International Water Management Institute

Project Brief
Transboundary Water Management in Southern Africa

Agricultural water and nutrient management solutions to support smallholder irrigation schemes: Lessons from 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 semi-arid areas. In regions experiencing water scarcity and variable water availability, such as the Ramotswa Transboundary Aquifer Area (RTBAA) (Figure 1) shared by Botswana and South Africa, and with an average annual rainfall of about 450 mm, 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).

A farmer taking readings from a Chameleon sensor and uploading the data using a cellphone in Glen Valley irrigation scheme, Botswana (*photo*: Manuel Magombeyi/IWMI).

Key messages

- **Significant irrigation water and nutrient savings under smallholder vegetable farming.** In RTBAA, Wetting Front Detectors (WFDs) and Chameleon (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 by about 40%, nutrient loss reduction by about 80%, and improved crop yield by about 35% and irrigation water productivity by about 162% 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 by about 30%, and labor costs for irrigation, weeding and chemical spraying by nearly 15%. 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 management supporting tools

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 method, 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 water and nutrient innovation and farmer practice managed 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. Water and nutrient innovation practice (using the management tools) versus farmer practice managed fields (not using the tools) were compared to assess the impact of farmers using soil-moisture and nutrient management tools (explained in Box 1) on water use, nutrient losses and water productivity in the cropping season from March to September 2018 (dry season in RTBAA). In practice, one crop per plot per cropping season is grown. The crops assessed included beetroot, tomato and cabbage, and the aggregated results for these crops are presented. Figure 2 shows the management tools (WFDs and Chameleon sensors) installed in a field with beetroot in Mogobane irrigation scheme.

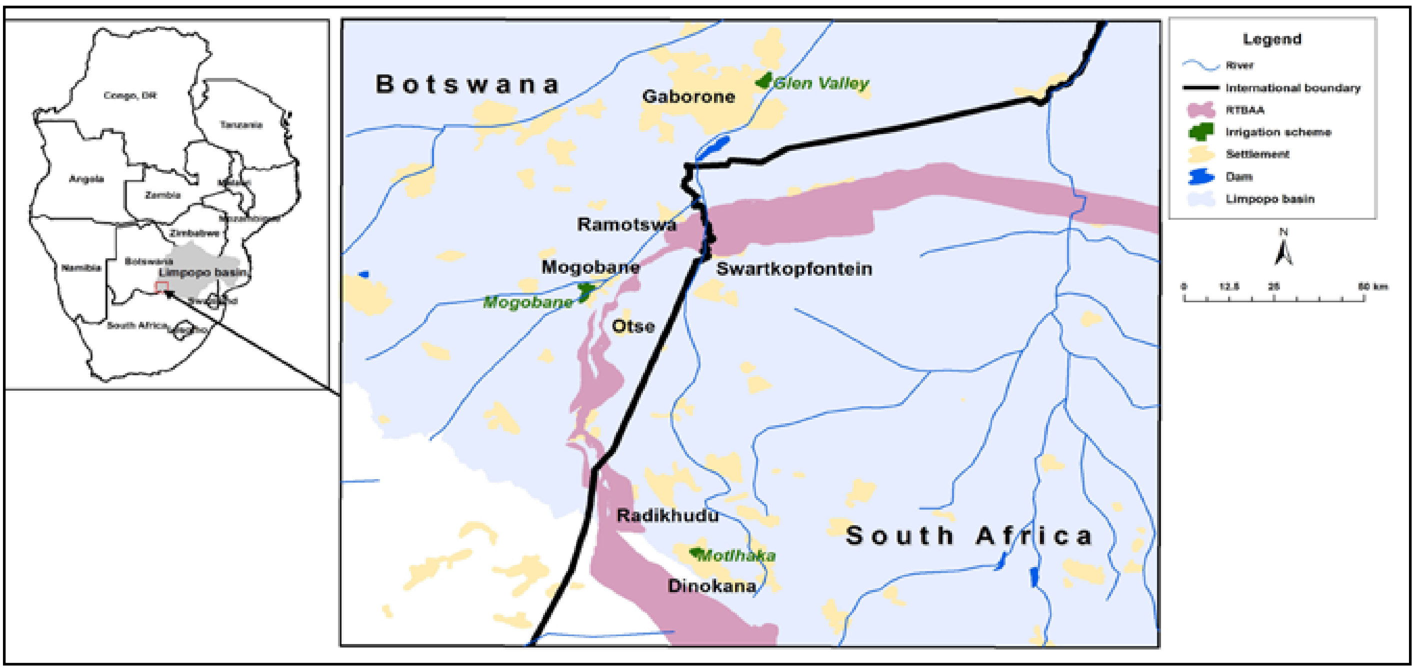

Figure 1. Location of the irrigation schemes: Motlhaka (South Africa), and Mogobane and Glen Valley (Botswana) within the Ramotswa Transboundary Aquifer Area (RTBAA) in the upper part of the Limpopo River Basin.

Source: Luxon Nhamo/IWMI.

Figure 2. Wetting Front Detector and soil-moisture (Chameleon) sensor installed in a field with beetroot in Mogobane irrigation scheme, Botswana (*photo*: Manuel Magombeyi/IWMI).

Box 1. How the management tools work.

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 installed at three depths in the field based on irrigation method and crop type (Figure 3[a]). In this case study, they were installed at 0.2, 0.4 and 0.6 m depths. The soil-moisture status 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 support farmer decision-making on when to start or stop irrigation and whether the field is sufficiently irrigated or under- or over-irrigated. The funnel-shaped WFD, which is used to monitor the movement of soil water after an irrigation event and capture drainage water in the soil profile, can be installed at any depth depending on crop type and root depth. In this case study, the WFD was installed at 0.3 m depth. When the funnel has collected sufficient drainage water, the indicator (a thin red plastic cap on the top end of the WFD [Figure 3{b}]) pops out. The drainage water is extracted by a syringe through a small tube connected to the bottom of the WFD 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 from the root zone. 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 to the Virtual Irrigation Academy (VIA) platform for sharing. The approximate investment cost of this package of tools is about USD 215, with little running cost for up to 5 years, provided the tools are not disturbed during watering, weeding and land preparation. These management tools were developed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia (Stirzaker et al. 2017), and manufactured by Rural Integrated Engineering (Pty) Limited in Pretoria, South Africa.

Figure 3. (a) Nitrate strips (left), Chameleon soil-water sensors (center), and sensor reader (right); (b) WFD to capture drainage water for monitoring of nitrate and EC; and (c) syringe (left), nitrate strips (center), and EC meter (right) for sampling the water collected in the WFD (*photos:* Manuel Magombeyi/IWMI).

Findings and lessons from the field

Soil-water 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 both drip and furrow irrigation. 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.

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 (Figure 4a). 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 a lot of nutrients from the 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 (Figures 5-8).

Figure 4. (a) Furrow irrigation, and (b) a young farmer using the water and nutrient management supporting tools in a field with cabbage in Motlhaka irrigation scheme, South Africa (*photos:* Manuel Magombeyi/IWMI).

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 the Wi-Fi. This enabled them to upload data collected from the sensor reader to the VIA website for sharing with the researchers and other interested stakeholders using similar management tools. 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. Increasingly, the farmers did their own data interpretation and decision-making on soil-moisture and nutrient management throughout the growing season, as they became more efficient in interpreting the data from the tools.

Significant savings in water and energy use. There is less water use per hectare in water and nutrient innovation practice plots compared to farmer practice plots (Figure 5) due to reduced frequency of irrigation in innovation plots. On average, water and energy savings of about 40% and 30%, respectively, were realized from the fields using the innovative practices.

Reduced nutrient loss below the root zone. Higher absolute nutrient savings were realized in fields under furrow irrigation compared to those under drip irrigation (Figure 6) due to traditional intensive irrigation in furrow irrigation (irrigating three to four times per week). Fertilizer was applied in inorganic or manure form, in total amounts of 18-105 kg N/ha, applied in solid form (44 kg N/ha) on the soil surface under furrow irrigation and as fertigation (18 or 105 kg N/ha) under drip irrigation. There was a significant reduction in average nutrient (nitrate) loss of 77% (from 16.3 to 3.7 kg NO_3/ha) under furrow irrigation and 78% (from 4.4 to 1.0 kg NO_3/ha) under drip irrigation at 0.3 m depth below the ground surface when comparing the farmer practice and water and nutrient innovation practice plots for cabbage (Figure 6). This reduced nutrient loss ensures that the crop has access to more of the nutrients applied for increased crop health and yield. Over-irrigation in farmer practice managed plots (especially furrow-irrigated plots) resulted in significant nutrient leaching beyond the root zone that could cause reduced yields and nitrate pollution of surface water and groundwater. Caution must be exercised in developing N-fertilizer recommendations that ensure applications of three to four small N-fertilizer doses during crop growth to limit the potential for nitrate leaching and groundwater contamination. Hence, by using the management tools, nutrient losses and, consequently, input and cost of fertilizers can be reduced, while retaining the correct nutrient status of the soil and achieving good yields.

Major improvement in irrigation water productivity. Through the use of the management tools, smallholder irrigation farmers realized an overall improved fresh yield irrigation water productivity of about 290% and 33% for furrow and drip irrigation, respectively (Figure 7). The increase in irrigation water productivity was greater for furrow irrigation (threefold) and lower for drip irrigation (by half). This increase was due to the greater increase in crop production per unit volume of water used for furrow irrigation. Irrigation frequencies were reduced to once or twice a week, in comparison to two to four times a week under traditional farmer practice. 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 by about 50% for the farmers, which can help improve farmer livelihoods and support further irrigation infrastructure investments. Also, importantly, the gain in yields facilitates increased food production in the future responding to rising food demand. In this study, farmers used simple soil moisture and nutrient data for field management, including deciding on when to irrigate and fertilize.

There is substantial unrealized potential for farmer learning from the use of management tools in semi-arid areas. The relevance of the tools across many areas in the world in terms of addressing water scarcity in poor farming communities, 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 great potential for out-scaling the use of these management tools.

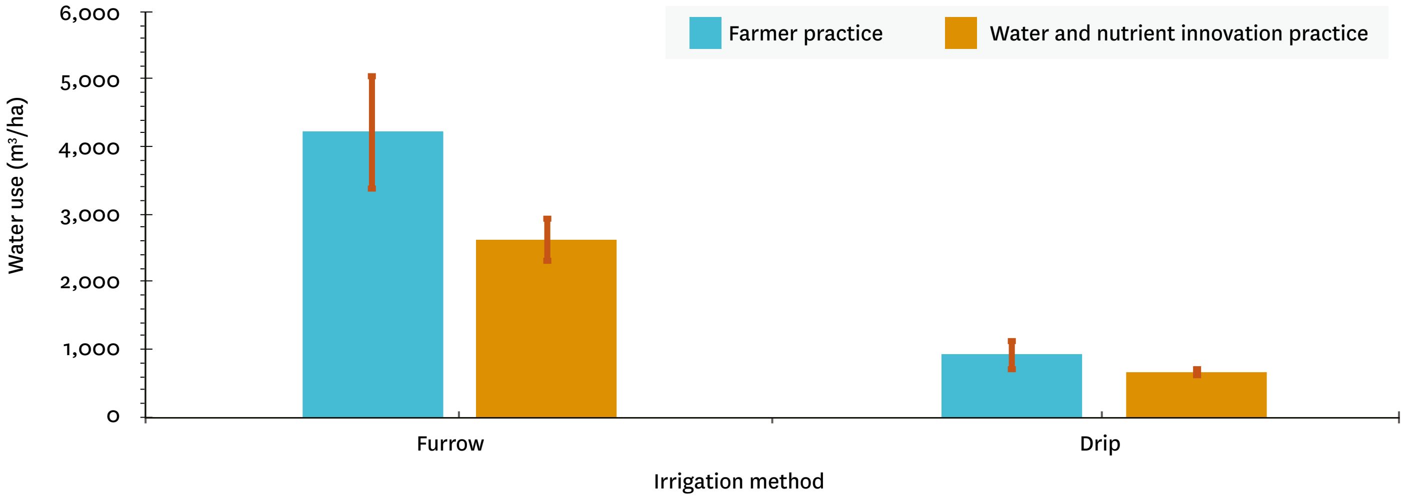

Figure 5. Mean water use per cropping season in farmer practice and water and nutrient innovation practice plots for drip and furrow irrigation methods for various vegetable crops. The error bars show the standard deviation (n=6 for each irrigation method).

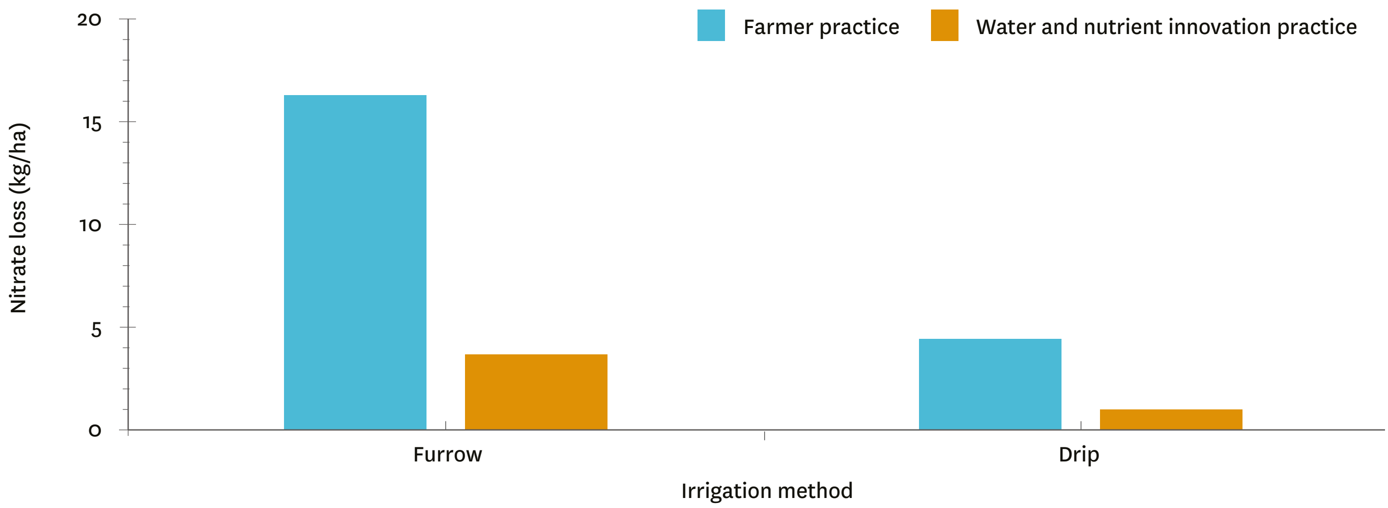

Figure 6. Average nitrate loss per crop from fields grown with cabbage from the time of planting to harvesting in farmer practice and water and nutrient innovation practice plots for furrow and drip irrigation. No error bars are shown because of fewer data points (n=2 for furrow and n=1 for drip).

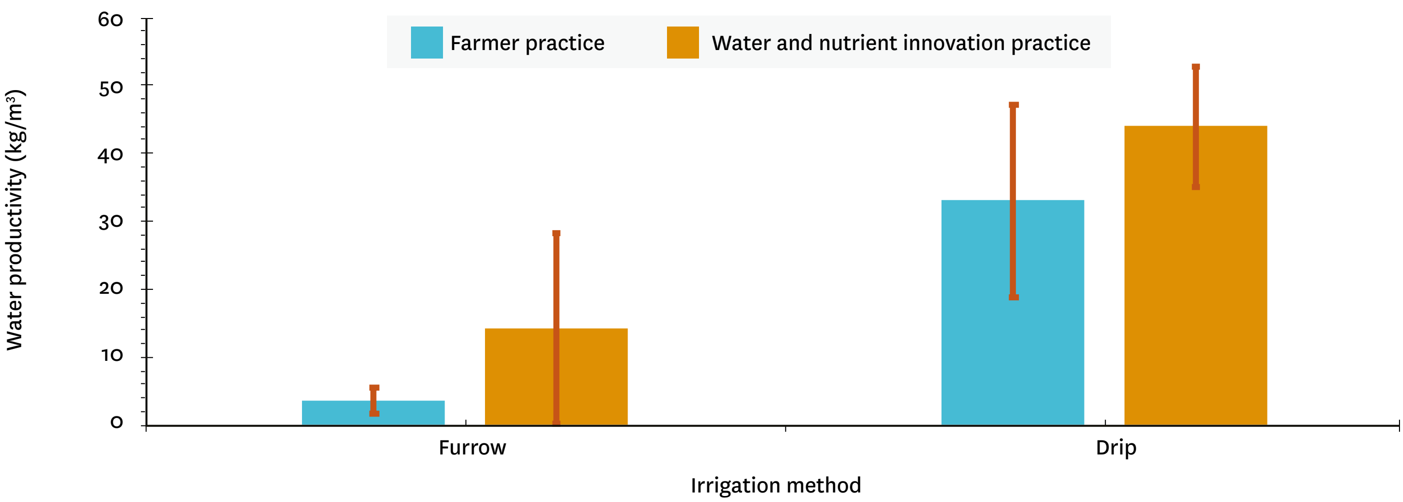

Figure 7. Overall irrigation water productivity in farmer practice and water and nutrient innovation practice plots for drip and furrow irrigation methods. The error bars show the standard deviation (n=6 for each irrigation method).

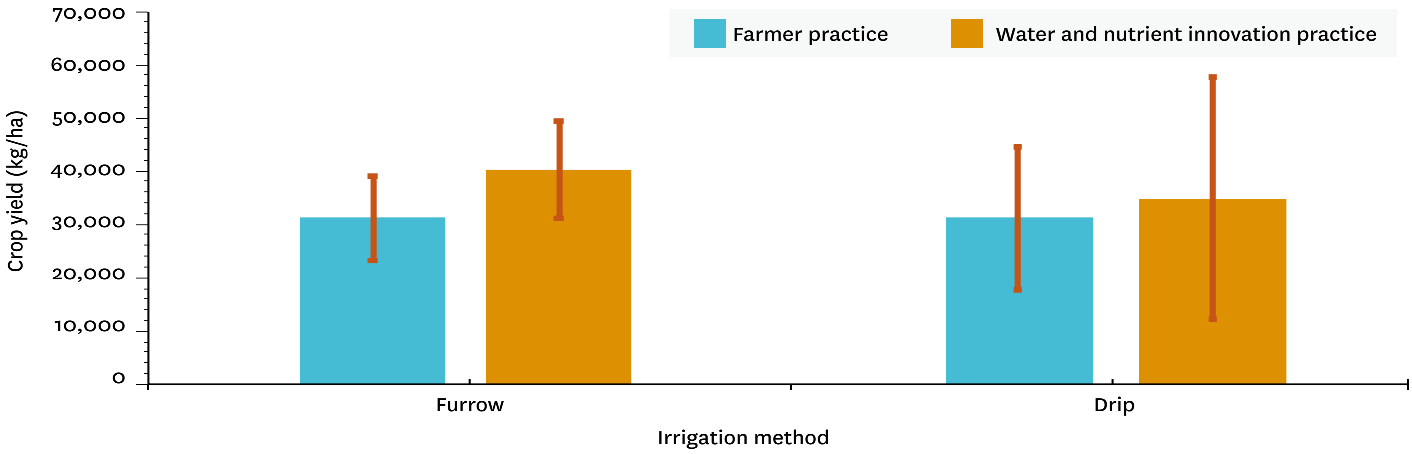

Figure 8. Overall crop yields per hectare for farmer practice and water and nutrient innovation practice plots. The error bars show the standard deviation (n=6 for each irrigation method).

Conclusions

Benefits of knowledge sharing and mutual learning. Co-learning between researchers and farmers was essential in the effective implementation 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 incomes. 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 into how water and nutrient management could be improved. Further, feedback from farmers provided evidence of sustainable behavior change. Through the practical use of the management tools, farmers had internalized the changes required for continued benefit. Women specifically benefited from reduced field labor demand and cost of fertilizer, and knowledge of crop water and nutrient interaction in crop growth. There was evidence of additional demand, as farmers who were not part of the project expressed interest to adopt the tools to improve their crop yields and incomes.

Recommendations

Expand the use and learning from 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 farmer learning and uptake of the tools under other farming and irrigation methods, 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. In addition, there is a need to further assess the relative costs and benefits of furrow and drip irrigation methods, including in other environmental and cropping contexts. Finally, there is a need to involve even more women to learn from the use of the tools. Impacts on groundwater and energy saving should also be further investigated.

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Project

This work was undertaken in the context of the *Potential Role of the Transboundary Ramotswa Aquifer 2* project that cuts across the countries of Botswana and South Africa and was funded by the United States Agency for International Development (USAID) under the terms of Award No. AID-674-IO-17-00003, and the CGIAR Research Program on Water, Land and Ecosystems (WLE). Additional support to develop this brief was provided by the USAID-funded project entitled *Conjunctive Water Management across Borders in SADC: Generating Principles through Fit-for-purpose Practice*. Both projects were led by the International Water Management Institute (IWMI).

For more information, visit http://conjunctivecooperation.iwmi.org/systems/ramotswa-ngotwane-system/

Acknowledgements

This brief was made possible by the support of the American people through the United States Agency for International Development (USAID). Its contents are the sole responsibility of the International Water Management Institute (IWMI), and do not necessarily reflect the views of USAID or the United States government. The authors would like to thank the Departments of Water and Sanitation (DWS) in Botswana and South Africa, Botswana Geoscience Institute (BGI), Water Utilities Corporation (WUC) of Botswana, and all the farmers from the Glen Valley, Mogobane and Motlhaka irrigation schemes for their willingness to assess the performance of the management supporting tools, and for providing data on irrigation and nutrient practices, and crop yields.

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Published: August 2021