are well recognized as creating links between farmers and stakeholders for open discussion of difficulties to tackle problems with input supplies, market links and other systematic problems (Van Paassen et al., 2014). The members of an AIP need to have a wide range of knowledge and resources, enhancing learning and increasing negotiation skills and readiness for change (Leeuwis, 2004). Many studies have reported on the performance of AIPs in various countries (e.g. Ayantunde et al., 2016; Makini et al., 2018; Schut, Kamanda et al., 2018; Van Paassen et al., 2014). The conclusion from these reports is that AIPs generate enthusiasm and bring stakeholders together to effectively address specific problems and achieve 'local' impact (Schut, Cadilhon et al., 2018). However, to be effective they need to be firmly embedded in or linked to public/private extension channels. They are not 'quick-win' approaches; they require time to mature and to become fully functional and achieve desired outcomes (Ayantunde et al., 2016). Schut, Cadilhon et al. (2018) say that a successful AIP should be truly demand-driven, participatory, based on collective investment and action, and able to bring together committed stakeholders, enabling innovations that are technically sound, locally adapted, economically feasible for farmers, and socially, culturally and politically acceptable.

### *The soil monitoring tools*

Despite many tools being available to measure soil moisture (Charlesworth, 2008) and other approaches based on monitoring plant stress and calculating water balances (Jones, 2004), scientific, objective irrigation scheduling (deciding when and how much to irrigate) is undertaken by very few farmers in developed or developing countries (Australian Bureau of Statistics, 2005; Stevens et al., 2005; Stirzaker, 2006).

There are many reasons why farmers do not adopt techniques and tools developed by scientists and experts. These mostly relate to the scientist/expert not understanding how the farmers make decisions and the constraints under which they operate (Vanclay, 2004). Research on irrigation scheduling has found that farmers want simple information that supports their own decision-making framework (Whitenbury & Davidson, 2009). For this project, two soil monitoring tools were introduced to provide appropriate information to farmers and to promote experimental learning. The Chameleon sensor (Figure 1(a)) was designed as a farmer-friendly learning tool to help farmers decide when and how much to irrigate (Stirzaker et al., 2017). The sensor array consists of three sensors buried at different depths in the plant root zone. The sensors monitor soil water status as 'soil water potential', which reflects how hard it is for the plant to access the soil moisture. Thus the Chameleon can be used without concern in varying soil types. At an interval of once or twice a week, the Chameleon reader is connected to the sensor array and displays the

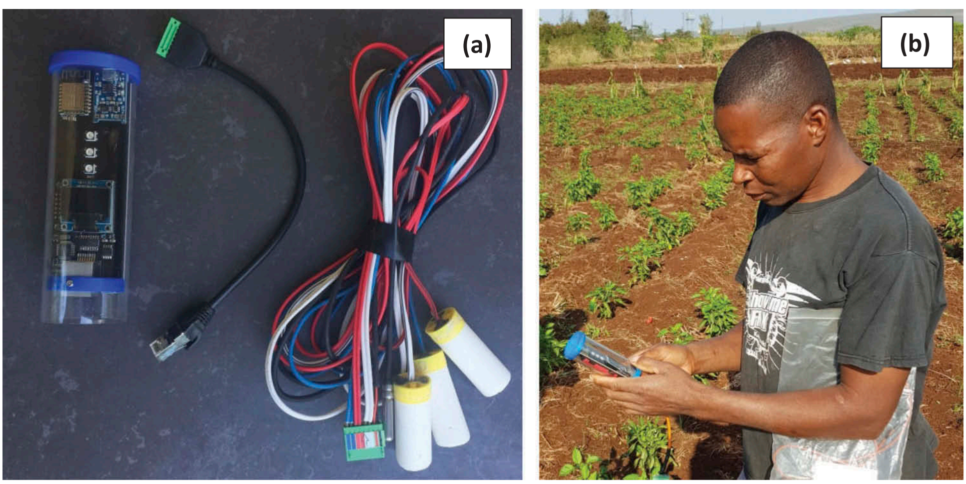


**Figure 1.** (a) The Chameleon reader with three sensors. (b) Farmer (David José Fumo) taking a reading from the buried sensors. (Photos: Evan Christen.)

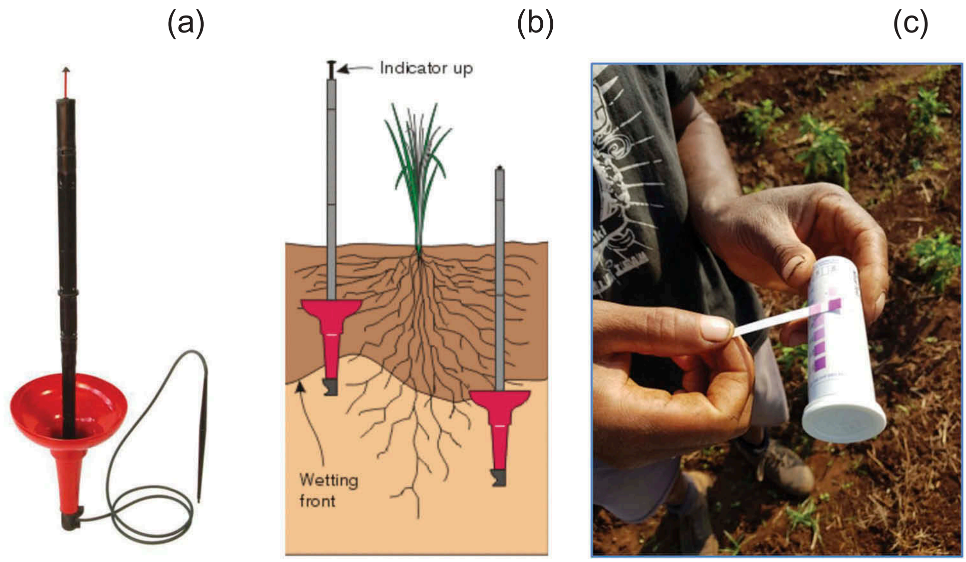


**Figure 2.** (a) The Full Stop wetting front detector. (b) Sketch of field installation. (c) Assessment of nutrient level. (Photos a and b from www.via.farm, c by Evan Christen.)

data as coloured lights, one light for each sensor: blue = wet, green = moist, red = dry. While the sensor array is fixed in the soil, the Chameleon reader is a portable handheld device, which was taken to each field to read the sensor arrays of the farmers (Figure 1(b)).

The second tool used was the FullStop (Figure 2(a)), which is a wetting front detector (WFD) that collects a soil water sample when a wetting front passes the depth at which the detector is buried (Stirzaker, 2003). Two detectors were placed at depths of one-third and two-thirds of the expected root zone (Figure 2(b)). Whenever the FullStop's above-ground flag pops up, it signals that a sample of soil water is available and can be extracted through a rubber hose using a syringe. The sample can then be analyzed for nutrients (nitrate, $NO_3^-$) using test strips (Figure 2(c)) and salinity using an electroconductivity meter. This nitrate reading provides two important pieces of information for the famers: the amount of nitrate in the soil at a specific depth (Figure 2(c)), and whether the nitrate is being leached below the root zone due to over-watering (Van der Laan et al., 2010). For a full description of the Chameleon and the WFD, see Virtual Irrigation Academy (https://via.farm/) and Stirzaker et al. (2017).

## *Materials and methods*

The general process of AIP implementation as described by Van Rooyen et al. (2017), Bjornlund et al. (2018), and Bjornlund et al. (2019) was followed. The project staff from Instituto Nacional de Irrigação (INIR) started by conducting semi-structured surveys with the farmers' association, to understand the general situation at the irrigation scheme. The information collected included:

- The administrative and social structure of the irrigation scheme (organization of farmers as associates and as individuals);
- Aspects of irrigation infrastructure (responsibilities for management, operation and maintenance of the system);
- Irrigation-related aspects (irrigation regime and costs involved);
- Market linkage aspects (from the purchase of inputs for production to the sale of crops);
- Identification of key actors in the value chain;
- Identification of 'champions'.

This activity provided crucial information for preparing the AIP. In April 2014, the first AIP meeting was held with the farmers and a wide range of stakeholders informed by the previous interviews. The following stakeholders were involved:

- Instituto Nacional de Irrigação (INIR), the National Irrigation Institute and the government irrigation agency;
- Input suppliers, such as Soluções Rurais, Becu & Filhos, Biochem and the Syngenta group;
- Japanese International Cooperation Agency (JICA);
- Provincial Directorate of Agriculture and Food Security (DPASA);
- District Services for Economic Activities (SDAE), including the agricultural extension services;
- União Distrital dos Camponeses (District Farmers Union);
- Financial Institutions: Banco Terra, Hluvuku, Agricultural Cooperative Development International (ACDI), and Volunteers in Overseas Cooperative Assistance (VOCA);
- Development programmes Pro-Poor Value Chain Development in the Maputo and Limpopo Corridors.

Following that, a visioning process was facilitated by the INIR staff through which the farmers developed a vision of what they would like their scheme and community to look like in five years' time, and the steps the community would need to take to reach that vision. Further AIP meetings brought the farmers and other stakeholders together to identify the barriers that prevented them from reaching their vision and identify processes by which these barriers could be overcome. Importantly, there were many one-to-one meetings between farmers and other stakeholders, and informal group meetings, in between the formal AIP meetings organized by INIR. The informal meetings were organized by the stakeholders themselves and then the outcomes later reported to the INIR staff. The participants, topics, issues and actions planned during the formal AIP meetings are shown in Table 1.

In August 2014, Chameleon sensors and WFDs were provided to 18 farmers, which was half of the farmers in the scheme at that time. The Chameleon sensors were read once or twice per week in the presence of the farmer, and a monthly meeting was held with all the farmers (both those with and without the tools), extension staff and project team members to discuss the data. The data were communicated as colour patterns and nitrate readings on paper printouts. The farmers then adapted their practices according to what they learned from the tools. The project team did not tell the farmers what to do in

**Table 1.** Agricultural innovation platform meetings.

| Meeting | Participants | Topics discussed | Key issues/problems | Actions planned | Responsibility |
|---|---|---|---|---|---|
| AIP 1 (April 2014) | Famers, project team members, INIR, DPASA, SDAE Boane, Becu & Filhos, Soluções Rurais, Biochem, Banco Terra, Hluvuku | - Vision process<br>- Vacant land management<br>- Farm production and productivity<br>- Market access<br>- Access to credit | - High irrigation costs<br>- No lined canals<br>- Technical problems with tractor<br>- Limited access to high-quality/certified seeds<br>- Access to vacant plots<br>- Limited access to credit | - Rehabilitate irrigation infrastructure<br>- Support farmers to access and purchase high-quality seeds and inputs<br>- Support farmers association to bring more farmers into the scheme<br>- Support farmers to access credit | INIR<br>Input suppliers<br>SDAE Boane<br>INIR/microcredit service providers (e. g. ACDI/VOCA) |
| AIP 2 (October 2014) | Farmers, project team members, INIR, SDAE Boane, VINESA Project, ACDI/VOCA | - Vision process (follow-up)<br>- Lining of canals<br>- Market access<br>- Crop production | - Farmers lack skills to prepare business plans<br>- Irrigation water takes too long to reach farmers' plots<br>- Cracks in the irrigation canals<br>- Low crop sale prices<br>- Canals below field level | - Train farmers in building business plan<br>- Rehabilitate the irrigation infrastructure and fields | INIR/UEM-FAEF<br>INIR |
| AIP 3 (May 2015) | Famers, project team members, INIR, DPASA, SDAE Boane, JICA | - Access to vacant plots by new farmers<br>- Limitations in farm machinery for different farm operations | - Plots mostly occupied by older people<br>- Lots of plots not being used by owners<br>- Limitations to transport farm products to the market | - Engage younger farmers in the irrigation scheme<br>- JICA corporation to support farmers with tractor and transport | SDAE/farmers<br>JICA |

Note: INIR = National Irrigation Institute; DPASA = Provincial Directorate of Agriculture and Food Security; SDAE = District Services for Economic Activities; JICA = Japanese International Cooperation Agency; UEM-FAEM = University Eduardo Mondlane – Faculty of Agronomy and Forestry Engineering; VINESA = Improving income and nutrition in eastern and southern Africa by enhancing vegetable-based farming and food systems in peri-urban corridors; ACDI = Agricultural Cooperative Development International; VOCA = Volunteers in Overseas Cooperative Assistance.

response to the colours (for detailed discussion of the learning process, see Parry et al., 2020).

Field data were collected from 23 farmers per crop, of which 62% had the soil moisture and nutrient measurement tools. The field data collected focused on green maize production, as it was the most commonly grown crop (79% of farmers). Between 2014 and 2018, six successive growing seasons of green maize were monitored. Researchers recorded the farming activities, such as the number of irrigation events; use and cost of farm inputs, such as fertilizer, labour and pesticides; planting and harvest dates; and data from the Chameleon and WFD. These data were collected via weekly visits when the tools were read, and farmers were asked about their farming practices in the previous week.

The yield data were collected when traders were at the farm buying the green maize cobs. The green maize was sold directly from the field, where farmers offered the buyers an area to harvest of either 6 × 6 m or 10 × 10 m. As the total area of maize grown by each farmer was in the range of 0.5 to 1 ha, there were multiple harvests through the cropping season. The project team members monitored one harvest per crop per farmer and used that to compute the yield per hectare. However, not all cobs within an offered area had commercial value as green maize, so about 20% of the cobs were left on the plants until dry and then harvested for home consumption.

Gross margin analysis is widely applied in agricultural sustainability analysis and constitutes an important financial indicator (Ha et al., 2015; Nash et al., 2013). The gross margin is the difference between income and variable costs. In research on crop production, it is generally expressed in monetary value per land use area. Three workshops were held with farmers and extension officers during which farmers were trained in computing gross margins for their crops. Using farmer recall data, gross margins were calculated per unit of land and labour (Ducrot et al., 2016). The input cost data from the workshops are used in this article to calculate the gross margins for each crop in MZN (US$ 1 = MZN 62). When computing the gross margin the total yield needed to be split into three parts reflecting three different values: the first-grade cobs were sold at MZN 18/kg; second-grade cobs were sold at MZN 12/kg; and the grain maize for home consumption was valued at MZN 17/kg dry grain weight (MASA, 2017). Farmers indicated that on average about 80% of the crop was sold and about 20% remained for home consumption. Of the 80% sold as green maize, about 65% was sold as first-grade quality, and the other 35% as second-grade.

In May 2017, at the end of the four-year project, a face-to-face household survey was conducted using a questionnaire to collect socio-economic and asset-specific data from the households. The questionnaire aimed to assess the changes due to the project interventions. The project staff who carried out the questionnaire participated in a two-day training workshop, at the end of which the questionnaire was pilot tested in the scheme and then revised. Of the 38 households in the scheme, 28 were interviewed for 1.5 to 2 hours. Cheveia et al. (2018) provide a detailed report of the survey results.

## Results and discussion

### *AIP process*

There was strong farmer engagement with the AIP, with 96% of households attending the meetings, due to the close contact between the INIR staff and the farmers, and a clear signal that at the meetings, the issues that had raised would be discussed with multiple stakeholders and approaches to addressing them established. By October 2014 the participants in the AIP meetings (Table 1) had identified the following barriers to productivity and profitability: high irrigation costs due to unlined canals, lined canals with cracks, canals below the level of the fields and an ageing pump and motor; constant breakdowns of the tractor and its implements; lack of transport to market; poor-quality seeds (low germination and poor vigour); unused land with potential for crop production; barriers to new farmers' occupying unused land; the older age of many farmers (average 57 at the start of the project); insufficient funds for farmers to invest in crop production and commercialization; and poor links between farmers and markets.

While it was not within the scope of the research project to line canals or to buy trucks or tractors, the fact that these issues were identified as critical in the AIP meetings lent credibility to the stakeholders undertaking to resolve them. INIR undertook to contact the government of Mozambique to discuss the need for refurbishment of the infrastructure, and DPASA (through SDAE) undertook to follow up with JICA regarding donating a truck and tractor, as JICA was looking for ways to support small-scale irrigation. On the strength of the shared identification of these problems by all the stakeholders, in 2015 INIR secured funding to rehabilitate the irrigation scheme. This consisted of lining 3 km of canals, levelling some fields, building a warehouse and a pump station, and repairing the pump motor. This was undertaken between July and November 2015 and cost approximately MZN 7,400,000 (about USD 123,500). On the same basis, DPASA convinced JICA to provide the association with a new tractor and a truck. All these actions were taken during the study period and before the end of the project survey.

Also, during the AIP meetings, particularly the second one, the finance organizations ACDI and VOCA became aware of the farmers' need for credit, which they then agreed to provide. As a result, 15 farmers accessed credit, and were able to invest in high-quality inputs, such as certified seeds. During the visioning exercise, the input suppliers (Becu & Filhos, Soluções Rurais, Biochem and Syngenta) became aware of the poor-quality seeds and their impact on farmers and agreed to take action. Consequently, a system is now in place by which the farmers contact a particular input supplier to purchase seeds as a group, and are thus able to negotiate better prices. This system also reduced the number of trips required to buy inputs.

At the AIP meetings a functional relationship was created between buyers and sellers. An introductory forum and then meetings between farmers and the buyers/sellers shifted the farmers' mindset regarding more profitable farming opportunities. The limited formal information on crop yields, production costs and selling prices made it hard for farmers and extension officers to assess the profitability of different crops and the impact on farmers' financial viability, and thus the sustainability of the scheme. To address these emerging issues it was decided at the AIP meetings to organize a series of three workshops in March and April 2016 to enhance cooperation between farmers, team members and extension officers (Ducrot et al., 2016; Parry et al., 2020). Activities at these workshops included mapping of the scheme to understand occupation (Figure 3); assessing the farmers' cropping strategies, including how to compute gross margins for their crops; developing individual business plans; and analyzing the cost of irrigation pump maintenance and the association's ability to pay for it.


**Figure 3.** Participatory mapping of the 25 de Setembro irrigation scheme. (Photo from Google Earth, edited by Wilson de Sousa.)

Through these activities, farmers learnt that it was up to them to understand and work within the market structures and meet market demands in terms of crop type, timing, quality and quantity. This can be shown in the farmers' deciding that they would introduce a base price for green maize so as not to undercut one another. This ensured that the buyers from Maputo did not manipulate them. Individual farmers have since continued to do gross margin analysis by themselves, which helps them evaluate their efficiency and supports adjusting their prices.

Based on the discussion at the AIP meetings, SDAE understood the need to resolve the problem with unused plots in the scheme. SDAE agreed to work with the District Farmers Union and the Farmers Association to address the problem. This problem had arisen as some farmers were deceased, others had left the area and the farmer population was ageing. Because it was very difficult to admit completely new people into the association to use the vacant land, it was agreed to approach the relatives of those owning the unused plots. To address engage more young people, the Farmers Association members decided to target young people and arrange a mentoring system with the older farmers to guide the new young farmers. This resulted in seven young farmers taking up 4 ha of unused land and more young farmers requesting land. There was then no more land available within the scheme, so the association decided to develop 2 ha of irrigated land in the vicinity to accommodate six more young farmers.

### *How the AIP-initiated activities influenced farmers' perceptions*

At the end of the project, there was a strong perception that both demand for and the variety and quality of information had increased: 74% of those surveyed said that their information needs had increased; 76% said that the range of information sources available had increased; and 96% said they were getting better agricultural advice (Table 2). The greater demand for information can be linked to the introduction of new crops and techniques, learning from the tools, and a better understanding of the value of information. These results are linked to the introduction of new stakeholders to the scheme through the AIP-initiated activities, such as the project team helping providing farmers with better agricultural practices and the SDAE arranging for an extension officer to visit the scheme twice a week and be available to the farmers by phone. The workshops on developing business plans and computing gross margins were also an important source of information for the farmers.

The even attendance between women and men at the AIP meetings suggests that the AIP has provided a context within which both genders feel comfortable, and women have used this forum to increase their presence and influence within the scheme. The surveys also found that women tended to access more information sources than the men (around 50% versus 40%). Seven percent or less of households accessed information jointly. All forms of information seem to be of interest to both men and women and equally accessible to both.

As a result of the various activities to improve farmers' links to input and output markets, in the end-of-project survey, most (86%) agreed that the range of input markets had increased, or increased a lot (Table 3), and 67% reported that the buying process had become easier, or much easier (Table 4). These changes have probably saved the farmers time and improved the quality of inputs. However, 75% stated that the prices of inputs had increased, or increased a lot. At the same time, 46% said that prices they received had increased, or increased a lot, and 39% said that crop prices had increased to meet the cost of production. The 34% inflation that occurred in 2016/2017 in Mozambique (Statista, 2017) is probably a factor in these input cost and crop price increases.

At the end of the project, 50% of respondents thought that the selling process was now easier, which is an important improvement for farmers. However, 14% said it was harder (Table 4), which could be due to growing new crops, like Irish potatoes, for which markets had to be found for the first time.

**Table 2.** Households' access to agriculture-related information, 2014 to 2017.

| Information needs have | Percentage of households |
|---|---|
| *Gone up* | 74 |
| *Stayed the same* | 22 |
| *Decreased* | 4 |
| Range of information sources used has | |
| *Gone up* | 76 |
| *Stayed the same* | 24 |
| *Decreased* | 0 |
| Getting more or better agricultural advice | 96 |

**Table 3.** Change in input and output markets, 2014 to 2017 (percentage of respondents).

| | Decreased a lot | Decreased | Stayed the same | Increased | Increased a lot |
|---|---|---|---|---|---|
| The range of input markets has | 0 | 11 | 3 | 75 | 11 |
| The range of buyers has | 29 | 21 | 14 | 25 | 11 |

**Table 4.** Change in buying and selling processes, 2014 to 2017 (percentage of respondents).

| | Much easier | Easier | The same | More difficult | Much more difficult |
|---|---|---|---|---|---|
| The buying process is now | 21 | 46 | 18 | 8 | 7 |
| The selling process is now | 29 | 21 | 36 | 14 | 0 |

**Table 5.** Farmers' knowledge about tools and their interpretation (percentage of respondents).

| | |
|---|---|
| Know what tools measure and their use | 93 |
| Of those who answred yes: | |
| 1) Interpretation of Chameleon lights: | |
| *A blue light means the soil is wet* | *100* |
| *A green light means the soil is moist* | *100* |
| *A red light means the soil is dry* | *100* |
| 2)Understanding of WFD: | |
| *Know what WFD measures* | *88* |

**Table 6.** Changes to farming practices as a result of the tools, 2014 to 2017 (percentage of respondents).

| | |
|---|---|
| Changed irrigation practices over the last four years | 86 |
| Changed irrigation practices due to Chameleon use | 93 |
| *Reduced frequency of irrigation* | 85 |
| *Reduced duration of irrigation* | 56 |
| Changed fertilization practices due to WFD use | 68 |
| *More fertilizer applied* | 6 |
| *Less fertilizer applied* | 28 |
| *Changed the way fertilizer is applied* | 67 |
| *Changed the time of fertilizer application* | 37 |

## *Tools and agricultural practices*

By the end of the project, 93% of the farmers knew what the Chameleon and WFD tools measured and what they were used for (Table 5). Considering that only 47% of farmers had the tools installed on their plot, this information must have spread informally from farmer to farmer. All the farmers understood that the coloured lights of the Chameleon reader indicated the level of available moisture in the soil. This indicates that the approach used to provide soil moisture data was easy to understand. Likewise, 88% of farmers understood that the WFD could be used to measure nitrate losses.

Most farmers (86%) had changed their irrigation practices (Table 6), and 80% reported that they did so in response to learning from the monitoring tools. Looking at those farmers who made changes, 93% did so by reducing the frequency and/or duration of irrigation events (Table 6). In addition, 68% changed their fertilization practices due to the WFD by changing the timing of fertilizer application (to avoid irrigation events), with a smaller proportion changing the rate of application.

The lower rate of changing fertilizer management may be because this can be a more complex decision than changing irrigation water management. Increasing the application of fertilizer or the frequency of application has costs in both time and money; reducing irrigation saves money on fuel and labour.

## *Impact of the interventions on green maize yield and gross margins*

Between 2014 and 2018, six green maize crops were monitored, as described in the Methods section. The details of the crops and timing of system refurbishment are shown in Table 7.

Figure 4 shows the change in irrigators' behaviour under the conditions described in Table 6. For the second cropping season, the average number of irrigation events farmers

**Table 7.** Information on crops and timing of irrigation scheme refurbishment.

| Crop | 1 | 2* | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Years | 2014/15 | 2015/16 | 2016 | 2016/17 | 2017 | 2017/18 |
| Months | Oct.–Jan. | Oct.–Jan. | May–Aug. | Oct.–Jan. | April–July | Nov.–Feb. |
| Season | Wet | Wet | Dry | Wet | Dry | Wet |
| Rainfall (mm) | 350 | 139 | 137 | 418 | 159 | 450 |

*Canals were lined in August/November 2015 before and during the second crop. A new warehouse and pump station were built in August 2015. Fields were levelled in November 2015. This was a very low-rainfall 'wet season'.


**Figure 4.** Average number of irrigations per crop.

applied declined by 7%, and for the third cropping season, after the scheme refurbishments, it declined by a further 17%. By the sixth cropping season, the average number of irrigation events was 33% less than at the beginning. This suggests a gradual adoption of the learning from the tools and an ongoing experimental learning process as farmers adjusted the timing between irrigations.

These analyses of the field data correlate well with the survey data, which reported that of farmers who made a change, 85% reduced the number of irrigation events, and 56% reduced the duration. Both changes reduce the time farmers spend irrigating (Table 6). Also, thanks to the upgrade of the canal infrastructure water was supplied to the fields more quickly, so farmers spent less time waiting for the water to get to their farms, which further reduced the time spent on irrigation and the cost of pumping.

The farmers' green maize yield increased over the six cropping seasons from 2014 to 2018 (Figure 5). Average yields in the second cropping season were 47% higher than the first. In the third cropping season, yields increased by a further 87% over the second crop. In seasons four to six the yields increased on average by 5% per year. Overall, by the sixth crop the yield was 313% as large as from the first crop. This dramatic increase can be attributed to the combination of tools, scheme refurbishment, better water and fertilizer management, and access to better inputs, such as certified seeds.

At the beginning of the project, 5.3 t/ha and 4.4 t/ha were reported as the average green maize wet-season and dry-season yields, respectively. At this time, farmers thought that 6 t/ha was a good yield. Now yields are averaging 16–18 t/ha. The dry-season yields (crops 3 and 5) are now as large as the wet-season yields (crops 4 and 6). This indicates


**Figure 5.** Average green maize yield.

that the farmers have improved their irrigation-water management and other agronomy skills.

The end-of-project survey identified three main improvements that farmers had experienced using the tools: saving money on fuel (70%), better utilization of water (60%), and time saved (30%). The farmers also said that they thought they could increase production using less water through the use of the monitoring tools. This is confirmed by the field data discussed in the next section.

## Overall effects of the changes

The result of the interventions discussed so far has been that 80% of farmers reported increases in income by 25% or more (Table 8).

A gross margin assessment of the six crops of green maize was undertaken to understand the financial benefit to farmers (Figure 6). Comparing the first and sixth crops, the gross margins increased six-fold. The combination of the impact of the actions initiated by the AIP, the tools, scheme refurbishment, and better input and farming practices improved yields and income, as reflected in the higher gross margins. The major increase in gross margin was due to yield increases, but also costs were reduced due to less frequent irrigation, which saved fuel and labour, and better marketing of the crop raised incomes.

Farmers are interested in understanding the return on their labour. To assess the benefits of the interventions for returns on labour, the opportunity cost of labour was calculated by dividing the gross margin without labour by the number of labour days (approximately 81; see Figure 7). The opportunity cost of labour was initially about MZN

**Table 8.** Farmer's perception of the effect of agricultural changes on their income, 2014 to 2017 (percentage of respondents).

| | |
|---|---|
| Reduced | 4 |
| The same | 17 |
| Increased | |
| *25% more* | 46 |
| *50% more* | 13 |
| *75% more* | 21 |

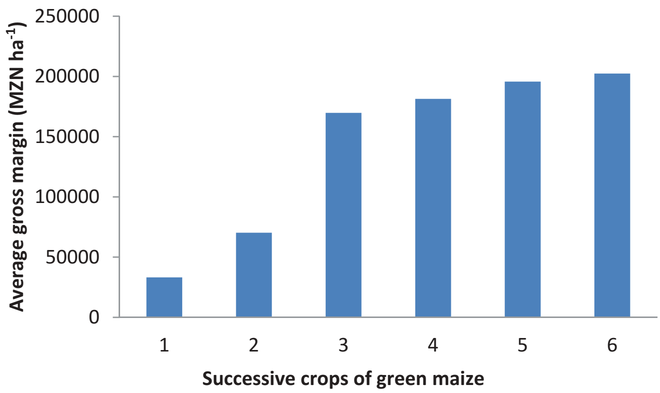


**Figure 6.** Average gross margin of green maize.
Note: US$ 1 = MZN 62.

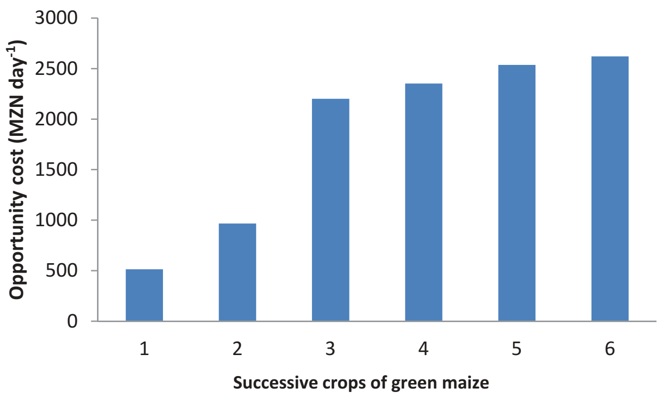


**Figure 7.** Average opportunity cost of labour.
Note: US$ 1 = MZN 62.

500 per day, but it had increased to about MZN 2500 per day by the end of the project. This increase can be attributed to the higher yields and gross margins, and less labour spent on irrigation. These changes can be compared to the government of Mozambique's minimum monthly wage for agriculture, which was MZN 3642 in April 2017 (Club of Mozambique, 2018), and the daily rate of MZN 200 that the farmers reported they paid for agricultural contract labour.

The analysis of factors that influence households' livelihoods and well-being shows very positive changes: 60–80% reported that their income, food security, health and capacity to pay for education were better, or much better, than at the beginning of the project (Table 9). Interestingly, 83% and 60% of households considered that both their farm and off-farm incomes were better or much better, respectively. There is a probable link between the two, as the farmers are likely to have more time for off-farm activities as they reduce the time spent on irrigation. These are critical outcomes, as better nutrition

**Table 9.** Perception of household changes in income and food security, 2014 to 2017 (percentage of respondents).

| Much worse | Worse | The same | Better | Much better | |
|---|---|---|---|---|---|
| Farm income | 0 | 11 | 7 | 62 | 21 |
| Off-farm income | 10 | 15 | 15 | 55 | 5 |
| Household food security | 0 | 11 | 21 | 64 | 3 |
| Health of family members | 0 | 14 | 25 | 50 | 11 |
| Capacity to pay for childrens' education | 0 | 11 | 18 | 54 | 7 |

and health increase households' capacity to work and children's capacity to learn, and more education paves the way for better future farming outcomes and livelihood options for those not continuing in farming.

When it comes to gender differences in the perception of changes in farm income, the findings are less clear, with more female-headed households reporting both worse and much better outcomes (Table 10). This aspect needs to be scrutinized further to understand why some farmers felt that their situation had worsened, and why there are differences between male and female farmers.

The positive financial results also increased participation in and payment for irrigation scheme maintenance (Table 11). Most farmers reported that they are now doing more scheme maintenance than they had four years earlier, and they were more willing and more able to pay for water. This was seen in the field, with regular weed and silt clearing from the canals, and can be attributed to the perception of a fairer water allocation process (Table 11), a better financial position and an appreciation of the better income-generation opportunities of the irrigation scheme (Tables 9 and 10).

This greater willingness to participate in irrigation scheme maintenance is important for the sustainability of the scheme and has important implications for government (e.g. budget saving), particularly in scheme refurbishment or the building of new schemes.

**Table 10.** Male and female head of households' perception of farm income, 2014 to 2017 (percentage of respondents).

| | Income change | | | |
|---|---|---|---|---|
| Head of household | Worse | Same | Better | Much better |
| Male | 0 | 18 | 73 | 9 |
| Female | 22 | 0 | 56 | 22 |

**Table 11.** Farmer participation in and payment for irrigation scheme maintenance (percentage of respondents).

| | |
|---|---|
| Participation in scheme maintenance | 89 |
| Willingness/preparedness to pay for water | 64 |
| Preparedness to pay for petrol for irrigation | 79 |
| Improvement and fairness in water allocation and use | 86 |

## Conclusions

The two interventions of soil moisture and nutrient monitoring tools and AIPs have improved farmer's well-being. This improvement was recognized by more than 83% of the farmers, who indicated that their farm income had increased, and 67% reported better food security. The field data supported these results, with average green maize yields increasing from approximately 6 t/ha to 18 t/ha and green maize gross margins and the opportunity cost of labour both increasing almost six-fold.

The AIP process confirmed critical challenges, such as the need for a tractor and the lining of the canals. Although the project did not have the resources to address these challenges, it is believed that the credibility of the AIP process resulted in the government and development agencies addressing these challenges with their own funding. The lining of the canals reduced water losses and made irrigating easier for farmers, while the tractor and truck reduced labour invested and the transaction costs of market produce.

By the end of the project in 2017, 93% of farmers reported that they had changed their irrigation practices, and of these, 86% said they had done so due to the tools. Since only 47% of the farmers had the tools, significant farmer-to-farmer learning must have taken place and contributed considerably to the observed results. The changes undertaken by farmers were to reduce the number and duration of irrigation events, by 85% and 53%, respectively.

The availability and range of input markets, and information sources and quality also increased substantially. This can be attributed to the AIP process, which facilitated connections between the farmers and input suppliers and crop buyers. This has saved time for the farmers, reduced the number of trips required to buy inputs, and made crop sales easier and more profitable, for example, by the farmers agreeing on a base price. This then allowed them to invest more money and time in their agricultural production.

The time saved in reduced irrigation has increased both farm and off-farm income, as well as farmers' ability to pay and willingness to participate in scheme maintenance. This is crucial for scheme sustainability, as well as to safeguard the food security and livelihoods of the farmers and their families. The current data suggest that women and men have had equal access to the benefits of this project's interventions, but further investigation is required.

The project provides significant insight and lessons for governments considering investing in new small-scale irrigation schemes or rejuvenating existing ones. Most importantly, it is critical to combine investment in hardware and technology with the introduction of multi-stakeholder processes to identify and resolve barriers to farmers' increasing yields and converting those higher yields to higher profitability. Once farmers see that the system delivers adequate water equitably and in a timely manner and that they are profitable, their willingness to participate in collective actions such as scheme maintenance and collective bargaining increases. With this collective action by farmers, schemes are more likely to be self-supporting and so require less aid from governments and overseas donors.

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