Strengthening water and nutrient management in smallholder irrigation schemes in the Ramotswa Transboundary Aquifer Area, Limpopo River Basin

Rural agricultural development has great potential to alleviate poverty, reduce food insecurity, and improve rural livelihoods and climate resilience in Africa. Despite the small area under irrigation, the value of irrigated agriculture in sub-Saharan Africa comprises about 25% of total agricultural output (Annandale et al. 2011; Stirzaker et al. 2017). Due to the significant amount of water used in agriculture, irrigation water should be applied efficiently, particularly in arid areas. In regions experiencing water scarcity and variable water availability, such as the Ramotswa Transboundary Aquifer Area (RTBAA), shared by Botswana and South Africa, conventional methods of irrigation scheduling – based on intuition or experience – may no longer be adequate. It is critical to stretch limited water resources in order to maximize the benefits derived from them. This objective can be supported by the use of soil-moisture and nutrient management tools (IWMI 2018).

Transplanting of vegetable seedlings and installation of soil-moisture and nutrient management tools in Motlhaka irrigation scheme, South Africa.

Photo: Manuel Magombeyi/IWMI
Key messages

- **Significant irrigation water and nutrient savings under smallholder vegetable farming.** In RTBAA, Wetting Front Detectors (WFDs) and Chameleon sensors (soil-moisture sensors) were installed in three irrigation schemes to test their potential for enhancing farmers’ decision-making related to the timing and frequency of field water application for agricultural production. Significant water savings, nutrient loss reduction, and improved yield and gross irrigation water productivity were achieved in plots using WFDs and Chameleon sensors, in comparison to plots where management tools were not used.

- **Significant savings in energy used for irrigation.** Water savings resulted in reduced energy expenses for groundwater pumping, labor costs for irrigation, weeding and chemical spraying. Pumping costs, in particular, reduced noticeably.

- **Potential use of management tools in smallholder agroecological contexts.** This work demonstrated the potential for using WFDs and Chameleon sensors in smallholder irrigation schemes. The use of such management tools can increase productivity and profitability through improved management of soil-moisture and nutrients. This results in increased income and food security. This study assessed the applicability of the tools in diverse environmental conditions and for various irrigation water sources.

Methods: Assessing water- and nutrient-saving tools in smallholder irrigation farms

Three irrigation schemes were selected as part of the RAMOTSWA 2 project (IWMI 2018): Motlhaka in South Africa, and Mogobane and Glen Valley in Botswana (Figure 1). Motlhaka irrigation scheme uses a furrow irrigation system, while Mogobane and Glen Valley use drip irrigation. Groundwater is used in the Motlhaka and Mogobane irrigation schemes, while Glen Valley uses treated effluent water. Eight experimental and control field plots of areas ranging from 0.2 hectares to 0.5 hectares were selected in the irrigation schemes, with soil textures of sandy loam, sandy clay loam and clay loam. Twenty-three farmers (9 men and 14 women) participated. Experimental (using the management tools) versus control field plots (not using the tools) were compared to assess the impact of using soil-moisture and nutrient management tools (explained in Box 1) over the crop growing period from March to September 2018. The crops assessed included beetroot, tomato, carrot and cabbage, and the results are presented for these lumped crops. Figure 2 shows the management tools (WFDs and Chameleon sensors) installed in a beetroot crop in Mogobane irrigation scheme.

Key findings

- **Farmer training is key.** Training was important to enable farmers to take readings and maintain the management tools. Farmers were trained in the installation and use of WFDs and Chameleon sensors, including connecting the sensor reader to Wi-Fi. This enabled them to upload data collected from the sensor reader to a website – Virtual Irrigation Academy (VIA) (https://via.farm/) – for sharing with the researchers and other interested stakeholders using similar management tools.
FIGURE 1. Locations of the irrigation schemes: Motlhaka (South Africa), and Mogobane and Glen Valley (Botswana) (source: Luxon Nhano, IWMI).

FIGURE 2. Wetting Front Detector and soil-moisture (Chameleon) sensor installed in a beetroot crop in Mogobane irrigation scheme, Botswana (photo: Manuel Magombeyi, IWMI).
The Chameleon sensors and WFDs are used to monitor the soil-moisture status in the crop root zone. The chameleon sensor consists of three sensors that are typically installed at 0.2, 0.4 and 0.6-m depths in the field. The range in soil-moisture is displayed by different colors, similar to those of a traffic light (blue – wet soil, green – moist soil, and red – dry soil). The colors are used to display the soil-moisture level in the crop root zone to indicate when to irrigate or stop irrigation. The funnel-shaped WFD, which can be installed at 0.3-m depth, is used to monitor the movement of soil-moisture after an irrigation event and capture drainage water in the soil profile. When the funnel has collected sufficient drainage water, the indicator (a thin red plastic cap on the top end of the WFD [see Figure 3]) pops out. The drainage water is extracted and used to assess nitrate and salt content in the root zone. The nitrate content is measured by the use of nitrate strips (Figure 3[a]) that are immersed into the drainage water; the color of the strips changes from white to deep purple depending on the nitrate content of the drainage water. If the WFD (Figure 3[b]) is installed at the bottom of the root zone, the nitrate content in the drainage water indicates a loss to the crops. Similarly, the salt level in the drainage water (not reported in this brief) is assessed by an electrical conductivity (EC) meter (Figure 3[c]), which also displays different colors according to the level of salinity. The Chameleon sensor reader is equipped to read, store and upload data on soil-moisture and temperature. The approximate investment cost of this package of tools is about USD 215.00, with little running cost, provided the tools are not disturbed during watering, weeding and land preparation. These management tools were developed by Dr. Richard Stirzaker at the Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia, and were manufactured by Rural Integrated Engineering (Pty) Limited in Pretoria, South Africa.

**BOX 1 How the management tools work.**

In the study area, acquiring good quality soil-moisture data required collection every second day, especially under hot weather conditions. Observed data trends were shared with the farmers to assess inefficiencies in soil-moisture and nutrient management. Following discussion, corrective measures were identified and implemented by the farmers immediately or in the following crop season. Increasingly, the farmers did their own data interpretation and decision making on soil-moisture and nutrient management.

- **Soil-moisture management tools worked successfully in RTBAA.** Use of the management tools led to improvements in irrigation water productivity and yields in smallholder irrigation schemes using relatively simple technology. This was achieved by...
avoiding over-irrigation, and the associated adverse environmental impacts of soil erosion and nutrient leaching beyond the root zone into surface water or groundwater resources. Overall, energy, water and labor savings were 33%, 40% and 14%, respectively, for drip and furrow irrigation systems. The tools were suitable and complementary to the existing practices and capacities of the farmers. Regarding maintenance, as long as minimum disturbance occurs during soil preparation, weeding or watering, the farmers can easily maintain the management tools and acquire spare parts or support from local tool manufacturers. As illustrated in Box 2, smallholder farmers were able to utilize and interpret the management tools. They changed their practices when exposed to simple tools that resonate with their objectives of increasing productivity, and reducing input costs and the overall risk of production failure.

- **Significant savings in water and energy use.** There is less water use per hectare in experimental plots compared to control plots (Figure 5) due to reduced frequency of irrigation in experimental plots. On average, water savings of 40% were realized from the experimental plots.

- **Reduced nutrient loss beyond the root zone.** Higher nutrient savings were realized on drip irrigation compared to furrow irrigation systems due to traditional over-irrigation (irrigating 3-4 times per week). Fertilizer was applied in solid form on the soil surface under the furrow system, and fertilizer mixed with irrigation water was applied under the drip system. There was a huge reduction in nutrient loss of 62% at 0.3-m depth below the ground surface when comparing the control and experimental plots (Figure 6). This reduced nutrient loss ensures that the crop has access to more

**BOX 2** Experiential learning by a young farmer in Motlhaka irrigation scheme.

A young farmer in Motlhaka irrigation scheme stated, “We planted butternut in one of our plots. One day, when the plant was flowering, we irrigated half of the plot during the day and left the other half irrigating overnight.” Following the training and use of the management tools on his plots, the farmer stated, “Now I realize why half of the butternut plot had stunted growth while the other half produced healthy butternuts. It is because the uncontrolled overnight irrigation washed away all the existing nutrients and applied fertilizer, and this resulted in poor yield compared to the other side of the plot, which did not receive excessive irrigation water.”

This experiential learning enhanced the farmers’ knowledge on the need to balance irrigation water and nutrient application for efficient water and nutrient management to improve crop yields and water productivity (Figure 4).

**FIGURE 4.** (a) Furrow irrigation, and (b) a young farmer using the water- and nutrient-saving tools in a cabbage crop in Motlhaka irrigation scheme, South Africa (photos: Manuel Magombeyi, IWMI).
of the nutrients for increased crop health and yield. Over-irrigation in control plots resulted in high nutrient leaching beyond the root zone that could cause nitrate pollution of groundwater. Hence, using the management tools, nutrient losses can be reduced, and consequently input and cost of fertilizers reduced, while retaining the correct nutrient status of the soil.

- **Major improvement in irrigation water productivity.** Through the use of the management tools, smallholder irrigation farmers realized an overall improved irrigation water productivity of 70%, from 17 to 29 kg/m³ (Figure 7). The increase in irrigation water productivity was greater for the furrow irrigation system (threefold) and lower for drip irrigation (by half). This increase was due to the rise in crop production per unit volume of water used for irrigation. Irrigation frequencies were reduced to once or twice a week, in comparison to two to four times a week under traditional farmer practices. These reductions in irrigation frequencies were similar to evidence obtained from South Africa, Mozambique, Tanzania and Zimbabwe (Maeko 2003; Adimassu et al. 2016; Stirzaker et al. 2017), where Chameleon sensors and WFDs were used in a cereal crop (maize).

- **Improved crop yield through the use of management tools.** Vegetable yields (crop produced per hectare) improved by 35% with the use of management tools (Figure 8). Increased crop yield resulted in improved returns for the farmers, which can be used for irrigation infrastructure investments. Also, importantly, the economic justification for adapting the management tools in terms of significant yield improvements facilitates increased food production in the future in response to rising food demand. In this study, we used simple soil-moisture and nutrient data for irrigation management to provide basic information to assist farmers in deciding on when to irrigate and fertilize.

- **There is substantial unrealized potential for use of the management tools.** The relevance of the tools across many areas in the world, and the relatively low cost of purchasing and maintaining the management tools – combined with demonstrated benefits elaborated above – present an incentive for the broader scale adoption of this technology by low-income farmers, provided they receive initial training. While some uptake is evidenced from other parts of Africa, there is likely greater potential for out-scaling the use of these management tools.
Conclusions

Benefits of knowledge sharing and mutual learning. Co-learning between researchers and farmers was essential in the effective use of the management tools. They learned from each other through interactions, and farmers were motivated to adapt their irrigation scheduling based on the soil-moisture data observed from the management tools. Appropriate scheduling minimized field irrigation water losses by reducing surface runoff and drainage, and evaporation from the root zone. It also reduced potential nutrient leaching to the subsoil and groundwater, and maximized crop production. Importantly, farmers had an economic incentive for adopting the management tools as it led to reduced input costs (labor, water, fertilizer, energy), and increased crop income. Simple information on soil-water-nutrient status obtained from sensors and detectors, when combined with farmers’ own experience and intuition, provided farmers with further insights on areas where water and nutrient management could be improved. Further, feedback from farmers provided evidence of sustainable behavior change – through the use of the management tools, farmers had internalized the change (in practice) required for continued benefit.

Recommendations

- Expand the use of soil-moisture and nutrient management tools in RTBAA and beyond. In the RTBAA, the use of such tools for smallholder farmers can be advanced through collaboration with the local departments of agriculture, agricultural input suppliers and nongovernmental organizations supporting agriculture. Outside the RTBAA, it may be worthwhile to undertake a mapping exercise to find areas with similar conditions to RTBAA for possible regional out-scaling of the management tools.
- Undertake research on other irrigation systems, such as sprinkler irrigation, and other crops, especially cereal crops. There is a need to assess the performance of the management tools under different environmental, climatic and agronomic conditions. Further, there is a need to compare: (i) the costs and benefits of applying the management tools to furrow irrigation systems, with a future aim of switching to drip irrigation; and (ii) converting furrow systems to drip systems and then applying the management tools. Impacts on groundwater and energy saving should also be further investigated.
References


Project

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