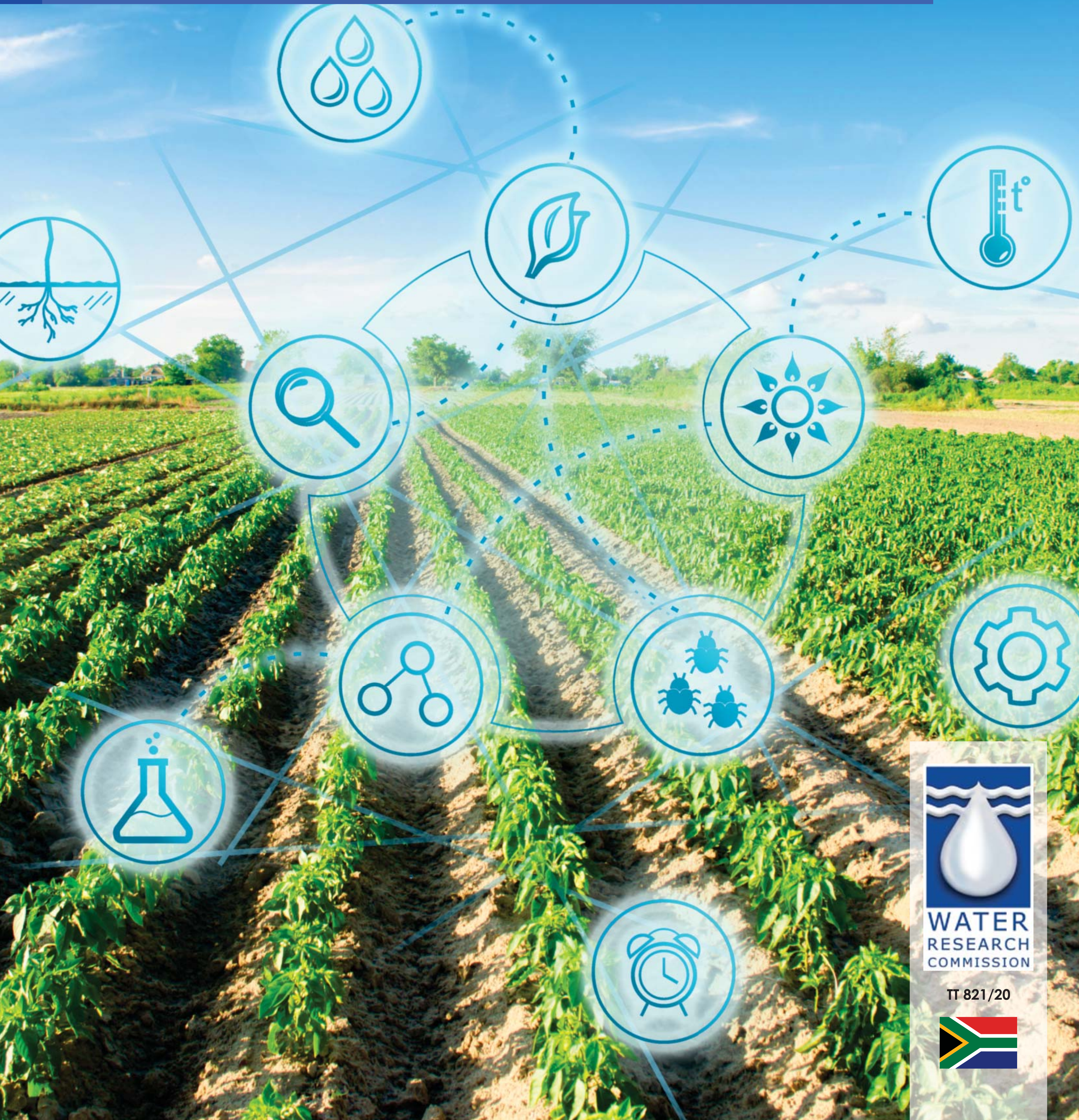
IMPROVING ON-FARM IRRIGATION WATER AND SOLUTE MANAGEMENT USING SIMPLE TOOLS AND ADAPTIVE LEARNING

JOE STEVENS, ANDREW SANEWE, MARTIN STEYN, JOHN ANNANDALE AND RICHARD STIRZAKER



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Improving On-Farm Irrigation Water and Solute Management using Simple Tools and Adaptive Learning

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Report to the

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Executive summary

South Africa is water scarce and it is facing increasing shortages in parts of the country as a result of climate change. Demand for water is also increasing as different sectors of the economy compete for reliable water supplies. Agriculture is the single biggest user of fresh water withdrawals in South Africa, accounting for 60% of existing water use. As the demand for water grows, the competition for water currently used for agricultural production will continue to increase in future. This report outlines the water situation in the country and the national plan to increase the area under irrigation. Improving agricultural land and water productivity is essential to solutions for sustainable water management and agriculture development. Achieving high irrigation water use efficiency and profitability in irrigated agriculture is to a large degree determined by the efficiency of irrigation water management. However, irrigation scheduling generally has left a lot to be desired, despite the fact that very useful research in this regard has been done in the country.

This project followed a different approach to the traditional methods of research that have been conducted in irrigation water management. It attempted to include the users of the knowledge (farmers) in its generation and address real-world problems by using a combination of disciplines. It tried to encourage dialogue between academic research and the applicants of the knowledge, the farmers. The aims of this project were to:

- Deploy farmer-friendly monitoring tools that measure soil water, nutrients and salt.
- Develop a system of quick data sharing through on-line visualization of data from the monitoring tools linked to a virtual discussion, learning and teaching space with skilled facilitators.
- Further refine simple monitoring tools to address on-farm farmer experiences.
- Determine how this combination promotes learning that improves irrigated farm productivity.

The project successfully achieved these objectives. It introduced simple low-cost tools (the Chameleon sensor and reader together with the Wetting Front Detector) that can be used by any farmer to improve crop yields through better management of irrigation water, soil nutrients and salt. These tools do not require expert knowledge to understand and interpret measurement data. The Chameleon soil water monitoring tool is an irrigation scheduling device which simplifies water measurement and the data is displayed as coloured lights on a reader. The Wetting Front Detector tells you how deep water moves into the soil during and shortly after irrigation and it also captures a soil water solution sample which can be extracted.

The Virtual Irrigation Academy (VIA) combines these irrigation monitoring tools with an on-line communication and learning system (https://via.farm/). Major improvements were made to the monitoring tools and the VIA platform during the course of the project with input from researchers, project team members and other users not only in South Africa but other countries which are part of the VIA community. The report briefly discusses the use of the Soil Water Balance (SWB) model to simulate Chameleon and Wetting Front Detector (WFD) patterns that have been visualized on the VIA platform.

The soil water monitoring tools have been designed to fit the way farmers think and to give a visual colour display that they can relate to and act on. Each time a Chameleon reader is monitored and the data is uploaded to the VIA platform a pattern of the change in the soil water status is generated. Each crop that is grown and monitored provides a unique colour pattern of water, nitrate and salt from which a farmer can learn. Farmers gain experience by observing crop growth during periods of supplying more or less than average water.

Chameleon sensors were installed in emerging commercial farmers' fields growing barley, sugarcane and citrus in different provinces. They were also installed in commercial potato, pecan and macadamia farms. The project investigated the link between the soil water patterns generated by the Chameleon during crop growth and the final yield. A major problem at most of the project sites was the poor collection and uploading of data to the VIA platform. Often development officers and others tasked with collecting data were occupied with other responsibilities. The model implemented in this project of primarily using development or extension officers to collect data did not achieve the desired outcomes. A better approach in future is to give field readers to the farmers so that they can monitor the tools regularly. Development officers can then upload the data once or twice a month when they visit the farmers.

The findings from the research showed that there were instances in barley, sugarcane and citrus crops, where there was a link between soil water patterns and yield and in other cases there did not appear to be a direct relationship. A number of crop management factors influence the production of yield, one of which is water. The report recommends that further research is needed to explain some of the results that were observed. Further work also needs to be done on Chameleon responses in potato production. The report highlights the fact that the purpose of this research was not to prove, through an experimental trial, that the use of the irrigation monitoring tools would definitively increase crop productivity. Instead, the aim was, among other things, to introduce user-friendly tools to farmers and see whether the tools identified obvious problems, such as fields that were too dry, nitrate deficient or saline and whether farmers could understand the information, learn from it and subsequently act on it.

The lessons learnt by farmers and researchers during the course of the project are discussed. Although not all farmers at the project sites used the Chameleon to manage their irrigation, some farmers did benefit from project because it helped them to get a better understanding of the water use of their crops. There were emerging commercial farmers who changed their irrigation practice as a result of using the Chameleon and the VIA platform. There were also commercial farmers, i.e. the macadamia and pecan growers, who found the tools and the VIA platform particularly beneficial and continue to use them. The researchers found that large commercial farms often have a wide selection of scientific irrigation scheduling tools to choose from whereas emerging commercial farmers often do not use any irrigation scheduling tool but follow fixed recipes that are given to them. Some large commercial farms chose scientific scheduling tools because of the many other issues that they have to contend with during crop production. They prefer to follow simple recommendations from a service provider and favour continuous logging devices.

Important observations were made by the researchers during the course of the project which not only relate to the use of the tools and the learning experiences but also the wider issues relating to irrigation water management and the emerging commercial farming sector. The report concludes that large private organisations such as RCL/TSGro, AB InBev/SAB and CGA/CRI, who support emerging commercial famers growing sugarcane, barley and citrus, could play an active role in ensuring that agricultural water is not only used more efficiently at a farm level but also at a scheme level. The responsibility for managing agricultural water use efficiently should not only be the obligation of farmers but also those who have an influence on water use in an entire irrigation scheme. Training of farmers in irrigation water management should receive greater attention.

The report highlights findings that have important implications for the National Development Plan and the land reform process. Several emerging commercial farmers that participated in this project had little knowledge of farming prior to receiving their land and are finding it difficult to farm, let alone run their farms as a business. Some of these farmers are in a difficult financial situation that forces them to look for work in other sectors. Although farmers have access to land, financial services, extension support and established markets through public-private partnerships, they do not own land and therefore do not have the necessary collateral to qualify for financing of farming operations. They also lack the incentives to re-invest their profits, which influences the long term sustainability of these farms.

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The reference group comprised of:

Prof. S Mpandeli	Water Research Commission (Chairman)
Dr GR Backeberg	Water Research Commission
Dr PS van Heerden	PICWAT
Prof. IK Mariga	University of Limpopo
Dr A Singels	South African Sugar Research Institute
Mr J Potgieter	Department of Agriculture, Forestry and Fisheries

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The project team wishes to acknowledge particularly the collaboration and willingness received from farmers and development officers at all the selected sites in South Africa where Chameleon sensors were installed and the VIA being tested. Great learning networks were established!

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List of acronyms and abbreviations

AED	Atmospheric Evaporative Demand
ARC	Agricultural Research Council
BFAP	Bureau for Food and Agricultural Policy
BWS	Bulk Water Supply
CASP	Comprehensive Agriculture Support Programme
CFs	Commercial Farmers
CPA	Community Property Association
CRDS	Comprehensive Rural Development Strategy
DAFF	Department of Agriculture, Forestry and Fisheries
DRDLR	Department Rural Development and Land Reform
DrRSDM	Dr Ruth Segmotsi District Municipality
DWA	Department of Water Affairs
DWS	Department of Water and Sanitation
EC	Electrical Conductivity
ECFs	Emerging Commercial Farmers
ET	Evapotranspiration
FABI	Forestry and Agricultural Biotechnology Institute
FAF	Financial Aid Fund
FAO	Food and Agriculture Organisation
FSU	Farmer Support Unit
GM	Genetic Modified
GTLM	Greater Taung Local Municipality
IBs	Irrigation Boards
KIB	Komati Irrigation Board
KOBW	Komati Basin Water Authority
LDA	Limpopo Department of Agriculture
LIB	Lomati Irrigation Board

NDA	National Department of Agriculture
NDP	National Development Plan
NIEP	Nkomazi Irrigation Expansion Programme
NLM	Nkomazi Local Municipality
NPC	National Planning Commission
PAWC	Profile Available Water Capacity
PDoA	Provincial Department of Agriculture
PLAS	Proactive Land Acquisition Strategy
PPP	Public Private Partnership
PTO	Permission to Occupy
RCL	Rainbow Chicken Ltd
SAB	South African Breweries
SASRI	South African Sugarcane Research Institute
SSG	Small scale Sugarcane Growers
SWB	Soil Water Balance
TSB	Transvaal Suiker Beperk
UAF	Umthombo Agriculture Finance
VIA	Virtual irrigation Academy
WRC	Water Research Commission
WWF	World Wildlife Fund

Part 1: Introduction and refinement of irrigation monitoring tools

Chapter 1: Introduction

1.1 Background

The 2030 vision for South Africa includes better integration of the country's rural areas, achieved through successful land reform, job creation and poverty alleviation (NDP, 2011). According to the National Planning Commission, the driving force behind this will be the expansion of irrigated agriculture, supplemented by dry-land production where feasible (NDP, 2011). The irrigation strategy of South Africa has set a target of an increase of more than 50% of irrigated land in the country (DAFF, 2015). In its recommendations to expand agriculture and create numerous jobs in the sector, the commission recommended, among other things, significant increase in investment in water resources and irrigation infrastructure where the natural resource base permits and improvement in the efficiency of existing irrigation to make more water available. However, the NDP recognizes water scarcity as a binding constraint to national development. Based on current usage trends, South Africa is expected to face a water deficit of 17% by 2030, and this shortage will only be worsened by climate change (WWF-SA, 2017).

South Africa receives summer rain that is poorly distributed, with droughts being common phenomena (Bennie and Hensley, 2001). South Africa has low rainfall and low per capita water availability in comparison to other countries: approximately 500 mm average annual rainfall and 843 m^3 water per capita per annum (WWF-SA, 2017). Rainfall is highly seasonal and variable, with greater variability in the dry interior. Most of the sub-humid to humid areas are non-arable due to steep slopes and/or poor quality soils. Only around 13% of the country is suitable for rain-fed crop production. The water deficit caused by low and erratic rainfall and high evaporative demand limits dryland crop production in most of South Africa. Irrigated agriculture is an attractive alternative under these conditions (Van Averbeke et al., 2011). Van Averbeke et al. (2011) stated that the South African Government has provided substantial support to irrigation development by providing subsidies to state irrigation schemes and irrigation board schemes. They reported that smallholder irrigation represented a considerable public investment, valued at R2 billion (R40 000 ha^{-1}). According to the Department of Agriculture Forestry and Fisheries (DAFF), approximately 1.6 million ha are presently under irrigation in South Africa, amounting to about 1.5% of South Africa's agricultural land (including both cultivated areas and rangeland), or 10% of the cultivated area (DAFF, 2015). A large proportion of irrigated land is in areas that are too dry for rainfed production, and the area is restricted largely by water scarcity. South Africa is approaching physical water scarcity by 2025, and its socioeconomic development has been directly hampered by the recent droughts (WWF-SA, 2017).

Demand for water is increasing; competing sectors of the economy need reliable water supplies. Agriculture is the single biggest user of fresh water withdrawals in South Africa, accounting for 60% of existing water use (DWS, 2015). Most of this water is used for irrigation of crops and for water-intensive grazing of livestock. While agriculture is expected to remain the sector responsible for most of South Africa's total water withdrawals, the most noteworthy increase is expected in the municipal sector. By 2035 the municipal sector will account for roughly 32% of total withdrawals, against 28% in 2017 (ISS, 2018). The rise in municipal consumption is driven by the country's growing and rapidly urbanising population, increasing incomes in the country and growth in the percentage of the population with access to piped water (ISS, 2018). As a result of the growing demand for water in the municipal as well as industrial water-use sectors, the competition for water currently used for agricultural production will continue to increase in future.

The water requirments of different sectors must be met in increased risks of rainfall variability as a result of climate change. Adaptive management practices in agriculture to prevent disasters and reduce crop failures will become increasingly more important. Less rain is predicted in the western half of the country and potentially more intense flood events in the east (WWF-SA, 2016). Improving agricultural land and water productivity is essential to solutions for sustainable water management and agriculture development. Further development of irrigated agriculture production, under increasing water constraints, is impossible without improving the methods of cultivation of agricultural crops, primarily irrigation technology (ISS, 2018). The WWF identified several actions to support water-related goals in South Africa. Among them included, becoming a water-smart economy and a leader in Africa in commercializing low-water technologies for industry and agriculture by adopting smart water technologies in irrigation techniques and water reuse to sustain the agriculture sector (WWF-SA, 2017). The National Development Plan (NDP) states that 'growth in agricultural production in South Africa has always been fueled by technology, and the returns on investment in agricultural research and development have always been high, because South Africa has specialized in adapting technology from all over the world to its circumstances' (NDP, 2011).

Achieving high irrigation water use efficiency and profitability in irrigated agriculture is to a large degree determined by the efficiency of irrigation water management (DAFF, 2015). According to DAFF (2015), irrigation scheduling generally leaves a lot to be desired, despite the fact that a lot of very useful research in this regard has been done in South Africa. There is considerable room for improvement in irrigation water management. The type of research that generated much of the knowledge in agricultural water management in South Africa has followed the conventional form of knowledge production. Problems have been defined in an academic context by scholars in the scientific community and their solutions are also formulated by academics. This research is controlled and takes place within the confines of scientific disciplines, which is often homogenous. The emphasis is often on accountability to peers (other researchers), and the evaluation of quality inside the academic community. As a result, the dissemination of newly produced knowledge and its context of applicability have sometimes not received sufficient attention. There has sometimes been little meaningful interaction between scientists and the recipients and users of the knowledge. This kind of knowledge production is referred to as Mode 1 knowledge production (Auranen, 2005; Coghlan, 2014). Its primary focus is the scientific community while recipients of the knowledge are the users, not the co-producers of the knowledge.

This research project followed the Mode 2 production of knowledge (Gibbons et al., 1994). This is an interactive production of knowledge within the context of application. It is characterized by social accountability where there is responsibility to outcomes and to the participants as well as sensitivity to the process of the research (Gibbons et al., 1994; Nieminen, 2005). It is not simply applied research or development. Mode 2 is joint knowledge production, where, knowledge producers in the field of academic research together with the knowledge produced and used by practitioners allow the two sides to work together (Frost and Osterloh, 2003). It is one of the requirements of Mode 2 that exploitation of knowledge requires participation in its generation (Gibbons et al., 1994). Unlike Mode 1 where the question of knowledge production is judged from the stance of the discipline, Mode 2 draws on a broader range of interests, such as its application, and from the perspective of different stakeholders (Coghlan, 2014). It recognizes that real-world problem-solving requires an integration of different discipline knowledge and skills (Sexton and Shu-Ling, 2009). The traditional users of the knowledge become active agents in the defining and solving of problems (Gibbons et al., 1994).

The aims of this project were to:

- Deploy farmer-friendly monitoring tools that measure soil water, nutrients and salt.

- Develop a system of quick data sharing through on-line visualization of data from the monitoring tools linked to a virtual discussion, learning and teaching space with skilled facilitators.
- Further refine simple monitoring tools to address on-farm farmer experiences.
- Determine how this combination promotes learning that improves irrigated farm productivity.

The project began with an initial report on site selection and detailed work plan, the motivation behind selection of sites was discussed. The selection of sites for the project was made with the following in mind: a) to cater for differences in scale of operation (from smallholder/emerging commercial to commercial scale); b) to cater for gender differences, wherever possible; c) sites with functional irrigation systems and d) irrigation areas/irrigators with current/prior relationship with project team members. Following site selection, key players in the project sites were contacted and invited for an inception meeting in Pretoria which aimed at highlighting project objectives and discussing methodologies for project implementation.

The inception workshop was held on June 28, 2016 at the Forestry and Agricultural Biotechnology Institute (FABI) Boardroom at the University of Pretoria, Hatfield. The workshop was conducted by various project team members. They presented the project overview, the development and application of the simple soil water and solute monitoring tools, thoughts on adaptive learning and the implementation of plans for each site that was selected. The first farmer training workshop was held at Nkomazi irrigation scheme in Mpumalanga on August 15th, 2016 by members of the project team. Several training workshops for farmers and extension officers were held in different provinces throughout the duration of the project.

Initially the project team planned to work at Nkomazi irrigation scheme in Mpumalanga Province with emerging commercial sugarcane growers and with emerging commercial barley farmers in Taung, North West Province. During the course of the project, emerging commercial citrus farmers situated in the Brits and the Mooinooi area of the North West, Limpopo and Eastern Cape Provinces were added. The project also worked with commercial potato growers in Limpopo and Western Cape Provinces. Several collaborators and researchers received the irrigation management tools and installed and tested them in their fields. Some of their experiences in using the tools are captured in this report.

Numerous factors can influence the production of crops including, among others, institutional and organisational arrangements, socio-economic constraints, agronomic constraints and infrastructural and water management constraints. In their 2010 Water Research Commission report on best management practices for smallholder irrigation schemes, Mnkeni et al. (2010) concluded that the main agronomic factors constraining productivity were basic management practices such as weed, water, fertiliser and plant population management, late planting and choice of cultivars. This report highlighted that these basic crop husbandry and irrigation management skills are all within the farmers' abilities to control. This project focused on the effect of one important agronomic factor on crop yield, the management of irrigation water.

The project team experienced several challenges, particularly with regard to collecting and uploading data into the VIA platform which are discussed in the report. Some of these challenges are not unique to this project but are typical of on-farm and (PAR) participatory action research methods. There are parallels between Mode 2 research and action research (Coghlan, 2014). The focus in PAR is on three principal activities; research, education and action. This requires involvement of people in the systematic assessment of specific problems; analysis and learning about the causes and possible solutions by a multi-disciplinary or interdisciplinary team of researchers together with participants; and practically implementing the findings (Selener, 1997). The lessons learnt through this research project are discussed not only with regard to managing irrigation water at a farm level, but also at a scheme and governance (policy) level.

1.2 Irrigation monitoring tools and the VIA platform

Only 18% of irrigation farmers in South Africa make use of objective irrigation scheduling methods, while the rest make use of subjective scheduling methods based on intuition, observation, local knowledge and experience (Stevens, 2006). Differences occur between farmers as well as between farmers and scientists with regard to the concept of "irrigation scheduling." These differences contribute to the communication gap between science and the practice of irrigation scheduling resulting in the unsuccessful communication between farmers and scientists and the ultimate low adoption rate (Stevens, 2006).

The Virtual Irrigation Academy (VIA) system introduces simple low-cost tools (the Chameleon sensor and reader together with the Wetting Front Detector) that can be used by any farmer to improve crop yields through better management of irrigation water, soil nutrients and salt. The tools can be used by back yard gardeners, farmers on smallholder irrigation schemes and commercial farmers growing a wide range of crops. They do not require specialized knowledge to record and interpret measurement data. The Chameleon soil water monitoring tool is an irrigation scheduling device which simplifies water measurement and the data is displayed as coloured lights on a reader. The Wetting Front Detector tells you how deep water moves into the soil during and shortly after irrigation and it also captures a soil water solution sample which can be extracted (Stirzaker, 2003). The Virtual Irrigation Academy (VIA) combines these irrigation monitoring tools with an on-line communication and learning system (https://via.farm/).

The VIA is not prescriptive, it does not tell farmers how much water to apply to their crops. It seeks to move away from the traditional model of technology transfer from scientists through extension to farmers. The VIA is not just about technology transfer of tools. It provides a platform for conversations between different stakeholders in the irrigation sector including, farmers, extensionists, researchers and managers. The VIA is centered on experiential learning, with the tools used to structure learning and stimulate local innovation (Stirzaker et al., 2017). It uses simple tools to facilitate people-centered learning for irrigation. People-centered learning recognizes that farmers with low levels of formal education can have considerable experiential (local) knowledge relevant to their own farms. The VIA approach is cost effective and useful compared to traditional methods of training irrigation water management because it uses a 'virtual academy' and farmers own experiential knowledge. The soil water monitoring tools have been designed to fit the way farmers think and to give a visual colour display that they can relate to and act on (Stirzaker et al., 2017).

1.2.1 Chameleon sensor

The Chameleon soil water monitoring tool helps farmers to see how deep roots are extracting water, how deep irrigation water penetrates and the optimal time and duration of irrigation. The sensors measure soil water suction or tension (what the plant experiences), not soil water content. The Chameleon sensor is comprised of an inner core of highly absorbent material that releases a lot of water in the 10 to 50 kPa suction range. This material effectively amplifies the soil water signal to get high resolution in the part of the soil moisture range most critical for irrigation farmers. This inner core is coated with gypsum to provide buffering of electrical conductivity. The resistance reading is also corrected for changes in soil temperature. The Chameleon consists of an array of three sensors that are installed at different depths in the soil, i.e. 20 cm, 40 cm, 60 cm (Figure 1.1). The sensor array is fitted with an ID chip (and temperature probe to account for soil temperature variability) so that each array can be uniquely identified (Figure 1.1).

The Chameleon sensor is fabricated with an inner core of sensing material surrounded by an outer coating of gypsum. At the heart of the sensor is two gold-plated electrodes that measure the resistance across a special medium in the centre of the sensor. This special medium is packed into the sensor in such a way as to calibrate the sensor as it is built. Gypsum is then cast as an outer casing. The gypsum allows moisture to move through to the sensing material while dissolving a small amount of gypsum into the water, creating a constant electrical conductivity environment, thus buffering the sensor. When salt levels in the soil exceed 4 dS/m the sensor calibration shifts.

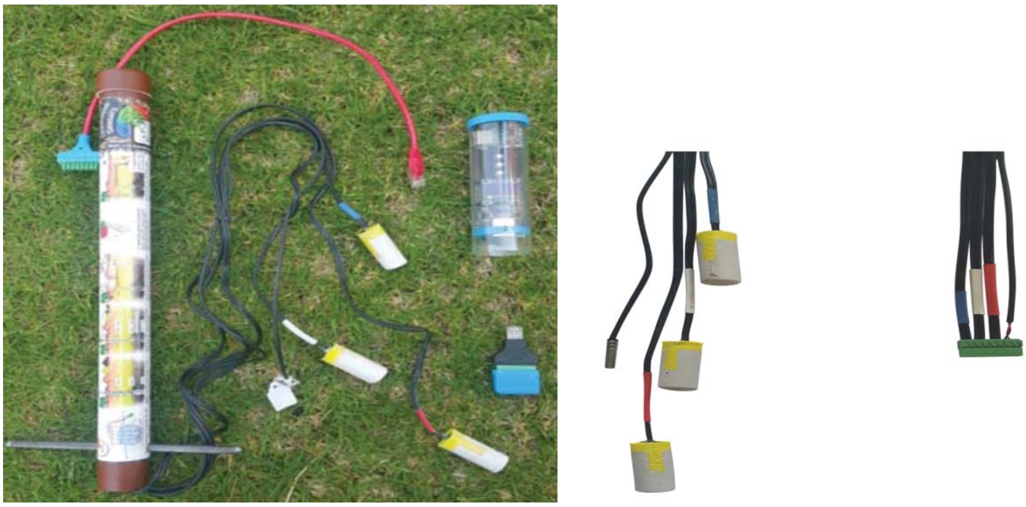

Figure 1. 1: Chameleon soil moisture sensor array (with ID and temperature probe)

Each soil type has a unique relationship between the soil water content (the amount of water in a given volume of soil) and the soil water suction (the water stress experienced by the plant). If soil water content is measured, there is a different 'number' for which farmers must irrigate each soil. If soil water suction is measured with a Chameleon sensor, the blue, green and red colours mean the same from the perspective of the plant stress, regardless of soil type. In other words, soil water suction sensors do not need to be calibrated for soil type.

1.2.2 Chameleon reader

Each sensor array is connected to a hand-held field reader that displays the soil moisture as different coloured lights. At each depth a light represents the soil water status on the Chameleon reader by reading blue (soil is wet), green (soil is moist) or red (soil is dry) (Figure 1.2). The lights give a picture of soil water conditions from the top to the bottom of the root zone. The colours prompt the irrigator to make a decision regarding irrigation scheduling, i.e. an indicator to the farmer whether it is important to irrigate or not. Continuous readings throughout the season give a colour pattern that shows the wetting and drying of the soil, the depth of rooting and how well irrigation or rain replenishes the soil (Stirzaker et al., 2017).

Red: ***Dry but OK at selected depths (>50 kPa)***

Green: ***OK for most crops most of the time (20-50 kPa)***

Blue: ***Wet and nutrients may be leached (<20 kPa)***

Figure 1.2: Chameleon field reader indicating different coloured lights

1.2.3 Wetting Front Detector

The management of water, salt and nitrate are closely linked. The Wetting Front Detector is a funnel-shaped instrument that is buried in the soil (Stirzaker et al., 2005) (Figure 1.3). The funnel concentrates the downward movement of water so that saturation occurs at the base of the funnel. The free (liquid) water produced from the unsaturated soil activates an electronic or mechanical float, alerting the farmer that water has penetrated to the desired depth. The detectors retain a sample of soil water that is used for nutrient and salt monitoring (Stirzaker et al., 2005). The Wetting Front Detector shows irrigators how deep wetting fronts penetrated into the soil and the solutes moving with them. Recently the WFD has been used more for managing nutrients in the soil than for irrigation scheduling. The detector provides information on the electrical conductivity and soil nitrate in the root zone from the water sampled from the wetting front. The use of simple colour test strips for nitrate and portable EC meter means that a water sample can be tested in-field.

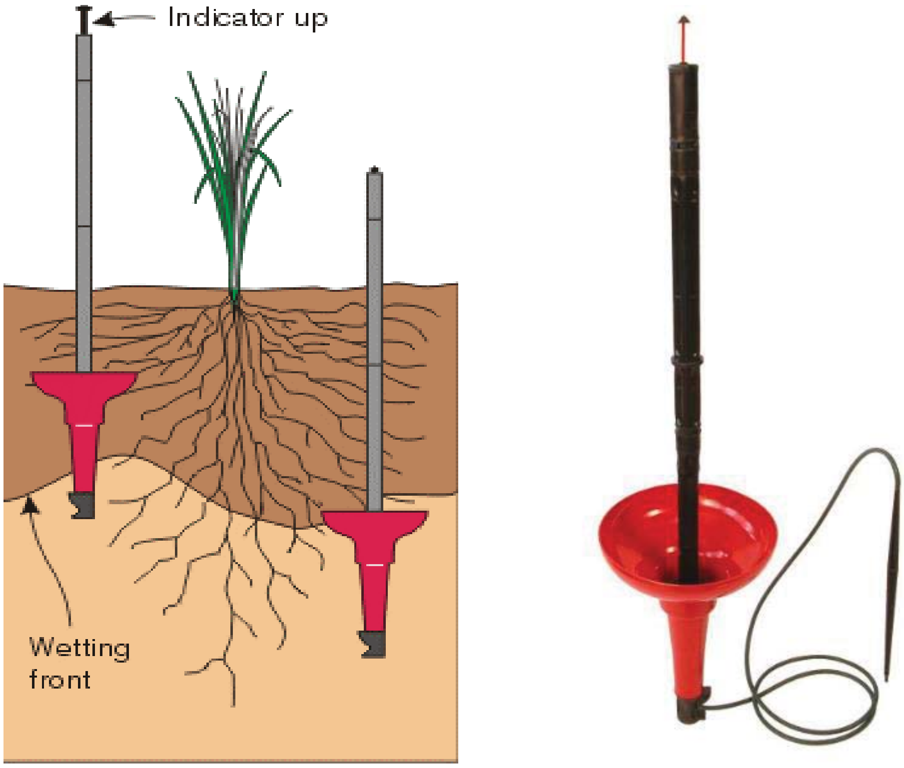

Figure 1.3: Wetting front detector

1.2.4 The Virtual Irrigation Academy platform

The Virtual Irrigation Academy (VIA) combines irrigation monitoring tools with an on-line communication and learning system. The VIA has several roles including:

- Physical data capture from farms and schemes on a daily basis, so that project leaders and agricultural advisors can understand the situation and assist farmers and mentor extension workers;
- Capture of the dialogue between farmers, extension workers and scientists for analysis of how learning occurs;

The VIA is a system that allows users to share data through on-line visualisation using the internet (https://via.farm/) (Figure 1.4). The purpose of Virtual Irrigation Academy website is to provide a place to learn how to improve crop yields through better management of irrigation water, soil nutrients, and salt. Simple tools (i.e. Chameleon soil water sensor and Wetting Front Detector) are used that can assist anyone who is willing to learn by monitoring, observation, and experimentation. Chameleon sensors are buried on farms in different areas throughout the country (and other places in the world) and the data is displayed on the website. Each crop that is grown and monitored provides a unique colour pattern of water, nitrate and salt from which a farmer can learn. Data collected by farmers and/or their advisors can be accessed through the 'our community' icon on the VIA home page https://via.farm/our-community/). Farmers have an option to make their data accessible to the public or for private viewing.

The purpose for developing the simple irrigation monitoring tools was to; a) Give farmers the ability to “see” what the crop is experiencing thereby providing a framework for learning how to improve water use and yield, and b) Use simple tools that build on farmers’ existing knowledge and help with pattern recognition and intuitive decision making. Utilizing visual observations alone to determine crop stress can be unreliable and misleading. For example, if wilting is used as an indicator, yield can be reduced before wilting is observed. In other cases, a soil surface that appears to be dry could in fact conceal a root zone that is moist.

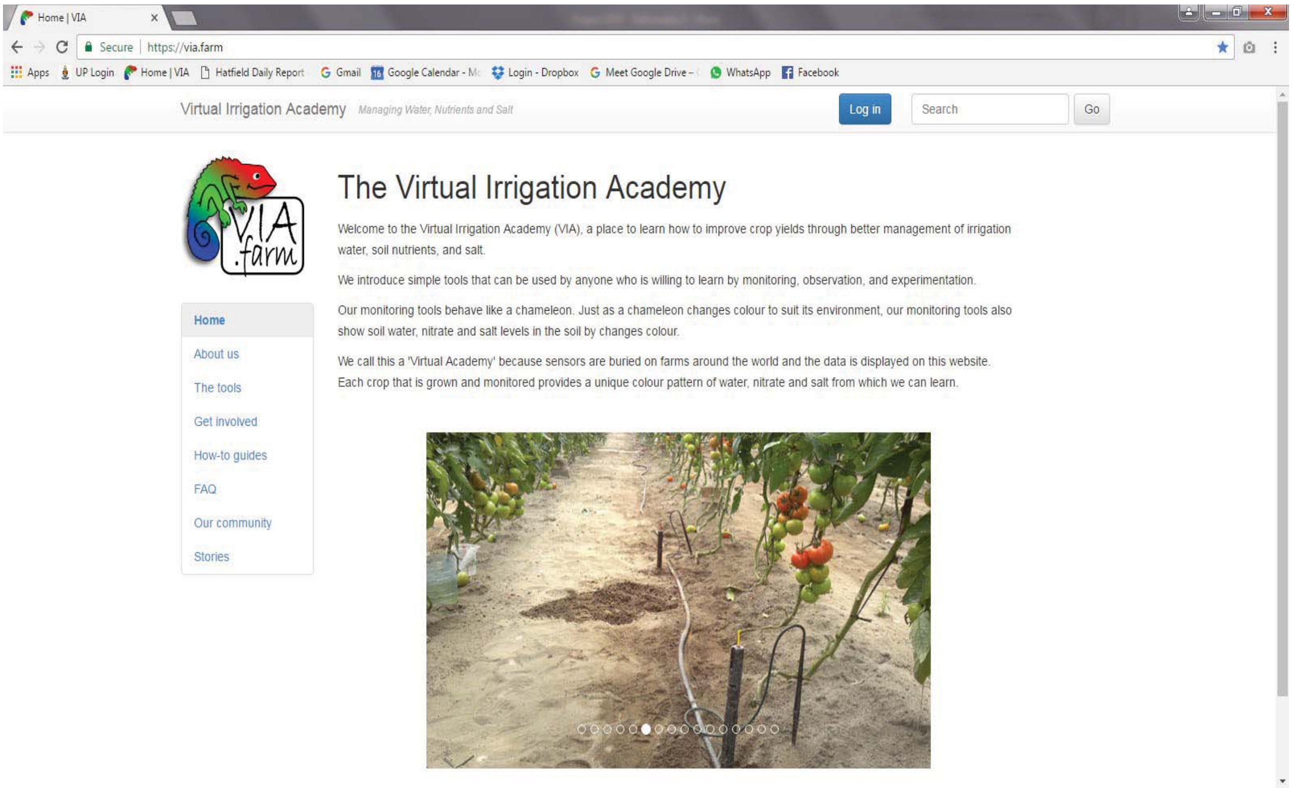

Figure 1.4: On-line visualization of data can be accessed through the Virtual Irrigation Academy website.

An aim of this project was to determine how the combination of using simple monitoring tools and on-farm farmer experiences promotes learning that improves irrigated farm productivity. Farmers gain experience by observing crop growth during periods of supplying more or less than average water. The objective of this project was to structure adaptive management of irrigation by providing tools that fit farmers’ way of thinking so as to engage them in a learning-by-doing approach. This approach, termed people-centred-learning, requires observation, monitoring, feedback and learning. Monitoring data is only valuable if farmers can understand it and act on their new knowledge. The farmer has two options in responding to Chameleon data – to change the amount of water at each irrigation, or to change the frequency of irrigation events. Consistently collecting data is very important in that it enables farmers and their advisors to monitor and visualise the subtle changes in soil water in the field.

Section 1.1 of this report clearly outlines the high-level overview of the coming national water crisis in South Africa with urban demand skyrocketing and the political necessity to increase the small scale irrigation sector. Although managing water at farm level is important, the responsibility of averting this crisis and improving agricultural water use appears to be largely placed on the shoulders of farmers who are at the lowest level influence (Level 1 in Table 1.1). There seems to be a disconnect between the national emergency and any steps that require people or organizations at all levels of influence to be responsible and accountable. Managing water should not just be an individual farmer 'problem'.

Table 1.1: Different levels of stakeholders supported by VIA

Level of User	**VIA service provided**	**Type of decision making**
Level 1: Farm scale	Individuals learn to manage their water more efficiently by comparing their Chameleon colours with their own crop performance.	Should I irrigate today? Did I irrigate too much or too little? How will I irrigate next time, next season?
Level 2: Scheme scale	Organisations and groups learn by comparing colour patterns and yields across the scheme and find more equitable and efficient management practices.	Is the scheme running out of water or overwatering? Which schemes are performing well? What happens when farmers irrigate at the same time, or too much?
Level 3: Governance	Data provided on irrigation scheme performance across a country. The way water is managed at the highest level nationally.	Which irrigation schemes should be prioritised for water? Benchmarking of schemes to see which are performing well or badly – scheme design change.
Level 4: Major projects	Automated reporting provided to large donors (i.e. international funding bodies) who have monitoring and evaluation requirements to track performance of their water investments.	Investment planning

The anticipated longer-term outcomes of the VIA are: Increasing productivity and profitability through better management of water and nutrients on smallholder irrigation farms; sustainable water and salinity management and improved economic returns from investments in irrigation infrastructure. The VIA has been designed to operate at four different levels, for four different clients, each with different interests in the data and capability to pay (Table 1.1).

Most irrigation scheduling methods are tactical in their use. They guide the farmer to answer the simple question, ‘should I irrigate today’? The responsibility is placed at one scale only, the farmer. In order to address the broader water use challenges facing the country, stakeholders at higher levels in the agricultural water sector need to also act as responsible stewards. Stakeholders who manage schemes or who produce or support the large-scale production of crops at scheme level should also feel responsible that water resources are used efficiently (Level 2 in Table 1.1). They are a vital link between the practice on the ground by individual famers and the looming crisis at a broader level. Often large agricultural support service organisations focus on various aspects of crop production but pay less attention to the impact of irrigation water use beyond the individual farm. These organisations have an important role to play in ensuring more efficient irrigation management is practiced at scheme level in order to preserve the water resources.

Chapter 2: Refinement of monitoring tools and the VIA platform

2.1 Introduction

One of the objectives of this project was to refine the monitoring tools, Chameleon reader and sensor, to address on-farm experiences. Farmers and other users of the monitoring tools reported challenges or problems that they experienced. The project team addressed many of the issues raised by users whilst others are still receiving attention. Feedback from users played a major role in the refinement of the tools and continues to do so. This Water Research Commission (WRC) project ran parallel to a bigger project funded by the Australian Centre for International Agricultural Research (ACIAR) entitled "A Virtual Irrigation Academy to Improve Water Productivity in Malawi and Tanzania and South Africa" which is on-going. This project is led by Dr Richard Stirzaker at the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Canberra, Australia. Phase 1 of the project began in 2015 and is due to end in June 2019, Phase 2 will continue for a further 4 years.

The WRC project benefitted immensely from significant developments made in the broader and more comprehensive ACIAR project. It is not realistic to isolate the refinements of the irrigation monitoring tools and the VIA platform made during the WRC project from the ACIAR project. The WRC project which began in April 2016 was an extension of the ACIAR project. The development and improvements to the tools and the VIA platform were undertaken by Dr Stirzaker and Matthew Driver from Solutech (a private company in Australia) in collaboration with other project team members and users. The development of the VIA tools was guided by the principle of the Minimum Viable Product (MVP), which enables the project team to run a continuous beta test program. The MVP allowed the team to reach the main users of the tools as early as possible in the development process, and to respond to their feedback. Fundamental to this concept is that it is a process of user-led design, so that the team found out what users want before it was implemented at scale. Some of the refinements to the tools and the VIA platform are discussed in this report.

Towards the end of 2018, the VIA had collected soil water, solute and yield data from over 2 500 crops in more than 20 countries. There are more than 2 000 crops captured on the VIA platform. Users range from homestead gardeners to commercial farmers. The VIA production facilities manufactured over 10 000 sensors in 18 months. The VIA is active in several SADC countries including Zimbabwe, Mozambique, Tanzania, Malawi, Lesotho, Eswatini, South Africa and in 16 countries around the world. Currently, South Africa has over 80 farms or schemes on the VIA platform located in seven provinces and there about 500 operational sensor arrays.

2.2 Chameleon reader and sensor

2.2.1 Refining the Chameleon sensor

The design of VIA required all aspects of the original Chameleon system to be redesigned. The Chameleon sensor and reader have been continually improved to i) respond to user feedback ii) increase functionality iii) increase robustness and iv) reduce fabrication costs.

The original Chameleon sensor consisted of two stripped, twisted and tinned wires that acted as 30 mm electrodes. The diatomaceous earth mixture was then packed around these wires and surrounded by a gypsum bandage casing. Attaining uniformity of packing around such electrodes was problematic, as was ensuring they stayed parallel. A potential flaw in the design was rough handling of the sensors that could cause the electrodes to vibrate and cause a small airgap between electrode and diatomaceous earth (DE). A systematic study was undertaken to try to understand the source of variability in sensor performance. The tinned wire electrodes were replaced with an Electrolysis Nickel Immersion Gold (ENIG) surface on a printed circuit board (PCB). This allowed an exact size of conductive but non-reactive electrode surface. The project team then embarked on 3D printing a 'cap' into which the electrodes were inserted so as to ensure consistent parallel spacing.

Later it turned out that some farmers dug up sensors after a crop in an attempt to move them to a new crop, but many sensors broke in the process. Thus, the team decided to print a plastic core to the sensors so they would be more robust and have a longer field life (the 3-D printed sensor cradle). Several other enhancements followed, including: i) moving from a parallel double-sided planar electrode on a single PCB to two opposite facing electrodes; ii) designing the cradle to allow easier insulation of the wire to PCB join; iii) designing the cradle to allow more uniform packing of the DE between the electrodes. The team experimented with different PCB surface coatings including HASL and Hard Gold in an attempt to find the balance between cost effectiveness and longevity of the sensor.

The most difficult aspect of improving the design has been the time taken in testing sensors and hence the efficacy of the refinements. First the team had to develop a medium in which to test sensors that retained high hydraulic conductivity over the suction range so that we could ensure uniformity of conditions over the depth of the sensor during drying. Second, we needed to ensure we could dry the material from 0 to 70 kPa in under a week, so we could push enough sensors through the test rig. Testing was conducted manually, i.e. a reading on a tensiometer gauge followed by connecting a hand held gypsum block resistivity meter to each set of sensor wires in turn, which had to be done seven days per week. The procedure was incredibly time consuming. The project team embarked on the huge undertaking of building automated Wi-Fi based test rigs that uploaded half hourly data onto the VIA, and stored all sensor switch points in the database.

A major improvement during this time was the realisation that the gypsum bandage, contained surfactants that affected sensor switch points (Figure 2.1).

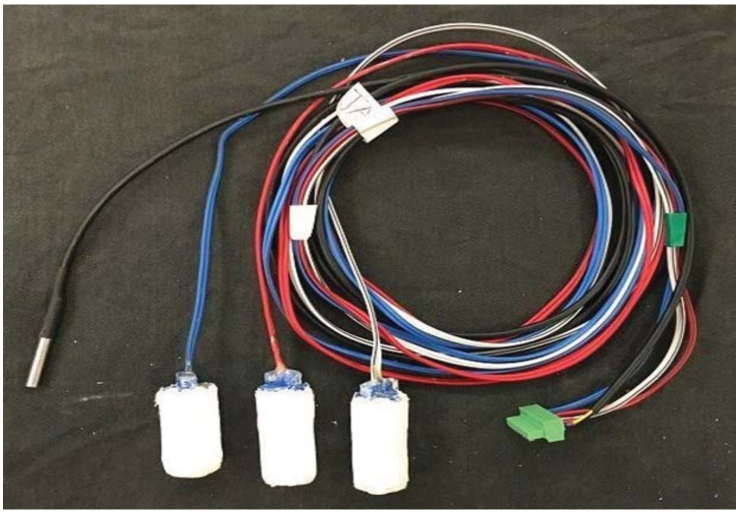

Figure 2.1: Initial Chameleon soil moisture sensor array with gypsum bandage

The surfactants changed the contact angle of the meniscus at the water-solid interface, and hence the suction force required to empty a pore. The surfactants were drawn into the DE during wetting and then dissipated over three or four wetting and drying cycles. This meant that sensor performance in the field would be largely unaffected, but sensor testing was always confounded by the degree of surfactant contamination, greatly slowing down progress as multiple tests were required of the same sensors. The latest design now uses casting gypsum in a neoprene mould that fits around the sensor cradle. This version is giving consistent results, so one of the major impediments to scale up has been overcome.

2.2.2 Improving the type and length of sensor cables

The Chameleon sensors are connected to three cables which are red, white and blue in colour (Figure 2.1). The sensors are buried in the soil at different depths, for example 20 cm, 40 cm, 60 cm. The order in which the sensors attached to the different coloured cables are buried is very important. The red cable sensor should be buried at the deepest level (i.e. 60 cm), the white cable sensor should be buried at the middle level (i.e. 40 cm) and the blue cable sensor should be buried at the shallowest depth (i.e. 20 cm). On the farm, however, farmers have often confused the order in which the sensors should be buried. Hence, the project team decided to adjust the lengths of the cables making the red cable the longest and the blue cable the shortest, thereby enabling the farmers to easily identify the depth at which each sensor should be buried. The project team also replaced the different colour cables with black cables (which are resistant to ultra violet light) which are less prone to breaking.

2.2.3 Improving the green connector plugs

One of the challenges that development/extension officers and farmers experienced was a problem with loose wires in the green plug that connects the sensors to the fielder reader (Figure 2.1). The issue of loose wires, particularly in the green connector plug, was simply and easily resolved by ensuring that farmers that have Chameleon sensors are also supplied with a suitable small screw driver. As the Chameleon sensor designs have evolved, so too has the cabling systems. The latest cabling system is a FL37 adapter. It has the benefit of spring-loaded push-in connectors instead of screw terminals.

2.2.4 Developing access points

Commercial farmers, in particular, repeatedly asked about the durability and the robustness of the green connector plug. Farmers also expressed their frustration in using the green plug to connect the sensor array to the field reader after the plug has been lying in the ground and has accumulated dirt. Another concern was having loose wires in the field which can attract vandals or thieves. Access points have been developed and are being sold to commercial farmers and installed in farmers' fields (Figure 2.2). These access points enclose the sensor and temperature cables as well as the cable connector plug.

Figure 2.2: Access point installed in a field

2.2.5 Refining the Chameleon reader

The development of the Chameleon reader has required similar effort to that of the sensor. Significant improvements to the reader have been made over the last few years. A very brief overview is provided here: The project team replaced the manual prototype reader with an ID chipped sensor array and a reader that could identify arrays and send data to the cloud via Wi-Fi. The new micro-processor version has many advantages including: i) allowing for temperature compensation to improve accuracy ii) reading an ID chip for error free data collection iii) sending readings to the database by Wi-Fi, and iv) recording and reporting errors such as short circuits and loose wires.

The project team added a storage chip to the reader for places where cellular coverage is poor. Access to cellular reception and Wi-Fi together with the use of a smartphone with the portable Wi-Fi hotspot function is essential in order to upload data onto the VIA website electronically. The alternative is to record data manually which some farmers and their advisors consider to be time-consuming and tedious. The reader can now store up to 1000 readings and will upload them to the VIA as soon as cellular or Wi-Fi contact is established. Major changes to the Chameleon reader based on feedback from users over past two years include: i) fixing the battery drain issue ii) adding a logging chip iii) adding a strengthened Micro USB charging jack to the bottom of reader iv) developing a prototype with LCD screen instead of OLED for better contrast in the sun.

2.3 The Virtual Irrigation Academy (VIA) platform

The VIA transitioned to be fully digital in 2017. Development of the VIA platform has been rapid and includes data archiving systems and the ability to create reports on water management and yield for different types of users (scheme level, project level, country level). Numerous improvements to the VIA have been made over the past few years, but only a few will be highlighted below.

Additions to the VIA platform include:

- Automated reporting of crop summary data from each scheme and country. This gives you access to a summary of your crops metrics and allows you to compare yields across seasons in an aggregated formatted.
- Reporting of active sensor arrays and monitoring activity at farm/scheme level.
- Addition of scheme details.
- Addition of soil fertility data.
- Ability to disaggregate data by gender and age.
- Refining the layout to cater for farms and schemes.

- A webpage that explains the VIA.
- A chart that shows the number of sensor arrays that sent data to the VIA over the last 12 months by country. This shows where the VIA is most active.
- Crop Moisture Triads that summarize the percentages of Red, Green and Blue for all the crops. This is averaged over all three depths for the duration of the monitoring period, i.e. the percentage each pattern that is Blue, Green or Red.
- A feature for archiving crops. The default view now only displays the current crops; past crops are available via a drop-down box.

As with any technology problems do occur with faulty equipment. A challenge that the project team faced was easily identifying on the on-line visualisation whether a specific colour pattern on the visualisation was due to a dry soil or faulty equipment (i.e. loose wires). Previously, for example, if one of the wires of the green connector plug for the sensors was loose, the on-line visualisation showed a red pattern (Figure 2.3). Similarly, if the soil was very dry the visualisation also displayed a red pattern. To prevent any confusion, the project team decided to change colour patterns such that a grey colour on the visualisation now indicates faulty equipment and the red colour continues to indicate a dry soil (Figure 2.3).

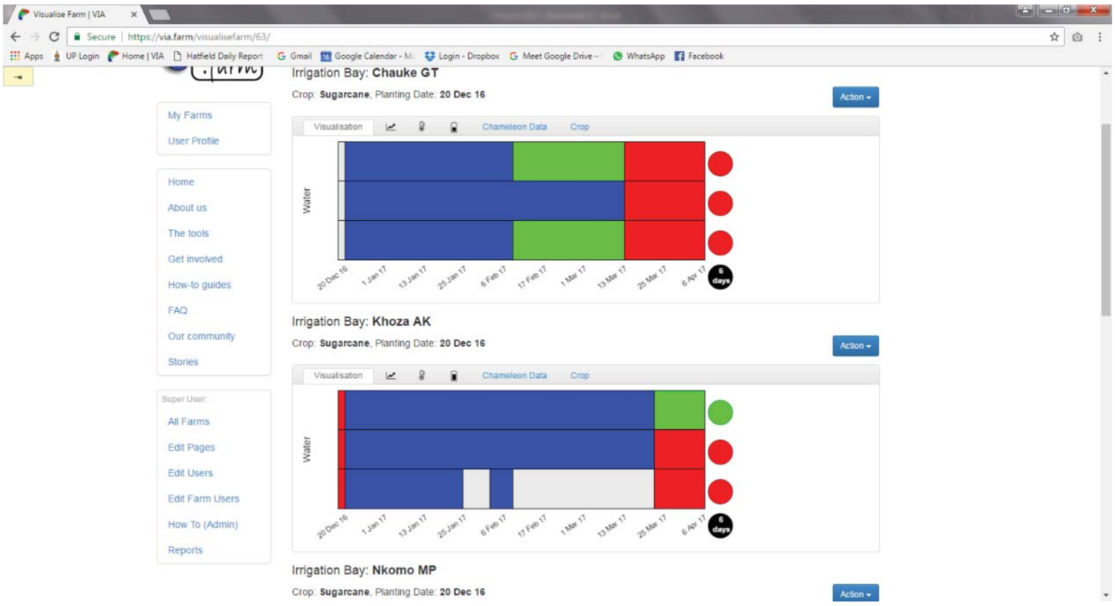

Figure 2.3: On-line visualisation showing the grey colour pattern due to faulty equipment and the red colour as a result of a dry soil.

The grey colour indicates the sensor is disconnected. When a sensor cable is disconnected (open circuit) the reader sees it as a very high resistance. On the visualisation, anything above 4000 kOhms is assumed to be an open circuit and is coloured grey to alert users to the fault. Users need to check the wiring, particularly at the green terminal block where it may have come loose. Sometimes the soil gets so dry (end of the red zone) that it goes beyond the accuracy of the Chameleon reader, this also shows up as grey on the visualisation and the colour will return when the soil is wetted again

A recent addition to the visualisations is the magenta colour pattern which shows Chameleon response in saline soils (Figure 2.4). The display indicates that users of the Chameleon need be aware that: i) salt needs to be measured because salinity could potentially be too high, and ii) the Chameleon colours will not be accurate at high electrical conductivity (EC) values. Users need to measure the EC using, for example, a Wetting Front Detector (WFD) and an EC meter (Stirzaker et al., 2005).

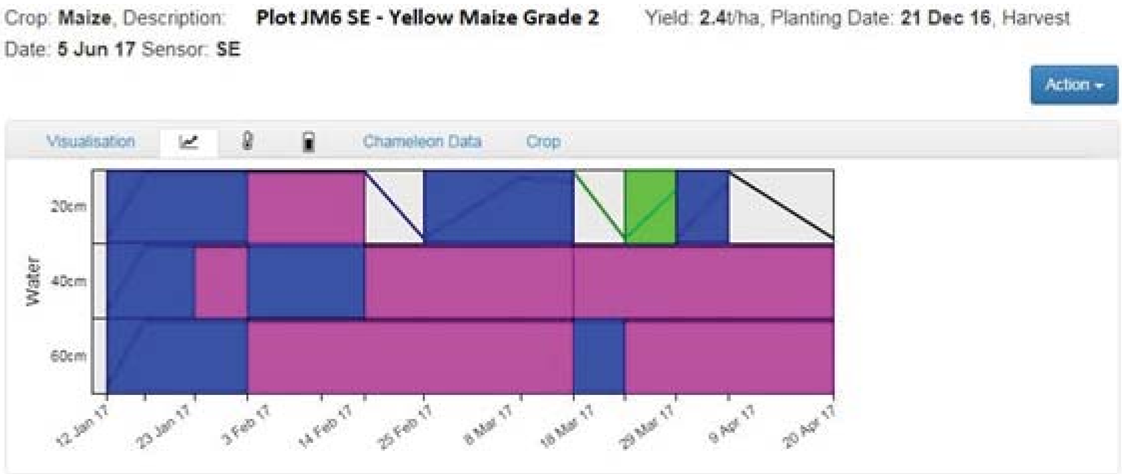

Figure 2.4: On-line visualisation showing the magenta colour pattern.

The display indicates that users of the Chameleon need be aware that; i) salt needs to be measured because salinity could potentially be too high and ii) the Chameleon colours will not be accurate at high electrical conductivity (EC) values. Users need to measure the EC using, for example, a Wetting Front Detector (WFD) and an EC meter (Stirzaker et al., 2005).

2.4 Conclusion

The development and refinement of the Chameleon monitoring tools followed the process of user-led design. The Chameleon reader and sensor have been improved specifically to address on-farm experiences. Farmers and other users of the monitoring tools reported challenges or problems that they experienced and these issues were incorporated into the new features of the tools. This feedback was not only provided by users of the tools in South Africa, but other countries such as Malawi and Tanzania where the tools are also being used. Enormous improvements were not only made to the tools during the course of the project but also to the VIA platform.

Chapter 3: Adaptation of Soil Water Balance (SWB) model to display Chameleon and Wetting Front Detector (WFD) patterns

3.1 Introduction

The Virtual Irrigation Academy (VIA) is a learning platform, designed to improve irrigator's understanding of the complex and dynamic soil-crop-atmosphere system they are managing. In addition, the tight link between water and solutes adds another layer of complexity to the system that farmers need to manage to improve crop production and protect environmental resources.

Great strides have been made in assisting farmers (from small scale resource-poor illiterate farmers, to large-scale well-resourced and highly technical farmers) to better understand and manage their irrigated fields, using Chameleon soil water sensors and Wetting Front Detectors or Fullstops. Results have been impressive, as the output of these tools, in easy to understand bright colours, have resulted in dramatically increased yields, reductions in labour required, and reduced water usage (Stirzaker et al., 2017). Additional information on the VIA can be found at https://via.farm.

However, Chameleon sensors and Wetting Front Detectors give us "snapshots" in time, and tools that can fill in the gaps between measurements to give us a better understanding of the behaviour of the system, would be very valuable. In addition, the in-field tools do not give us a quantitative understanding of implications of our management actions (e.g. amount of nitrate or salt leached, water lost through over-irrigation), nor do they make the assessment of the implementation of alternative management scenarios possible. In addition, the effect of atmospheric evaporative demand (ETo) and the size of the canopy and depth of the root system, are inextricably linked to the rate of crop water use, and fundamental to the interpretation of the colour patterns displayed by the in-field monitoring tools.

A dynamic soil water balance model (Annandale et al., 1999) can address these shortcomings, but the challenge is to generate model output in a similar, easy to understand and learn from-format, as is generated by the in-field tools. Because the SWB (Soil Water Balance) model has been developed with WRC support over several decades, and has been parameterized for many crops, this model was selected to generate such colour patterns to add value to (interpret) the in-field measurements. The model will be able to be run under various management constraints that relate to a farmer's ability to adjust timing and amount of irrigation, as well as the management of nutrients and salt. SWB will then be able to give a plausible yield estimate, and quantify drainage and solute leaching, in an easy to understand format through the generation of intuitive colour patterns.

It is envisaged that this will build a communication bridge between scientists/researchers and irrigators, to enable them to engage in discussions on soil water and solute dynamics in a comprehensible manner considering the high illiteracy rate, cultural differences and limited technology of small holder farmers in particular, but also with more sophisticated, well informed, large-scale irrigators.

The objective of this part of the project was to adapt a soil water balance model to display water and solute balance output in a format similar to that found on the VIA platform for Chameleon Sensors and Fullstop wetting front detectors.

3.2 Methods

Because the SWB (Soil Water Balance) model has been developed with WRC support over several decades, and has been parameterized for many crops, this model was selected to generate such colour patterns to add value to (interpret) the in-field measurements. The SWB model was modified as follows:

An output colour visualisation icon (rainbow) was added to the opening screen, to set-up the boundaries between colours for matric potential, salt and nitrate levels (Figure 3.1).

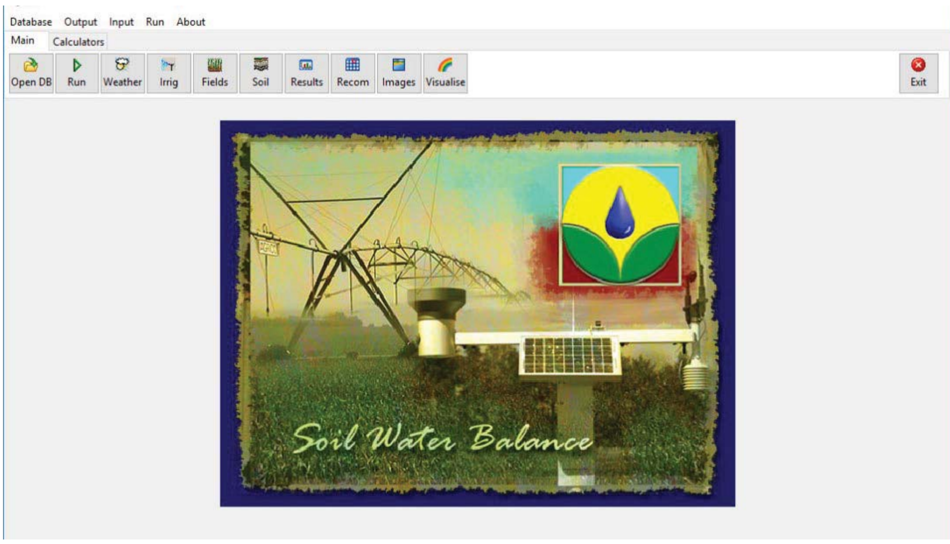

Figure 3.1: Opening screen of SWB

There are two main reasons for developing the visualisation set up screen. Firstly, as the Chameleon sensors are continually being refined, it is quite likely that the boundaries between colours may change over time. This set-up will make it easy to change the boundary between colours. Secondly, when evaluating solute (nitrate and salt) concentrations, a distinction needs to be made between saturation extract concentrations, extracts from Wetting Front Detectors that sample at a soil matric potential of -2 kPa, or soil solution samples extracted at *in-situ* potentials using suction cup lysimetry.

In addition, the set-up enables output colour ranges to be specified for atmospheric evaporative demand, and relative yield. This is displayed in the figure below.

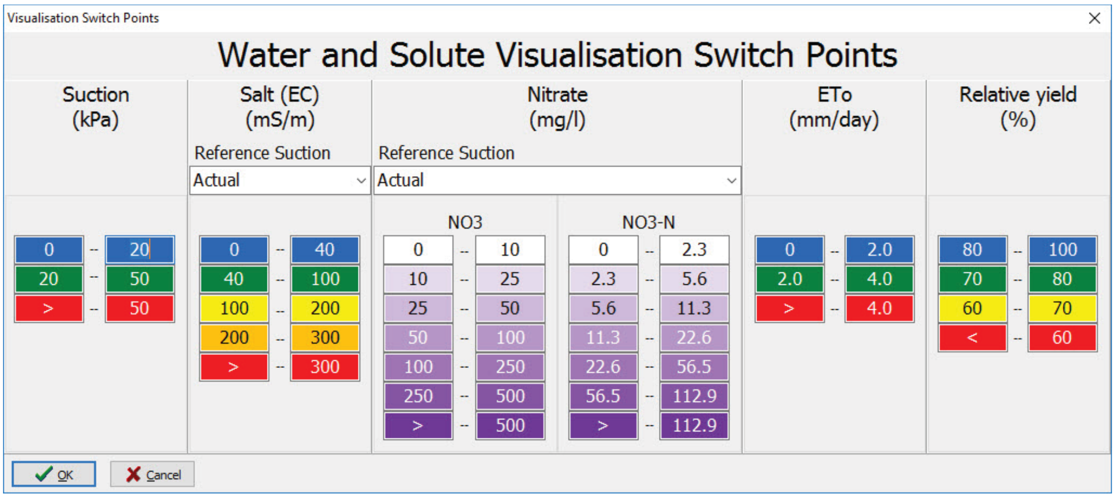

Figure 3.2: Visualization screen to set the limits between colours for soil suction, salinity, nitrate, ETo and relative yield

Figure 3.3 demonstrates the ability to select the reference soil water potential for salinity output.

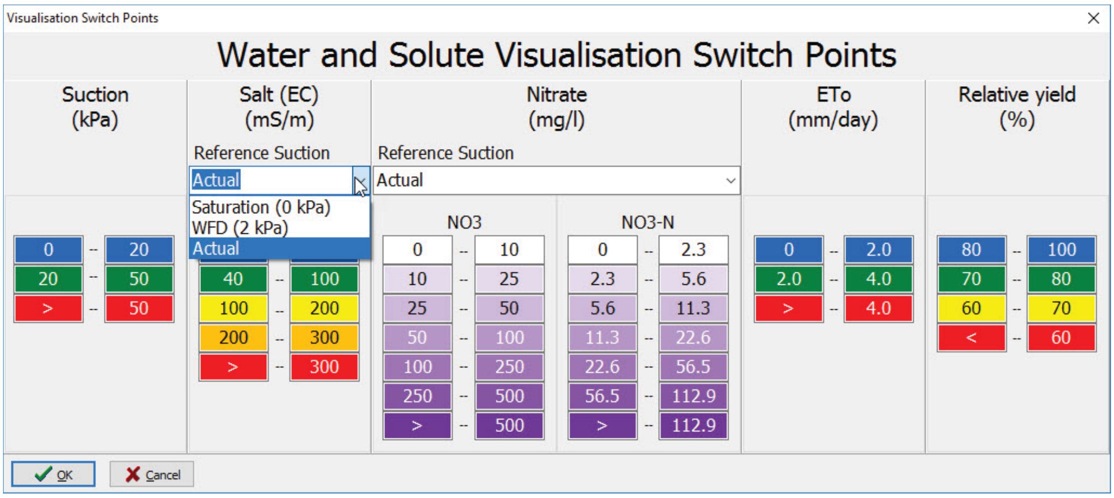

Figure 3.3: The visualization screen showing the drop down menu to select the reference soil water content at which salinity is measured

Similarly, the selection of the reference soil water potential for nitrate output is demonstrated in Figure 3.4. The nitrate output can be presented in units of nitrate (NO_3) in mg/l, or nitrate nitrogen (NO_3-N) in mg/l. This is to cater for different units used to express nitrate in soil solutions.

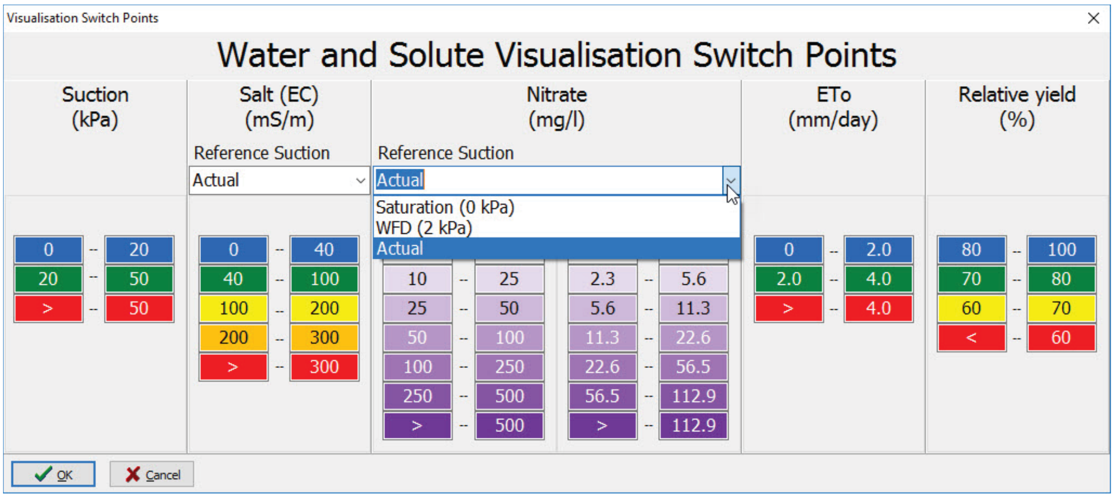

Figure 3.4: The visualization screen showing the drop down menu to select the reference soil water content at which nitrate, in mg NO_3 per litre or mg N per litre, is measured

All of the boundaries between colours can be modified by the user, based on preference and in order to relate model output to the colour output of monitoring equipment used. The nitrate and nitrate-N output is linked, and changing nitrate colour boundaries automatically sets the nitrate-N ranges between colours.

3.3 Model output

3.3.1 Matric potential

To demonstrate the visualisation output, an example simulation was generated, and is presented in Figure 3.5. The output has three layers. The top figure (in green) shows canopy growth (FI – Fractional Interception of radiation). Below this, atmospheric evaporative demand (AED) is displayed, with blue representing days with low AED, and red indicating warm, windy and dry high AED days. The bottom colour coded figure shows soil suction over depth and time for this simulation. The white line in the soil suction figure displays root depth, to indicate from what part of the profile we can expect water to be extracted.

Below the colour coded figures, quantitative estimates of components of the water and solute balance are presented, with a colour coded yield estimate, and values for crop ET and N uptake, to the right of these figures.

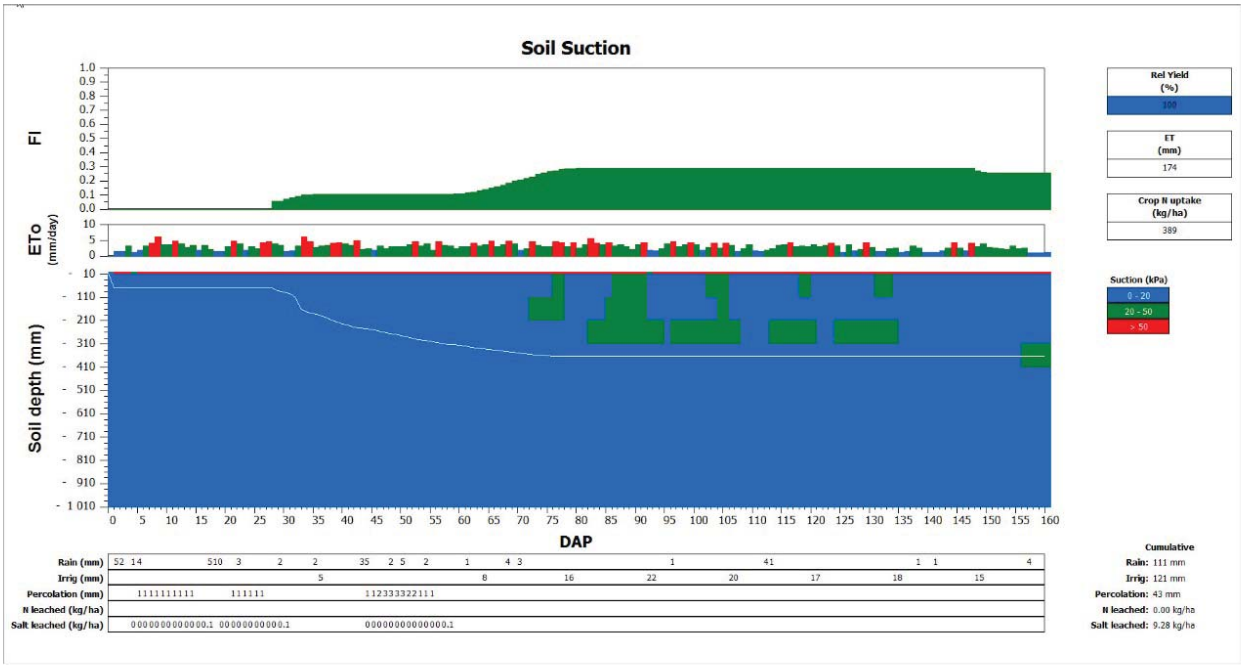

Figure 3.5: Example output showing temporal changes in fractional canopy cover (top), ETo (middle) and soil suction over depth

Root depth is illustrated by a white line in the profile graph. Below the colour coded output is the model estimate of components of the water and solute balance, with a colour coded yield estimate, and values for crop ET and N uptake, at the right of the visualization

3.3.2 Nitrate

An example of changing nitrate concentration in soil solution, at different reference water contents, over time and depth, are presented below. Estimates of crop N uptake and N leaching are also provided. It is clear from the colour patterns, that wetter reference soil matric potentials, dilute nitrate concentrations.

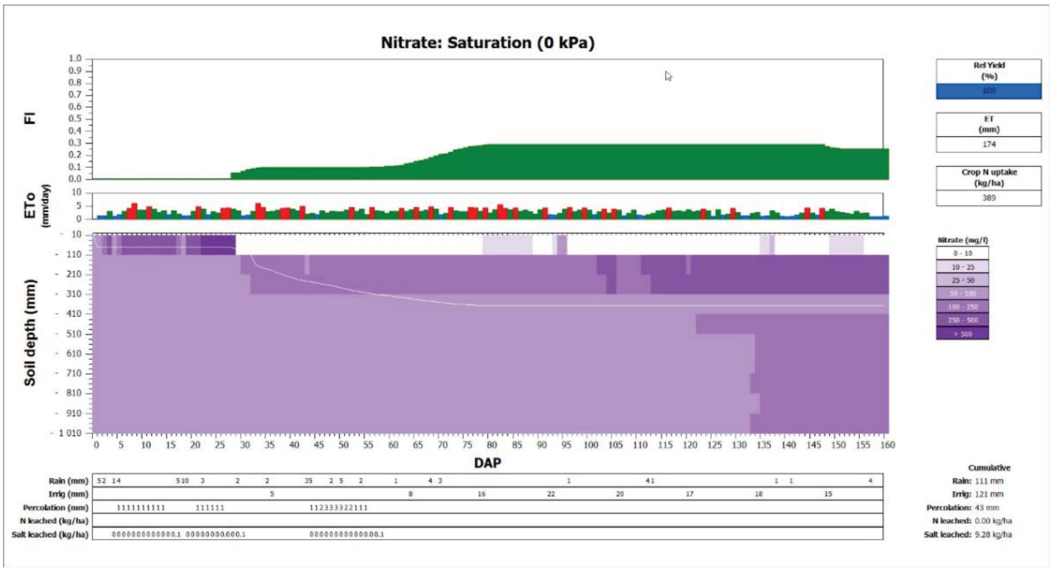

Figure 3.6: Colour coded output for nitrate under saturated soil conditions

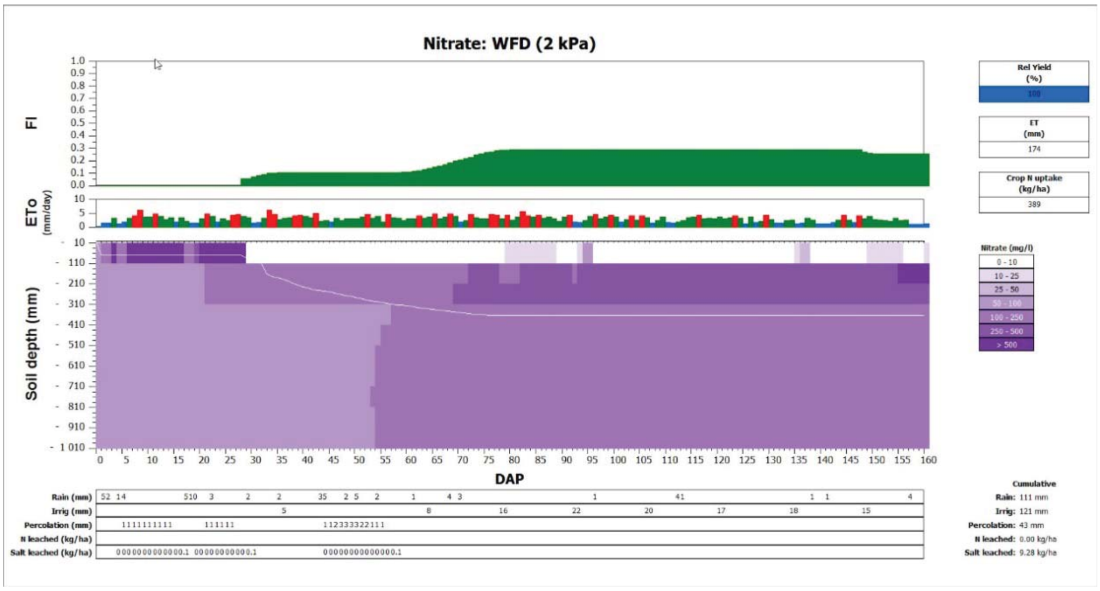

Figure 3.7: Colour coded output for nitrate under soil suction conditions expected when sampling with a Fullstop wetting front detector

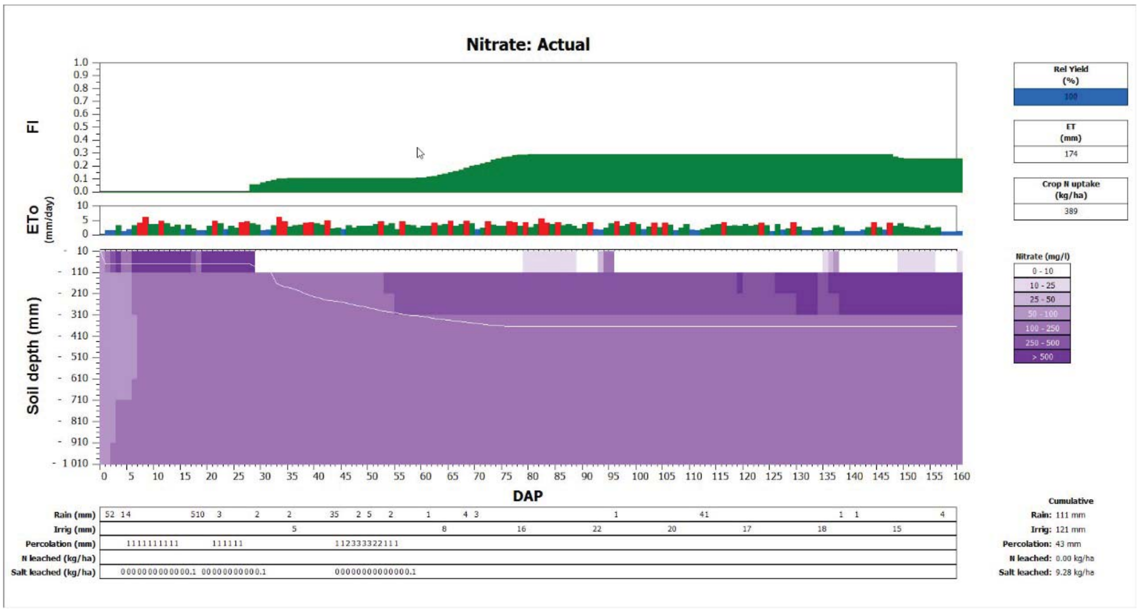

Figure 3.8: Colour coded output for nitrate at actual modeled soil suction conditions. This is comparable to samples obtained through lysimetery

3.3.3 Nitrate - N

Identical patterns, but in different units to those displayed for nitrate are generated when Nitrate-N is considered. This is displayed in Figures 3.9 to 3.11.

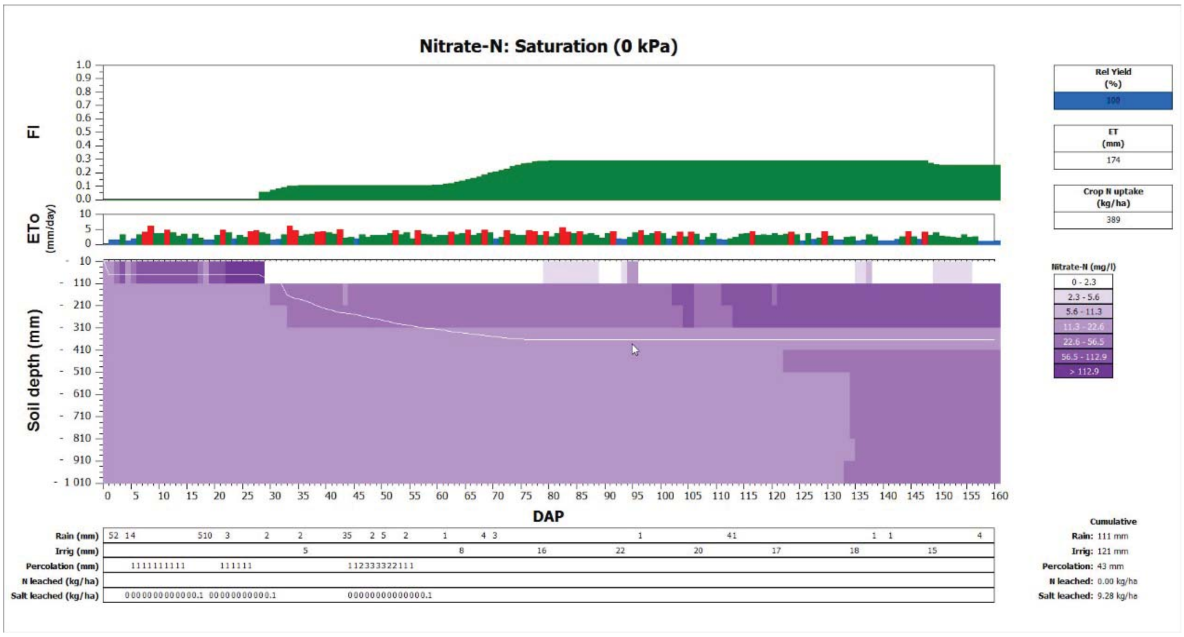

Figure 3.9: Colour coded output for nitrate-N under saturated soil conditions

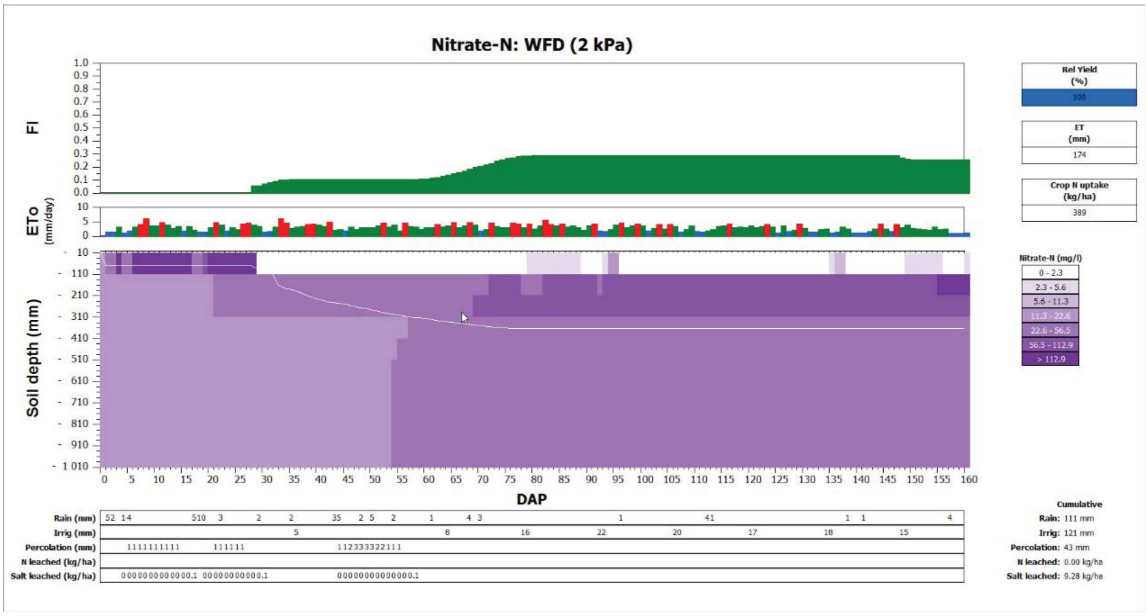

Figure 3.10: Colour coded output for nitrate-N under soil suction conditions expected when sampling with a wetting front detector

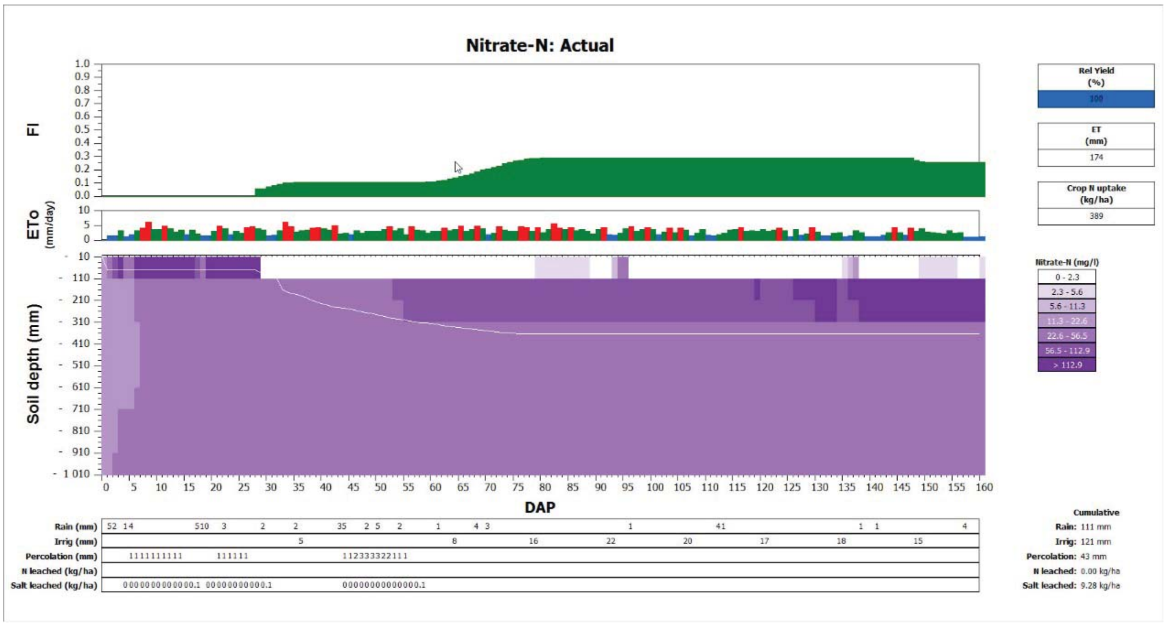

Figure 3.11: Colour coded output for nitrate-N at actual modeled soil suction conditions. This is comparable to samples obtained through lysimetery

3.3.4 Salinity - EC

Finally, changing salt concentrations in soil solution, at different reference water contents, over time and depth, are presented below (Figures 3.12-3.14). Estimates of relative crop yield and salt leaching are also provided. It is clear from the colour patterns, that wetter reference soil matric potentials dilute salt concentrations.

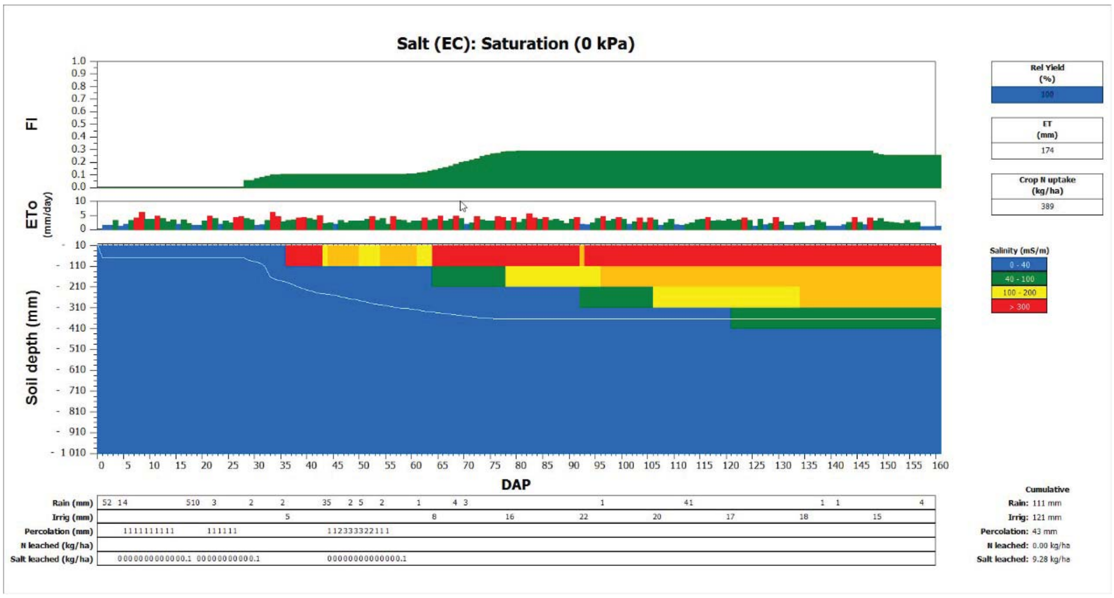

Figure 3.12: Colour coded output for salinity under saturated soil conditions

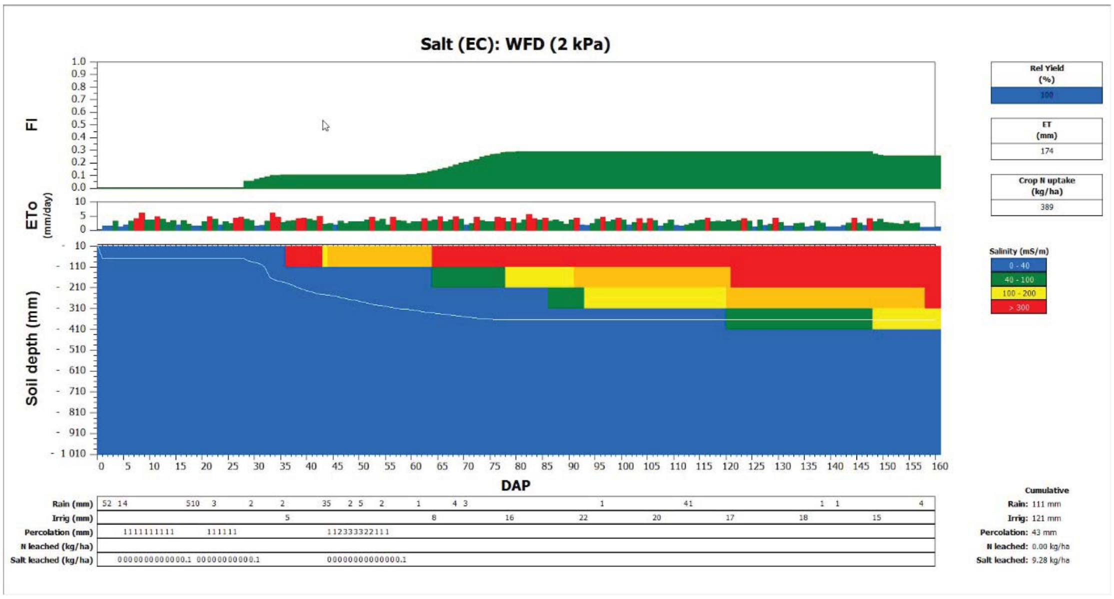

Figure 3.13: Colour coded output for salinity under soil suction conditions expected when sampling with a wetting front detector

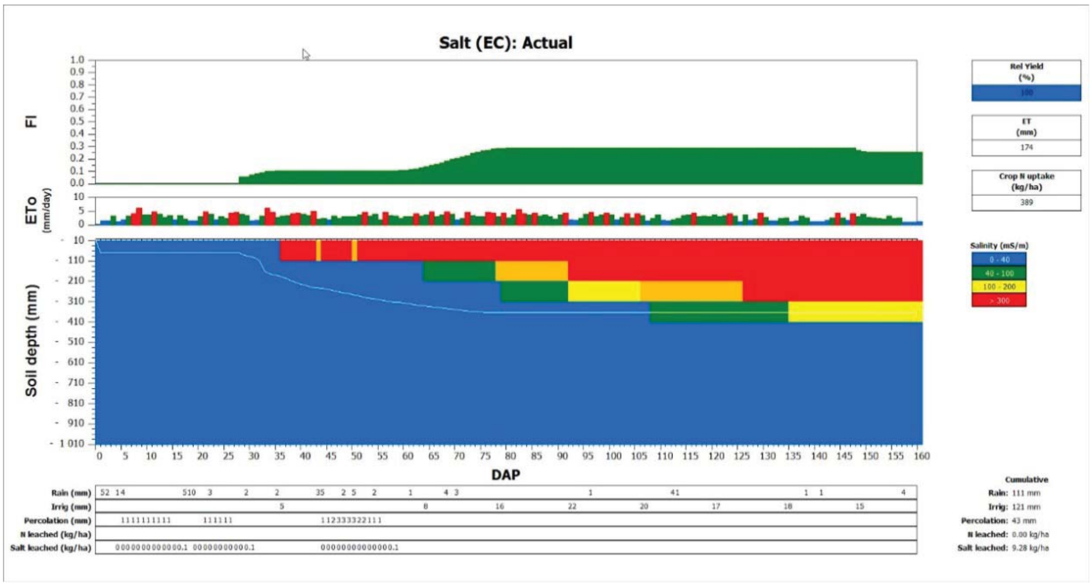

Figure 3.14: Colour coded output for salinity at actual modeled soil suction conditions

3.4 Application

As an illustration of the use of this visualization feature of SWB, a student working on another WRC project, one that focuses on mine water irrigation, used the SWB model to predict water and salt balances of a 19 ha centre pivot that was planted to maize in the 2017/18 season. Irrigation was with untreated pit water from a Highveld Colliery.

SWB was calibrated to realistically simulate crop growth with saline water. For this exercise, measured canopy cover and crop growth data, as well as additions of water and salt through rain and irrigation was used. The simulation of root depth, leaf area index, top and harvestable dry matter and profile water deficit is presented in Figure 3.15. Lines are simulations, and dots with error bars are measured data points. It is clear that crop growth is well estimated from this figure and the statistics output by SWB.

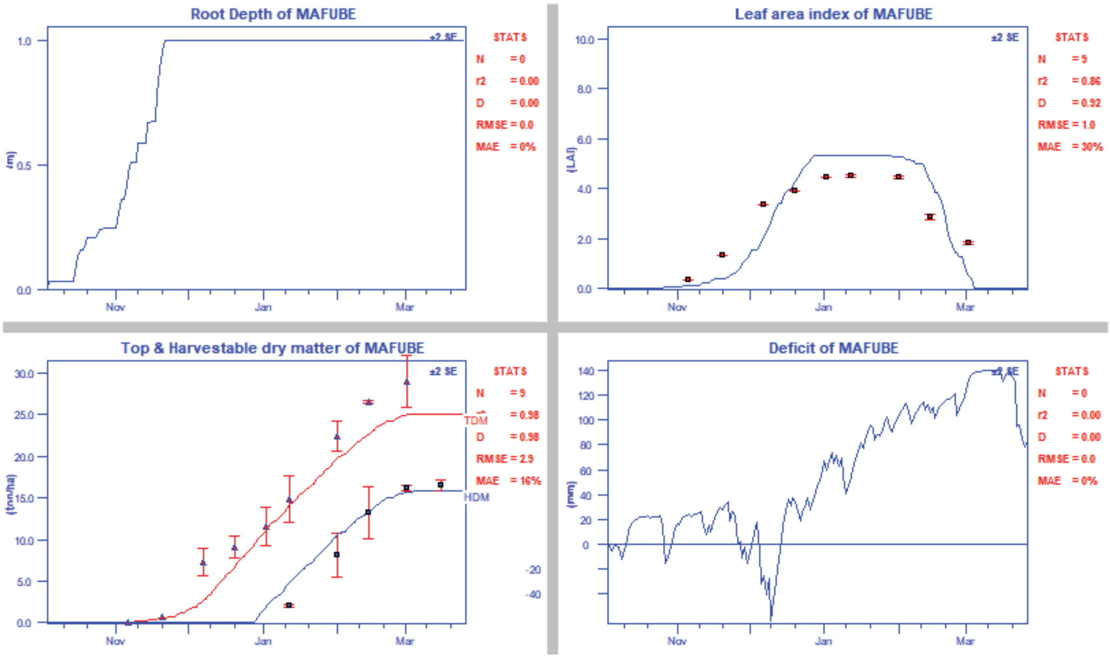

Figure 3.15: SWB calibration simulation of a maize crop irrigated with saline mine water. Lines are simulations, data points with error bars represent observed values. The following output is displayed: root growth (top left), leaf area index (top right), top and harvestable dry matter (bottom left) and soil water deficit (bottom right). Statistics are displayed to the right of each graph

The irrigation water used on this colliery is circum-neutral, and dominated by Ca and SO_4. The yield was very good and it is clear at this early stage that salinity is not of major concern. This may change as irrigation continues, as maize is not particularly salt tolerant, and soybean may be a better choice of summer crop. The visualization of profile salinity in Figure 3.16 shows a buildup of salt as the season progressed as one would expect, as well as an increasing salinity with depth, including salt accumulation below the root zone.

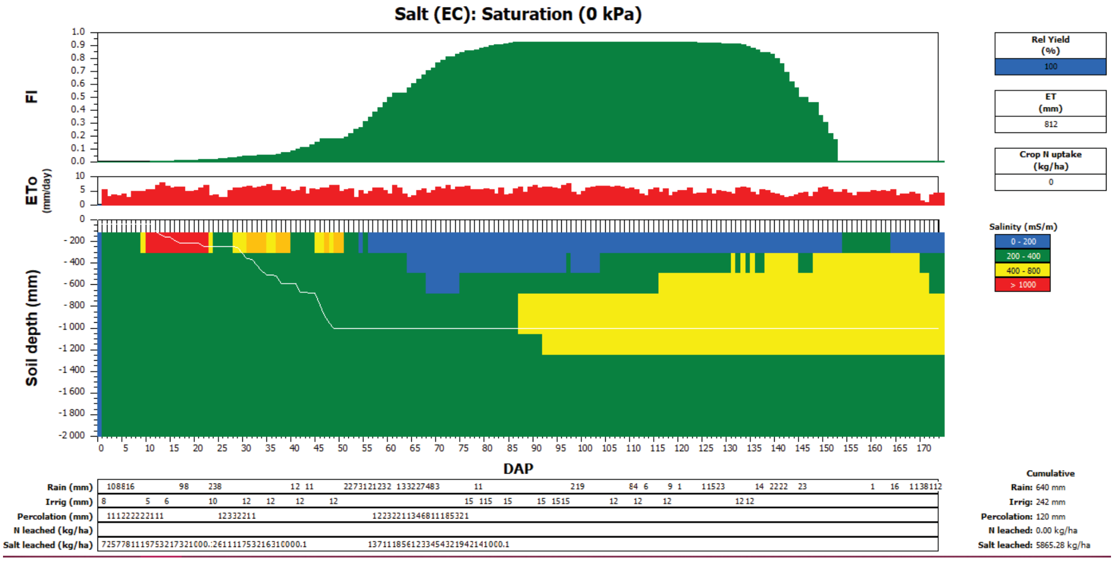

Figure 3.16: Visualization of modelled soil profile salinity changes with depth and time for a field irrigated with saline mine water

Quantitative estimates of salt leaching are particularly useful – in this case nearly 6 tons per ha, which cannot be estimated from observing measured colour patterns on their own. The model can now be used to run scenario simulations to see if the profile will become too saline for maize over the long term, or the effect of different irrigation strategies on crop production and leaching. Once favoured management strategies have been developed through modelling, one will be able to observe the colour patterns generated by such a scenario, and this should provide guidance on how to manage the field in real life, based on feedback from chameleons and wetting front detectors, to achieve the desired strategy.

3.5 Conclusion

An interface to set the boundaries between colours for matric potential, nitrate, EC, ETo and relative yield has been developed in SWB. It is hoped that this will prove to be a valuable tool to assist VIA participants to better understand the complexities of the dynamic water and solute relations at play in irrigated fields. It is also hoped that this output will make it convenient to develop alternative management strategies to improve water and solute management. Finally, it is envisaged that this intuitive output will add value to the "snap shot in time" colour patterns generated by the chameleon soil water sensors and wetting front detector soil solution samples, and will be useful in communicating the implications of certain management decisions with irrigators.

Part 2: Deployment of irrigation monitoring tools

Chapter 4: Emerging commercial farmers in Taung Irrigation Scheme, North West Province

4.1 Introduction and background

The Taung Irrigation Scheme is located in Greater Taung Local Municipality (GTLM) of Dr Ruth Segomotsi Mompati District Municipality, in the North West province of South Africa. The North West province is situated in the north of South Africa on the Botswana border, fringed by the Kalahari Desert in the west, Gauteng province to the east, and the Free State to the south (NWPG, 2009). The Province has a population of 3.9 million people and about 65% live in rural areas (Statistics South Africa, 2011). Dr Ruth Segomotsi Mompati District Municipality covers an area of 43 699 km^2 and has a population of 463 815, which constitutes 13% of the total population of the North West Province (Statistics South Africa, 2011). Greater Taung Local Municipality with a population of 177 642 people is one of five local municipalities that constitute the Dr Ruth Segomotsi Mompati District Municipality in North West Province. The GTLM covers an area of approximately 563 955 hectares or 11.8% of the Dr Ruth Segomotsi Mompati District. About 98 percent of the population is Tswana speaking and Taung is the headquarters of Greater Taung Local Municipality (GTLM, 2012).

Greater Taung Local Municipality is a typical rural municipality with 106 villages which are mostly concentrated adjacent to the N18 and the Dry-Harts River. The settlement pattern in Greater Taung Local Municipality is fragmentary, with small, low-intensity urban areas scattered throughout, and surrounded by vast rural areas (GTLM, 2012). Most of the population live in small, low-intensity settlements consisting of mostly informal housing that are scattered throughout the eastern parts of the municipal area and has the highest population density within the Dr Ruth S Mompati District Municipality (DrRSDM, 2013). It has a population density of between 33 and 35 people per km^2 and nearly 60% of the population in Greater Taung Local Municipality reside within the Bathlaping Ba Ga Phuduhutswana main-place.

Figure 4.1: Location of Taung irrigation scheme

The area has a semi-arid climate, characterised by very hot summers and cool winters, and a predominantly summer rainfall. The mean annual precipitation is 477 mm (weather stations Jan Kempdorp and Vaalharts), with Taung receiving 450 mm. Wind occurs predominantly in the north-west direction at a speed between 3.5 and 5.6 m/s. The first heavy frost in the area is likely to occur during the second half of May and stops towards the end of July. The number of days with heavy frost is between 23 and 32 days per year.

The soils in the area are described as Kalahari Sand and are mostly Hutton forms that are suitable for crop production. Underlying the red Kalahari Sand is the Dwyka shale and tillite, calcrete (Harts – Dry Harts Valley) and Ventersdorp lava, with sedimentary rocks (quartzite) of the Bothaville formation occurring towards the east. These rocks do, however, provide an excellent foundation for large or heavy structures.

4.2 Land type and soils

The irrigation scheme is predominantly flat as 70% of the area comprises of slopes less than 1%. In the Rethuseng area, soils are between 30 cm and up to 120 cm deep, while in other areas there are places with only 50 cm effective soil before mother rock is found. According to Eksteen, Van der Walt and Nissan (1981) irrigation soils in Taung are generally classified as sandy loam, and available soil moisture is taken as 120 mm/m. Excess rain or irrigation water either collects on or runs off the soil surface. Too much water can in some cases result in a partially sealed soil surface. If the soil surface is sealed, infiltration may be negatively disturbed, therefore more run-off takes place

4.3 Economic activity

Currently 32.6% of the population in Taung is employed, and according to Statistics South Africa (2011) agriculture is the main economic activity in the area, consisting of cattle farming in the largest parts of the municipality, while intensive agriculture (irrigation) occurs in the Great Hartsriver Valley. Agricultural households in GTLM stand at 18 255, and livestock contributes 38.1% of the economy, poultry (41.9%), vegetables (6.0%) and other crops (4.3%) (Statistics South Africa, 2011). Majority of the population constitutes the historical disadvantaged groups, and poverty level in the area stands 49.8%. Most of the households in area have also been noted to rely on external economic activities, especially government grants (Statistics South Africa, 2011). Studies conducted by Tekana & Oladele (2011) show that pensions (33%) are a great contributor to many households in the area.

Greater Taung Local Municipality has relatively large household sizes with an average of 4.4 persons per household. Majority (52.8%) of households are headed by men as compared to 48.2% for females in 2010. With reference to education, a large proportion of the population (75%) have completed secondary school education, while 13% have obtained tertiary education (Statistics South Africa, 2011).

4.4 Irrigation

At present 3 764 ha is developed for irrigation in Taung with 411 farmers participating. Centre pivots cover 2 756 ha and sprinklers 1 008 ha. No surface irrigation is practiced (cf Vaal Harts). When the Taung irrigation scheme was initially developed, it consisted of small plots of between 1.5 and 1.7 ha. During the development of the irrigation scheme in 1978, flood irrigation was replaced by centre pivots and overhead sprinklers. Larger units of up to 10 ha replaced the small plots. The choice for installing centre pivots was made in the late 1970s (under Agricor) with the objective to mitigate against the rising water tables in the existing surface irrigation scheme. It was felt that the greater application efficiency of pivots over flood irrigation would minimise losses to deep percolation, so controlling and eventually lowering the water table. The main crops that are cultivated in the Taung region are barley, maize, groundnuts, wheat, vegetables and fruit trees.

Water used by the Taung irrigation scheme is sourced from the Vaal River at Warrenton weir. There is a main canal from the weir at Warrenton to the three Taung dams. The north canal enters the Taung irrigation scheme at the eastern comer of the irrigation area, at an elevation of ±1 145 m AMSL. The capacity of the north canal carrying water from Warrenton to Taung is 245 m^3/s at the rightful discharge rate. The three dams in the irrigation scheme feed smaller dams as well as the Mokassa pipelines. The water allocation rights for the area were amended in 1979 when the allocation increased from 7 700 $m^3/ha/a$ to 8 678 $m^3/ha/a$.

Table 4.1: Flow rates of the canal at various Cooperatives

Farmer Support Unit	**Flow rate of canal (m^3/h)**
Tshidiso north and mid	2 360
Tshidiso south	2 030
Pudimo	3 014
Bosele	2 281
Ipelegeng	2 030
Rethuseng	gravity pipeline

Three receiving dams feed other smaller dams. A water bailiff controls the water at each dam. This means that water is distributed to different areas or Farmer Support Units (FSUs) by water bailiffs. The water bailiff is supposed to check the dam levels and report to the relevant section to open or close the water. One problem that is currently experienced is that the capacities of the Pudimoe dams are small, and cannot carry enough water for the 640 ha of cultivation.

The dams in the five FSUs (farmer cooperatives) as well as the number of centre pivots supplied by them are as follows:

- *Tshidiso*

  Tshidiso irrigation is supplied by Dam 6. There are three feeder dams at Tshidiso. They are the Jim Molale Middle dam with six centre pivots, the Jim Molale South dam with four centre pivots and the Jim Molale North feeder dam with four centre pivots.

- *Bosele*

  Bosele is supplied by Dam 1 and has four small dams. They are Molale East with five centre pivots, Molale West also with five centre pivots, Bogosing Northeast dam with two centre pivots, and Bogosing Middle and West with six centre pivots.

- *Ipelegeng*

Ipelegeng has three dams, namely Mokgareng North with six centre pivots, Mokgareng South with six centre pivots and Smous dam with six centre pivots (of 20 ha each).

- *Rethuseng*

Rethuseng is under overhead sprinklers supplied directly from Dam 1. The water is gravitationally supplied.

- *Pudimoe*

Pudimoe is supplied by Dam 7. It is the lowest area and suffers the most from poor water distribution. There are two small dams, namely Pudimoe South with six centre pivots (of 40 ha each), and Pudimoe Middle and South with ten 40 ha centre pivots. This FSU sometimes stays for three days without water, and naturally, this affects the grain yield.

There is a tendency amongst farmers to irrigate up to 7 mm during the first irrigations after planting. The pivots run at 100% speed and are accordingly only able to deposit a relatively small quantity of water. This form of irrigation is practiced for almost eight weeks after planting and the result is that water shortages are often experience during this period (Kokome, 2017).

4.5 Organisational structure of Taung

The Taung Irrigation Scheme was established in 1939 by the South African government as part of the Vaalharts Irrigation Scheme. During the 1970s, political and administrative independence of the Bantustan or native area was encouraged, resulting in the central government's withdrawal and homeland administration taking over. This prompted the incorporation of the Taung Scheme into the Bophuthatswana homeland during the independent homeland era, which lasted from 1970 until 1990s and was an integral part of the economic development of the homelands (Tekana & Oladele, 2011). Taung irrigation scheme was an effort to expand the welfare of small scale farmers socially and economically through job creation so as to promote rural development in the area. Institutions such as South African Breweries (maize and barley); Cotton South Africa (cotton); North West Department of Agriculture, Conservation and Environment; and Department of Water Affairs were brought together for better management of the scheme (Golder Associates, 2004; DoA, 2013).

Small scale irrigation farmers are selected from local people living in abject poverty by the Taung Traditional Authority and the Department of Agriculture. The sustainability of Taung

Irrigation Scheme depends on the existing institutional structures, which includes the formation of farmers' cooperatives or support units and a management committee (DoA, 2013).

- **Farmer Cooperatives**

Farmers' cooperatives represent the farmers in five areas of the scheme in the management committee. The cooperatives are the selection of an appropriate legal entity for the ownership and self-management of the scheme by the farmers. Farmers are responsible for minor repairs and the replacement of electrical cable in the case of cable theft. The cooperative management committees consist of the following members: chairman, secretary and treasurer. The management of the cooperatives meets every second week of the month. New management is selected after three years.

- **Management Committee**

The scheme also has a Maize and Barley Industrial Committee. These management committees are composed as follow:

Composition:

- The producers agreed on two barley/maize producers from each F.S.U.
- The committee is composed of the following members: chairperson, vice chairperson, the secretary, deputy secretary and two members.
- Any barley/maize producer, who is above 18 years of age may be elected on the industry committee.

Powers:

- Provision of barley/maize information in the Taung irrigation scheme, exercise, for and on behalf of producers.
- Arrange meetings on their own and invite SAB if need be.
- Acquire information on the crop: agronomical, market, new cultivars and provide farmers information.
- Arrange farmers days or green days for the barley/maize producers.
- Arrange walk and talk with barley farmers in conjunction with SABM.
- Becomes a member of another cooperative or of any association or organization which promotes any matter in which barley /maize production is an interest.
- Act as an agent of barley/maize producers in connection with any development in the Taung irrigation scheme.
- Give information and guidance to barley/maize producers.

The opinion of SAB is that this committee is not functioning well and new initiatives should be identified to address the challenges. The use of external contractors for fertilising, spraying in Taung is not effective from a SAB point of view, but should rather be farmer driven. This committee can play a major role in the identifying of potential farmers for these jobs, if it is properly functioning. This has resulted in the farmers not having proper and communicable channels through which they can raise their concerns, needs and problems with the strategic partners. Also, this has led to poor relations with other stakeholders hence poor management of the scheme (BFAP, 2015).

- **Strategic partners**

  The scheme is operated as a public-private partnership that involves small scale farmers, Department of Agriculture, Conservation and Environment (North West), Department of Water Affairs, traditional authority and South African Breweries (SAB) or currently known as Anheuser BuschInBev.

  a. SA Breweries (Anheuser BuschInBev).

  The role of SAB Breweries is:

  - To ensure a sustainable source of income for smallholder farmers on the scheme by providing a market for them
  - To provide off-take contracts to farmers in the scheme (barley and maize), thereby providing the farmers with a secure market for their produce, as long as they produce acceptable quality and quantity.
  - Full time agricultural advisor support barley and maize farmers (weekly visits to farmer groups and fields)
  - To ensure that farmers are irrigating and applying the correct fertilisation

  b. FARMSOL

  FARMSOL plays a role as input supplier and crop financier, especially in cases where farmers are planting alternative crops (not GM free maize and barley). Since no formal agreement /contract exist between the Tribal Authority and the farmers, that show they own the land, they find it hard to successfully apply for finance. This is a very important role that is played to ensure sustainable crop production on Taung, since through this initiative the production of other crops like groundnuts, maize for silage, lucerne, etc. are enclosed in the crop rotation.

  c. Department of Water Affairs/Vaalharts Water User Association

  The Department of Water Affairs is the custodian of the Vaalharts bulk water system, while Vaalharts Water Users Association (VWUA) is responsible for the operation, management and maintenance of the bulk water system. This includes the inlet structures and tunnel in the weir, the balancing dams and all sluices along the system. Clearing of vegetation along all the canals is the responsibility of the VWUA. This process is currently in place through an existing tender process. The clearing of vegetation on the community furrows is the responsibility of the farmer.

The irrigation canals are more than sixty years old, while most of the drainage canals are forty years and older. These canals need to be refurbished urgently. The main canal was enlarged by raising the concrete lining to increase the capacity from 28 m^3/s to 48 m^3/s. This action increased the leakages through the old deteriorating concrete lining. The secondary and tertiary canals were not enlarged and are also in a bad condition.

d. Department of Agriculture, Conservation and Environment (North West)

The pivots of the irrigation project are maintained by the Provincial Department of Agriculture North West through CASP funding, while technical assistance with regard to engineering, crop management (especially for crops other than maize and barley), research and financial support are rendered. The Department facilitates training workshops to improve farmer skills. It provides machinery such as tractors, ploughs and planting equipment for production.

e. Traditional Authority

The Traditional Authority provides land for irrigation farmers through the administration of PTO's on the irrigation scheme.

4.6 Production of barley

Different production factors have an important effect on the yield and malt quality of barley. The most essential are planting date, planting density, nitrogen fertilisation and irrigation (ARC, 2016). The project sites at Taung irrigation scheme where barley was grown and project data was collected during the winter of 2018 are: Bosele, Ipelegeng, Pudimoe, Rethuseng and Tshidiso. Two farmers from Bosele and two from Ipelegeng participated in the project in the 2018 winter cropping season. Their data is not discussed in this report. Unfortunately, very little data was collected during the first winter season of the project (2017) because of the SAB extension advisor's other work commitments. More consistent data collection took place during the second winter season (2018). This report does not discuss the data collected from all the installations of Chameleon sensors in every plot in Taung but looks at some interesting observations.

4.6.1 Pudimoe

A total of 16 centre pivots covering 640 ha are at the Pudimoe site at Taung (Figure 4.3). Twenty-eight growers who farm an area of 330 ha participated in the project in the 2018 winter barley cropping season (Table 4.2). Each farmer planted one variety of barley, Overture, at a seeding rate of 70-75 kg/ha, on a 10 ha plot. However, some farmers had more than one irrigation plot at Pudimoe. The previous crop on all the plots at Pudimoe was groundnuts. The soil types on the different plots mostly ranged from sandy loam to clay loam, but three of the plots had sandy soils. A split application of fertilizer was applied before planting through the centre pivots at a rate of 101 kg N/ha, 30 kg P/ha and 45 kg K/ha on all the plots at Pudimoe. An additional 34 kg N was applied six weeks after planting. A further 0-30 kg N/ha was applied on some farmer's plots through fertigation between heading and maturity. Barley was planted in all plots towards the end of June and Chameleon sensors were installed at depths of 20, 40 and 60 cm in each plot between the last week of June and first week of August (Table 4.2).

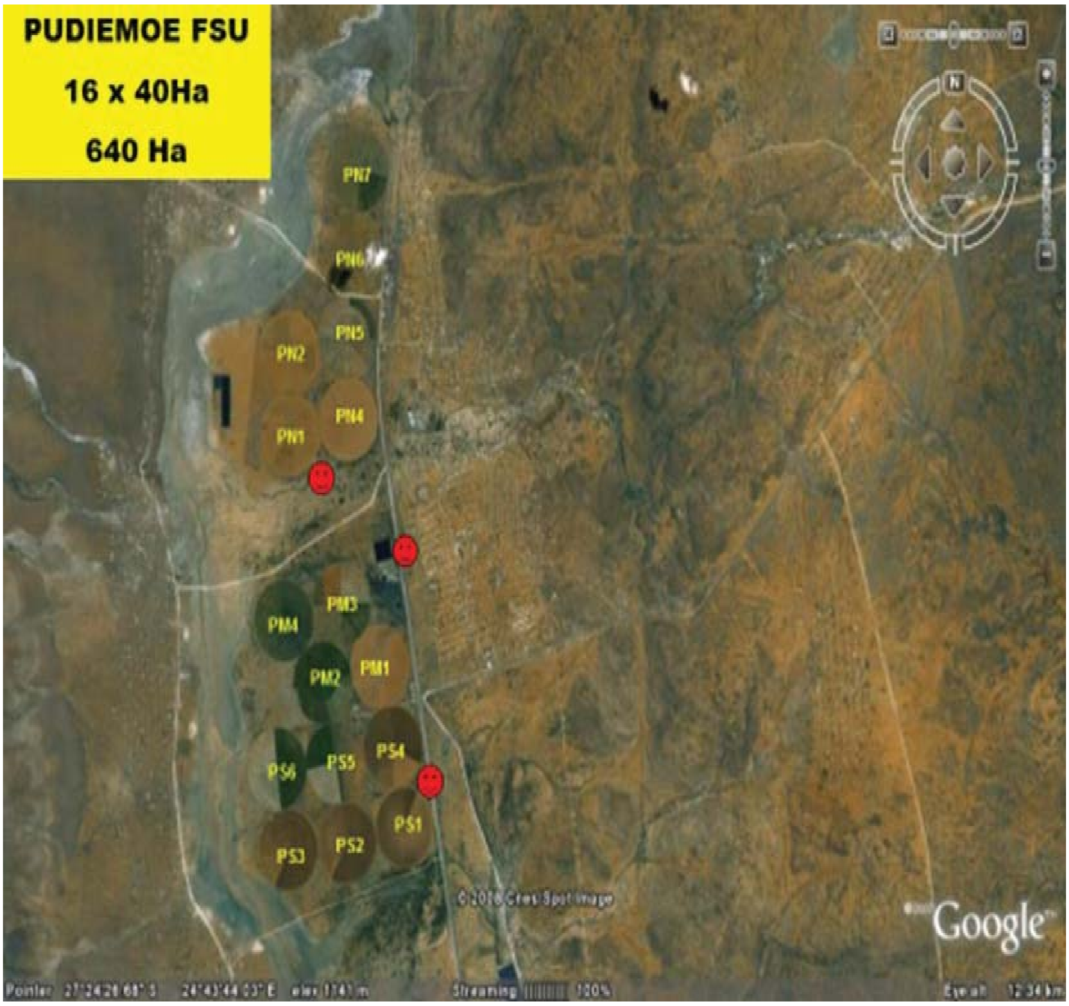

Figure 4.2: Centre pivots at Pudimoe, Taung.

Table 4.2: Land number, plot size, planting date and sensor installation date at Pudimoe, Taung.

Land no	Size (ha)	Planting date	Date of sensor installation
PM2 SW	10	21-Jun	07-Aug
PM2 NW	10	21-Jun	31-Jul
PS6 SW	10	23-Jun	23-Jun
PM2 NE	10	21-Jun	31-Jul
PS3 NW	10	21-Jun	01-Aug
PM2 SE	10	21-Jun	31-Jul
PS2 SE	10	21-Jun	31-Jul
PS3 SW	10	21-Jun	23-Jul
PN5 SW	10	21-Jun	08-Aug
PN5 NW	10	21-Jun	08-Aug
PN5 NE	10	21-Jun	08-Aug
PM3 SW	10	23-Jun	24-Jun
PM3 NE	10	23-Jun	30-Jun
PM3 SE	10	23-Jun	03-Jul
PM3 NW	10	23-Jun	24-Jun
PN2 NE	10	21-Jun	08-Aug
PS1 NW	10	21-Jun	01-Aug
PS1 NE	10	21-Jun	31-Jul
PS1 SW	10	21-Jun	31-Jul
PS1 SE	10	21-Jun	31-Jul
PS3 SE	10	21-Jun	31-Jul
PS3 NE	10	21-Jun	01-Aug
PS4 NE	10	21-Jun	31-Jul
PS4 NW	10	21-Jun	31-Jul
PS4 SE	10	21-Jun	31-Jul
PS4 SW	10	21-Jun	31-Jul
PS5 NE	10	21-Jun	23-Jun
PS5 SW	10	21-Jun	23-Jun
PS5 NW	10	21-Jun	23-Jun
PS6 NE	10	23-Jun	23-Jun
PS6 SE	10	23-Jun	23-Jun
PS6 NW	10	23-Jun	24-Jun
PN2 NW	10	21-Jun	23-Jun

The soil water patterns on the farmers' plots varied widely as shown in the triad below (Figure 4.3). Each point on the triad represents a single crop, by integrating the Chameleon pattern to give percentage blue, green and red colour. For example, the soil water pattern for plot PS6 NE on the left of the triad had 86% blue, 11% green and 3% red colour, whilst the pattern for PM3 SW on the right of the triad had a 14% blue, 56% green and 30% red colour. Most of the patterns were clustered between 20-60% blue, 10-30% green and 20-60% red.

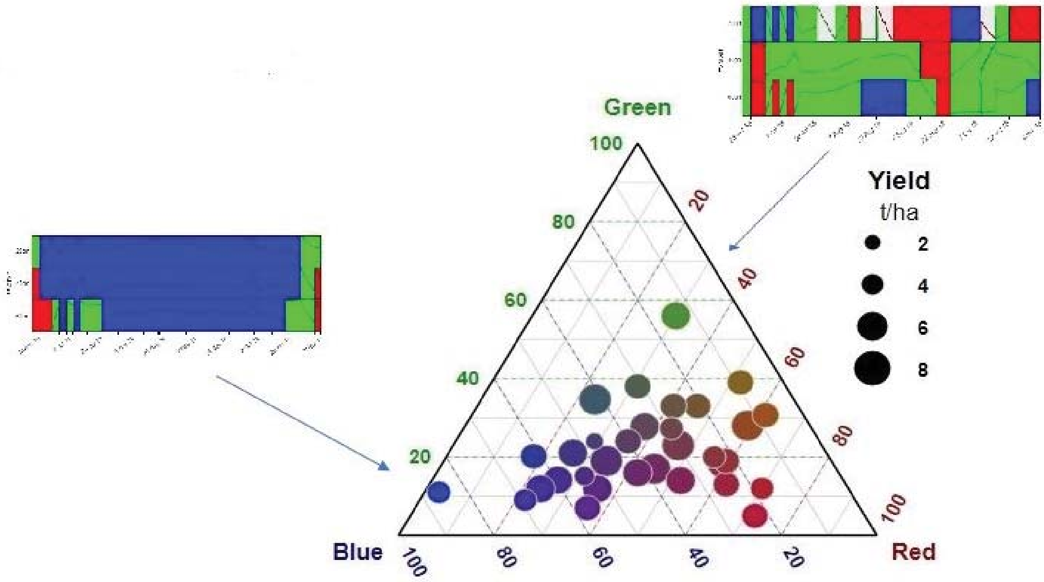

Figure 4.3: Integrated Chameleon soil water patterns for barley grown at Pudimoe, Taung.

None of the plots were more than 75% blue throughout the crop growth period, except PS6 NE. In this plot, the soil remained wet (blue) for most of the crop growth period except at the beginning and end of crop development (Figure 4.4).

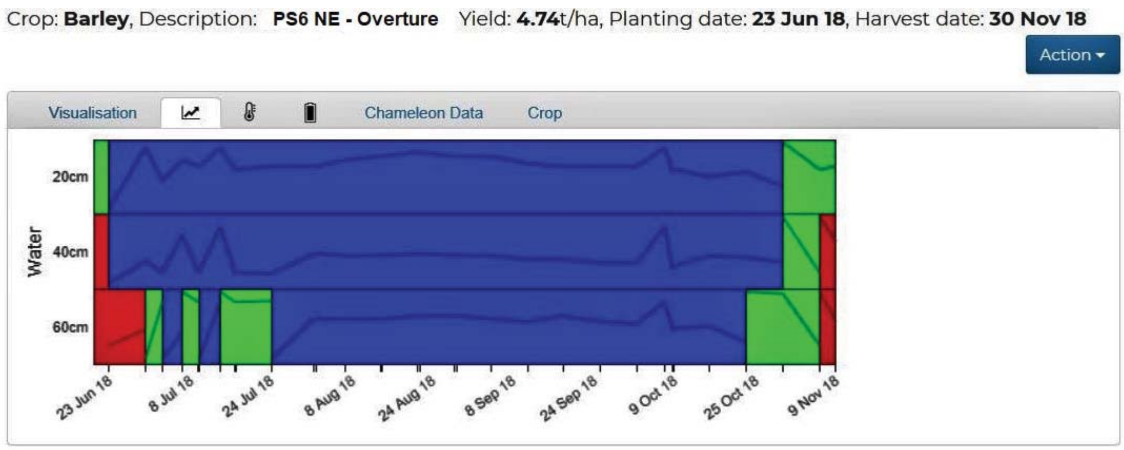

Figure 4.4: Chameleon soil water pattern for barley grown by plot PS6 NE at Pudimoe

However, the black line (showing the trend within the colour patterns) in the two bottom blue patterns shows that although the soil was wet, it was not excessively so, it remained within the middle of the range. This farmer achieved a yield of 4.74 t/ha. Although her yield was lower than the average yield among project participants at Pudimoe, which was 5.9 t/ha, it is difficult to conclude that this was solely a result of the wet soil profile through the crop growth period.

It is likely that other factors besides over-irrigation, such poor crop husbandry, may have contributed to the relatively low yield.

The highest yield at Pudimoe among project participants was achieved by the farmer on plot PS3 SE who harvested 7.2 t/ha and the lowest yield was 3.4 t/ha which was achieved by PM3 SW (Figure 4.6). During the first two months of crop growth, the sensors in plot PM3 SW plot primarily showed a blue colour at all three depths (Figure 4.5). However, the black line in the bottom blue pattern shows that although the soil was wet it was at the bottom of the range (closer to a moist soil of 20-50 kPa). The grey colour in the pattern indicates that the sensor cables were disconnected (open circuit). Sensors were red at two depths from the beginning of September and all three depths from the middle to the beginning of October.

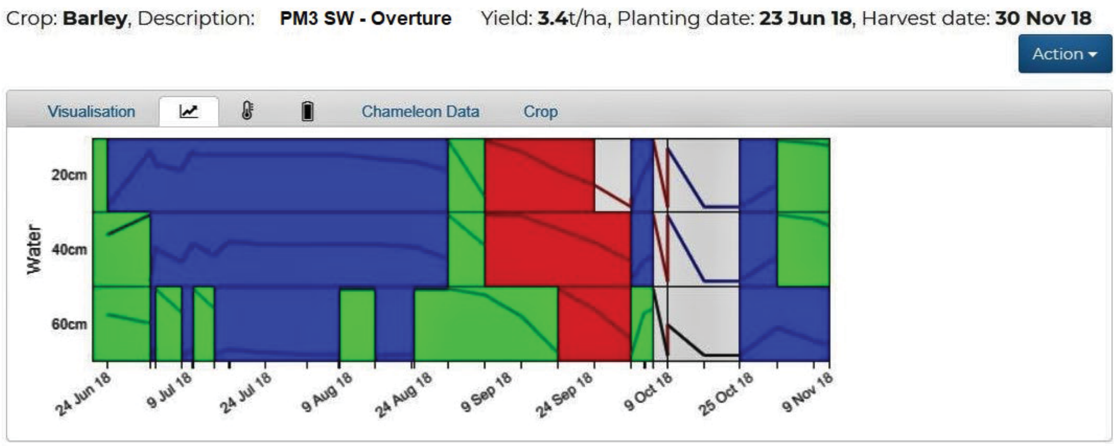

Figure 4.5: Chameleon soil water pattern for barley grown on plot PM3 SW at Pudimoe

Barley needs different amounts of water during different growing stages. During the hot sunny days of September and October the centre pivot should be run at slower speeds to replace the water that is lost due to evaporation (Kokome, 2004). This hot summer period coincides with the reproductive phase of barley when soil moisture is critical for establishing a good yield. It could be argued that the low yield of the farmer on plot PM3 SW (at least in part) is a result of the water stress that the crop experienced at a critical stage.

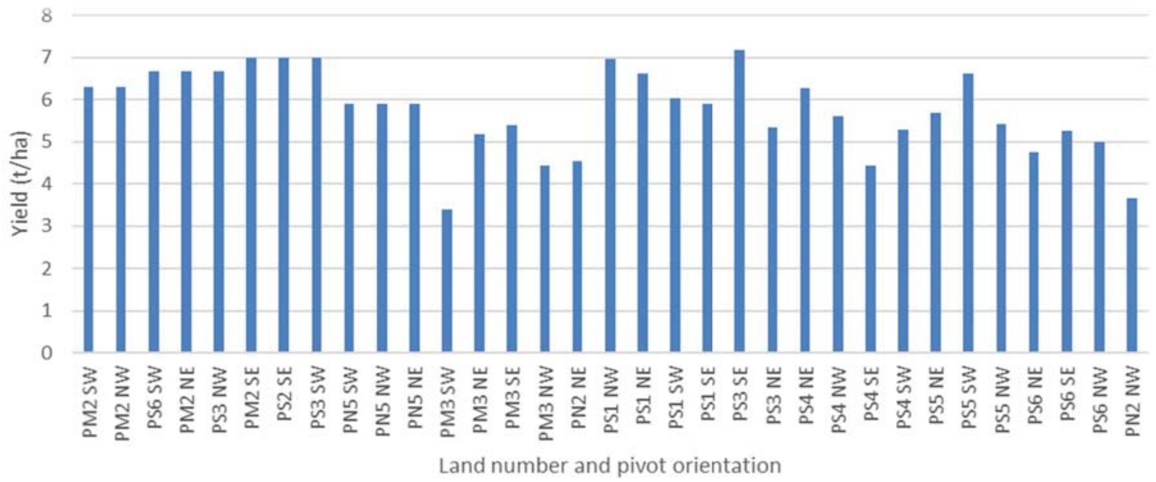

Figure 4.6: Barley yields of project participants at Pudimoe, Taung.

4.6.2 Rethuseng

Seven farmers covering an area of 55 ha participated in the project in the 2018 winter cropping season (Table 4.3). All the farmers at Rethuseng use a sprinkler irrigation system and planted one variety of barley, Christalia, at a seeding rate of 70 kg/ha. Six farmers planted barley on 7.5 ha and one planted on 10 ha. The previous crop at Rethuseng was maize. The soil types on the different plots varied from sandy loam to clay loam. A split application of fertilizer was applied before planting at a rate of 101 kg N/ha, 30 kg P/ha and 45 kg K/ha on all the plots at Rethuseng and an additional 34 kg N was applied six weeks after planting. Barley was planted in all plots in the second week of June and Chameleon sensors were installed at 20, 40 and 60 cm depths in each plot in August (Table 4.3).

Table 4.3: Land number, plot size, planting date and sensor installation date at Rethuseng, Taung.

Land no	Size (ha)	Planting date	Date of sensor installation
2F17	10	11-Jul	07-Aug
2F3	7.5	10-Jul	07-Aug
2F4	7.5	12-Jul	30-Aug
2G11	7.5	11-Jul	02-Aug
2G9	7.5	10-Jul	07-Aug
B2-7	7.5	08-Jul	02-Aug
E9	7.5	12-Jul	07-Aug

The integrated points of the soil water patterns on the farmers' plots were all above 40% blue and less than 35% red (Figure 4.7). The point at the edge of the blue corner of the triad is the pattern of plot 2F4 (Figure 4.7).

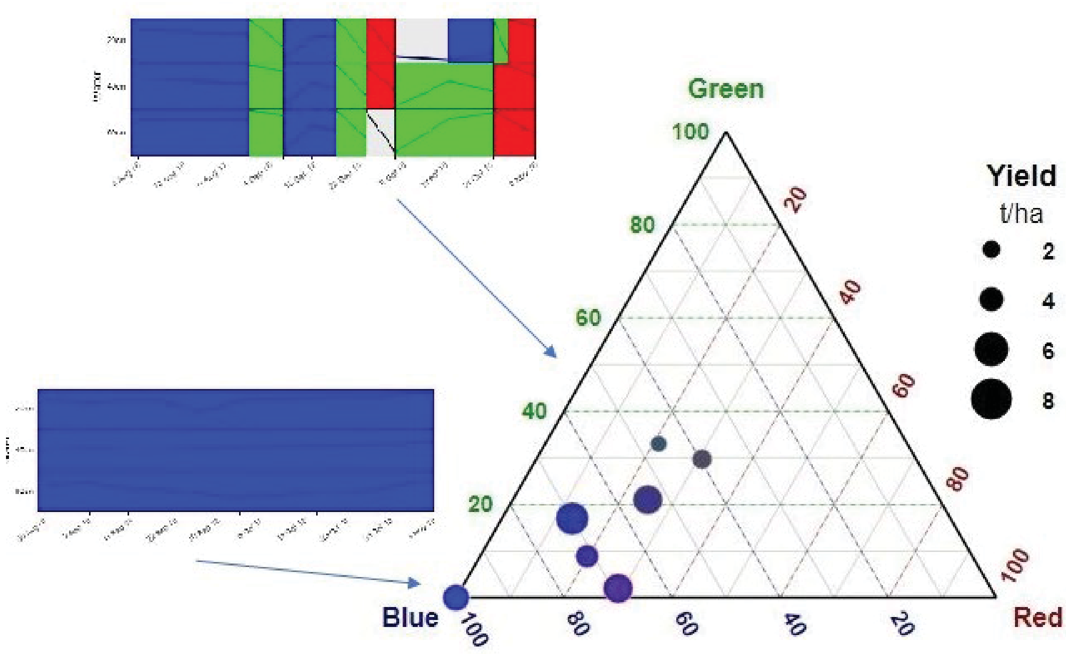

Figure 4.7: Integrated Chameleon soil water patterns for barley grown at Rethuseng, Taung.

The sensors on this plot were blue (wet) from 30 August to 8 November (Figure 4.7 and 4.8). Unfortunately, the sensors were installed 1½ months after the crop was planted therefore there is no record of the early stages of crop development. The soil remained wet throughout the latter stages of crop growth until early November. Although excessive irrigation after the crop is well developed could promote lodging, this did not occur in this instance (FAO, 2012). The farmer on plot 2F4 obtained a yield of 4.51 t/ha.

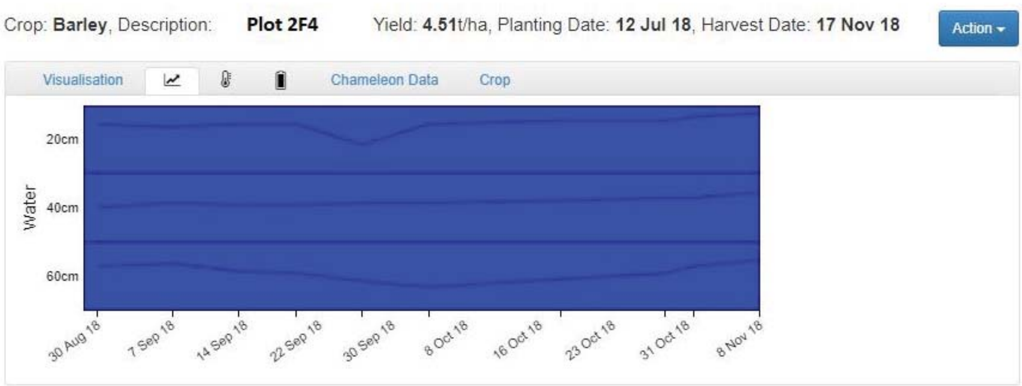

Figure 4.8: Chameleon soil water pattern for barley grown on plot B2F4 at Rethuseng

The highest yield at Rethuseng among project participants was achieved by the farmer on plot 2F17i who harvested 6.5 t/ha and the lowest yield of 2.04 t/ha was achieved by the farmer on plot B2-7 (Figure 4.9). The latter was also the lowest yield among all the farmers that grew barley at Taung in 2018. The average yield among project participants was 4.55 t/ha.

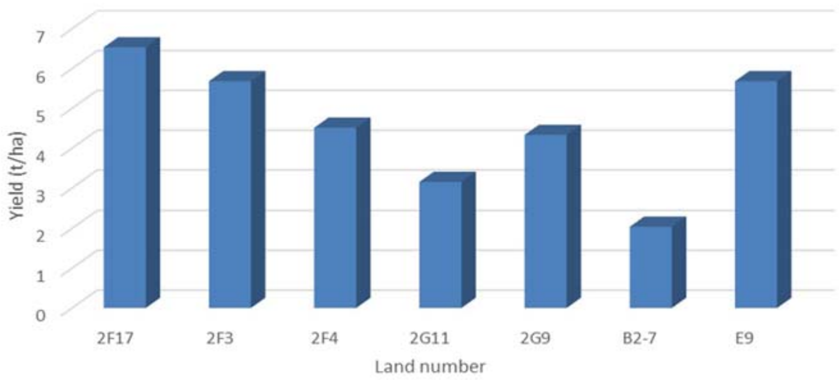

Figure 4.9: Barley yields of project participants at Rethuseng, Taung.

The soil water pattern of plot B2-7 did not look very different from other farmers patterns participating in the project at Rethuseng (Figure 4.7 and 4.10). During the first two months of crop growth, the sensors in plot B2-7 showed a blue or green colour at all three depths. The sensors remained red for only a few days before irrigation was applied and the sensors turned blue or green. At the end of October and towards the time of harvest, the sensors turned red for a period of one week. This pattern does not indicate prolonged periods of water stress during critical stages of crop development. In fact, the pattern is typical of many of the other plots at Rethuseng and other sites. It is apparent that the very low yield of plot B2-7 points to other contributing factors with regard to crop management that resulted in the poor harvest.

Figure 4.10: Chameleon soil water pattern for barley grown on plot B2-7 at Rethuseng

4.6.3 Tshidiso

A total of 14 centre pivots covering 560 ha are at the Tshidiso site at Taung (Figure 4.11). Twenty-two farmers covering an area of 220 ha participated in the project in the 2018 winter cropping season (Table 4.4). Each farmer planted barley (Overture) on a 10 ha plot at a seeding rate of 70-75 kg/ha. The previous crop on all the plots at Tshidiso was groundnuts. The soil types on the different plots varied from sandy loam to clay loam. As was the case at Pudimoe, a split application of fertilizer was applied before planting through the centre pivots at a rate of 101 kg N/ha, 30 kg P/ha and 45 kg K/ha on all the plots. An additional 34 kg N was applied six weeks after planting. A further 0-30 kg N/ha was applied on some farmer's plots through fertigation between heading and maturity. Barley was planted in all plots from the second half of June to the first week of July and Chameleon sensors were installed at 20, 40 and 60 cm depth in each plot between the last week of June and first week of August (Table 4.4).

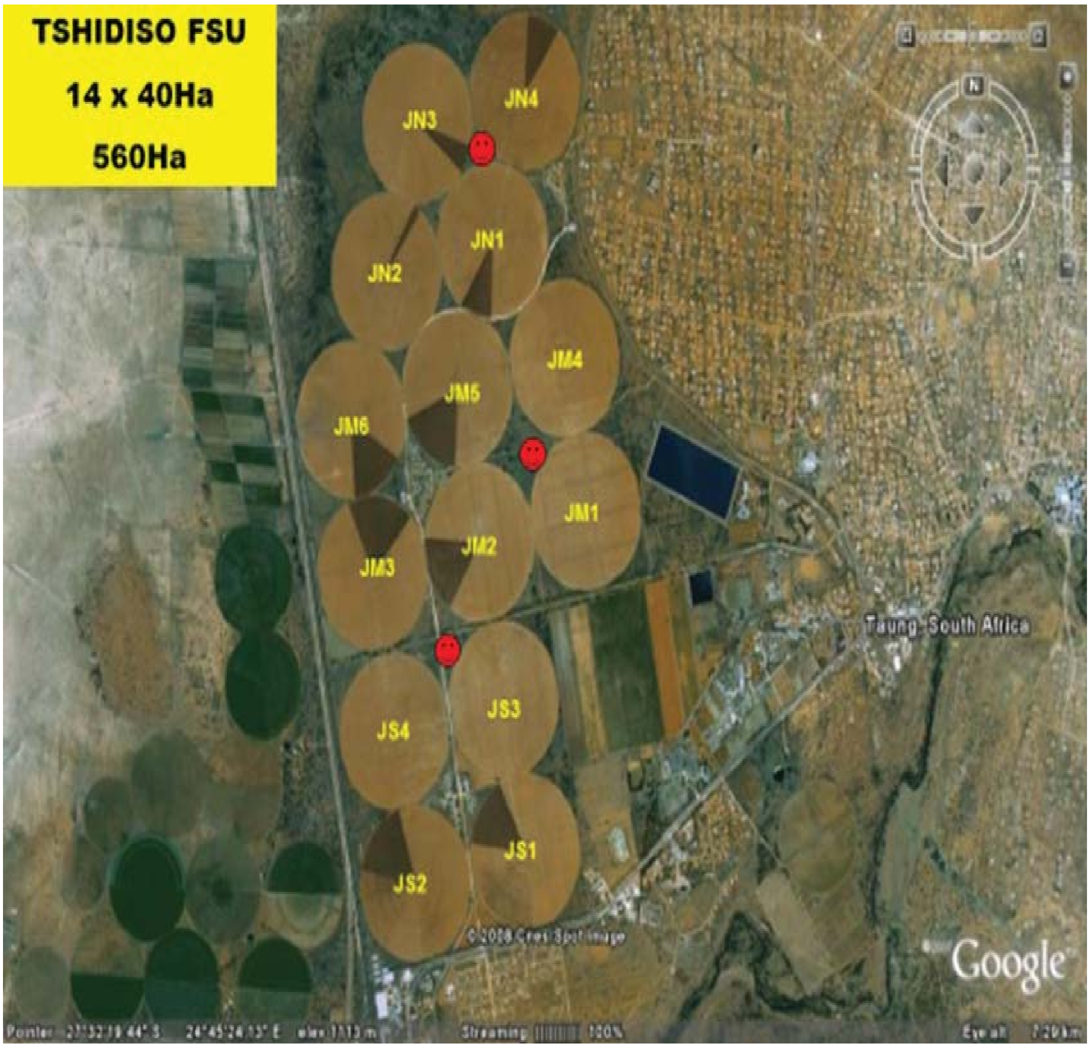

Figure 4.11: Centre pivots at Tshidiso, Taung.

Table 4.4: Land number, plot size, planting date and sensor installation date at Tshidiso, Taung.

Land no	Size (ha)	Planting date	Date of sensor installation
JM1 NW	10	15-Jun	03-Aug
JM3 SW	10	25-Jun	28-Jun
JM3 SE	10	25-Jun	28-Jun
JM4 NW	10	15-Jun	03-Aug
JM4 SE	10	15-Jun	03-Aug
JM4 NE	10	15-Jun	03-Aug
JM5 NW	10	19-Jun	03-Aug
JM5 SW	10	19-Jun	03-Aug
JM6 NW	10	02-Jul	03-Aug
JM6 SE	10	02-Jul	03-Aug
JM6 NE	10	02-Jul	03-Aug
JM6 SW	10	06-Jul	03-Aug
JN4 SE	10	16-Jun	03-Aug
JN4 NW	10	16-Jun	01-Aug
JN4 NE	10	16-Jun	03-Aug
JS2 SE	10	21-Jun	28-Jun
JS2 SW	10	19-Jun	03-Aug
JS2 NW	10	21-Jun	26-Jun
JS3 SW	10	18-Jun	03-Aug
JS4 SW	10	20-Jun	28-Jun
JS4 NW	10	20-Jun	28-Jun
JS4 SE	10	20-Jun	26-Jun

The integrated soil water patterns on the farmers' plots were widely distributed in the triad in Figure 4.13. Most of the patterns were clustered between 30-60% blue, 10-30% green and 20-60% red. Two of the plots were more than 80% blue throughout the crop growth period. Both of these soil water patterns remained blue for most of the crop growth period except brief times when the sensors turned green (and in one case the top sensor turned red).

In plot JM6 NE (bottom left pattern in the triad) the top sensor only showed a red colour for brief period between the end of September and the beginning of October, whilst the bottom two sensors were green mainly between the end of September and the middle of October (Figure 4.12 and 4.13).

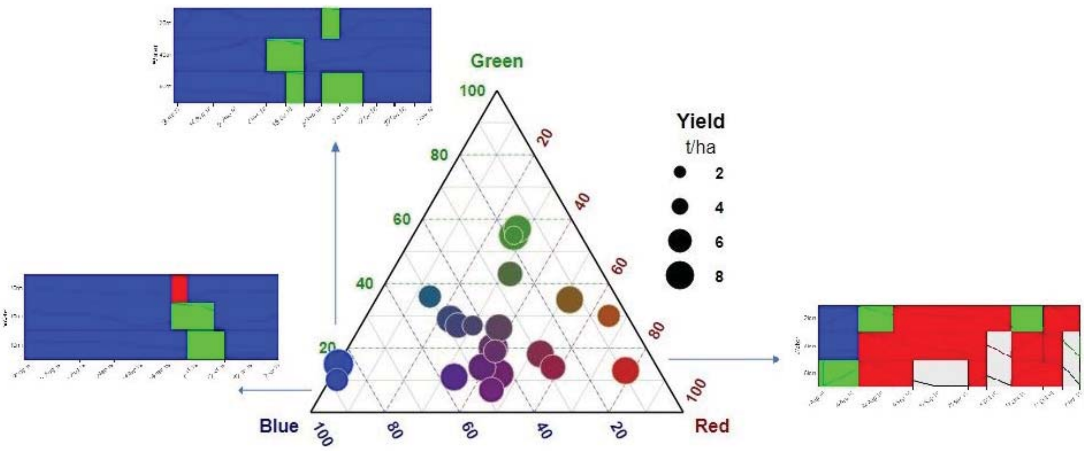

Figure 4.12: Integrated Chameleon soil water patterns for barley grown at Tshidiso, Taung.

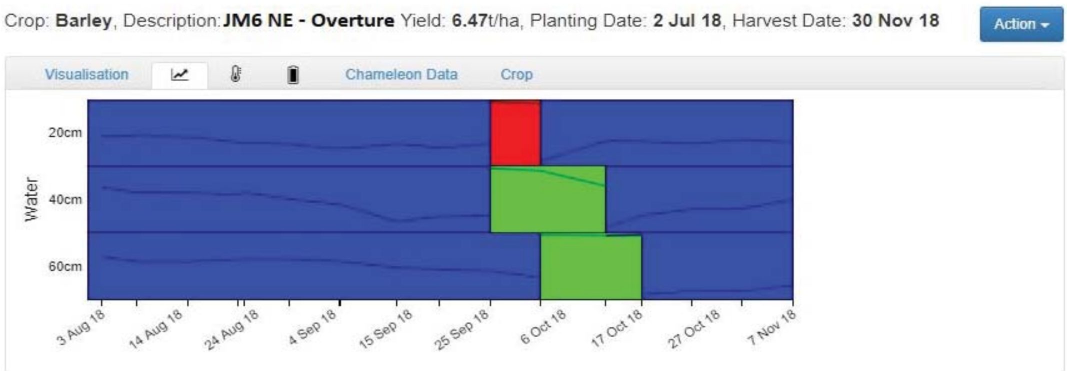

Figure 4.13: Chameleon soil water pattern for barley grown on plot JM6 NE at Tshidiso

In the case of plot JS3 SW, the soil water pattern never showed a red colour from the beginning of August to the beginning of November (Figure 4.14). The sensors at all three depths switched between blue and green from September to October. In both cases (Figure 4.13 and Figure 4.14), although the soil water patterns were mainly blue throughout the crop growth period indicating that the soil profiles were wet, the black lines within the blue patterns show that the soil, although wet, was not extremely damp. The seasonal water requirements for barley depend on the cultivar, target yield and crop management. Barley requires between 450 and 650 mm of water for optimum yield (FAO, 1986). Malt barley may require better water management than feed barley to maintain the protein content of the grain and meet the standards set by maltsters (Kokome, 2004). As with many crops, the mid-season stage (flowering and grain setting or yield formation) of crop growth is most sensitive to water shortages (FAO, 1989). This is mainly because it is the period of the highest crop water needs. If water shortages occur during the mid-season stage, the adverse effect on the yield will be severe. Observing contrasting soil water patterns, at opposite corners of the triad, with dry and wet soil profiles at the onset of the reproductive stage of crop growth raises interesting points of discussion (Figure 4.12). The soil water pattern for JM4 NW (Figure 4.15) was completely different to that of JM6 NE (Figure 4.13) and JS3 SW (Figure 4.14). Whereas plots JM6 NE and JS3 SW were over 85% blue, that of JM4 NW was 78% red.

Figure 4.14: Chameleon soil water pattern for barley grown on plot JS3 SW at Tshidiso

As is the case for all crops, the response of barley to water stress depends on timing, duration, and severity of the stress (FAO, 2012). Stress effects on yield may range from slight enhancement, to virtually no effect, to different ranges of yield reduction, and even to crop failure.

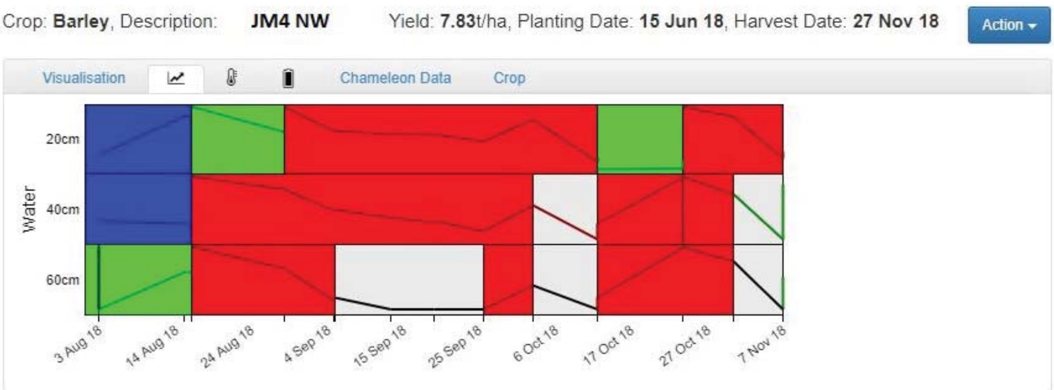

Figure 4.15: Chameleon soil water pattern for barley grown on plot JM4 NW at Tshidiso

The bottom two sensors of plot JM4 NW show that the soil was dry from the middle of August to the beginning of November (Figure 4.15). The top sensor was also dry for a significant period of time. The duration of the dry period appeared to cover the entire mid-season stage of crop growth. In fact, the soil was so dry (end of the red zone) that it went beyond the accuracy of the Chameleon reader showing this as a grey colour on the visualisation. It is important to note that more frequent readings during this period would have given a better picture of the changes that were taking place in the soil water status. The Chameleon sensors remain in the green colour for relatively short periods of time and quickly switched to red. The relatively dry soil profile of plot JM4 NW does not appear to reflect the respectable yield of 7.83 t/ha that the farmer achieved (Figure 4.15). His yield was the same as the average yield of all project participants (7.83 t/ha) at Tshidiso.

The highest yield at Tshidiso among project participants was achieved by plot JS3 SW which produced 9.2 t/ha and the lowest yield of 4.77 t/ha was achieved by JN4 SE (Figure 4.16). The latter was the only farmer among the project participants at Tshidiso to achieve less than 5 t/ha.

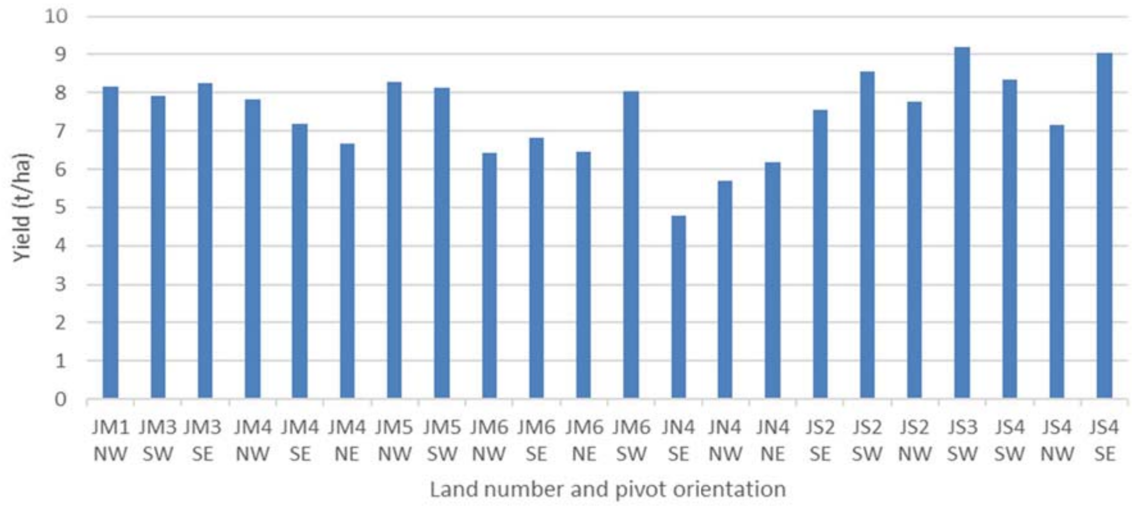

Figure 4.16: Barley yields of project participants at Tshidiso, Taung.

The pattern of plot JN4 SE switched between green and red from the end of August to the beginning of November (Figure 4.17). The pattern never showed a blue colour from the beginning of September until the beginning of November. Again, more frequent readings during this period would have given a better picture of the changes that were taking place in the soil water status. The visualisation of plot JN4 SE clearly shows that the soil water status was better than that of JM4 NW, yet the latter achieved 3 t/ha more.

Figure 4.17: Chameleon soil water pattern for barley grown on plot JN4 SE at Tshidiso

4.6.4 Production of barley during the winter season summary

The average production yield for barley for the various projects at Taung varied between 4.6/ha (Rethuseng) and 7.83 t/ha (Tshidiso) (Figure 4.18). These differences between projects are mainly because of management practices. All project sites make use of centre pivot irrigation, except for Rethuseng where hand shift irrigation systems are used. All project sites with the exception of Rethuseng receive a weekly irrigation recommendation supplied by a private irrigation scheduling agent using Aquacheck sensors. At Rethuseng farmers make use of handshift systems through gravitation and use a fixed weekly irrigation schedule based on the recommendations of the SAB extension agent and their own observation. The reason for this difference is because farmers of Rethuseng are not prepared to pay an additional fee for the private irrigation scheduling recommendations. Also at Rethuseng the main and sub-main lines are relatively old (approximately 20 years) and leaking pipelines is a major constraint for farmers. Farmers do not want to replace the current system (hand-shift) with centre pivots, although they complain about the labour intensity required for shifting pipes, they are of the opinion that the sharing of one water source by four farmers is not a sustainable solution. Farmers using the Chameleon plus the recommendations provided by the extension agent, produced slightly (4%) more than farmers that only followed the recommendations of SAB.

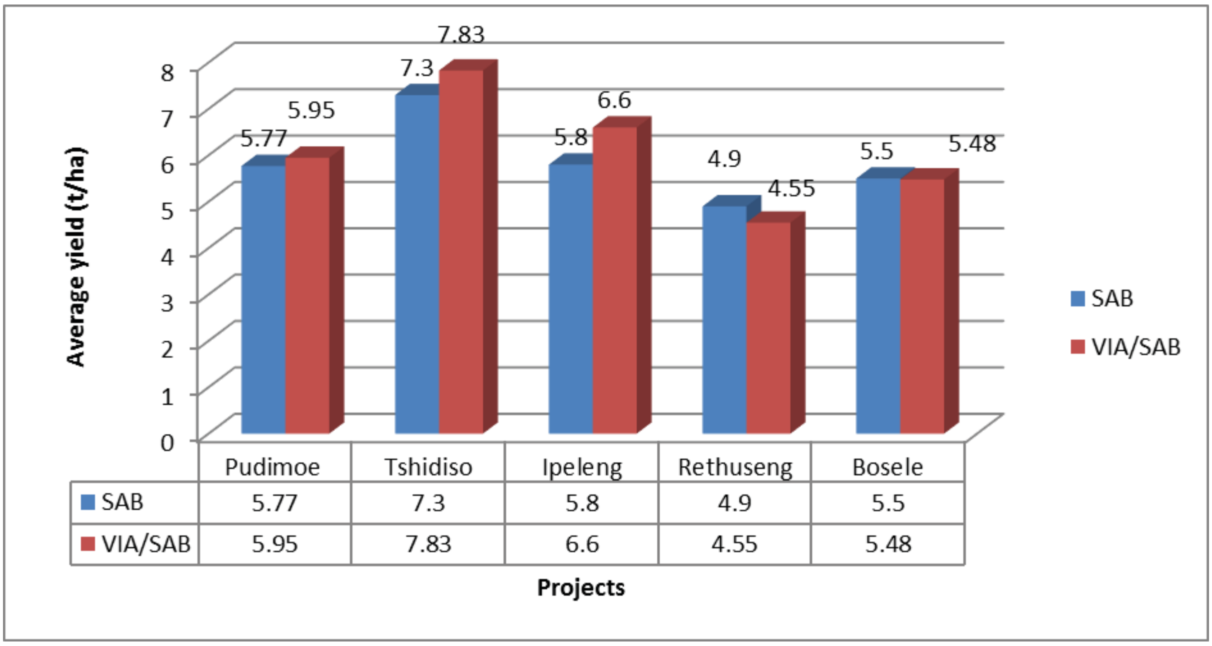

Figure 4.18: Average barley yields for the various sites at Taung during 2018

At Tshidiso farmers that made use of VIA plus Aquacheck recommendations produce on average 7% higher than their fellow farmers who only followed the Aquacheck recommendations provided weekly. At Tshidiso the cooperative is well organised and farmers have access to the Chameleon patterns every week (usually on Thursdays) when they receive Aquacheck irrigation recommendations. After access to the Chameleon patterns, farmers took an informed decision how much to irrigate. It is difficult to conclude that the higher production of farmers who have access to Chameleon data on these projects was purely because of the tools.

Apart from access to the Chameleon data, Tshidiso has enough water to irrigate all the plots. At Pudimoe farmers experience problems with poor water availability, as this project is supplied by Dam 7, which is the last dam served by the Vaalharts Water User Association. It is situated in the lowest area of the irrigation scheme and the canals feeding this project are old and leaking, and in general are too small to supply the irrigation project as well as Sedibeng (municipality) water Pudimoe Therefore it may happen that the flow rate of the canals are very low, which affects grain yields on the project. Pudimoe farmers using Chameleon data plus SAB recommendations produced on average 3% better than their fellow farmers who made only use of SAB recommendations. The data collector (who is also a leader farmer in Pudimoe) collected Chameleon data every week during the barley season, and played an active role in the sharing of weekly Chameleon patterns with farmers, since he was one of a few farmers who had a smartphone. The cooperative does not function well like the Tshidiso cooperative and members of this cooperative also do not have access to a computer where information like Chameleon patterns can be shared. Despite these stumbling blocks, Pudimoe farmers using the Chameleon perceived that the tool helped them extremely during periods of water availability challenges.

4.7 Production of non-genetically modified maize during the summer season

Twelve Chameleon sensor arrays were installed in the farmers' fields at Taung irrigation scheme during the summer of 2016-2017. The project sites at Taung irrigation scheme where non-genetically modified maize was grown are: Pudimoe, Reaitlhoma and Tshidiso. The monitoring of the Chameleon tools and the collection of data was consistent at all the project sites in Taung during the first summer season (2016-2017). The SAB extension advisor together with a lead farmer regularly uploaded data onto the website every week. Unfortunately, this was not the case during the 2017-2018 summer season when poor data collection and inconsistent uploads were experienced. Two famers who participated in the project during the summer of 2016-2017 grew groundnuts at Ipelegeng and Bosele. Their production is not covered in this report.

4.7.1 Pudimoe

Four farmers participated in the project in the 2016-2017 summer cropping season. Three of the farmers planted 10 ha of yellow maize (Grade 1) under centre pivots at Pudimoe, while one farmer planted 20 ha at Pudimoe under two different centre pivots (PS2 and PS3). Non-GM maize (varieties P1814R and P1816R) was planted under centre pivot PM3 (plot PM3 NE and plot PM3 SW) on 24 December 2016 and centre pivot PS2 (plot PS2 NW and plot PS2 SE) on 8 December 2016. All four plots had a plant population of 80 000 plants/ha and 137.5 kg N/ha fertiliser was applied. Chameleon sensors were installed on 11 January 2017 in all 4 plots

Chameleon sensors showed the blue colour (wet soil) for over 90% of the time in three of the four farmer's fields at Pudimoe (Figure 4.19). Each point on the triad represents a single crop, by integrating the Chameleon pattern to give percentage blue, green and red colour.

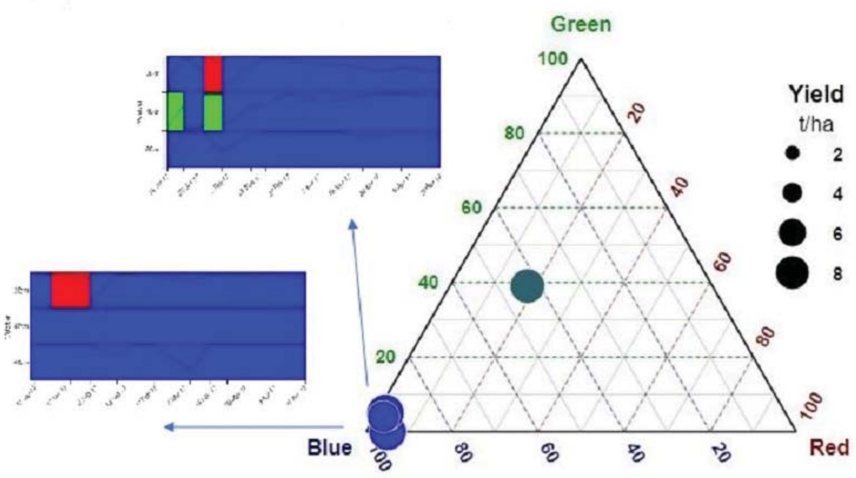

Figure 4.19: Integrated Chameleon soil water patterns for maize grown at Pudimoe, Taung.

In the plot PS2 SE, the top two sensors showed green or red colour for short periods in the first month or two after the sensors were installed but thereafter the Chameleons remained blue until irrigation was stopped before the dry off period for harvesting (Figure 4.20). The soil water patterns of PM3 NE and PS2 NW shown in Figure 4.19 were similar to that of PS2 SE (Figure 4.20).

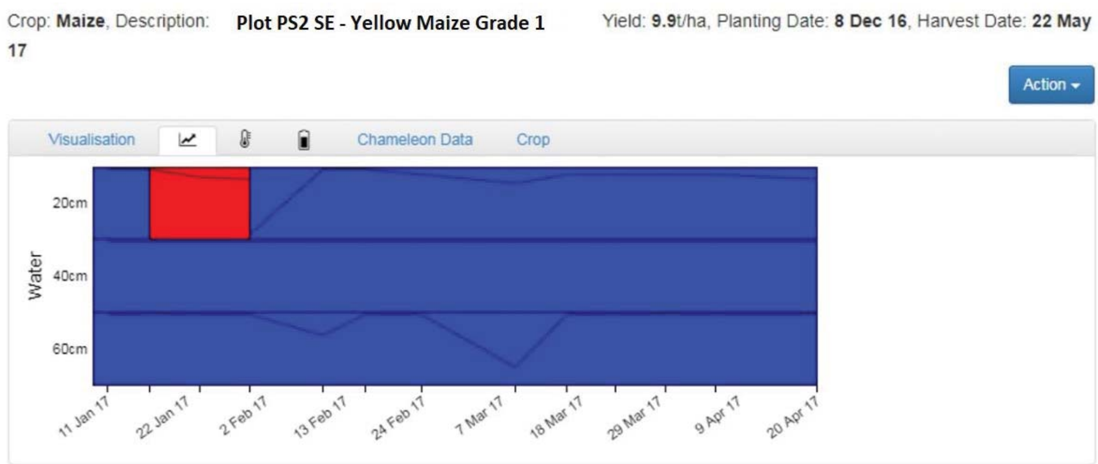

Figure 4.20: Chameleon soil water pattern for maize grown on PS2 SE at Pudimoe, Taung.

Chameleon sensors on the fourth plot PM3 SW showed blue for 43% of the time, 39% of the time the sensors were green (moist soil) and only 18% of the time red (dry soil) (Figure 4.21). The red pattern was visible at the 60 cm depth and a closer inspection shows that the black line was actually at the top of the red pattern (closer to a moist soil of 20-50 kPa rather than a very dry soil of >50 kPa).

Figure 4.21: Chameleon soil water patterns for maize grown on PM3 SW at Pudimoe, Taung.

The overall soil water patterns of the four farmers at Pudimoe show that the soil water status was mostly moist or wet. The predominantly wet soil conditions of three of the farmers did not seem to adversely affect their yield. In all three cases there were times when the black line in the blue pattern fluctuated, indicating some drying in the soil (the plant root taking up water). The four farmers that participated in the project at Pudimoe achieved an average of 9.1 t/ha. Table 4.5 shows the date of harvest and the yield of each farmer.

Table 4.5: Land number, harvest date and yield for maize grown at Pudimoe, Taung.

Land number	Harvest date	Tons	Ha	T/Ha
PM3 SW	21 June 2017	90.26	10	9.03
PS2 SE	22 May 2017	198.08	20	9.90
PM3 NE	20 June 2017	94.82	10	9.48
PS2 NW	2 June 2017	80.13	10	8.01

4.7.2 Tshidiso

Four farmers participated in the project in the 2016-2017 summer cropping season at this site. Two farmers planted 10 ha of yellow maize (Grade 2) and two farmers planted yellow maize (Grade 1). Maize (variety 33Y56) was planted under centre pivot JM6 (JM6 NW and JM6 SE) on 21 December 2016 and variety 33Y74 was planted at pivot JS2 (JS2 NW and JS2 NE) on

15 December 2016. All four plots had a plant population of 80 000 plants/ha and 125 kg N/ha fertiliser was applied. Chameleon sensors were installed on 12 January 2017.

Chameleon sensors showed the blue colour (wet soil) for 60-65% of the time in three of the four farmer's fields at Tshidiso. In these three plots, JM6 NW was 60% blue, 17% green and 23% red, JS2 NW was 65% blue, 24% green and 11% red and JS2 NE was 62% blue, 29% green and 9% red. Figure 4.22 illustrates that farmers tend to keep their soil relatively wet (>60% blue). Plots JS2 NE and JS2 NW had similar soil water patterns.

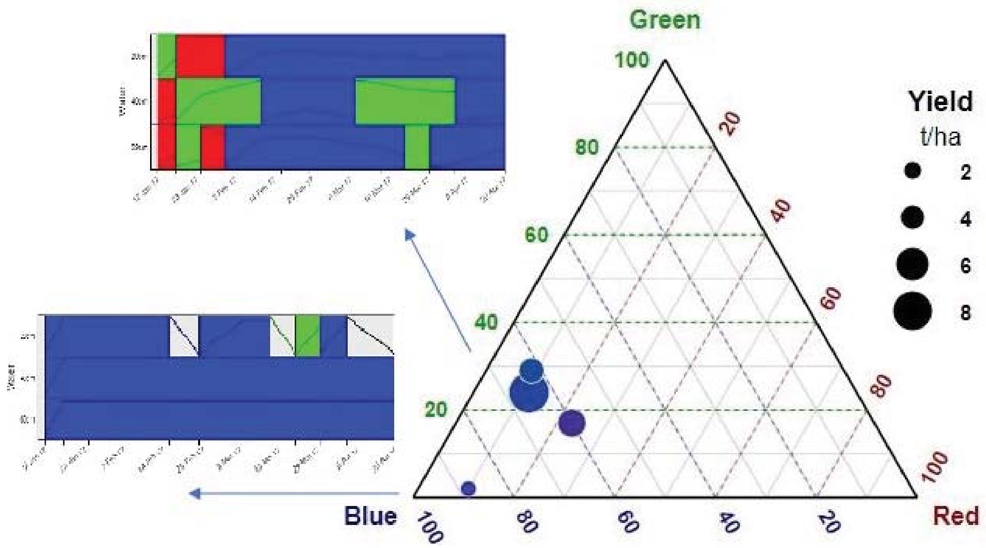

Figure 4.22: Integrated Chameleon soil water patterns for maize grown at Tshidiso, Taung.

Plot JM6 SE was 88% blue, 2% green and 10% red (Figure 4.23). In this plot, the bottom two sensors buried at 40 and 60 cm stayed continuously blue (< 20 kPa) from January to April. More importantly, the black lines at these depths show horizontal lines that do not fluctuate throughout the period that the crop is growing. The line remains at maximum throughout this period indicating that the soil was extremely wet.

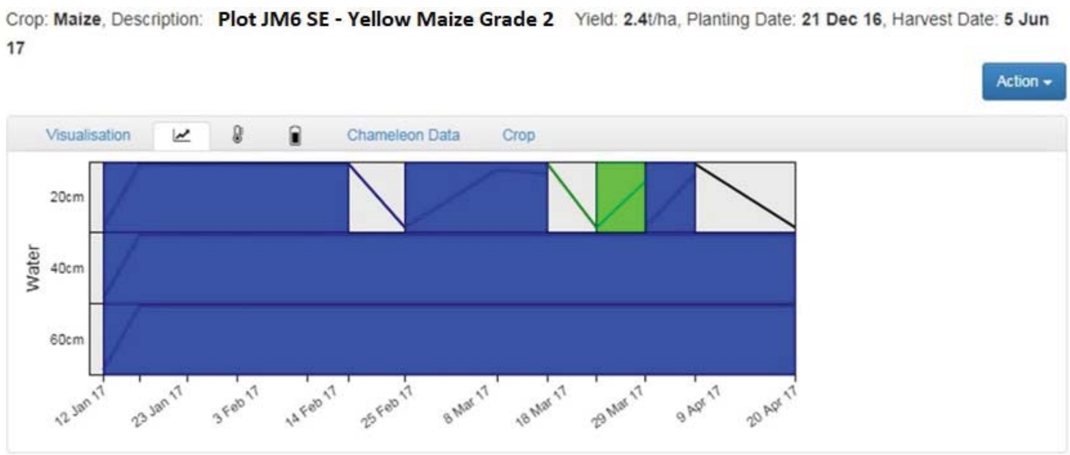

Figure 4.23: Chameleon soil water patterns for maize grown on JM6 SE at Tshidiso, Taung.

Not only were the soil water patterns for the other three farmers similar throughout the crop growth period, the crop and field management practices for all four farmers were comparable. In fact, plot JS2 NE and plot JS2 NW grew the same variety of yellow maize (33Y74), on the same day, under the same centre pivot (JS2), followed the same production practices and harvested on the same day. Figure 4.24 shows the pattern of plot JS2 NW.

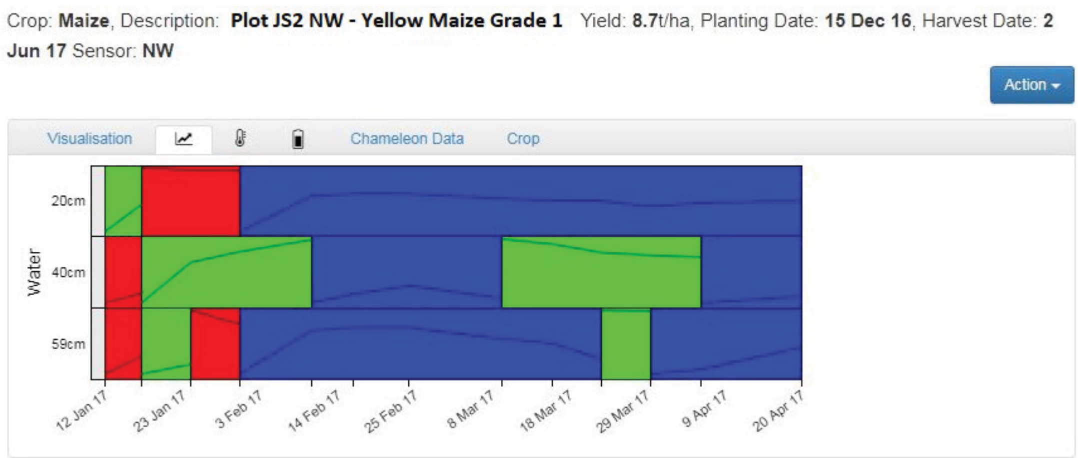

Figure 4.24: Chameleon soil water patterns for maize grown by JS2 NW at Tshidiso, Taung.

The four farmers that participated in the project at Tshidiso achieved an average yield of 5.3 t/ha. Table 4.6 shows the date of harvest and the yield of each farmer's plot. Three of the four farmers at Tshidiso had maize yields that are well below that of their fellow farmers at Taung. Plots JM6 NW, JM6 SE and JS2 NE achieved an average yield of 4.2 t/ha. This yield is considerably less than the average yield of the other farmers at Pudimoe (9.1 t/ha) and Reaitlhoma (8.8 t/ha).

Table 4.6: Land number, harvest date and yield for maize grown at Tshidiso, Taung.

Land number	Harvest date	Tons	Ha	T/Ha
JM6 NW	5 June 2017	55.02	10	5.5
JM6 SE	5 June 2017	24.89	10	2.4
JS2 NW	2 June 2017	87.26	10	8.7
JS2 NE	2 June 2017	46.49	10	4.6

Plot JM6 NW and plot JM6 SE grew the same variety of yellow maize (33Y56), on the same day, under the same centre pivot (JM6), followed the same production practices and harvested on the same day, yet plot JM6 NW obtained more than double the yield of plot JM6 SE. Although JM6 NW's yield of 5.5 t/ha was not as high as the top performers at Taung, that of plot JM6 SE was a disaster. In fact, plot JM6 SE achieved the lowest yield (2.4 t/ha) of all the maize farmers at Taung during the 2016/2017 summer season. A contributing factor to this low yield was the excessively wet soil profile as a result of over-irrigation. It is likely that any nutrients that could have benefited the growing maize crop following fertiliser application were leached from the very wet soil.

Recently, a new feature was added to the VIA platform with a new Chameleon colour that appears as magenta (reddish-purple) (Figure 4.26). The aim of this colour is to display Chameleon responses in salty soil. When salinity levels in the soil are above 4 dS/m, which is bad for plants, a wet Chameleon will read 0.5 K Ohm or lower (the extra salt in the water makes the sensor more conductive). The idea is to alert the farmer that there appears to be a salt problem and to interpret the Chameleon with caution. Farmers need to know that i) salt needs to be measured and ii) the Chameleon colours will not be accurate at high electrical conductivity (EC) values. The same soil water pattern for plot JM6 SE is shown with the new feature (Figure 4.25).

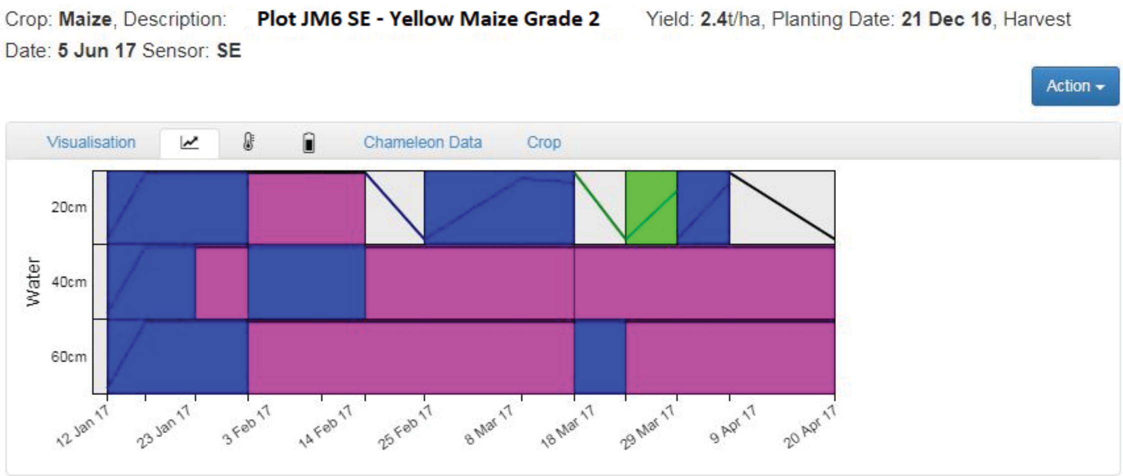

Figure 4.25: Chameleon soil water patterns showing the magenta colour for maize grown on plot JM6 SE at Tshidiso, Taung.

Unfortunately, the project team did not collect a water sample to test the electrical conductivity (EC) because no Wetting Front Detectors were installed in any of the plots at Taung. Therefore, we could not conclude that salinity affected the yield on plot JM6 SE. A constant magenta colour at 60 cm could be a water table with salinity above 4 dS/m. However, the soil water pattern of plot JM6 NW which is under the same centre pivot as JM6 SE showed no magenta colour (Figure 4.26).

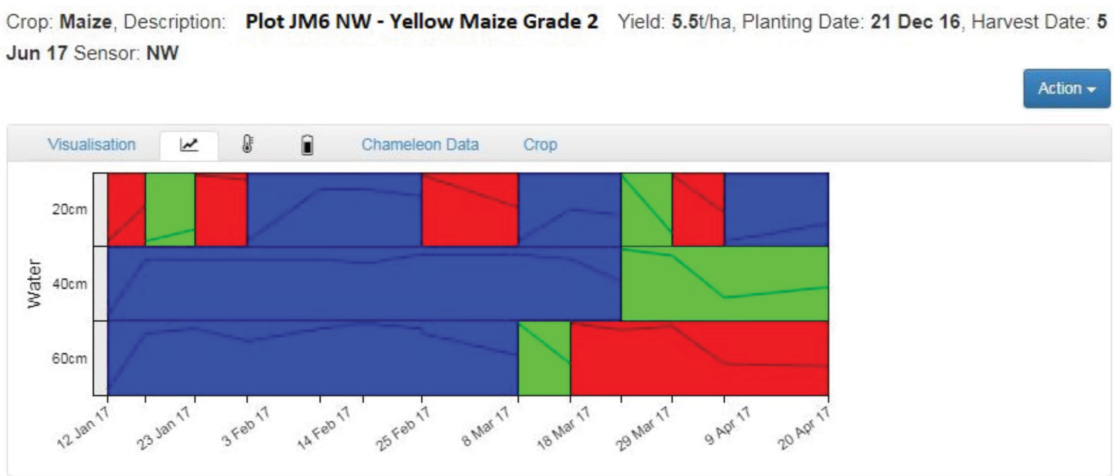

Figure 4.26: Chameleon soil water patterns for maize grown on plot JM6 NW at Tshidiso, Taung.

4.7.3 Reaitlhoma

Two farmers participated in the project in the 2016-2017 summer cropping season at Reaitlhoma. Both farmers planted 10 ha of yellow maize (Grade 1) under centre pivot PN5 on 11 December 2016. Variety P1816R was planted on plot PN5 NW and variety P1814R was planted on plot PN5 SE. Both plots had a plant population of 80 000 plants/ha and 137.5 kg N/ha fertiliser was applied. Chameleon sensors arrays were installed on 12 January 2017.

The soil moisture summary for plot PN5 NW shows that the Chameleon sensors were blue 64% of the time, green 11% and red 25% of the time (Figure 4.27). For a period of two to three weeks (between the end of February and the middle of March), all three sensors were red. However, this did not significantly affect the maize yield. The farmer obtained a high yield of 9.2 t/ha.

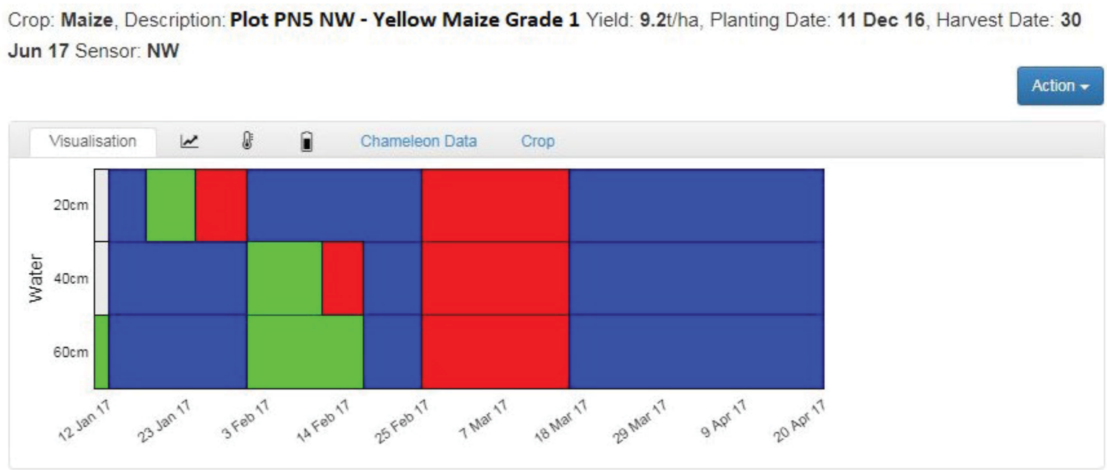

Figure 4.27: Chameleon soil water patterns for maize grown on plot PN5 NW at Reaitlhoma, Taung.

The soil moisture summary for plot PN5 SE was 51% blue, 10% green and 39% red (Figure 4.28). In this plot, although the sensor buried at 40 cm was red for a significant amount of time, the sensors at 20 cm and 60 cm indicated that there was sufficient moisture in the soil. He achieved a yield of 8.53 t/ha.

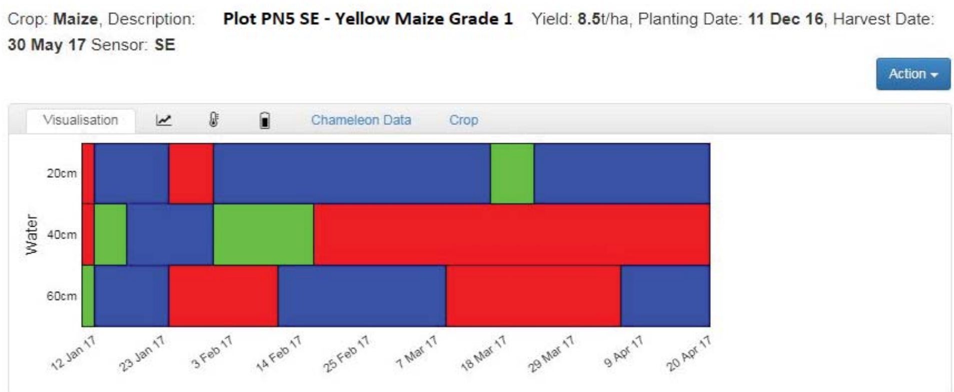

Figure 4.28: Chameleon soil water patterns for maize grown on plot PN5 SE at Reaitlhoma, Taung.

4.8 Conclusions

It is clear from the above results at Taung that there are instances where there is a direct link between soil water patterns and yield and in other cases there does not appear to be a direct causal relationship. As mentioned previously, a number of crop management factors influence the production of yield, one of which is water. The apparent inconsistencies that were observed in some of the data from Taung between the soil water patterns and the yield are not always simple to explain. In many cases, more frequent readings of the Chameleon and detailed records of the management practices during crop development would have provided a clearer picture of the changes in the soil water status and its effect on yield. In other instances, the preliminary observations need further investigation. The findings from the research done at Taung do not undermine the value of the Chameleon and the VIA platform but rather highlights their function. The purpose of this research was not to prove, through an experimental trial, that the use of the irrigation monitoring tools would necessarily increase crop productivity. Instead, the aim was, among other things, to introduce user-friendly tools to a group of farmers on a scheme and see whether the tools identified obvious problems, such as fields that were too dry, nitrate deficient or salty and whether farmers could understand the information and use it (Stirzaker et al., 2017). At times these problems could easily be identified and in other situations the problems need further examination.

At Taung irrigation scheme, famers at different project sites participated in the installation of Chameleon sensors in their individual plots. They discussed their soil water patterns with the SAB extension advisor. However, they also made use of a private irrigation scheduling agent using Aquacheck sensors to manage their irrigation. Unfortunately, it was not possible to compare the recommendations of the private agent with the Chameleon data because the data from the agent was not available.

The objectives of this project included addressing on-farm farmer experiences and determining how the combination of irrigation monitoring tools and the VIA platform promoted learning and improved irrigated farm productivity. In comparing the average yields of the SAB only and SAB/VIA irrigators, it is difficult to determine to what extent the use of the tools and the VIA benefitted the individual farmers. Figure 4.18 shows a marginal increase in the average yields of farmers who participated in the project compared to those who did not at some of the sites but we cannot conclude that this is a direct result of the project's intervention. The perceptions and learning experiences of the farmers who used the irrigation monitoring tools at Taung are discussed in Part 3 of this report.

Chapter 5: Emerging commercial sugarcane growers in Nkomazi irrigation scheme, Mpumalanga

5.1 Introduction and background

The construction of the Driekoppiesdam by the Komati Basin Development Programme in the early 90s was the main driver for rural and farming development in the area. The KwaNgwane administration initiated the Nkomazi Irrigation Expansion Programme (NIEP) for development of skills with communities experiencing high unemployment. Starting in the 1980s, sugar cane production was extended to the people of the area through irrigated projects financed by the South African government and run by Agriwane, a parastatal under the KaNgwane administration. Production by small scale cane growers expanded in three distinct phases between the early 1980s and the mid-2000s:

a. Agriwane-led period of development during the 1980s;

b. Nkomazi Irrigation Expansion Program (NIEP) Phase One during the mid-1990s,

c. NIEP Phase Two or 'Land Bank Projects' during the mid-2000s.

A total of 37 small scale development projects were created covering roughly 10 292 ha of irrigated land and incorporating about 1200 small scale growers into sugar cane production. These development projects each have supporting infrastructure which includes a resource centre (where monthly meetings take place), irrigation systems, roads and other structures relating to farming activities (Slabbert, 2011). The project sizes ranged from 41.2 to 839.8 ha and individual plot sizes ranged from 2 to 20 ha. Within projects, plot holders typically shared the pumps and distribution infrastructure used to deliver water from local rivers to farmers' fields. Some of the responsibilities were transferred to the Department of Agriculture in Mpumalanga in 1994 (Brown and Woodhouse, 2004) and land was made available for sugarcane cultivation.

Small scale growers' cane is delivered to Malelane and Komati sugar mills owned by RCL (formerly known as TSB Sugar). Small scale sugarcane farmers in Nkomazi received considerable assistance from government as well as from the private sector in establishing sugar enterprises. This was in the form of land, equipment and implements, financial assistance, training programmes and extension services (Stevens, 2006). The majority of both large and small scale sugar growers reside in the Nkomazi Local Municipality (NLM) (Figure 5.1).

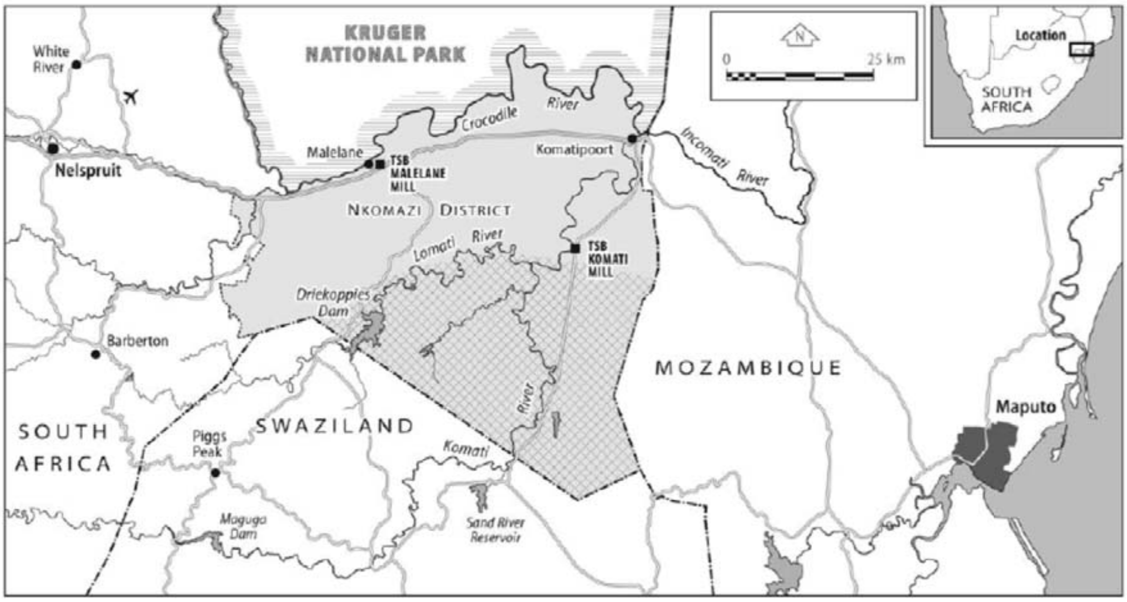

Figure 5.1 Nkomazi irrigation area

Nkomazi has a population of approximately 400 000 people (StatsSA, 2011). The demand for small scale sugar plots is constrained by available irrigated land and as such, it is necessary to understand the mechanisms by which certain households were able to acquire plots, while the majority were evidently unable to do so. The allocation of land for any type of use has remained under the control of the tribal authorities throughout the history of the area. Given the limited number of sugarcane plots and the apparently high demand for agricultural opportunities, there has existed a degree of competition for farms and contestation over the ability to access land (Brown and Woodhouse, 2004). From interviews conducted with small scale sugarcane growers (SSGs) during the fieldwork phase it was suggested that in certain cases, close familial ties to the chief or to other members of the tribal authority played a role in the allocation of land.

Table 5.1 presents a breakdown of the current projects by area and the tribal authorities in which they are located. The allocation of plots in Nkomazi is done through a permission to occupy (PTO) certificate issued to farmers by the local traditional authority. A PTO does not amount to a freehold title to the land and is essentially an agreement between the traditional authority and the farmers that allows occupation of the land. A PTO could in principle be rescinded and the land transferred to someone else.

Table 5.1: Current emerging sugarcane grower projects in Nkomazi irrigation scheme (TSGro, 2016)

Project	Area
Malelane mill	
Tikonthele	314.1
Blue Dot	41.4
Boschfontein 1	249.1
Boschfontein 2	128
Buffelspruit	232.4
Langeloop 1	426.5
Langeloop 2	299.3
Mbongozi	178.9
Middelplaas	68.4
Ngogolo	591.4
Nhlangu East	136.6
Nhlangu West	122
Schoemansdal	92.9
Vlakbult	43.2
Subtotal	**2924.2**
Komati mill	
Figtree A	256.6
Figtree B	241.3
Figtree C	426.5
Figtree D	407.4
Lugedlane	342.6
Madadeni	422.6
Mangweni	131.5
Mbunu B	392.1
Mfunfane	333.9
Shinyokane	197.2
Sibange	381.2
Spoons 7	240.9
Spoons 7B	93.8
Spoons 8	628.7
Walda	839.8
Mbunu C	157.4
Mangane	152.1
Phiva	250.8
Mzinti	285.8
Ntunda	313.9
Sikwahlane	400.1
Magudu	427
Ntunda B	45
Subtotal	**7368.2**
Total	**19292.4**

Farmers pay an initial fee to the relevant traditional authority for a PTO to be issued. Such fees vary between authorities and at different times, although they are usually in the range of 500 to 1000 Rand, regardless of the area of land acquired through the PTO. In most cases farmers also have to pay an annual fee for their PTO. This system of land titling has a number of consequences for farmers; most significantly it creates circumstances that may hinder farmers' access to credit from commercial banks. The information contained within a PTO is typically vague, usually denoting only an approximate area of land without formal demarcation.

As land allocation is mediated by traditional authorities, it is to be expected that the allocation of sugarcane land reflects the social status of recipients. Therefore, there is an element of social seniority in the individuals who have become SSGs, shown in Table 5.2. Almost 75% of the SSGs were found to be aged over 50. An ageing population, and the lack of succession apparent in small scale sugarcane farming, has implications for the industry as sugarcane farming is a very physical job. Furthermore, many small scale plots are located significant distances from residential areas so that where SSGs don't have access to transport, farm supervision is increasingly difficult.

Table 5.2: Age profile of SSGs (James &Woodhouse, 2017)

	Age				Total
	20-30	31-40	41-50	50+	
Male	3	7	9	43	62
Female	1	3	7	33	44
Total	4	10	16	76	106

5.2 Climate and soil

The precipitation of the area varies from as high as 855 mm at Kaalrug to as low as 581 mm at Vergelegen. Normally the rainfall season falls between October and May, peaking in January, February. During this period, almost 90% of the annual precipitation is received (Table 5.3).

5.3: Average rainfall and daily temperatures (Accuweather, 2019)

	Vergelegen (Malelane)	Kaalrug (Malelane)	Hoechst (Malelane)	Tenbosch (Komatipoort)	Coopersdal (Komatipoort)
Average rainfall	539.2	781.2	729.2	537.5	589.2
Max temp during Nov-Jan (°C)					
Nov **(High)**	29 40.4	28.3 43.4	29.4 40.7	30 41	30.1 40.5
Dec **(High)**	30.5 41.7	30 45.5	30.9 41.6	31.6 41	31.6 40.7
Jan **(High)**	30.7 41.6	30.2 43.4	31.6 42.9	32 42.5	32 42.5
Min temp during Jun-Aug (°C)					
June	9.8	11.6	7	8.8	8.4
July	9.8	11	7.4	9.1	8.9
Aug	11.9	13.3	10.4	11.2	11.5

The Nkomazi region is situated on the high plateau grasslands of the middleveld, and the elevation above sea level rises from 189 m along the Lebombo Mountains to 369 m at the foothills of the Drakensberg at Malelane. Archaic granite and geneiss rock with prominent outcrops of granite blocks cover the entire stretch of country comprising the lowveld. The soil types in the area vary from highly suitable for irrigation to very unsuitable. The most important soil types are shown in Table 5.4. With the huge variation in soil types, it can be assumed that a significant degree of production variation in sugar cane between different projects can be attributed to soil types.

Table 5.4: Main soil types found in Nkomazi scheme and their parent material (MBB, 2000)

Dominant parent material	Soil type	Remarks
Beaufort series (Swaziland Basic Rock)	**Red soils:**	
	a. Hutton b. Shortlands	Very good irrigation soils
	Black, blocky structured soils	
	Arcadia Rensburg Milkwood	Marginal soils for irrigation
Eca series (Granite)	Glenrosa	Marginal soils, shallow in places
	Cartref	
	Sterkspruit	Marginal – poor drainage
	Estcourt	Totally unsuited for irrigation
	Longlands	Marginal – poor drainage
	Kroonstad	
	Katspruit	Totally unsuited for irrigation
	Mayo	Marginal soils, shallow in places
	Hutton	High quality irrigation soils

5.3 Irrigation

The 2 400 km^2 Nkomazi Irrigation area is in the shape of a triangle, which is surrounded by Swaziland on the western side, by the Kruger National Park on the north, and by Mozambique on the east. In the Nkomazi region, the water uses are basically for irrigation purposes (222 million m^3), drinking water (11 million m^3), and forestry (12 million m^3) (DWAF, 2001; 2002). The National Water Resource Strategy (NWRS) assesses a current negative balance of 39 M cubic metre but this calculation does not take into account the Maguga Dam, which increases the yield by 65 M cubic metre. Table 5.5 illustrates the irrigation allocated areas in both Lomati and Komati Irrigation Boards, where a charge for managing water is applicable.

Table 5.5: Allocated area (ha) for Komati and Lomati Irrigation Boards (DWAF, 1999)

Irrigation Board	Type of farmers	Area (ha)
Komati Irrigation Board	Commercial farming	12 000
	Emerging commercial farming	8 000
Lomati irrigation Board	Commercial farming	9 209
	Emerging commercial farming	2 566
Total		**31775**

Since the 1990s, several severe water shortages occurred in the region. Water availability is a constraint for development for both commercial farmers (CFs) and emerging commercial farmers (ECFs). Before the building of Matsamo Dam, there used to be tensions between ECFs and CFs of the Lomati Irrigation Board (LIB), as well as among CFs during periods of drought (Waalewijn, 2002). Since this dam has started operating, it has released water for both the Lomati Irrigation Board and the Lower Komati, which eased tensions.

In the Lomati River and in the Lower Komati, the irrigation use never prevents the drinking water schemes from functioning correctly but, in the Upper Komati, there was a need to integrate irrigation and drinking water uses. In this part of the river, the Tonga Weir is used by the Tonga drinking water scheme to provide water to the surrounding villages. In periods of water scarcity such as 2016-17, the small scale irrigation schemes in Upper Komati sometimes have to stop irrigating so as to ensure that there will be enough water in the weir for the Tonga scheme pump to function correctly. The decisions to restrict irrigation upstream of the Tonga Weir are taken informally by the Department of Water Affairs (DWA), the Komati River Irrigation Board (KIB), and representatives of the district and local municipalities (MBB, 2016). The Matsamo Dam on the Lomati and the Maguga Dam on the Komati ensure enough water for both existing farmers and the requirement of 1.1 m^3/s flow downstream at the junction with the Crocodile River. The Komati Basin Water Authority (KOBWA) is in charge of the dams, with the aim of satisfying the needs of the farmers while meeting the international and legal requirements of a tripartite agreement between South Africa, Mozambique, and Swaziland (Eswatini), and the ecological reserve in South Africa.

The two irrigation boards (LIB and KIB) and KOBWA are currently facilitating cooperation regarding water management in this area. Every week, the commercial farmer sends records of his/her consumption of water during the past week, the water demand for the next week and an estimation of the demand for the week after to the respective irrigation board. The emerging commercial farmers do the same, but at scheme level. The IBs collate this information and order a total amount from KOBWA, which then releases enough water so as to make sure that the requirement at the downstream junction with the Crocodile River is met (Armitage, 2016)

During normal years, farmers are allocated a quota of 8 500 m^3/ha in the Lomati Irrigation Board and 9 950 m^3/ha in the Komati River Irrigation Board. Water meters installed in the Lomati and Komati Rivers enable control of the quotas. In the Komati River Irrigation Board, the Lower Komati was equipped with water meters in August 2003. The two systems are slightly different, in that Lomati farmers receive a message each week on their cell phones indicating the amount of water they are entitled to. They schedule this amount into an electronic device attached to the water meter installed on the pump, which stops the flow once the quota is attained. Each week, each farmer also sends his/her water consumption details to the Lomati Irrigation Board's office, which organizes some random checking. The Komati River Irrigation Board chose a more complex system, with a telemetric transmission of water consumption and an automatic cut-off system once the quota is attained.

During the 2016/17 drought, DWA published general volumetric quotas per zone to manage the drought. In Lomati, this allocation led to a 35% availability of the quota for commercial farmers and 60% for emerging commercial farmers. These figures amount to approximately 2 hours of irrigation per day for commercial farmers and 4 hours for emerging commercial farmers. In Komati, the allocations amounted to 20% availability for commercial farmers and 35% for emerging commercial farmers.

Sugarcane farming in Mpumalanga is reliant on irrigation due to the extremely seasonal distribution of rainfall in the Lowveld. This has implications for sugarcane farming on a small scale in Nkomazi. First, due to the high capital investment costs involved in setting up an irrigated farming operation, numerous small scale plots are grouped together with collectively owned infrastructure. The collective ownership of infrastructure exists alongside individual responsibility for assets and investments within each farm. Small scale projects are typically located close to the main rivers or dams and outside the principal residential areas. This is a result of both the need to be close to water sources for irrigation purposes and the historic processes of villagisation. The physical location of sugarcane farms thus differs substantially from rainfed small scale sugarcane farming in KwaZulu-Natal where farms are typically dispersed and each contains the SSG's homestead.

The second key challenge of practising irrigated agriculture in this area is the relatively high costs involved in production. High capital costs associated with irrigated sugarcane farming mean many small scale growers need access to credit to maintain production. The majority of SSGs use Akwandze Agricultural Finance, a financing leg of Rainbow Chicken Ltd (RCL). In the next part of this chapter, a brief overview of the organisational structure is provided to illustrate the support rendered by the private industry.

5.4 Organisational structure

Twenty percent of sugarcane for Malelane and Komati Mills under the auspices of RCL Foods Ltd is supplied by 800 small scale growers in the Nkomazi region of Mpumalanga. To support them the following organisational structures were established:

5.4.1 Rainbow Chicken Ltd (RCL)

In 2013 the sugar industry in Nkomazi was constituted by a single milling company (TSB) operating two mills: Malelane (built 1967 and extended several times) with nominal milling capacity of 1.83 million tonnes of cane per year and Komati (built 1994, expanded 1998 and 2006) with nominal milling capacity of 2.5 million tonnes of cane per year. In early 2014 TSB was sold by its owner, Remgro group, to Rainbow Chicken Ltd (RCL), also owned by Remgro, as part of a restructuring of the group, a move the group claims will enable better integration between different elements of its agricultural business. RCL runs a refinery at Malelane which takes the output from the Malelane Mill and also part of the raw sugar output from the Komati Mill. The remainder of Komati Mill's raw sugar output is exported *via* Maputo. Also at Malelane is Molatek, a TSB-owned animal feed enterprise using the molasses by-product from sugar mills.

Two joint venture services companies – Akwandze Agricultural Finance and TSGro – have been established between RCL and the small scale cane growers in Nkomazi to provide the latter with financial and agricultural/business support services that they wouldn't otherwise have access to.

5.4.2 TSGro

TSGro was launched in 2013, and offers services such as irrigation, input supply and farm management not only to farmer cooperatives but also to individual small scale growers. In addition to TSGro's services like procurement, application of fertilizer and herbicides, extension services and support with bookkeeping, they introduced a bulk water-supply service (BWS) in 2015. The purpose of the BWS is to repair, maintain and protect the infrastructure that provides water to the field edge – and some 630 individual growers and seven cooperatives (representing another 456 farmers) signed up for the service. In the first half of 2016, these farmers reported only a 2.1% decline in their cane yield, compared to 9.1% for those not supported by the BWS (TSGro, 2016). According to Armitage (2016*),"small scale growers' average yield declined by about 1 ton per hectare* *during the 2016/17 drought, but their cane quality actually improved as a direct result of the BWS. This, along with higher sugar prices, meant that small scale growers' income actually increased by almost R100 million in 2016".*

TSGro is also assisting with upgrading hardware and optimise systems in specific grower projects. They have also established seed cane nurseries around Nkomazi to ensure that quality seed is available for replanting. More replanting than normal was necessary because of the drought, and growers required assistance in this by means of loans at reduced interest rates, through Akwandze Agricultural Finance. In partnership with the Jobs Fund, Akwandze strengthened the farming community's resilience to drought through a five-year, R50 million project to rehabilitate irrigation infrastructure and enable better irrigation management going forward. Due to these challenges experienced by TSGro and BWS, monitoring tools (Chameleon sensors and VIA) were deployed in the area to help with irrigation management at field level and overall scheme or project management.

5.4.3 Akwandze Agricultural Finance

The majority of SSGs use Akwandze Agricultural Finance, a financial body created in wake of the collapse of the industry's Financial Aid Fund (FAF) (later renamed Umthombo Agricultural Finance (UAF)) that operated between 1973 and 2006 across the whole of South Africa's small scale sugar sector. After the FAF/UAF collapse, the Mpumalanga section of the loan book was the only part deemed financially viable. TSB then formed a 50-50 partnership with Liguguletfu Co-operative Limited, a new cooperative representing 889 SSGs in the Mpumalanga region. Each partner contributed R25 million while a further partnership with Khula Enterprise Finance Initiative founded the Khula Akwandze fund capitalised to a total of R100 million also to provide credit for SSGs (Armitage, 2016).

There are two broad channels of credit used by SSGs to invest in their farms. The first is through a *crop proceeds retention scheme* (hereafter retention savings), a savings scheme administered by Akwandze that holds money for SSGs, deducted from earnings from previous year's crop (at a fixed rate per ton of cane delivered), to provide working capital for field production costs. The second channel (*the Khula Akwandze Fund)* provides loans repayable over periods of between one and six years designed to meet costs not covered by retention savings (or in which there is a shortfall in retention savings). These include repairs and replacement of equipment, such as irrigation sprinklers, and costs of cane replanting.

Loans from Khula Akwandze fund are largely intended to finance less regular, higher-cost investments such as cane replanting, upgrading or replacing irrigation infrastructure and purchasing additional sugarcane plots. The ‘communal’ land tenure system of SSG projects implies they have few options for obtaining credit. Land Bank and Akwandze are the only options available.

5.5 Use of monitoring tools to assess irrigation practices

Chameleon sensors were installed at 20, 40 and 60 cm depths in thirty five farmers’ fields at Langeloop, Sibange, Walda, Buffelspruit, Spoons 7, Sikhwahlane and Siboshwa in the Nkomazi area.

The soil types at these project sites range from sandy to heavy (red – Hutton and Shortlands) soils (Table 5.4). Chameleon sensors were installed in the farmer fields in the respective projects in Nkomazi irrigation area (Table 5.6) and the categorisation of soil types indicated in the table is based on terminology used by development officers and farmers (namely good, moderate or poor potential for irrigation and production). Good soil refers to deep red soils (usually Hutton) with good drainage attributes, and well suited for irrigation. Moderate soil refers to average soil potential, and usually varies substantially with regard to depth, while poor soil refers to rocky, sandy soil which is unsuited for irrigation. Although the soil types vary extensively in the area, the majority have a definite compaction layer at approximately 30 cm, which impede root development and soil water penetration (Botha, 2003 as cited in Stevens, 2006).

Table 5.6: Farmer plot sizes, plant and harvest date and yields of selected projects in Nkomazi

Grower	Soil	Irrigation system	Variety	Area (ha)	Plant date	Harvest date	Yield	Plant date	Harvest date	Yield	Fertilser
					2016	2017	t/ha	2017	2018	t/ha	(kg N/ha)
a. Langeloop, Malelane (427 ha)											
18	Good	Sprinkler	N36	7.3	20-Apr-16	09-Sep-17	139.2	04-Oct-17	25-Sep-18	101	120
10	Moderate	Sprinkler	N23	7.2	01-Aug-16	08-Sep-17	61	03-Oct-17	24-Sep-18	46	140
47	Moderate	Sprinkler	N41	7	22-Jun-16	03-Jul-17	81.6	03-Aug-17	24-Jul-18	99.4	162
16	Moderate	Sprinkler	N36	10	04-Jun-16	13-Sep-17	72	13-Oct-17	25-Jun-18	156.8	131
b. Walda, Komati (839ha)											
23C	Moderate	Drip	N19	10	18-May-16	10-Jun-17	96.6	20-Jun-17	11-Jul-18	81.7	175
76H	Good	Drip	N36	10.9	12-Jul-16	03-Sep-17	120.3	07-Sep-17	24-Oct-18	116	170
6A	Moderate	Sprinkler	N41	9.5	08-Apr-16	17-Apr-17	45.4	19-Apr-17	26-Apr-18	44.1	168
3B	Moderate	Drip	N19	5.2	20-Aug-16	28-Sep-17	64.5	01-Oct-17	05-Nov-18	100.9	140
64G	Good	Drip	N19	9.9	24-Jun-16	07-Aug-17	63.4	07-Sep-17	02-Jul-18	60.6	153
c. Sibange, Komati (381.2 ha)											
48	Moderate	Sprinkler	N49	7.7	Carried over	12-Feb-18	74	12-Apr-18	08-Apr-18	76	120
47	Good	Sprinkler	Mixed	7	Carried over	12-Mar-18	104	03-Apr-18	03-Apr-18	99	128
50	Good	Sprinkler	N19	7.4	11-Jul-16	11-Jul-17	101	19-Jul-17	23-Aug-18	117	186
17	Moderate	Drip	N36	7.3	04-Jul-16	04-Jul-17	84	08-Jul-17	19-Oct-18	64.6	160
8	Moderate	Sprinkler	N19	7.3	10-Sep-16	01-Oct-17	44	18-Oct-17	16-Oct-18	48.6	120
d. Buffelspruit, Malelane (232.4 ha)											
5C	Good	Sprinkler	N53	7.5	N/A	N/A		14-Jun-17	12-Sep-18	107.6	160
10B	Good	Sprinkler	N53	7	N/A	N/A		30-Jun-17	22-Sep-18	107	160
7C	Good	Sprinkler	N41	7.2	N/A	N/A		26-Jun-17	14-Aug-18	99.4	160
10	Good	Drip	N49	9.3	N/A	N/A		04-Dec-17	09-Oct-18	111.5	160
1	Good	Drip	N32	8.6	N/A	N/A		05-Aug-17	16-Sep-18	77.1	91
e. Spoons 7, Komati (240.9 ha)											
21	Moderate	Sprinkler	N19	11.7	N/A	N/A	104	19-May-17	27-May-18	113.8	122
26	Moderate	Sprinkler	N19	9.4	N/A	N/A	63	16-Jun-17	30-Jun-18	91.6	166
17	Good	Sprinkler	N19	9.4	N/A	N/A	86	13-May-17	20-May-18	114	161
19	Moderate	Sprinkler	N19	9.7	N/A	N/A	91	07-May-17	23-May-18	94.5	150
20	Moderate	Sprinkler	Mixed	8.8	N/A	N/A	68	06-May-17	23-May-18	90.4	154
12	Good	Sprinkler	N36	9.2	N/A	N/A	114	14-May-17	23-May-18	111.2	144
10	Moderate	Sprinkler	Mixed	10	N/A	N/A	93	03-Jul-17	28-Jun-18	107.3	160
2	Moderate	Sprinkler	N36	9.5	N/A	N/A	80	09-Jun-17	05-Jul-18	89.4	120
15	Good	Sprinkler	Mixed	9.9	N/A	N/A	110	10-May-17	26-May-18	126.4	154
4	Poor	Sprinkler	Mixed	11.4	N/A	N/A	74	24-Jun-17	19-Jun-18	61.1	135
f. Sikhwahlane,Komati (384 ha)											
42	Moderate	Sprinkler	N49	7	N/A	12-Aug-17	78		13-Aug-18	101.5	160
27	Moderate	Sprinkler	N36	6.9	N/A	03-Jun-17	62		14-Aug-18	105.4	160
34	Moderate	Sprinkler	N36	6.8	N/A	01-Oct-17	85		15-Aug-18	42.3	160
8	Moderate	Sprinkler	N57	6.9	N/A	17-Sep-17	78		16-Aug-18	82.6	160
g. Siboshwa, Komati (100.2 ha)											
1	Good	Sprinkler	N36	10	N/A	05-Oct-17	45.8		28-Nov-18	52.2	100
4	Good	Sprinkler	N36	10	N/A	08-Oct-17	52		07-May-18	70.9	100

The irrigation schedule generally followed by farmers depends mainly on the restrictions that are prescribed by the different irrigation boards (as mentioned earlier in section 5.3). Water allocations of 8500 $m^{3/}$/ha under the Lomati Irrigation Board and 9500 $m^{3/}$/ha under the Komati Irrigation Board apply. However, during drought periods as farmers experienced during 2016/17 when the project was started, farmers were restricted and could not exceed 4 hour irrigation per day. During the 2018 production season, due to good rainfall farmers were allowed to irrigate their full allocation. During 2018 production season farmers irrigated 6-12 hours per day with sprinkler irrigation. Typically farmers will start early in the season with 6 hours/day irrigation once a week and towards the last quarter of the season farmers will irrigate up to 12 hours/ day once a week. The spacing of the sprinkler system is usually 12x18 m and the average discharge of sprinklers is 20 l/h. The drip irrigation system used by farmers is spaced at 0.6 m and the delivering is 1.0-1.2 l/h. This fixed irrigation schedule is an irrigation schedule that is followed over many years by SSGs, and they do not use any scientific irrigation scheduling tools.

The initial project plan consisted of introducing the tools to development officers and farmers, which happened during a two day workshop held in August 2016. Thereafter, the plan was to deploy the tools in farmer fields selected in collaboration with development officers and make farmers responsible for the taking of data and uploading to the VIA website. However, it was soon discovered that very few farmers owned smartphones required for uploading of data to the website and furthermore the Wi-Fi reception in the majority of selected sites was very poor. Based on these experiences in the field, and in collaboration with TSGro management, it was agreed that development officers responsible for their specific projects would collect data on a weekly basis and upload it to the website. The project plan was for development officers to regularly show visualisation patterns to selected farmers, either individually or during farmer cooperative meetings held every month. Farmers were asked to continue with their normal or "traditional" irrigation management practices based on irrigation board allocations, recommendations provided by BWS and their own experiences (mental model).

The next part of the report does not discuss data collected from all installations of Chameleon sensors in every plot in Nkomazi, but looks at some interesting observations. The financial data displayed in the report was obtained from TSGro for production seasons 2017 and 2018.

5.5.1 Langeloop (Malelane mill area)

At Langeloop four farmers participated in the project, and all of them were using hand shift irrigation systems for irrigation. The soils vary between moderate and good, and various cane varieties were planted namely: N36, N23 and N41. Unfortunately, Chameleon sensors were not monitored regularly and data was not uploaded consistently during the 2016-2017 growing season at Langeloop. This however improved slightly during the 2018 production season after the project team consulted with TSGro management and the specific development officer.

Table 5.7 illustrates that the number of readings and uploads increased from an average of six readings for 2017 production season to 21 readings and uploads for 2018 production season.

Table 5.7: Soil water patterns and production yields of Langeloop sugarcane growers for 2017 and 2018 seasons

Farmer	Area (ha)	Visualisation pattern 2017	No of readings 2017	Production yield 2017 (t/ha)	Visualisation pattern 2018	No of readings 2018	Production yield 2018 (t/ha)
18	7.3	100% blue; 0% green 0% red	4	139	24% blue; 22% green 53% red	21	101
10	7.2	82% blue; 18% green 0% red	8	61	83% blue; 5% green 12% red	21	46
47	7	54% blue; 5% green 41% red	7	82	46% blue; 18% green 36% red	24	99
16	10	100% blue; 0% green 0% red	5	72	51% blue; 26% green 23% red	16	157

Table 5.7 illustrates that irrigation patterns of farmers slightly changed from trying to keep the soil primarily blue to more of balanced approach of wet (blue) and moist (green). According to the development officer, regular discussions of the Chameleon patterns helped to make farmers aware of the danger of over irrigating. Data collection during the first season was irregular and ended in some cases prematurely before the harvest date. As a result of the short duration of data taking during the 2016-2017 season, no meaningful interpretation can be made from these patterns during the 2016/17 season that could have a bearing on the development of the crop and the final yield that the farmers obtained.

The average yield of farmer No 16 was significantly more than that of other farmers during 2018 growing season due to the fact that he re-established new cane at the beginning of 2018 production season and also because of his improved irrigation and fertilisation practices (Table 5.7).

Farmer No 10 was the only participant whose production yield decreased dramatically (by nearly 25%) form the previous season due to a possible number of reasons, of which over-irrigation practices is but one (Figure 5.2). The pink colour or magenta that appears during December 2017 displays the Chameleon's response in salty soil. When salinity levels in the soil are above 4dS/m, a wet Chameleon will read 0.5 K Ohm or lower because the extra salt makes the sensors more conductive. This pink colour helps to alert the farmer that possible salinity problems may occur and that the readings of the Chameleon will not be accurate.

These possible reasons however severely impacted on his net farm income per ha, which was only 9.4% of what other participating farmers in Langeloop earned.

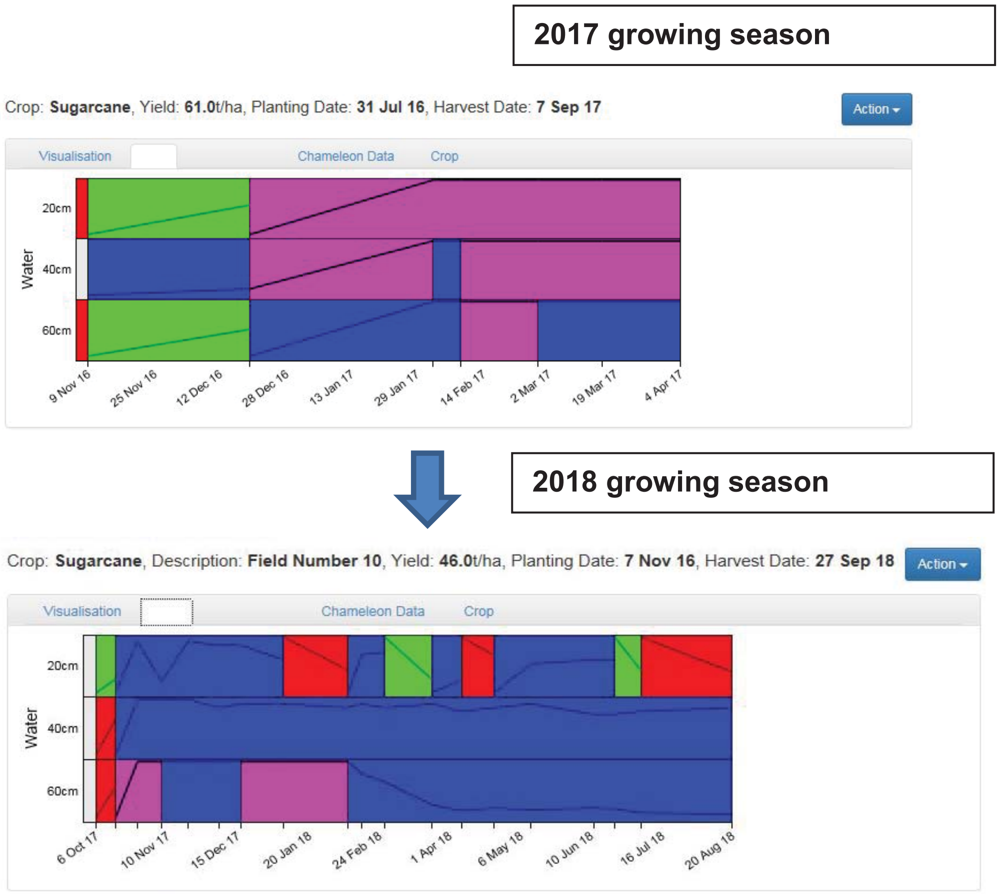

Figure 5.2: Chameleon soil water patterns for 2017 and 2018 growing seasons for Farmer No 10 at Langeloop

5.5.2 Walda (Komati mill area)

At Walda, five farmers participated in the project of which only one used sprinkler irrigation while, the other four farmers used drip irrigation (0.6 m spacing, 1 l/h delivery) (Table 5.8). Chameleon sensors were installed between the emitters, within the wetting pattern of the dripper at 20, 40 and 60 cm depths on 9 November 2016. Fertilizer application for the five farmers ranged from 153-175 kgN ha^{-1}.

Table 5.8: Soil water patterns and production yields of Walda sugarcane growers for 2017 and 2018 seasons

Farmer	Irrigation system	Field size (ha)	Soil water pattern 2017	No of readings 2017	Yield 2017 (t/ha)	Soil water pattern 2018	No of readings 2018	Yield 2018 (t/ha)
23C	Drip	10	98% blue; 2% green; 0% red	11	96.6	97% blue; 2% green; 1% red	10	81.7
76H	Drip	10.9	47% blue; 10% green; 43% red	23	120.3	No readings	Stolen and not replaced	116.0
6A	Sprinkler	9.5	100 blue; 0% green; 0% red	18	54.4	72% blue; 8% green; 20% red	18	44.1
3B	Drip	5.2	87% blue; 11% green 2% red	17	64.5	67% blue; 28% green; 5% red	18	100.9
64G	Drip	9. 9	69% blue; 3% green; 28% red	13	63.4	94% blue; 1% green; 5% red	24	60.6

Table 5.8 illustrates that Chameleon sensors were not monitored regularly and data was not uploaded consistently at some plots at Walda. Data was collected on the plots of Farmer No's 6A, 23C and 3B for a period of about 4 months during 2017 production season, and therefore the soil water patterns at all three depths were mainly blue. The taking of readings and uploading increased slightly during the 2018 growing season, which made more interpretations possible.

Farmer No 76H harvested an average of 120 t/ha sugarcane in August 2017, which was the highest average yield in comparison to other participants. It is a very high average yield if one takes into account that it was achieved during a drought period. The farmer started off with a wet profile on all three depths, and then towards the end of the season, before the "official dry off period", the soil became dry (Figure 5.3). The average drying off period for cane before harvesting is approximately 28-30 days (TSGro, 2016). The soil water pattern shows 41% red, 49% blue and 10% green colours. Unfortunately the chameleon sensors were stolen early during the 2018 production season, and no readings could be taken. However, this farmer once again produced the highest average cane yield per ha, specifically 116 t/ha.

During early growth, sugarcane can tolerate mild water stress, but is most sensitive during the stalk stage (Meyer and Wood, 2001). As with other crops, the frequency of irrigation depends on the stage of development of the cane. According to the Department of Agriculture, Forestry and Fisheries sugarcane production guidelines, as the root system for newly planted crops extends into deeper and deeper soils, the irrigation intervals should be extended, and the amount of water applied with each irrigation increased (DAFF, 2014). As the cane approaches maturity, extended irrigation intervals should be scheduled to reduce the rate of vegetative growth, dehydrate the cane, and force the conversion of reducing sugars to recoverable sucrose.

Figure 5.3: Chameleon soil water patterns for sugarcane grown by Farmer No 76H at Walda

In contrast to the plot of Farmer No 76H, the plot of Farmer No 3B was kept between moist and wet at all depths for the majority of 2017 production season (Table 5.8) The average cane yield for 2017 was only 65 t/ha and after the development officer showed the farmer the Chameleon patterns of 2017 at the end of the season, the irrigation management practices for 2018 was slightly adapted. This change in irrigation management practices showed a positive improvement of production yield during 2018 with an increase of 36%.

5.5.3 Sibange (Komati mill area)

At Sibange five farmers participated in the research. Of the five farmers only one farmer used a drip irrigation system, while the others used sprinkler irrigation. Two farmers planted a new crop of sugarcane during 2017, and therefore harvest was postponed till early 2018.

Table 5.9: Soil water patterns and production yields of Sibange sugarcane growers for 2017 and 2018 seasons

Farmer	Irrigation system	Field size (ha)	Soil water pattern 2017	No of readings 2017	Yield 2017 (t/ha)	Soil water pattern 2018	No of readings 2018	Yield 2018 (t/ha)
46	Sprinkler	7.7	34% blue; 15% green; 51% red	30	74	28% blue; 12% green; 60% red	57	76
47	Sprinkler	7.0	34% blue; 16% green; 50% red	25	104	38% blue; 13% green; 49% red	36	99
50	Sprinkler	7.4	88% blue; 0% green; 12% red	15	101	*No readings	0	117
17	Drip	7.3	100% blue; 0% green; 0% red	16	84	50% blue; 13% green; 37% red	19	65
8	Sprinkler	7.3	39% blue; 3% green; 58% red	25	44	55% blue; 13% green; 32% red	34	46

** Grower removed sensors after first season*

The plots of Farmers No 47 and 46 had good soils, whilst the other three plots had moderate soils. Chameleon sensors were installed on Farmer No 46's plot on 11 January 2017, while installation took place in other four plots on 20 December 2016. The sensors were installed at depths of 20, 40 and 60 cm in all five plots, and sensor arrays were installed between drippers in the case of Farmer No 17.

Chameleon sensors were also not monitored regularly and data was not uploaded consistently during the 2016-2017 growing season. The taking of readings and regular uploading improved after a meeting with the specific development officer and management of TSGro during August 2017. The soil water pattern for farmer No 50 was 88% blue, 0% green and 12% red during the first season (Table 5.9). The farmer's average cane yield /ha for 2017 and 2018 was 101 and 117 t/ha respectively. However, after the specific development officer shared the visualisations with participating farmers at the end of 2017 production season, the farmer decided to remove the sensors from the field and not to replace them. The reason provided for this action, was that she was afraid that she will be penalized for using too much irrigation water, especially during a period of severe drought conditions in Nkomazi. However, the fact that only 15 readings were taken during the first production season provided a skewed reflection of the actual soil water status, which in this case led to this farmer not continuing using the Chameleon.

The soil water patterns for Farmer No 46 and Farmer No 47 were very similar for 2017 growing season, the distribution of the colour patterns in the visualizations differed. The soil water pattern for Farmer No 46 showed that during two periods (from the second week of March to the first week of April and from mid-May to the beginning of August) the soil was dry at all three levels (20, 40 and 60 cm) at which the sensors were buried. In contrast, the soil water pattern for Farmer No 47 for the top sensor (20 cm) remained either blue or green from December to September with only a very brief period when the sensor was red. The bottom two sensors were red from March to September. During the following season, the soil water patterns changed for these farmers. The pattern for Farmer No 46 was 28% blue, 12% green and 60% red (Figure 5.4), while that of Farmer No 47 was 38% blue, 13% green and 49% red. The average cane yield for these two farmers differed significantly during 2018, respectively 76 and 99 t/ha, which had a great influence on the net farm income of the two farmers.

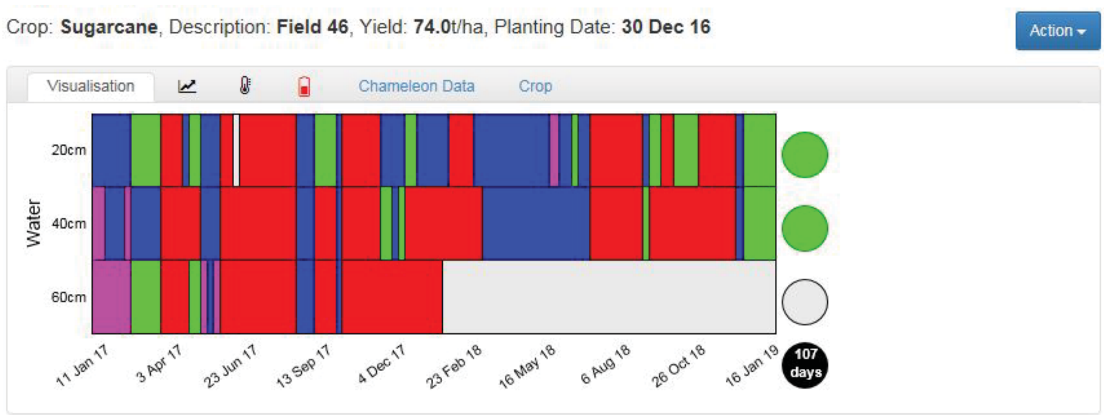

Figure 5.4: Chameleon soil water pattern for sugarcane grown by Farmer No 46 at Sibange, Nkomazi

The soil moisture patterns for Farmer No 8 was 55% blue, 13% green and 32% red during 2018 growing season and 39% blue, 3% green and 58% red during 2017 growing season (Table 5.9). This farmer averaged the lowest average cane yield during 2017 and 2018, specifically 44 t/ha and 48.6 t/ha. The pink colour or magenta that appears just after the Chameleon was installed in the farmer's field displays the Chameleon's response in salty soil. As indicated earlier this pink colour helps to alert the farmer that possible salinity problems may occur. A possible reason for this occurrence may be because of the period of relative low flow of the Komatiriver during 2016/17 when this area was experiencing severe drought conditions. Furthermore, a possible buildup of Ca and Mg levels in soils under irrigation in the northern irrigated sugar areas can also be a reason (Meyer *et al*., 1998).The effect of high soluble salts in the soil causes an accumulation of salts in cane juice, which in turns lower the purity and sucrose levels (Meyer and Wood, 2001).

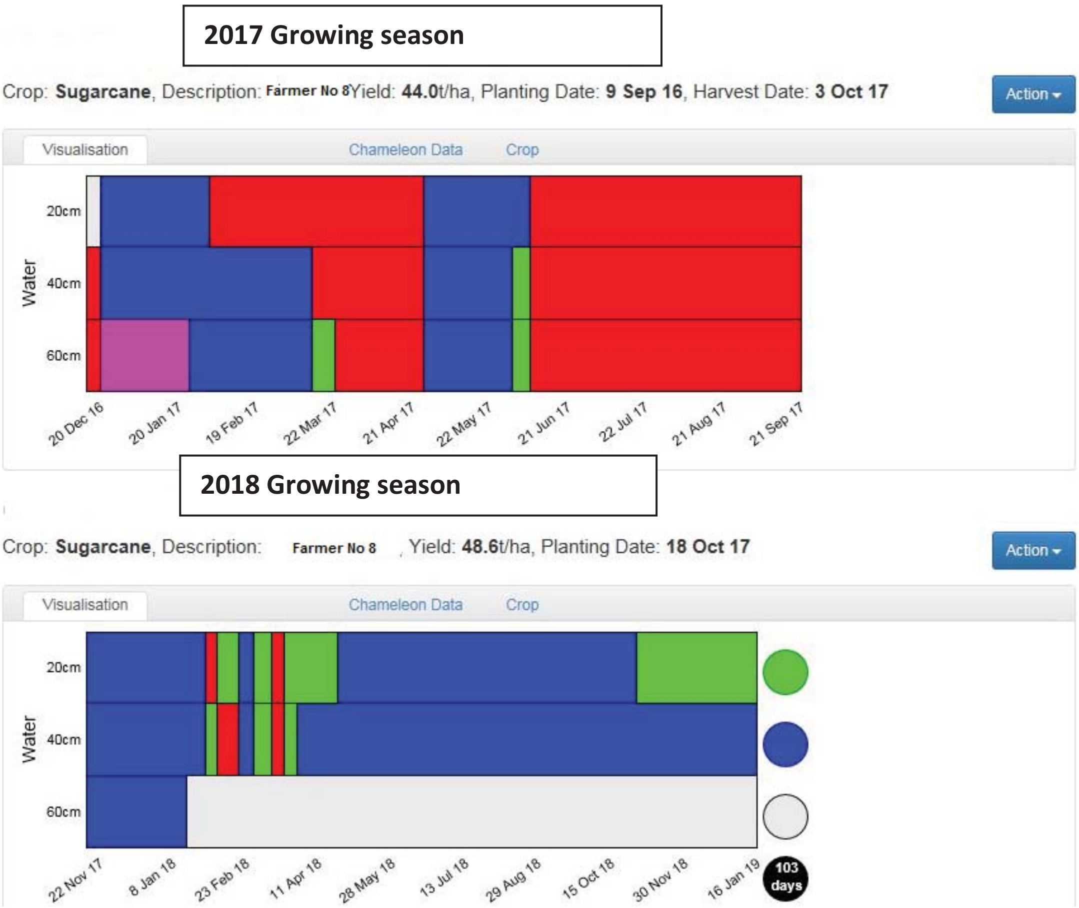

Figure 5.5: Chameleon soil water patterns for sugarcane grown by Farmer No 8 at Sibange, Nkomazi

The project faced many challenges at the Nkomazi irrigation scheme during the 2016-2017 production seasons, and on 29 and 30 August, the project team met with development officers and senior managers from TSGro to discuss challenges and difficulties of the previous season. The project team emphasized the importance of collecting data consistently throughout the crop growing period. During this meeting, TSGro development officers as well as senior management undertook to collect data more regularly. Following this meeting four additional sites were added for the 2018 production season namely: Buffelspruit, Siboshwa, Sikhwahlane and Spoons 7.

5.5.4 Spoons 7 (Komati mill area)

At Spoons 7, Chameleon sensors were installed in the fields of ten farmers during September 2017. The soil types of these project sites ranged from moderate to good soils and all of these farmers use sprinkler irrigation systems. Table 5.10 displays soil water patterns and average cane yields for production season 2018.

Table 5.10: Soil water patterns and production yields of Spoons 7 sugarcane growers for 2017 and 2018 seasons

Farmer	Irrigation system	Field size (ha)	Soil water pattern 2018	No of readings 2018	Yield 2017 (t/ha)	Yield 2018 (t/ha)
21	Sprinkler	11.7	28% blue; 12% green; 60% red	13	82	113.8
26	Sprinkler	9.4	28% blue; 13% green; 59% red	13	54	91.6
17	Sprinkler	9.4	88% blue; 4% green; 8% red	13	81	114
19	Sprinkler	9.7	87% blue; 5% green; 8% red	15	95	94.5
20	Sprinkler	8.8	33% blue; 12% green; 55% red	12	72	90.5
12	Sprinkler	9.2	96% blue; 0% green; 4% red	15	112	111.2
10	Sprinkler	10	No uploading and poor data taking	1	88	107.3
2	Sprinkler	9.5	Sensors stolen	1	68	89.4
15	Sprinkler	9.9	Sensors stolen	14	93	126.4
4	Sprinkler	11.4	64% blue; 23% green; 13% red	14	60	61.1

The highest yield at Spoons 7 was obtained by Farmer No 15 who harvested an average of 126 t/ha, but due to the limited data collected before the sensors were stolen, no meaningful analysis could be made. Farmer No 26 obtained the highest net farm income /ha, namely R276 427/ha, notwithstanding the fact that he preferred to keep the soil relatively dry at the beginning of the season.

Figure 5.6 illustrates that some farmers tend to keep their soil wet (close to 20-50 kPa), while others prefer to keep their soil relatively dry (red), but never the less still achieve high yields. This observation suggests that other factors besides irrigation management such as general crop husbandry may have contributed to these results.

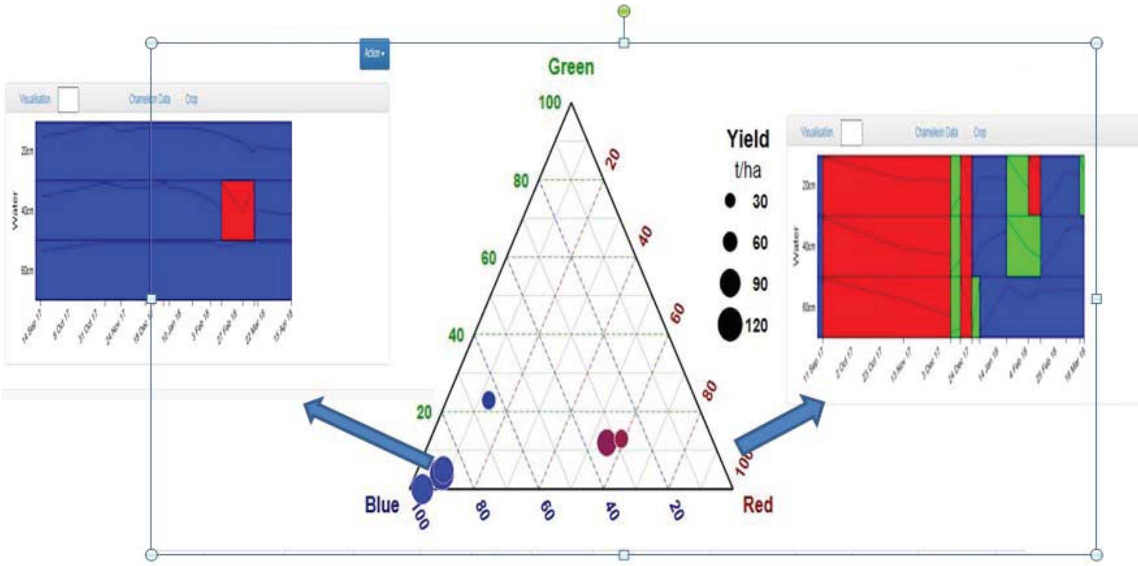

Figure 5.6: Integrated Chameleon patterns for sugarcane production at Spoons 7, Nkomazi

5.5.5 Sikhlwahlane (Komati mill area)

At Sikhlwahlane Chameleon sensors were installed in the field of five farmers during late 2018 (Farmers 42 and 27) and early in 2019 (Farmers 34 and 8) (Table 5.11). The soil types of these project sites were moderate and farmers only use sprinkler irrigation systems.

Table 5.11: Soil water patterns and production yields of Sikhlwahlane sugarcane growers for 2017 and 2018 seasons

Farmer	Irrigation system	Field size (ha)	Soil water pattern 2018	No of readings 2018	Yield 2017 (t/ha)	Yield 2018 (t/ha)
42	Sprinkler	7	33% blue; 33% green; 33% red	7	78	101.5
27	Sprinkler	6.9	32% blue; 25% green; 42% red	7	62	105.4
34	Sprinkler	6.8	No readings	7	85	42.3
8	Sprinkler	6.9	No readings	7	78	82.6

Due to the time of sensor installation in these fields, very little data was collected or uploaded to the VIA platform and therefore no meaningful interpretation of data was possible.

5.5.6 Siboshwa (Komati mill area)

At Siboshwa, farmers received funding for operation and capital development from Landbank and RCL mills. However, since farmers failed to repay these loans (both capital and operational loans), TSGro was approached to help these cooperatives to grow sugarcane. TSGro was appointed as managing partner in this joint venture with farmers and is responsible for helping farmers at an agreed management fee (which includes an irrigation and bookkeeping fee). The soil types of these project sites are good and all of these farmers use sprinkler irrigation systems. Chameleon sensors were installed at the three depths in field 4 and field 1 of the cooperative during November 2017. Table 5.12 illustrates that these farmers have improved their production since TSGro began to assist them in 2017.

Table 5.12: Soil water patterns and production yields of Sikhlwahlane sugarcane growers for 2017 and 2018 seasons.

Farmer	Irrigation system	Field size (ha)	Chameleon pattern (2018)	No of readings 2018	Cane yield (t/ha) (2017)	Cane yield (t/ha) (2018)	Difference (t/ha)
Coop F1	Sprinkler	10	24% blue; 0% green; 76% red	9	45.8	52.2	+ 6.4
Coop F4	Sprinkler	10	57% blue; 25% green; 8% red	9	52	70.9	+18.9

Due to the relatively few numbers of readings no meaningful interpretation could be made for the 2018 season to illustrate how irrigation practices could have impacted on the improvement of the final cane yield obtained. It is however interesting to note that the Chameleon patterns recorded for these two cooperatives were not much different from what the rest of farmers from other projects at Nkomazi displayed. Most probably the irrigation practice adopted for field F1 could have contributed to the relatively poor final cane yield obtained. If so, it should be a concern that it appears that project managers of TSGro are perhaps also requiring urgent training with regard to effective irrigation management.

5.5.7 Buffelspruit (Malelane mill area)

Chameleon sensors were installed in five farmers' fields in Buffelspruit during September 2017. The soil types of these project sites are classified as good and farmers use both sprinkler and drip irrigation systems. The irrigation system, soil water patterns and average cane yields for 2017 and 2018 are shown in Table 5.13.

Table 5.13: Soil water patterns and production yields of Buffelspruit sugarcane growers for 2017 and 2018 seasons.

Farmer	Irrigation system	Field size (ha)	Chameleon pattern (2018)	No of readings 2018	Cane yield (t/ha) (2017)	Cane yield (t/ha) (2018)	Difference (t/ha)
5C	Sprinkler	7.5	67% blue; 3% green; 30% red	13	23	107.6	+84.6
10B	Sprinkler	7.0	66% blue; 3% green; 31% red	15	Not planted	107	+107
7C	Sprinkler	7.2	56% blue; 15% green; 29% red	18	38	99.4	+61.4
10	Drip	9.3	0% blue; 0% green; 100% red	2	56	111.5	+55.5
1	Drip	8.6	0% blue; 0% green; 100% red	2	77	77.1	+0.1

The average production yield of all participating farmers increased significantly from 2017 till 2018, with the exception of Farmer No 1, whose improvement was insignificant A possible reason for this trend may be the fact that farmers received their full irrigation water allocation during 2018, and were therefore not restricted with water availability as they were during the 2017 growing season.

Poor data taking is evident in Table 5.13 for farmers 1 and 10, and no meaningful interpretation could be made of data. The yields and soil water patterns of Farmer No 5C and Farmer No 10B were very similar, however the net farm income of Farmer 5C was a little higher possibly due to better quality cane delivered (better RV %), since cane payment in South Africa is based on RV (Recoverable Value) percentage.

5.6 Conclusions

The aim with the research at Nkomazi was to introduce user-friendly tools to emerging commercial sugarcane farmers, and to record the experiences of farmers in trying these tools on their farms. A number of challenges were identified, and many of the technical shortcomings experienced in applying these tools in sugarcane farming were addressed. However, some institutional and other problems experienced require further examination.

Although the aim of the research was not prove that the use of irrigation monitoring tools would increase cane yields and crop productivity in general, a few interesting observations were made. The average production yield for the 2018 growing season of the various projects at Nkomazi as indicated in Figure 5.7 varies between 62 t/ha (Siboshwa) and 100 t/ha (Langeloop, Spoons 7 and Buffelspruit). A significant improvement of average cane yield occurred in Langeloop, Buffelspruit and Spoons 7. Possible reasons for this could be because of better climate conditions experienced during 2018 in comparison to 2017. Although the conclusion cannot be irrefutably made that the improvement of cane yields during 2018 growing season was solely because of improved fertilisation and irrigation practices, they definitely contributed to improved cane yields. The fact that farmers received their full water allocation from Lomati and Komati Irrigation Boards also contributed to this outcome as farmers were using their full allocation. The use of full quota of irrigation water was evident in the frequency of the occurrence of magenta visualisations during 2018 in comparison to 2017.

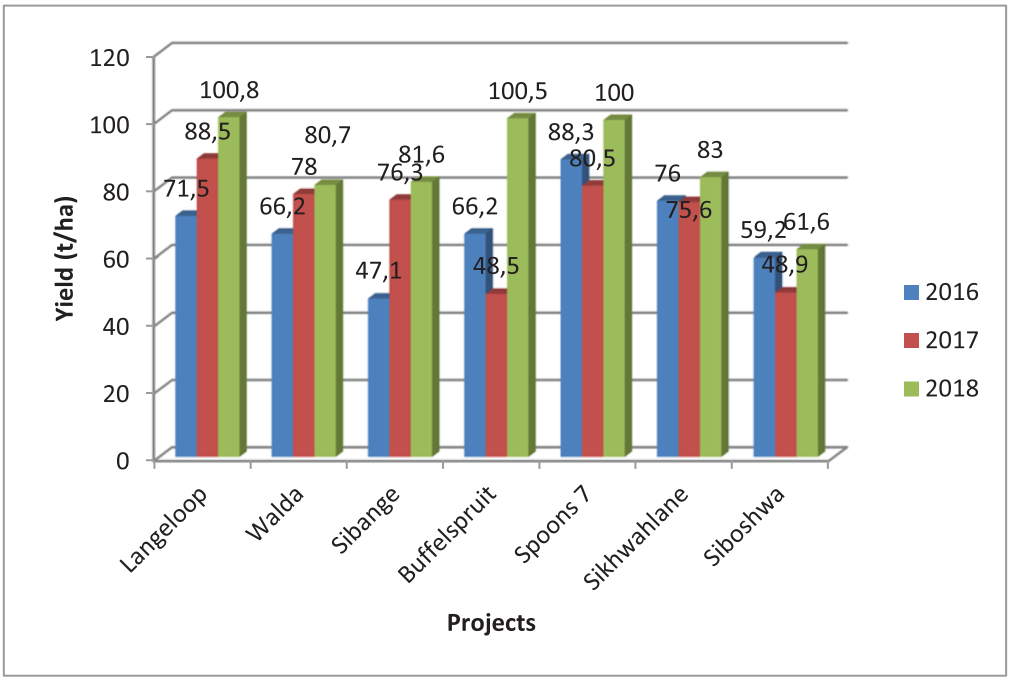

Figure 5.7: Average sugarcane yield of participants at Nkomazi as per project

The apparent inconsistencies that were observed in some data from Nkomazi between soil water patterns and yields are not simple to explain. In many of the cases more frequent readings and detailed records of production records like quality and exact amount of irrigation water used per farmer could have provided a clearer picture of the changes in yield.

It is interesting to observe that although the application efficiency of drip irrigation systems are much higher than that of sprinkler systems (90% versus 75%), farmers participating in this project with drip systems did not manage to outperform farmers using handshift sprinkler systems. The highest yield recorded under drip and sprinkler were 116 t/ha and 157 t/ha respectively. A possible reason for this may be the general poor condition of drip irrigation systems used on the projects (systems are 15 years and older) and also because very few farmers properly maintain their drip irrigation systems Apart from the condition of irrigation systems, many farmers use the same irrigation schedule for drip and sprinklers.

The development officers of TSGro indicated in personal interviews that were conducted after the completion of research in Nkomazi that some farmers showed interest in the Chameleon after they were made aware of the Chameleon patterns based on their irrigation practices. Since farmers do not use any other irrigation scheduling tool apart from following a fixed schedule plus applying their implicit knowledge (intuition, experience and observation), they found these patterns interesting and others very shocking. It is only at Siboshwa where farmer cooperatives used tensiometers, but poor data taking prohibited any comparison of data between the Chameleon and tensiometer.

Chapter 6: Emerging commercial citrus growers in North West, Limpopo and Eastern Cape Provinces

The following part of the report reflects the learning experiences from emerging citrus farmers in North West, Eastern Cape and Limpopo Provinces in the deploying of the Chameleon and the use of the VIA. These emerging citrus farmers were selected with the support of the development officer of Citrus Growers Association of South Africa through the Citrus Grower Development Company (CGA). Initially after the introduction of the tools to the development officer, intensive training followed at the University of Pretoria in the use of the monitoring tools.

6.1 North West Province

In the North West Province four citrus farmers were selected with the support of the CGA development officer to participate in the project namely: Batlhako Primary Cooperative; Zoutpansdrift Citrus; Elandskraal Projects Pty Ltd and Healthy Life for Achievers Pty Ltd. These farms were attained through the proactive land acquisition strategy (PLAS) which identified four categories of beneficiaries: (1) households with no or very limited access to land; (2) small scale farmers farming mainly for subsistence and selling some produce locally; (3) medium-scale farmers already farming commercially but constrained by insufficient land; and (4) large-scale commercial farmers with potential to grow but disadvantaged by location and farm size. These are all emerging commercial citrus farmers (category 4) that lease land from the Department of Rural Development and Land Reform (DRLDR) through the State Land Lease and Disposal Policy (SLLDP) of 2013.

6.1.1 Batlhako Temo Primary Cooperative Ltd

The Batlhako Primary Cooperative commenced farming activities in 2011. The farm Hartbeespoort measures 61.44 ha and consists of portions 595 and 588, and is leased on a five year lease agreement. All cooperative members have some background in farming, but not specifically in the production of citrus. The farm Hartbeespoort 215JQ is located on the Thabazimbi road, approximately 25 km north-east of Brits in the North West Province.

The size of the arable land on the farm is 38 ha of which 21.7 ha is currently planted with citrus. A variety of oranges are produced on 21.7 ha land planted with 16 000 trees, which has a great potential yield if the correct irrigation, pruning, fertilisation and tree treatment are applied. Arable land is available to increase the production area by a further 10 ha, and the farmer is currently busy with the process of orchard establishment. The varieties include Valencias, Tambo, Manyolas and Premiers.

6.1.1.1 Climate and soil

The farm is situated in an area with summer rainfall, hot summers and cold winters (Figure 6.1). The annual rainfall averages 540 mm, with most rainfall occurring during midsummer. Frost occurs sporadically in winter rendering the farm only suitable for semi cold-tolerant crop types. The historical incidence of hail is about once every 8 to 10 years.

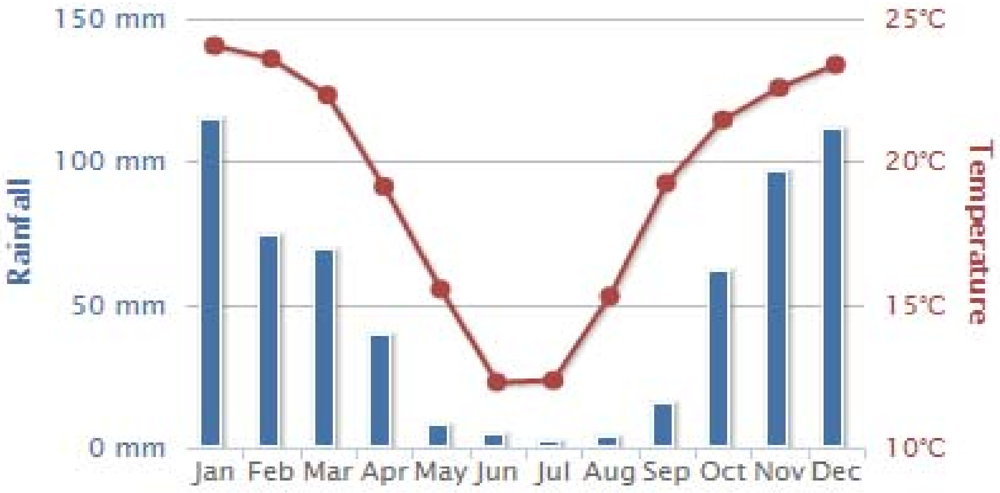

Figure 6.1: Average monthly temperature and rainfall for the farm Hartbeespoort, Sanddrift, Brits from 1960-2000

Deep well drained mainly reddish-brown sandy-loam soil occurs on the farm which is highly suitable for orchard crops.

6.1.1.2 Irrigation

The irrigation water is sourced from a canal (*via* a lined earthen dam with two pump stations on the farm). The water allocation to the farm totals 61 ha (6700 m^3 /ha) and the canal is managed by the Hartbeespoort Irrigation board.

The farm implemented initially a “guideline system” for irrigation because of the poor state of the irrigation system with transfer of land. In 2016, the micro jet system was replaced on half of the orchard, while the other half still makes use of manual irrigation. All orchards are irrigated with one micro-sprinkler per tree, positioned 0.5 m away from the tree with a delivery rate of 9.5 mm/hour. The current irrigation schedule followed on the farm is irrigation for 2 hours, 3 times per week or aiming to apply approximately 570 l/week. The production manager appointed by Batlhako Temo Primary Coop Ltd is a person who obtained a three year agricultural diploma from the previous Lowveld Agricultural College. He is well trained and has the necessary experience in irrigation management.

6.1.1.3 Use of monitoring tools to assess the irrigation practices

Chameleon sensor arrays were installed in two citrus orchards, Block B2 (Tambor) and Block V1 (Valencia Late) on 6 September 2017. During 2018 after the attendance of a workshop held at University of Pretoria where farmers were invited to share their learning experiences, more sensors were installed in Block P1 (Premier) and Block B1 (Tambor) during February 2018.The sensors were installed at 20, 40 and 60 cm depths between the micro-sprinkler and the tree within the drip line of the trees and the wetting pattern of the micro-sprinkler.

Table 6.1: Soil water patterns for citrus orchard blocks at Hartbeespoort, North West Province

Block	Size (ha)	Variety	Planting spacing (mxm)	Soil	Visualisation pattern (2017)	No of readings 2017	Visualisation pattern (2018)	No of readings 2018
B2	1.6	Tambor	5.8x2.6	Kranskop form	100% Blue; 0% Green and 0% Red	82	73%blue; 9% green; 18% red	114
V1	2.1	Valencia Late	6x3	Kranskop form	90% Blue; 10% Green and 0% Red	85	64%blue; 9% green; 27% red	106
P1		Premier	5.8x2.6	Kranskop form	N/A	N/A	69%blue; 7% green; 24% red	77
P2		Premier	5.8x2.6	Kranskop form	N/A	N/A	68%blue; 6% green; 26% red	79

Since the installation of the sensors in September 2017, the soil water pattern for Block B2 remained 100% blue with no green or red colours (except at sensor installation) (Table 6.1). A similar tendency was evident for Block V1 where the pattern was 90% blue and 10% green. When the farmer was asked about this approach, he admitted that he aimed to keep the soil wet as his perception was that “blue” is the best option to aim for. After the March 2019 workshop held at the University of Pretoria’s experimental farm where the farmer was informed about the dnager of this irrigation practice, i.e. the possibility of nutrient leaching and predisposing the trees to root diseases, the irrigation pattern changed dramatically as visible in Table 6.1. Both the farmer and his farm manager attended the workshop. At the workshop, the farmer said that he finally understood that maintaining a blue colour pattern was not necessarily the best practise. He recognized that this could have negative financial implications for him with regard to leaching fertilisers and possibly encouraging root diseases. He also planned to take more frequent readings in order to keep the soil moist (green pattern) rather than trying to maintain a wet pattern. Table 6.1 illustrates that the farmer indeed increase the frequency of data taking after the workshop. The change in irrigation management practices is illustrated in Figure 6.2.

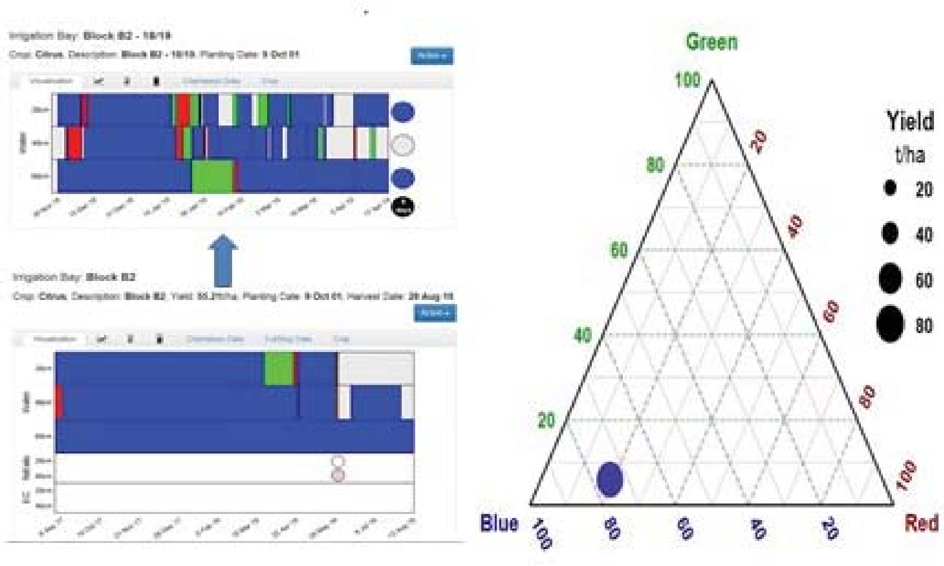

Figure 6.2: Integrated Chameleon soil water pattern for citrus growing at Hartbeespoort, North West Province

Two sets of wetting front detectors (WFDs) were also installed in September 2017, at 20 and 50 cm depths in blocks B1 and V1 (Figure 6.3) to monitor salinity in the root zone as well as possible nitrate leaching out of the root zone. Data was collected from the wetting front detectors weekly. With the initial irrigation scheduling practice it was evident after installing of WFDs that nutrients quickly leached to a depth of 50 cm, as the NO_3 readings were much higher (250ppm) in the 50 cm zone than in the 20 cm zone (10ppm). This implied that nutrients were leached beyond the effective root zone of the citrus tree, which is between 20 and 30 cm as it was observed during installation of monitoring tools. Even with the adapted irrigation scheduling practices, where the farmer tried to move away from keeping the soil wet all the time, NO_3 readings were still between 250 and 500ppm in the 50 cm zone.

Figure 6.3: Full stop installation showing leaching of nutrients

The farmer indicated in an interview conducted at the end of the project after he used these tools for two consecutive seasons, that he found the use of the Chameleon very valuable in terms of making decisions about irrigation scheduling on the citrus. According to the irrigation manager the trees are looking much healthier during the 2019 production season (no frequently occurring yellow leaves which indicated possible water logging and over-irrigation) and the yield as well quality of fruit has visibly improved. The farmer will start harvesting by the end of May 2019. Both the irrigation manager and farmer are very satisfied with the Chameleon and also did not experience problems with the uploading of data to the VIA.

The current irrigation scheduling practice from the previous season is showing benefits (economically and ecologically) and the farmer is happy with the improvement of productivity on the farm. During the 2017 production season the majority of fruit (90%) was used for processing (juice) through a local factory in Brits. However, during the 2018 production season a substantial improvement was visible in the improvement of yield and quality of fruit due to better spraying, fertilisation and irrigation management practices. The export percentage for 2018 increased to 14.6%, followed by 37.2% of fruit sold locally and only 48.2% produced for the juice factory (Table 6.2).

Table 6.2: Production of citrus on the farm Hartbeespoort for 2018

Variety	Market	Production (2018)	
		Ton	Percentage
Minneolas (2.4 ha)	Juice	52.32	46
	Local bakkie hawkers (informal)	60.63	54
Premier (5.1 ha)	Juice	68.98	59
	Local market (formal)	47.50	41
Tambor (2.6 ha)	Juice	76.01	30
	Export	120.62	48
	Local bakkie hawkers (informal)	55.01	22
Valencia (11.6 ha)	Juice	420.70	53
	Export	65.94	8
	Local bakkie hawkers (informal)	287.87	36
	Local market (formal)	25.05	3
Total		**1280**	

6.1.2 Zoutpansdrift Citrus

Portions 313, 314 and 315 of the farm Zoutpansdrift 415 JQ is owned by the Department of Rural Development and Land Reform (DRDLR) and is leased to Gaman 67 CC. on a five year lease agreement. The farm is situated near Brits in the Madibeng local municipality area and the Department of Rural Development and Land Reform (DRDLR) provided a grant funding for the recapitalisation of the farm. The local Provincial Department of Agriculture (PDoA) is responsible for coordinating the disbursement of infrastructure grants like Comprehensive Agriculture Support Program (CASP), which forms an integral part of the infrastructure development on the farm.

The farm is 80 ha in size and comprise of the following (Figure 6.4):

- Orchard ZP 1 (5.2 ha): Valencias and mid-season oranges planted in 2007/08
- Orchard ZP 3 (21 ha: A mixture of Valencias, Mid-seasons and Minneola's and Jashinto planted in 1995/96.
- Orchard ZP 2 (12 ha): Currently temporarily cultivated with cash-crops
- Rocky outcrops and grassland only suitable for grazing (±37 ha)
- Buildings, roads, dams and other infrastructure (±5 ha)

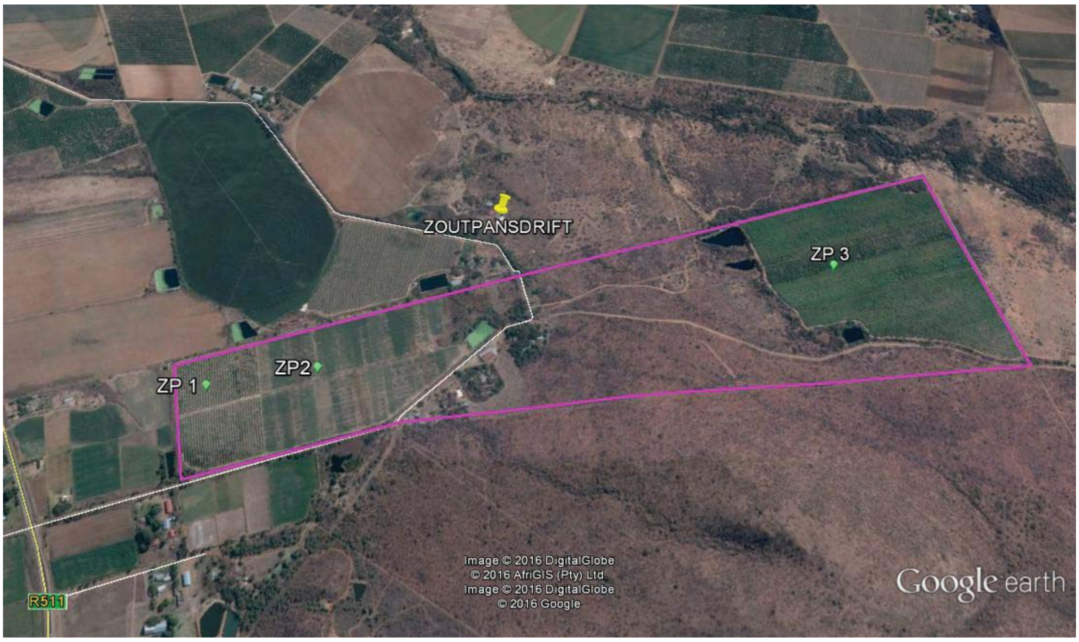

Figure 6.4: Farm map and orchard layout of Zoutpansdrift

6.1.2.1 Climate and soil

The farm is situated in an area with summer rainfall, hot summers and cold winters. The annual rainfall averages 600 mm and frost can occur sporadically during the winter. The soil on the farm is deep well drained mainly reddish-brown sandy-loam highly suitable for orchard crops.

6.1.2.2 Irrigation

The farm has two boreholes of which one is operational and equipped to supply water for domestic purposes. The irrigation water is sourced from a canal (*via* three earthen dams with two pump stations on the farm). The water rights from the canal allocated to the farm totals 38 ha (6700 m^3/ha) and the canal is managed by the Hartbeespoort Irrigation Board. The irrigation system consists of a mixture of both micro sprinklers and drippers. The spacing of the drippers is 0.6 m and their delivery rate is 1 l/h, while the micro sprinklers are spaced at 1 m away from the tree, and the delivery rate varies because of a mixture of nozzle sizes installed in the same irrigation system. The farmer used a fixed schedule by irrigating three times a week for 2-4 hours/day, depending on the phase of fruit development.

6.1.2.3 Use of monitoring tools to assess irrigation practices

Three sets of Chameleon sensors were installed during September 2017 in orchard Block ZP3 and Block M1ZP where oranges (Midknight) were planted. The sensors were installed at 20, 40 and 60 cm depths between the micro-sprinkler and the tree within the drip line of the trees and the wetting pattern of the micro-sprinkler.

Unfortunately, the farmer experienced some problems with the irrigation management on the farm, including not taking readings due to a faulty reader (which occurred in late 2018 and was changed for a new one) and infrequent uploading of data due to poor Wi-Fi reception. The farmer only took 11 readings at these blocks during 2017 and 2018 production seasons. The grey pattern at the deepest sensor (60 cm) in Figure 6.5 shows that there was a loose wire at the green plug that connects the field reader to the sensor array. The irregular data taking and uploading of data by the farmer prevents any in-depth interpretation of data.

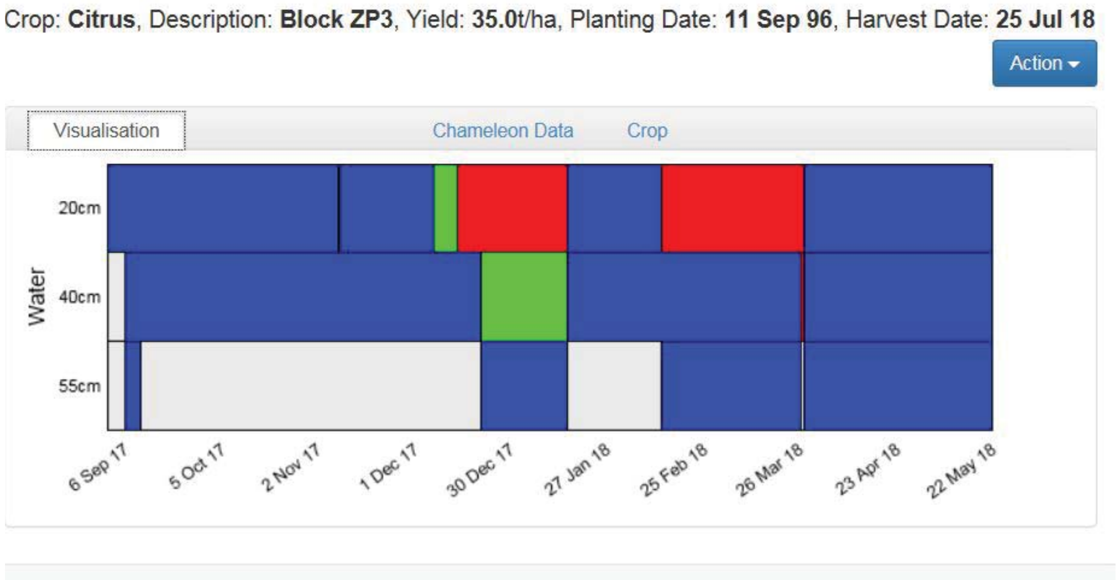

Figure 6.5: Soil water pattern for Block ZP3 on Zoutpansdrift, North West Province

6.1.3 Elandskraal Projects (Pty) Ltd

This farm was acquired in April 2015 through the Department of Rural Development's Proactive Land Acquisition Strategy (PLAS) and leased for a 30 year lease period. The Department of Rural Development and Land Reform (DRDLR) provided grant funding for the recapitalisation of the farm and the PDoA in North West is responsible for infrastructure development through the Comprehensive Agriculture Support Program (CASP). This farm is situated close to Mooinooi in the Bojanala Platinum district municipality of North West Province.

Citrus is currently produced on 6.3 ha on Elandskraal and 28 ha on Buffelshoek – totalling 34.3 ha with approximately 12 300 trees (Figure 6.6). The orchards comprised mostly of oranges (Valencias/Navels), lemons and limited new-type soft citrus. The orchards are predominantly old, with 56% of the trees older than 30 years.

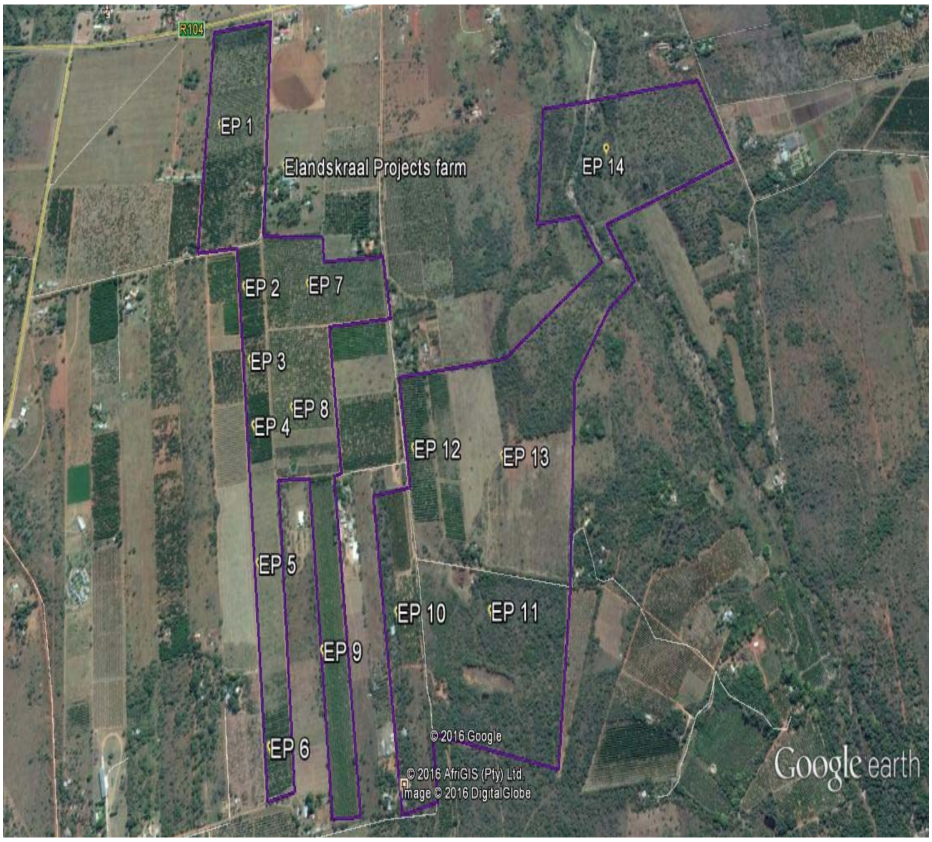

Figure 6.6: Farm map and orchard layout for Elandskraal

6.1.3.1 Climate and soil

The farm is situated in an area with summer rainfall, hot summers and cold winters. The annual rainfall averages 580 mm with sporadic frost occurring during the winter. The farm is characterised almost entirely of deep well drained soils, mainly reddish-brown and sandy-loam which is highly suitable for orchard crops.

6.1.3.2 Irrigation

Although part of the farm is adjacent to the Maretlwana River, irrigation water used is pumped from boreholes with storage available in two dams. There are currently 22 boreholes on the farm of which 10 are functional and equipped. The remaining 12 need to be re-equipped and there is also a fountain shared with three neighbouring farmers. The current water allocation is for 34 hectares.

Irrigation is applied through micro sprinklers placed 1 m from the tree and water is pumped via three filter dams. The micro sprinkler system in use was not in a good condition at the time of installing monitoring tools, nozzle sizes varied and problems were experienced with pressure, which had an impact on the irrigation delivering. These shortcomings were highlighted to the farmer during the installation of tools. As in the case mentioned earlier with other citrus farmers, the Department of Rural Development and Land Reform (DRDLR) provided grant funding for the recapitalisation of the project, and the PDoA in North West was appointed to support farmers through the disbursement of infrastructure such as irrigation infrastructure. One of the main challenges that the farmer faced was the lack of necessary knowledge about basic irrigation management. CASP provide support as far infrastructure and immediate extension services. Very often, extension services do not have the necessary technical competency to support irrigation farmers, which often leaves farmers to make use of technically incompetent service providers without realising it.

6.1.3.3 Use of monitoring tools to assess irrigation practices

Chameleon sensors were installed in Block 28 and 33 at 20, 40 and 60 cm depths on 5 September 2017. Sensors were installed between the micro sprinkler and the tree, within the drip line of the tree.

Table 6.3: Soil water patterns for citrus orchards at Elandskraal, North West Province

Block	Size (ha)	Variety	Planting spacing (mxm)	Visualisation pattern (2018)	No of readings 2017/18
28	6.2	Eureka	6x3	68%Blue; 9% Green; 23% Red	84
33	28.0	Valencia	6x3	83%Blue; 6% Green; 11% Red	39

Table 6.3 indicates the overall soil water patterns for 2018, but is not an accurate reflection of the changes in the soil water pattern, because there were long periods in which no data was collected. Initially this farmer had difficulty in collecting data. That was followed by a period where he could not upload any data to the VIA platform from 14 December 2017 to 14 February 2018. The reason for this was problems that occurred with the storing of data on the logging reader. After this problem was resolved the farmer collected data more consistently.

6.1.4 Healthy Life for Achievers (Pty) Ltd

This farm was acquired in April 2015 through the Department of Rural Development's Proactive Land Acquisition Strategy (PLAS), and leased on a 30 year lease from DRDLC. This farm is situated close to Mooinooi in the Bojanala Platinum district municipality of North West

Province. The Department of Rural Development and Land Reform (DRDLR) provided grant funding for the recapitalisation of the project and PDoA in North West is responsible for rendering support services through the disbursement of CASP grants.

Citrus is currently produced on 21 hectares with the remainder of the farm being utilized for grazing (Figure 6.7). It is estimated that the citrus operations can be extended to a total of 58 hectares.

Figure 6.7: Farm map and orchard layout at Mooinooi

The variety distribution of the current 22 ha orchards are comprised mostly of Valencias (30%); Mid-season oranges (30%) and various soft citrus varieties (60%). The orchard age distribution varies between younger than 10 years up to 30 years.

6.1.4.1 Climate and soil

The farm is situated in an area with summer rainfall, hot summers and cold winters. The annual rainfall averages 580 mm and frost occurs sporadically during the winter. Deep well drained soil occurs, mainly yellow-brown sandy-loam highly suitable for orchard crops.

6.1.4.2 Irrigation

The farm has 17 boreholes of which 12 are currently equipped. The current water allocation to the farm is as follows:

- Portion 44: 4.12 ha
- Portion 45: 6.9 ha
- Portion 181: 9.0 ha

The micro sprinkler irrigation system in use is not in a good condition due to vandalism before the farm was officially taken over. CASP funding obtained from the PDoA is earmarked to address the problem. A fixed irrigation schedule is applied of 2 hours irrigation every second day with the aim to irrigate 80 l/tree/week.

6.1.4.3 Use of monitoring tools to assess irrigation practices

Chameleon sensors were installed in three orchards namely B14, B16 and B21 on the farm on 5 September 2017 (Table 6.4). Sensors were installed between the micro sprinkler and the tree, within the drip line of the tree and the wetting pattern of the micro-sprinkler.

Table 6.4: Soil water patterns for citrus orchards at Mooinooi, North West Province

Block	Size (ha)	Variety	Planting spacing (mxm)	Visualisation pattern (2017)	No of readings 2017
B14	4.0	Clementine	6x3	72%Blue; 17% Green; 11% Red	24
B16	6.9	Valencia	6x3	69%Blue; 9% Green; 22% Red	25
B21	9.0	Valencia	6x3	59%Blue; 13% Green; 28% Red	22

The farmer experienced problems with the taking of data and especially with uploading data to the VIA. Irregular data taking and poor uploading since February 2018 impeded proper analysis of data.

6.2 ZEBEDIELA CITRUS (PTY) LTD, Limpopo Province

The Zebediela Citrus Estate was selected in Limpopo Province to participate in the project due to the size of the operation and the fact that it is regarded as a successful joint venture between a commercial farmer and the local community. The farm is owned by the Bjatladi Community Property Association since 2003 when the farm was transferred *via* Restitution of Land Rights, No 22 of 1994. There are 1 073 beneficiaries from different villages in Lepelle-Nkumpi local municipality who are represented by trustees on the Board of Zebediela Citrus (Pty) Ltd. This farm of 5 973 ha is located in the Limpopo Province in the Capricorn district, 22 km west of Lebowakgomo and 34 km east of Mokopane and is currently managed through a lease agreement between a commercial farmer and the Community Property Association (CPA) in a joint venture.

The farm consists of:

- 921 hectares citrus and macadamia orchards in production
- ±700 hectares of abandoned orchards (cultivated up to the early 1990s)
- ±250 hectares developed to housing, recreational facilities, offices, pack houses, cold stores, etc.
- ±200 natural wetland
- ±3900 hectares natural veld.

The basic lay-out of the current orchards on the estate is illustrated below (Figure 6.8) where the citrus orchards are numbered and the macadamia orchards indicated with an M. Most of the citrus orchards existing on the farm are reaching the end of their productive lifespan.

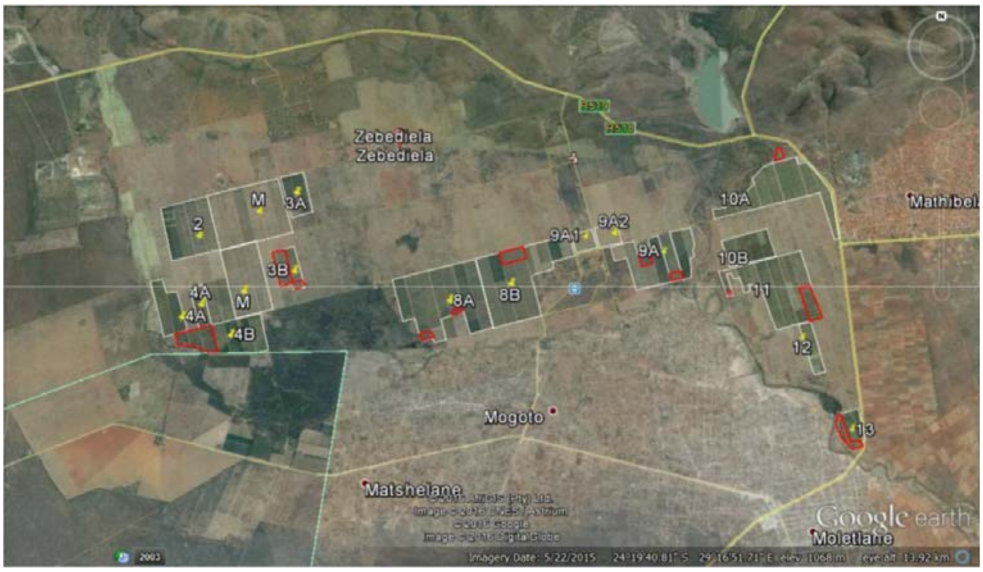

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Figure 6.8: Farm map and orchard layout

The produce of the farm is either exported, or marketed locally or used for processing (juice). The farm consists of a very old packhouse with a very complex and unproductive layout and most of the equipment being on the verge of becoming non-functional and obsolete due to the old technology.

6.2.1 Climate and soil

The area has predominantly summer rainfall with an average of 610 mm per annum. The historical incidence of frost and hail is low. The farm has mainly reddish-brown sandy loam (10-20% clay) of colluvium origin, predominantly slightly calcareous and well drained which is suitable for orchard crops.

6.2.2 Irrigation

The irrigation water for the farm is acquired from 70 boreholes (with deliverance between 6-7000 l/h) and water is also pumped from the Nkumpi dam. This dam collects water from the Nkumpi River and via an interception canal from the Monomane River. These water sources are connected *via* an intricate and complex system (>150 km long) of canals and pipes to the orchards situated in the various sections of the estate. Unfortunately, the condition of these canals and pipes as well as the equipment servicing the boreholes and filter-stations has deteriorated. Apart from the Nkumpi dam scheme there are 18 low capacity filtration dams constructed on the farm.

The irrigations systems, pumps and filters servicing the irrigation systems are generally not in a good state and require a major re-capitalization programme to re-furbish and upgrade (Swanepoel, 2017). According to Swanepoel (2017), in-effective pressure of the supply lines between the filter systems and the micro-sprinklers results in poor delivery rates of micro-sprinklers. The norm for the nozzle or spinner combination of micro-sprinklers used at Zebediela is that the wetting radius should be approximately 1.6 m, while it was yielding less than 1 m radius during the installation of monitoring tools. This aspect together with the placement of the micro-sprinklers too close to the trunk of the trees (less than 0.3 m) resulted in excessive water stress, whilst at the same time also causing waterlogged conditions favourable for *Phytophtora* induced root-rot around the tree trunks (Mbedzi, 2017). The placing of micro sprinklers was addressed by the farmer after the farm visit. Currently micro-sprinklers are placed 80 cm from the tree. The farmer is irrigating for 2-3 hours every week. Before the installation of the Chameleons the effectiveness of this schedule was tested by regular use of a soil auger to determine the wetness of the soil (hand feel method) after irrigation. The farm manager responsible for irrigation management on Zebediela is also a graduate from an agricultural college, and therefore understands the first principles of irrigation management.

6.2.3 Use of monitoring tools for assessing irrigation practices

Twenty four Chameleon sensor arrays were installed in several orchards at Zebediela Citrus Estate between 9 and 11 November 2017 (Table 6.5).

Table 6.5: Soil water patterns (2017/18) for citrus blocks at Zebediela

Section	Orchard no	Variety	Planting date	2017/18 visualisation	No of readings 2017/18
A	10A-1	Eureka	Oct 78	61%Blue; 12% Green; 27% Red	17
A	10	Palmer	Oct 79	48%Blue; 16% Green; 36% Red	18
A	10-1L	Eureka	Nov 81	44%Blue; 31% Green; 25% Red	68
A	11-L	Palmer	Nov 78	35%Blue; 19% Green; 46% Red	61
A	11-0	Du Roi	Sept 08	41%Blue; 31% Green; 28% Red	68
B	*9A-PN	Palmer	Oct 83	75%Blue; 0% Green; 25% Red	17
B	12	Eureka	Oct 2000	60%Blue; 18% Green; 22% Red	67
B	9A-LV	Late Valencia	Oct 2010	80%Blue; 5% Green; 14% Red	56
B	9B-G4	Gran Ester	Oct 2017	51%Blue; 26% Green; 23% Red	26
B	9B-1	Nova	Oct 2010	48%Blue; 34% Green; 18% Red	72
B	9B-2	Eureka	Oct 84	67%Blue; 12% Green; 21% Red	65
C	8B-MKN	Midknight	Oct 2015	45%Blue; 22% Green; 32% Red	12
C	*8B-PN	Palmer	Oct 2014	100%Blue; 0% Green; 0% Red	2
C	*8A-B1	Delta	Oct 85	100%Blue; 0% Green; 0% Red	2
C	8B-B4	Midknight	Oct 2016	32%Blue; 22% Green; 46% Red	70
C	*8B-B6	Midknight	Oct 85	100%Blue; 0% Green; 0% Red	2
C	*8B-B8	Midknight	Oct 86	89%Blue; 11% Green; 0% Red	2
D	2A	Delta	Oct 88	60%Blue; 10% Green; 30% Red	55
D	3A	Delta	Oct 85	40%Blue; 19% Green; 41% Red	68
D	4B-B1	Delta	Oct 81	69%Blue; 10% Green; 21% Red	71
D	4B-B4	Midknight	Sept 85	18%Blue; 26% Green; 56% Red	73
E	3A-B2	Boumont	Oct 08	58%Blue; 11% Green; 32% Red	72
E	3A-B5	Boumont	Nov 08	32%Blue; 14% Green; 54% Red	61
E	4A-B7	Boumont	Oct 08	25%Blue; 25% Green; 50% Red	68
E	4A-B8	Boumont	Oct 08	22%Blue; 23% Green; 55% Red	7

**Sensors stolen*

All the sensor arrays were installed at 20, 40 and 60 cm depths. The sensors were installed between the micro-sprinkler and the tree within the drip line of the trees and the wetting pattern of the micro-sprinkler. Although the soil water patterns for Orchard No: 10 A1 (61% blue; 12% green and 27% red) and Orchard No: 12 (60% blue; 18% green and 22% red) look similar, the patterns were very different. In the case of Orchard No: 10 A1, the top sensor (20 cm) has remained mostly blue. In contrast, in Orchard No: 12 there was greater variation in the soil water status observed during the production season. Unfortunately the farmer could not provide harvesting yields per block, which would have helped to illustrate whether these differences in the patterns had any effect on the yield and quality.

In citrus production the greatest challenge is to measure the needs of the trees accurately. Therefore producers tend to keep soils relatively wet to avoid water stress that may affect yield and quality of production. Matured citrus requires approximately 830 mm ha^{-1} $annum^{-1}$ (CRI, 2007). Citrus is extremely sensitive to water stress during blossom stage and cell division, phase 2 of the season when fruit size and sugar levels are determined. In citrus production the readily available water (RAW) is of great importance and lies between full water capacity (FWC) and approximately -50 kPa. The water tension for the soil will differ for the variation in clay content. (CRI, 2007).

The farmer received wetting front detectors to install during the March 2018 workshop and one of these sets was installed in Nova block (Block 9B-1) (Figure 6.9). The purpose of the installation was to assess whether nutrients are leached with the irrigation practises applied. The irrigation manager acknowledged that they were curious about leaching nutrients when following the 3 hour irrigation application, and after witnessing the effect on nitrate leaching beyond the 20 cm zone, they decided to reduce irrigation to 2 hours/week.

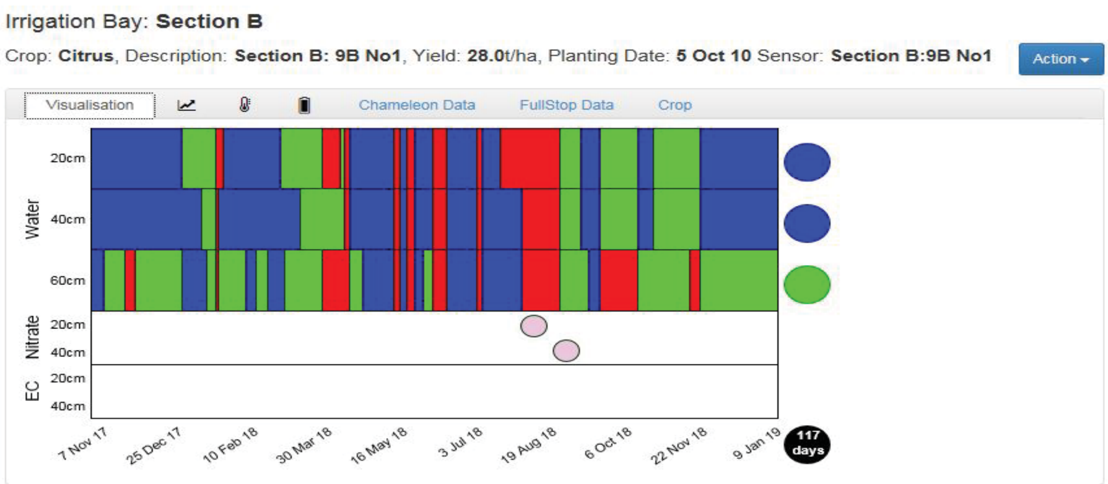


Figure 6.9: Soil water pattern for the Nova block (Block 9B-1) at Zebediela showing WFD responses to irrigation

If the soil water patterns are analysed, they align with the strategy of the farmer to keep citrus blocks at approximately 50+ % blue during the season. A possible reason for the fluctuation in soil water patterns between blocks are the availability of water, especially during the period of record keeping (2017). Unfortunately harvesting records were not taken per block, but only per citrus variety (Table 6.6). Therefore no meaningful interpretation was possible to compare for instance the soil water pattern of a block 2A (Section D, Delta) where the soil was kept at 60% blue with block 3A (Section D, Delta), where the soil was kept at 40% blue.

Table 6.6: Average citrus production yields for the 2018 production season

Variety	Planted area	Average production (t/ha)
Lemons (Eureka)	170	41
Navels	319	21
Novas	28	28
Midknights	86	35
Delta Valencia	115	31
Late Valencia/du Roi	46	27

According to the farm manager the production figures displayed in Table 6.6 were far below the area average due the high percentage of old orchards and mismanagement in the past. However, the production yields for 2018 was better than for 2017, especially quality of the fruit. The main reasons according to the CEO of the company are because of improved irrigation and fertilisation practices that were used during 2018.

The occurrence of the magenta colour in the Chameleon patterns during 2017 was more prominent than during 2018, because of the very dry conditions that were prevailing, and the fact that the water quality of boreholes on the farm was also deteriorating because of the drought. This display of the pink colour in the Chameleon patterns was most probably the effect of salinity present in the soil. With the increase in rainfall during 2018, and the fact that the Nkumpi river level increased, the water quality improved and less magenta effects were recorded as illustrated in Block B12 (Figure 6.10).

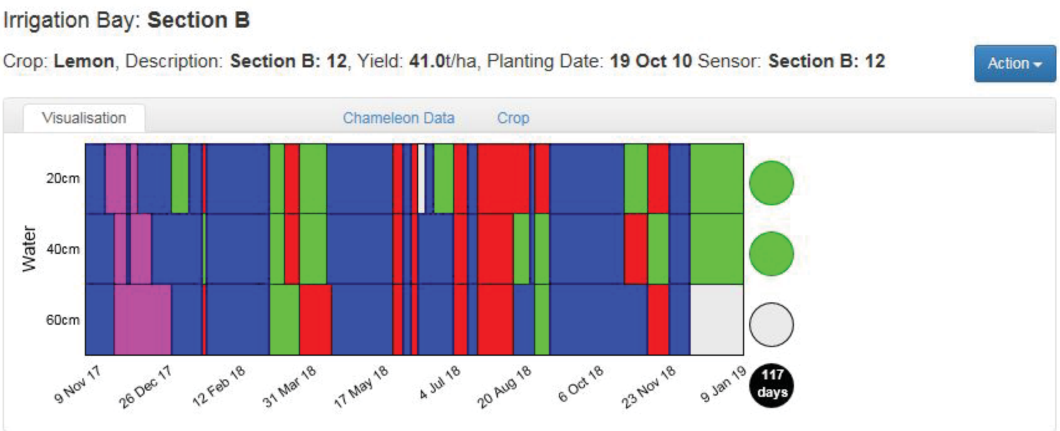


Figure 6.10: Chameleon soil water patterns for Block B12 at Zebediela

6.3 Ripplemead Citrus Farm, Eastern Cape

The Mgadle Family Trust is currently trading as Ripplemead Farm on the farm Groet Place. The farm is situated 47 km from the town of Alice on the southern bank of the Keiskamma River in the Eastern Cape Province and measures 86 ha. The land is owned by the proprietors.

A variety of citrus are produced on the 45.2 ha of land planted, which include oranges (45.2 ha), lemons (1.81 ha) and soft citrus (6.63 ha) (Figure 6.11

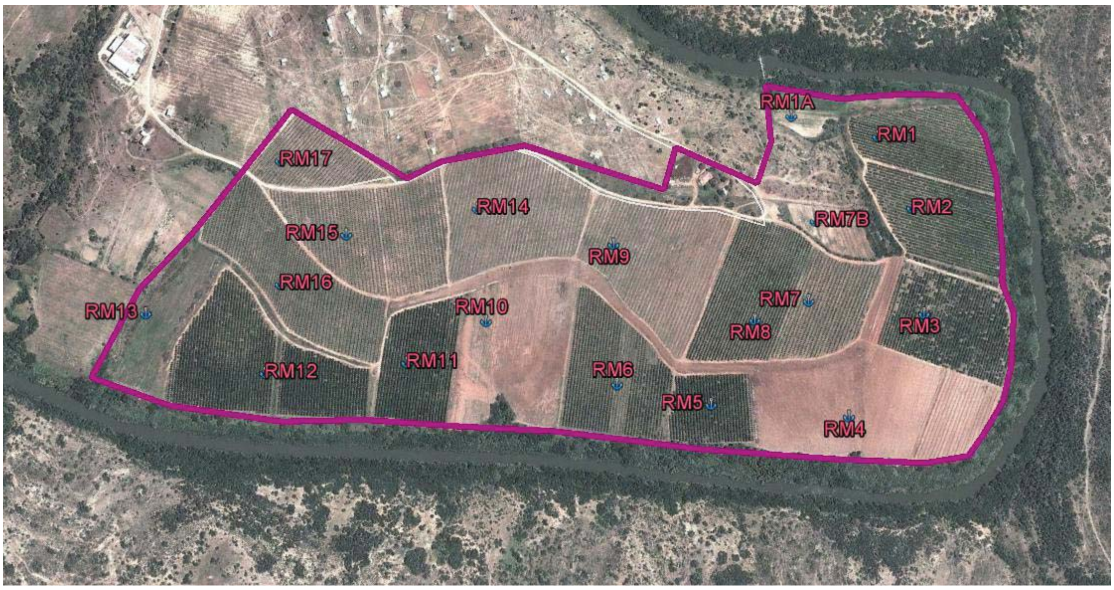


Figure 6.11: Orchard layout of the farm Ripplemead

6.3.1 Climate and soil

The farm is situated in an area with summer rainfall, hot summers and cold winters. The annual rainfall averages 800 mm. Frost occurs sporadically in winter rendering the farm only suitable for semi cold-tolerant citrus crop types. The farm has well drained soil, which is highly suitable for orchard crops.

6.3.2 Irrigation

The irrigation water is sourced from the Keiskamma River by direct pumping from the river. The availability of water from the river is reported to be very stable and the flow of the river is further stabilized by the large Sandile and Binfield dams. The owners received permission to irrigate 65 ha and has a water allocation of 572 583 m^3. The farm uses micro sprinkler and drip irrigation system in the orchards. Trees are irrigated by one micro sprinkler per tree, positioned approximately 90 cm from the tree, with a delivery rate 11.6 mm/hour. The drip irrigation system comprises of a single dripper line, where drippers are spaced at 0.6 m and with a delivery rate of 2 l/h. The current irrigation schedule followed with the micro sprinklers comprises of 4 hour irrigation three times per week, while 8 hour irrigation three times per week is followed with the drip system. The farmer uses the hand feel method to monitor the soil water status on a regular basis, and the current irrigation schedule was developed with the help of EPI Irrigation (a private company) based in Kirkwood.

6.3.3 Use of monitoring tools to assess irrigation practices

The farmer initially started with the installation of two sets of sensor arrays in the soft citrus during March 2018, and on request received another two sets which were installed during October 2018 (Table 6.7). Sensor arrays were installed at 20, 40 and 60 cm in four citrus orchards. Sensors were installed between the micro sprinkler and the tree, within the drip line of the tree. The farmer is making use of a single drip line, and here it was installed between emitters.

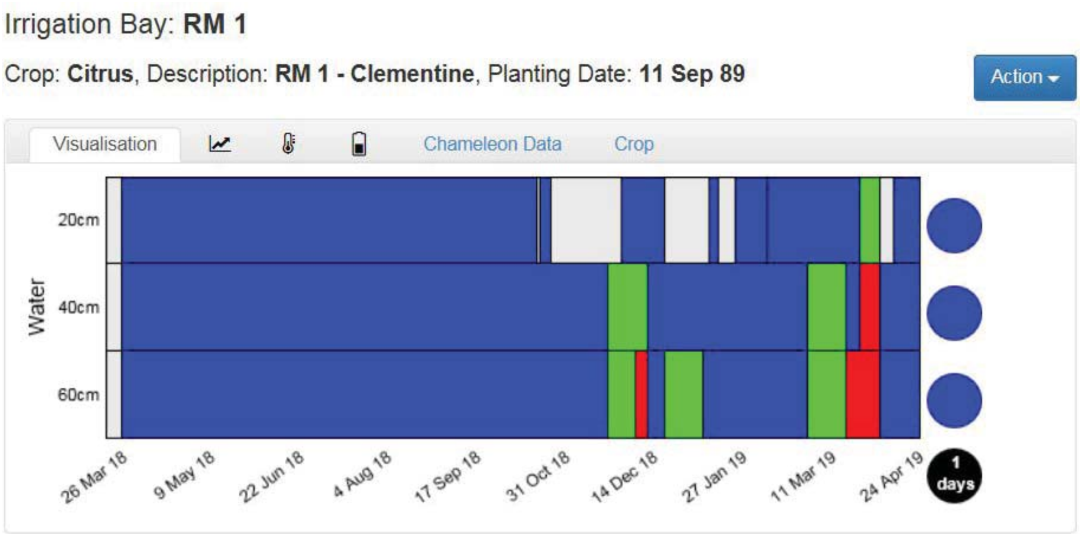
Table 6.7: Soil water patterns for citrus orchards at Ripplemead, Eastern Cape

Block	Size (ha)	Variety	No of trees /ha*	Irrigation system	Soil	Visualisation pattern (2018)	No of readings 2018
RM1	2.53	Clementine	565	Drip	Sandy clay loam	88%blue; 5% green; 7% red	44
RM15	4.34	Lane Late	544	Micro jet	Sandy loam	68%blue; 5% green; 27% red	40
RM4	5.89	M7 Navel	544	Micro jet	Sandy loam	81%blue;10% green; 19% red	39
RM 9	4.16	Washington Navel	540	Micro jet	Sandy loam	43%blue; 10% green; 57% red	37

**Spacing: 6 x 3 m*

The soil water patterns of the four orchards illustrated that the farmer is applying more irrigation on the Clementine orchard to keep it relatively wet (88% blue), while for the Washington navel orchard the soil was relatively dry (56% red) for a major part of the season (Figure 6.12). A possible reason for this irrigation practice is the fact that soft citrus is more sensitive to stress (especially insufficient irrigation) than oranges. The grey colour patterns illustrated possible loose wires on the sensor cables.

The farmer indicated his satisfaction with the current irrigation schedule on the farm in an interview which was conducted after the first production season of testing Chameleon sensors. The Chameleon sensors were installed to monitor the irrigation schedule followed on the farm. This farmer found it easy to use the Chameleon as well to upload the data, and therefore regular weekly data taking and uploading was recorded. The biggest challenge to the farmer in using the monitoring tools is to find time to take readings and continue to upload it on a regular basis.



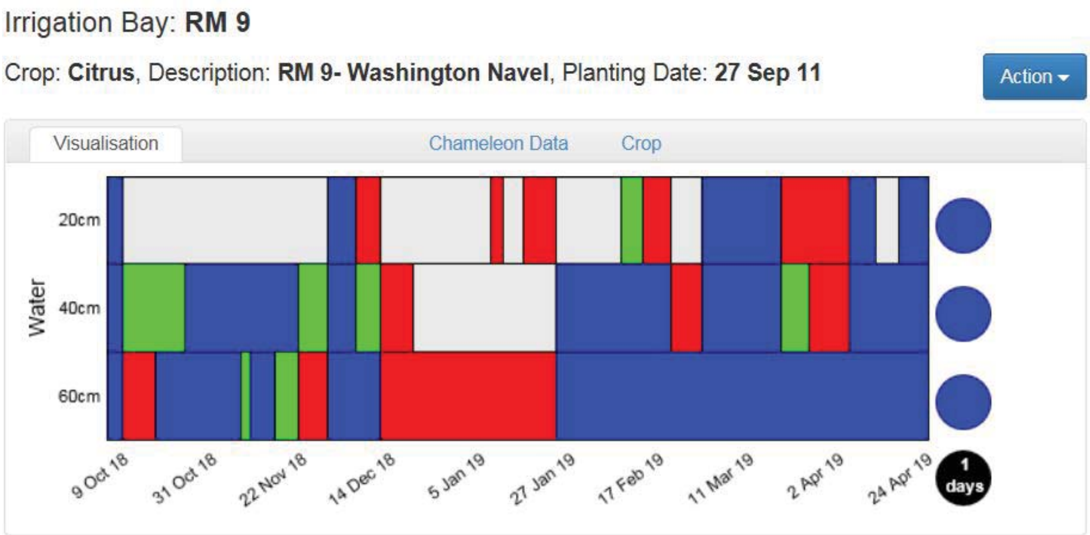


Figure 6.12: Soil water patterns for the farm Ripplemead

The farmer was asked what he hoped the project team (VIA team) would attend to in the near future, and he expressed the following:

- Provide more tool (sensors and wetting front detectors) to the specific farmer and his fellow citrus farmers in the area
- To meet the farmers face-to-face through farmer group meetings or conducting of training workshops to share knowledge and experience of farmers using these tools
- Visit farmers to help them to design an appropriate irrigation scheduling plan

6.4 Conclusions

It is clear from the discussion of the results amongst emerging commercial citrus farmers that there are a number of challenging aspects that these farmers face that have very little to do with just irrigation management practices *per se*. For instance farmers in all six case studies have inherited orchards with trees which are relatively old and perhaps at the end of their production cycles or beyond it. Furthermore, the irrigation systems with the exception of Ripplemead, are all in a very poor state and require urgent attention, which implies capital investment. All of citrus farmers are participating in land reform programmes (restitution, PLAS and recapitalisation), and were purposefully selected for these land reform projects. Interventions with farmers illustrated that some of them have the necessary willingness, aspiration and commitment to farm, while in some cases it was clear farmers lack these prerequisites for farming, and therefore found themselves in very challenging positions.

Also evident from interaction with farmers was that the emphasis with these settlement projects was mainly on pre-project planning and not post-project sustainability. Apart from the onerous concern about business plans and establishment of legal entities (CPA's and cooperatives), very little attention was provided to the long term support of beneficiaries once they took over ownership of farms. The post settlement support is mainly provided by the Provincial Department of Agriculture (North West, Eastern Cape and Limpopo) and Citrus Growers Association. The average farming knowledge of the majority of respondents was relatively low, with the exception of Zebediela, where an experienced CEO was appointed to manage the farm. A great asset in the cases of Zebediela and Batlhako Temo Coop was the employment of well-trained managers with specialisation in irrigation management, which was clearly observed by the ease with which these managers used the Chameleon sensors and the VIA, especially the confidence of uploading and using of the data.

The aim with the research was not to prove, through experimental trials, that the use of the Chameleon will improve citrus productivity, but rather to introduce user-friendly tools to farmers. The aim was to assess whether these tools were indeed user-friendly and if they can help farmers to make more informed irrigation management decisions. In all the cases, farmers used very broad guidelines to steer and plan irrigation practices on their farms, and none of these farmers used any scientific scheduling methods to help them with decision making. In the case of Batlhako Temo Coop, Zebediela and Ripplemead the tools were well accepted and used to inform decision making. In the other cases, unfortunately the monitoring tools did not help farmers to improve decision making in the field for a variety of reasons. Since all of emerging citrus farmers belong to CGA study groups in their respective areas, this platform was used to introduce the tools and the VIA to fellow farmers. At all six citrus farms yields were not recorded per orchard block; therefore detailed analysis of the possible influence of irrigation practices on crop productivity was not possible. However, in the case of Batlhako Temo Coop, the percentage of export and quality of fruit improved substantially since 2016/17. However, we cannot conclude that this was solely because of the improvement in irrigation practices.

Chapter 7: Commercial potato farmers in Limpopo and Western Cape Provinces

7.1 Limpopo commercial growers

7.1.1 Background to the Limpopo region

Limpopo is the highest potato producing region in the country, contributing about 30% of the country's total potato production (Potatoes SA, 2017). Potato production is spread out across the province, and is mainly determined by the availability of irrigation water and suitable soils. The most important soil types in the eastern parts of the country are laterite (red, leached, iron-bearing soil), unleached subtropical soils, and gleylike (i.e. bluish grey, sticky, and compact) podzolic soils (highly leached soils that are low in iron and lime) (Britannica, 2017). Limpopo is therefore characterised by diverse soils, which vary in productivity (LDA, 2017). The varied soils and climates of Limpopo Province allow the production of a wide range of agricultural produce, ranging from tropical fruits, such as banana and mangoes, to cereals such as maize, wheat and vegetables such as tomatoes, onion and potatoes (LDA, 2017). The most limiting resource in Limpopo province is water and dryland production on a commercial basis is only possible on the Springbok flats. Irrigation farming is predominant in the province and the production of high-value crops, such as potatoes, is not possible without irrigation (LDA, 2017).

The potato is a temperate, drought sensitive crop and is therefore dependent on optimal water supply for high tuber yield and quality (Steyn et al., 1998, Steyn and Du Plessis, 2012). Limpopo is a summer rainfall region of the country, but due to its low altitude, the summer months are too hot for potato production and therefore the crop is grown under full irrigation during the winter and early spring (Haverkort et al., 2013). Water used for irrigation of crops in the region is either from boreholes or rivers (Limpopo, Mogol, Sand Rivers). The distribution of potato plantings is therefore limited to areas with perennial rivers or sufficient suitable subsurface water, namely Dendron, Vivo, Tolwe, Tom Burke districts, as well as along the Limpopo River.

Each of the commercial potato growers in Limpopo produce on average 50 to 100 ha of potatoes annually. Potatoes are often grown in rotation with onions, maize and butternut pumpkins, but due to limited available irrigation water, fields are often planted to a fodder cover crop (e.g. fodder sorghum) after potatoes and then left fallow for 3 to 4 years until the next potato crop.

The objective of this part of the study was to evaluate the usefulness of chameleon sensors for the irrigation management of potatoes by commercial growers in Limpopo Province.

7.1.2 Evaluation in Limpopo during the 2016 and 2017 seasons

The Limpopo Province growers that were selected for participation in the project were all commercial potato growers. One of the growers also installed his Chameleon sensors on a follow-up maize crop. Table 7.1 gives the details of the selected growers, their field details and achieved yields. All these growers produce potatoes under centre pivot irrigation systems and they all practice a high level of management, with some of them already making use of some form of irrigation scheduling tools (e.g. capacitance probes or tensiometers). This presented the opportunity to compare Chameleons data with capacitance probe data, where available.

Table 7.1: Details of commercial potato farmers in Limpopo who participated in the project

Grower Name	District	Crop	Field area (ha)	Soil Type	Plant date	Harvest date	Yield (t/ha)
Mossie Jongbloed	Dendron	Potatoes	10	Sandy loam	16 May 2016	19 Sep 2016	55
		Potatoes	2.7	Sandy	9 May 2016	9 Sep 2016	59
		Maize	10	Sandy	21 Nov 2016	10 Jul 2017	9.0
		Potatoes	13	Sandy / loam	15 Mar 2017	24 Jul 2017	52
Marthinus Roets	Vivo	Potatoes	11.8	Sandy loam	16 May 2016	31 Aug 2016	58
		Potatoes	13	Sandy loam	8 May 2017	31 Aug 2017	55
Jako Nel	Tom Burke	Potatoes	20	Sandy	16 May 2016	11 Oct 2016	64
Japie van der Goot	Vivo	Potatoes	20	Sandy	1 May 2017	5 Sep 2017	50.8
		Potatoes	20	Sandy	23 May 2017	2 Oct 2017	54.8

In all cases, the three Chameleon sensors per array were installed at 15, 25 and 40 cm depths in the potato row on the ridge, with the temperature sensor installed at 25 cm.

7.1.3 Results: Limpopo 2016 and 2017 seasons

a. Grower Mossie Jongbloed – Dendron

This grower made ten Chameleon probe installations in five different fields during 2016 and 2017. Initial results in the 2016 winter season were disappointing form a grower's point of view, as his Chameleon patterns were mostly in the blue range (86.0% Blue; Figure 7.1), suggesting over-irrigation and thus very wet soils. However, tensiometer readings from the same fields did not suggest too wet soils due to over-irrigation. Since potatoes are shallow-rooted and quite sensitive to drought, growers prefer to maintain their soils relatively wet to limit the risk of drought stress. Especially when crops are grown under centre pivot irrigation, a complete irrigation cycle may take more than 3 days to complete for larger pivots. The irrigation interval will then be once every 3 days. If a breakdown in equipment or a sudden heat wave occurs, growers may risk not being able to "catch up" with the demand and crops may suffer from drought stress, with detrimental consequences for yield and quality.

The sensors that were installed during 2016 had a blue-to-green switch point of about -25 kPa, which should be suitable for most field crops, but since the patterns remained mainly blue, they provided limited management information to potato growers who manage their soils relatively wet, even though no gross over-irrigation usually occurs. It was, therefore, decided to try out sensors that change colour from blue to green earlier ("wetter" switch points of around -18 kPa) in order to establish whether that could provide growers with more useful management information.

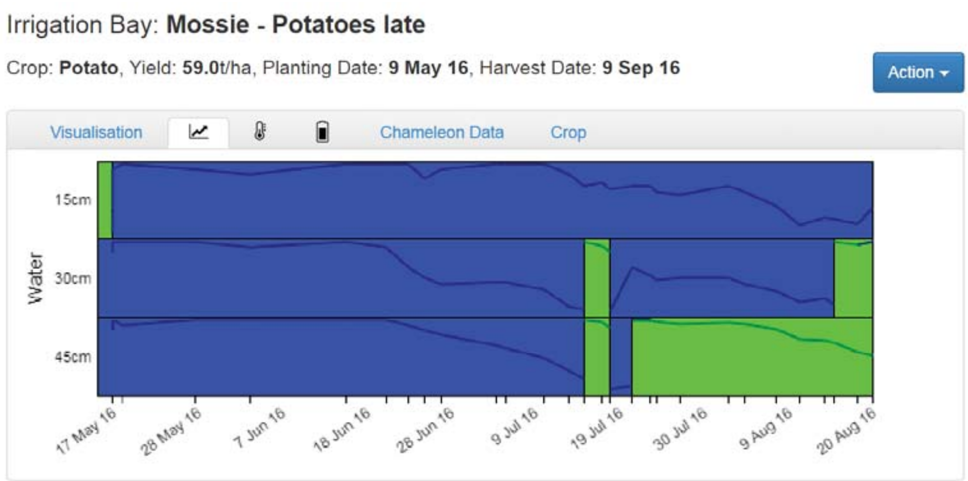


Figure 7.1: Example of Chameleon soil water patterns for potatoes (field M8 – clay), Dendron 2016, when sensors had a blue-to-green switch point of about -25 kPa.

During the 2017 winter season, the sensors with "wetter" (-18 kPa) blue-to-green switch points showed more variable colour patterns (51% Blue; 41% Green and 8% Red), and from a grower perception that gave a more useful indication of small changes in the wet soil water potential range (Figure 7.2). During this growing season, DFM capacitance sensors were also installed in the same field (Figure 7.3) and although the two types of sensors give different measures of soil water status (Chameleon measures soil water potential, while capacitance probes use a relative scale of soil water content), trends over the growing season could be compared.

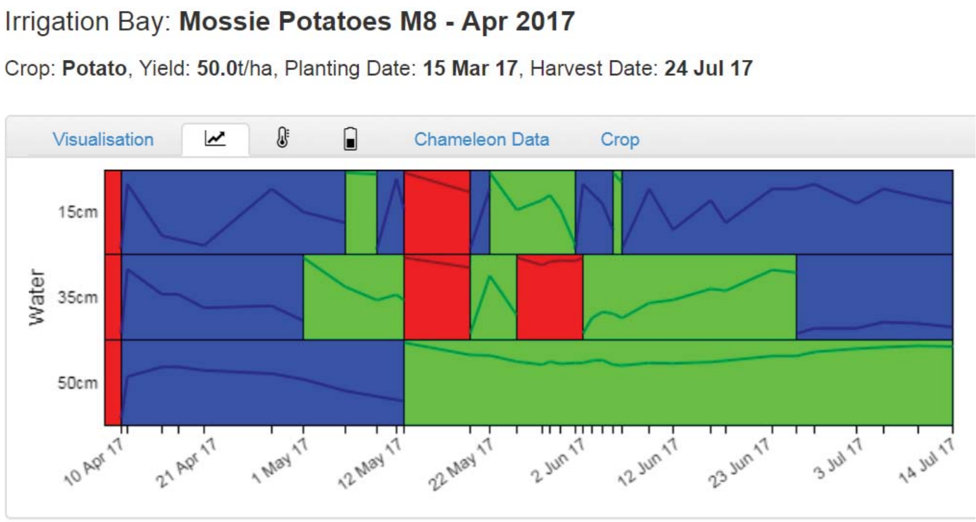


Figure 7.2: Chameleon soil water patterns for potatoes (field M8 – loam), Dendron, 2017, when sensors had a blue-to-green switch point of about -18 kPa.

Figure 7.3: DFM soil water patterns for potatoes (field M8 – loam), Dendron, 2017. Top section of graph shows water content of the total root zone (0-40 cm), while middle section shows the top roots (0-20 cm) and bottom section shows the buffer zone (40-60 cm).

According to Figure 7.2, the Chameleon sensor patterns were mostly in the blue to green range in the upper soil layers, and green at the bottom of the profile for most of the season, suggesting good management and a low risk of drainage and leaching of nutrients. There was even a short mid-season period when sensors turned red in the upper two layers, suggesting water stress. Although the Chameleons, which were installed in the potato row on the ridge, turned red, the grower observed that the soil was still quite wet in the furrows between rows when auguring. He, therefore, withheld water in an effort to stimulate water extraction from the wetter furrows, resulting in the Chameleons to register red for short periods.

Figure 7.3 presents the changes in soil water content as measured with the DFM probe. The green zone represents the acceptable range of soil water content, while the blue zone is too wet (above field capacity) and the red zone represents dry conditions. Similar to the Chameleon graph (Figure 7.2), the DFM graph shows that for the first part of the growing season until about mid-May, the soil water content fluctuated mostly within acceptable limits (green zone of the DFM graph). The DFM graph unfortunately stops at the end of May, but similar to the Chameleon graph, shows some stress periods (SWC line drops into the red zone) on about 17 and 27 May, at least for the topsoil. The Chameleon and DFM graphs (Figures 7.2 and 7.3), therefore, showed similar trends and would probably have resulted in the same management decisions. Good yields of 52-59 t/ha were achieved in both seasons.

b. Grower Marthinus Roets – Vivo

This grower made four Chameleon probe installations in two different potato fields during 2016 and 2017. In 2016, manual readers (without data storage capacity) were used and data was only entered on the VIA website at the end of the growing season. Since data was not available for regular online perusal, the grower did not use the data for management purposes. Similar to other growers, results in the 2016 winter season showed that the Chameleon patters remained exclusively in the blue range, suggesting very wet conditions (100% Blue; 0% Green and 0% Red; Figure 7.4). However, less than 400 mm of irrigation was applied and a good yield of 58 t/ha was achieved, compared to a long-term irrigation requirement of ±445 mm for a winter season in this region (Steyn et al., 2016), suggesting that gross over-irrigation did not occur.

In the 2017 season, the grower had access to a logging reader and two sets of sensors with -18 kPa switch points (blue-to-green) were installed in one potato field.

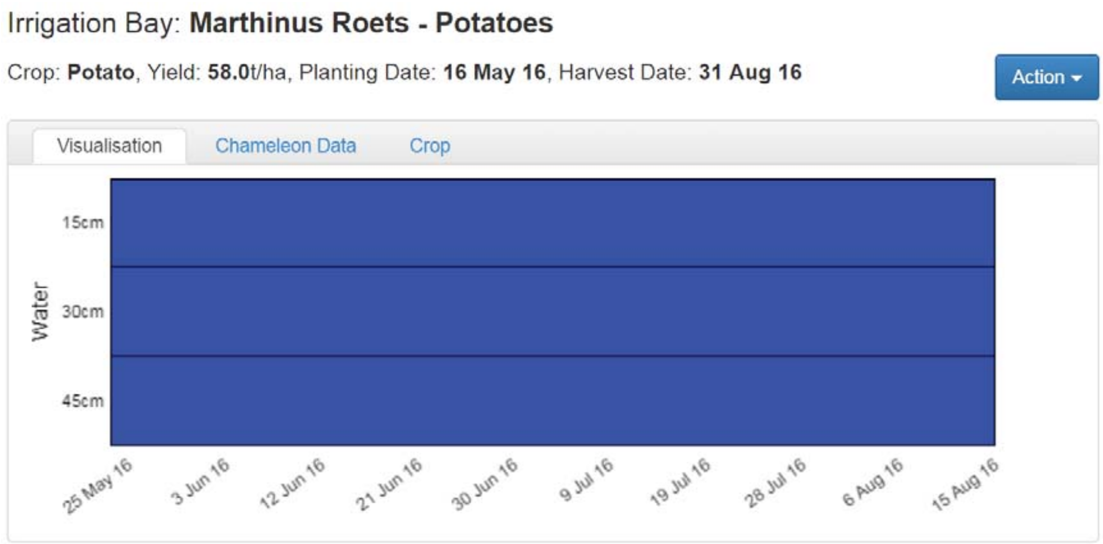


Figure 7.4: Chameleon soil water patterns for potatoes (field MS2), Vivo, 2016.

The grower made use of DFM capacitance probes to manage his irrigation, and Chameleon data (Figure 7.5) was collected for evaluation purposes only. Similar to the situation in 2016, the Chameleon sensor pattern was mostly blue (85% Blue; 10% Green and 5% Red; Figure 7.5), with the exception of a few occasions when sensors gave green patterns and even one occasion of red in the subsoil. An acceptable potato yield of 55 t/ha was recorded in this season.

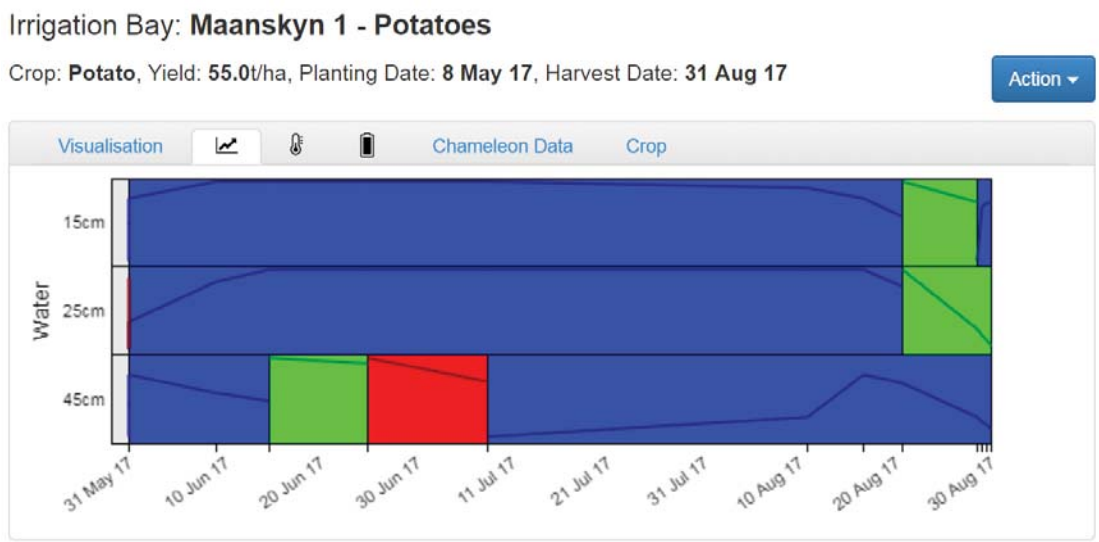


Figure 7.5: Chameleon soil water patterns for potatoes (field MS2), Vivo, 2017.

c. Grower Jako Nel – Tom Burke

During the 2016 growing season, this grower used a manual Chameleon reader and two sensor arrays with -25 kPa blue-to-green switch points were installed in a 20 ha potato field. The Chameleon sensor data was not used for irrigation scheduling and the data was monitored for evaluation purposes only. The Chameleon data shows that the pattern was 84% Blue, 6% Green and 11% Red (Figure 7.6). The bottom sensor indicated that early on in the growing season the subsoil was dry for almost a month. The grower initially did not believe that this was possible, but it was confirmed after the soil was augured. Irrigation was then adjusted upwards until the whole profile became quite wet (blue) for the remainder of the season. This suggests that the soil was maintained too wet, which may have resulted in some drainage losses. However, since sensors with drier switch point (-25 kPa) was used, this was probably not the case, as was observed for other growers in 2016. A very good yield of 64 t/ha was harvested, using 459 mm of irrigation.

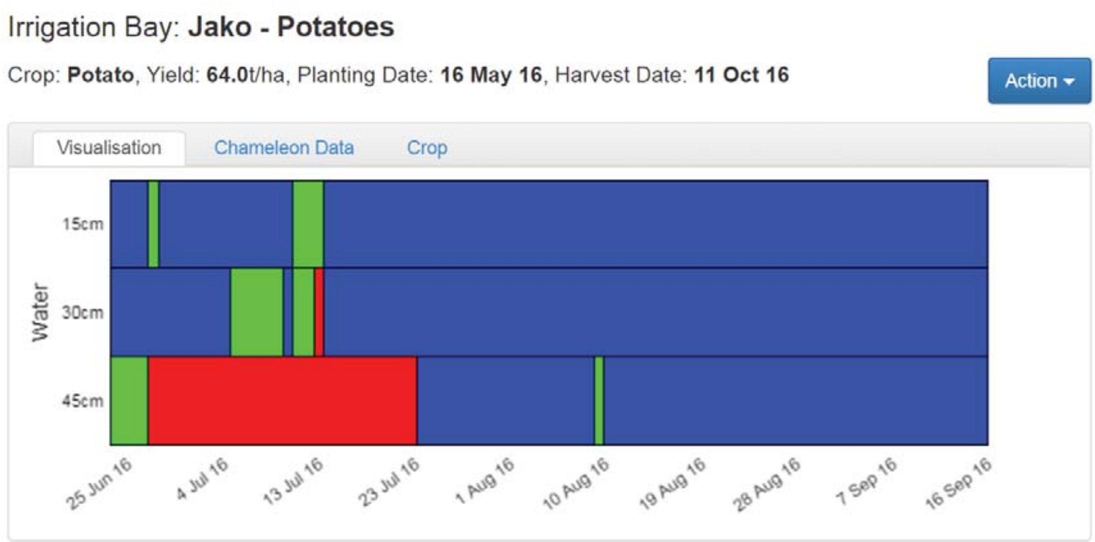


Figure 7.6: Chameleon soil water patterns for potatoes, Tom Burke, 2016.

d. Grower Japie van der Goot – Vivo

For this grower Chameleon probes were installed in three potato fields during 2017. A logging reader was used and the Chameleon sensors had blue-to-green switch points of -18 kPa. Japie had no other scheduling tools and used the Chameleons to manage his irrigations. The results for two of the fields are presented in Figures 7.7 and 7.8, as example.

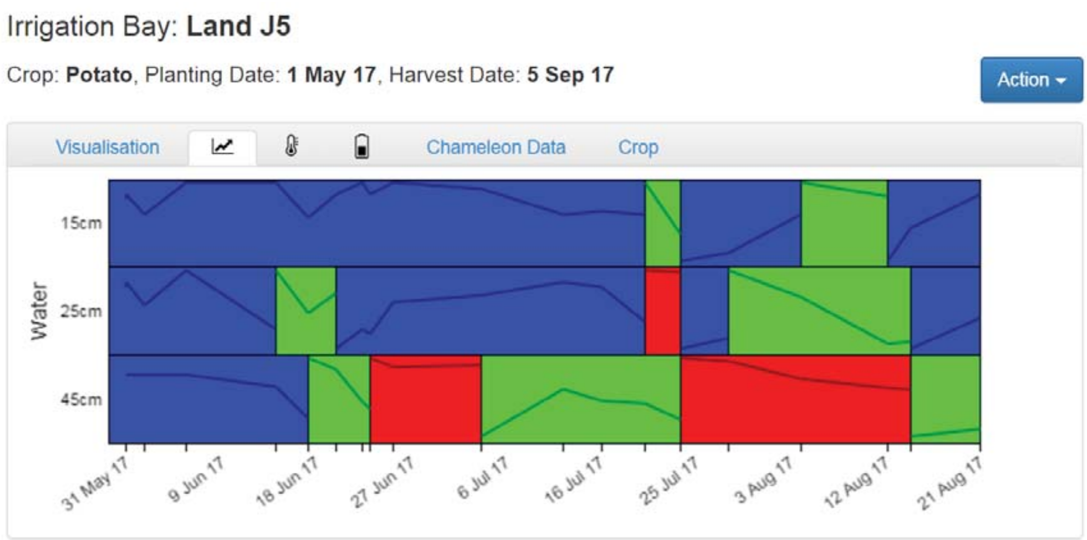


Figure 7.7: Chameleon soil water patterns for potatoes (field J5), Vivo, in 2017.

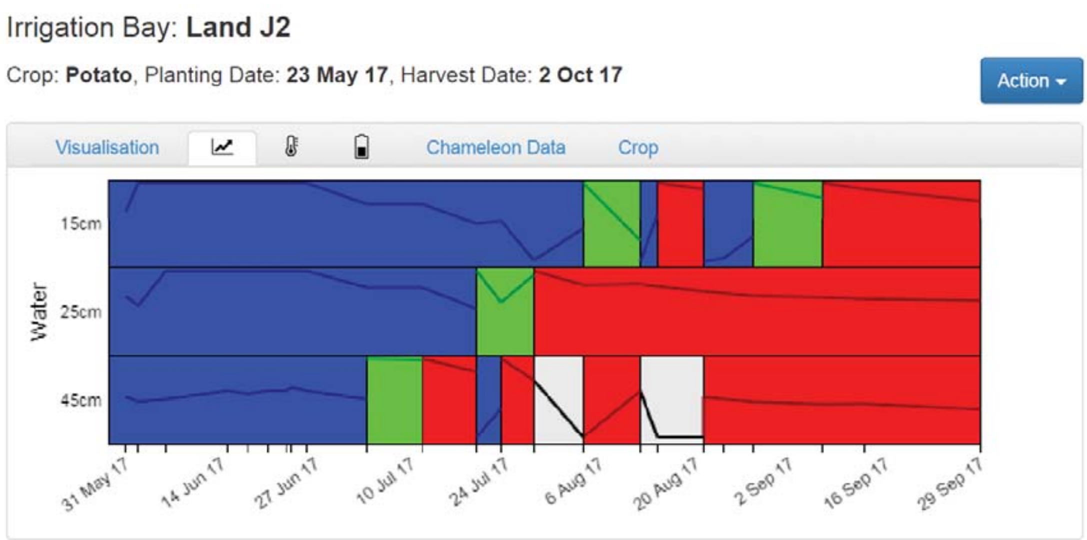


Figure 7.8: Chameleon soil water patterns for potatoes (field J2), Vivo, in 2017.

The boreholes on this farm are not strong and the focus is thus strongly on water saving. The grower started the growing season on a full profile (sensors at all levels are blue) and his strategy was to then gradually dry out the underground towards the end of the growing season. This strategy ensures maximum water use efficiency and furthermore the slightly drier soil facilitates easier harvesting and improved tuber skin quality (faster skin set and lighter skin colour). The sensor patterns over the growing season were 58% Blue, 27% Green and 15% Red for field J5, while for field J2 it was 44% Blue, 9% Green and 46% Red. Good final yields of 50.8 t/ha for J5 and 54.8 t/ha for J2 were achieved.

7.2 Sandveld commercial potato farmers

7.2.1 Background to Sandveld region

The Sandveld region of the Western Cape falls within the fynbos biome of South Africa and is recognised as an important protected area (Archer et al., 2009; Franke et al., 2011). Potato and rooibos production are the two most important economic activities in the region. Although the clearing of natural vegetation for agricultural production may have negative implications for the ecosystem, farming forms the backbone of the local economy. Potato production provides employment to locals in the region and supplies 90% of potatoes to the Cape Town metropole, making it an important industry in the Western Cape (Archer et al., 2009).

The Sandveld is one of the most important potato production regions in the country and about 6400 ha of potatoes are grown annually (Steyn et al., 2016). Commercial potato growers in the region produce on average 50 to 200 ha of potatoes each. Potatoes are usually not grown in rotation with other crops due to the limited water resources available. After potatoes, the fields are usually planted to a small grain crop (e.g. oats or triticale) to protect the soil from wind erosion, and then left fallow for 3 to 4 years until the next potato crop.

The region has a Mediterranean climate, with rainy, cool winters and hot, dry summers. In most parts of the Sandveld, potatoes can be grown throughout the year, but due to the low (<250 mm p.a.) and unreliable rainfall distribution, successful production of the crop is only possible under irrigation. Most of the water needed for irrigation is pumped from springs and underground aquifers, and over exploitation may impact negatively on the ecosystem. Furthermore, the Sandveld soils are sandy (<5% clay), with very low water (and nutrient) holding capacities (±50 mm/m plant available water), which makes efficient management of these input resources very difficult (Steyn et al., 2016). Sustainability of irrigation and fertilisation in this fragile ecosystem is thus reliant on efficient management practices to enhance crop productivity and minimise water and nutrient losses to the environment.

The objective of this part of the study was to evaluate the usefulness of Chameleon sensors for the irrigation management of potatoes grown by commercial growers on very sandy soils of the Sandveld region.

7.2.2 Evaluation in the Sandveld during the 2018/19 production seasons

During the 2018/19 production year, a study was undertaken in the Sandveld with the aim of quantifying losses of inputs such as water and nutrients in order to improve management practices and optimise nutrient and water use efficiencies of potato production systems. Various types of equipment were installed to monitor water and nutrient inputs and losses from the fields. Each of the monitored fields was equipped with two DFM capacitance probes, which are commonly used by growers as irrigation management tools. However, in this study the sensors were installed to monitor water movement in (and possibly water drainage from) the sandy soil profiles. The study, therefore, presented an opportunity to install Chameleon sensors alongside the capacitance probes in some of the fields, for comparison purposes. The Chameleon sensors had -18 kPa blue-to green switch points and were installed at the same depths as for the Limpopo study (15, 25 and 40 cm). It is important to note that neither of the two sensor types was used by the growers to make any management decisions. Both types were monitored by the research team for evaluation purposes only.

Although a total of nine fields were monitored during the study period (March 2018-February 2019), only 12 Chameleon probes were installed in six of the fields, and useful comparable data from both sensor types could only be retrieved for five of the installations (Table 7.2).

Table 7.2: Details of participating commercial potato Sandveld fields

Field	Plant date	Rain (mm)	Irrigation (mm)	Tuber yield (t ha^{-1})
10B	28 Mar	258	486	51.6
R12	2 May	232	313	41.5
9A	27 Jun	143	562	49.8
KD2	18 Jul	71	522	53.9
R4.1	3 Mar	271	260	34.7
R4	25 Jun	156	545	57.5
GP	9 Jul	154	381	51.2

Graphs for each Chameleon sensor and its corresponding DFM probe are presented together to facilitate comparisons between response patterns. Although the two sensor types present different types of data (soil water potentials vs. relative soil water contents), the purpose of the comparison was to assess whether the same management decisions (when to irrigate) would have been made from the available information.

7.2.3 Results: Sandveld 2018/19 seasons

a. Field 10 B East

The Chameleon patterns for all three the soil layers of this field remained blue for almost the entire growing season (98% blue), suggesting that the field remained very wet throughout the crop growth period (Figure 7.9). When compared with the DFM probe data, it is clear that the soil profile was indeed quite wet for parts of the growing season, when the soil water content (SWC) lines entered the blue zone on the graphs. However, the DFM graphs indicate that the SWC lines were in the green zone of the graph most of the time, suggesting that soil water contents were mostly in the "acceptable" range. Also, on a few rare occasions (e.g. around 6 May and 16 May) the DFM probe measurements showed that the soil was on the dry side (SWC line entering the red zone), while the Chameleon graphs suggest that the soil was still wet throughout the entire soil profile. The DFM probes also clearly indicated sharp peaks in soil water content after large rainfall events (e.g. 29 May and 15 June), which are not reflected on the Chameleon graphs. If it is assumed that the DFM probes gave a true reflection of the real situation in the field, the presented data suggest that the Chameleon sensors were not able to provide the same level of management information, and different management decisions may often have been taken.

b. Field RF12 Top and Bottom

Figures 7.10 and 7.11 present the Chameleon and DFM probe data for two different positions in field RF12. Unfortunately the Chameleon sensor at the top part of the field was not read frequently early in the season, but the available data suggest that the topsoil remained wet throughout the entire growing season (100% blue), while the patterns of the 25 and 40 cm layers indicated that the soil water status was intermediate to dry for the entire cropping season. The DFM probe, however, indicated moderate to wet conditions throughout the growing season, which is supported by frequent rainfall events that were recorded during the crop growing season (data not presented). At around 10-13 July, the DFM probe at the bottom part of the field (Figure 7.11) showed a relatively dry period, when the SWC line for the top roots dipped into the red zone, while the line representing the entire root zone also approached the red zone. However, this response was not observed for the corresponding Chameleon sensor. This suggests that different management decisions would have been made if the two sensor types had been used to manage irrigation.

Figure 7.9: Chameleon sensor data for three soil layers (15, 25 and 40 cm) (top graph) and DFM soil water contents (bottom composite graph) for the total root zone (top pattern), top roots (middle pattern) and buffer zone (bottom pattern) of field 10B East.

Crop: **Potato**, Description: **Field RF12**, Planting Date: **2 May 18**, Harvest Date: **17 Sep 18** Sensor:

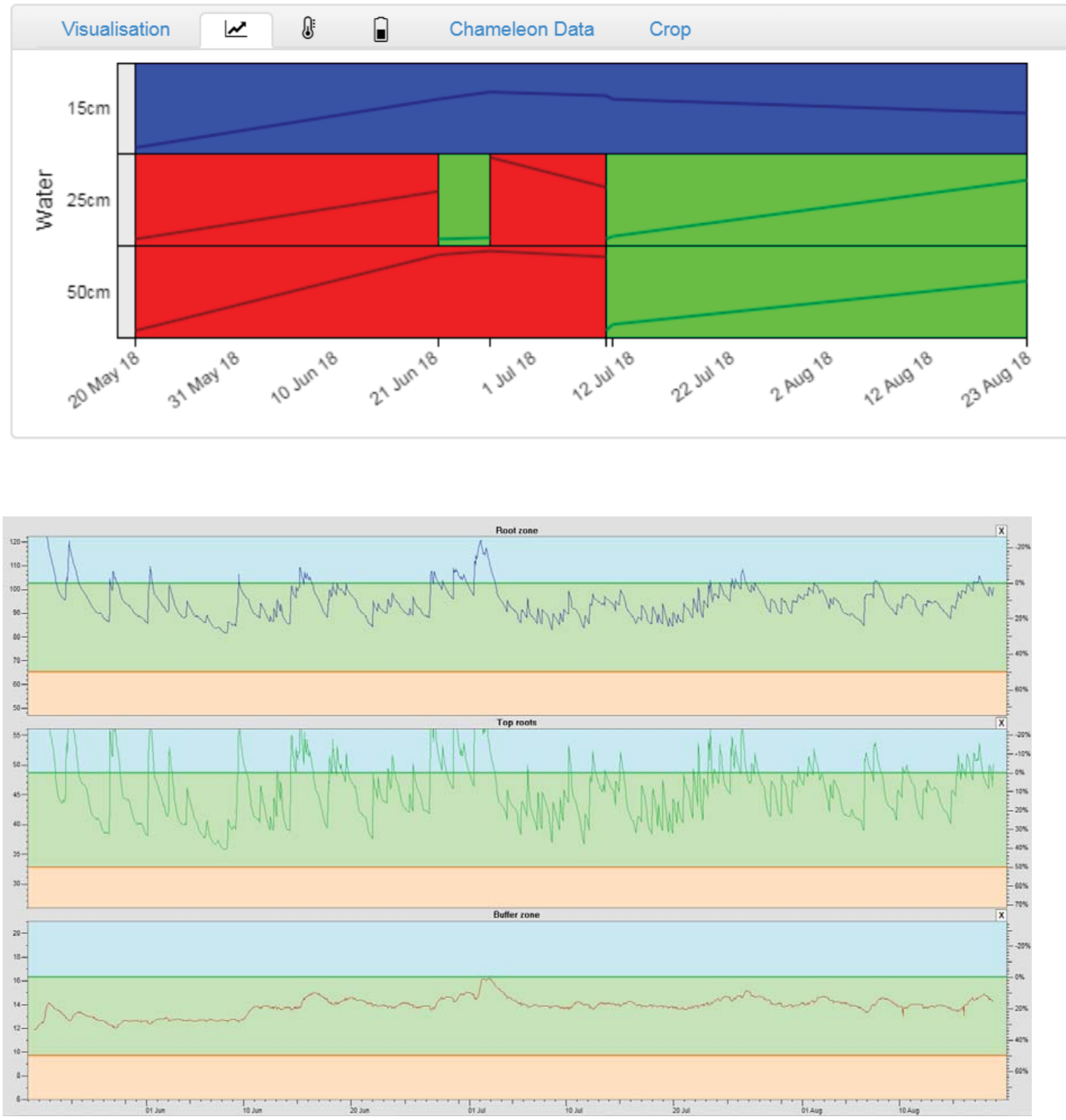


Figure 7.10: Chameleon sensor data for three soil layers (15, 25 and 40 cm) (top graph) and DFM soil water contents (bottom composite graph) for the total root zone (top pattern), top roots (middle pattern) and buffer zone (bottom pattern) of field RF12 Top.

Crop: **Potato**, Description: **Field RF12**, Planting Date: **2 May 18**, Harvest Date: **17 Sep 18** Sensor:

Figure 7.11: Chameleon sensor data for three soil layers (15, 25 and 40 cm) (top graph) and DFM soil water contents (bottom composite graph) for the total root zone (top pattern), top roots (middle pattern) and buffer zone (bottom pattern) of field RF12 Bottom.

c. Field KD2 East and West

The Chameleon and DFM probe data for the Eastern and Western sides of field KD2 are presented in Figures 7.12 and 7.13. The Chameleon sensors on both sides of the field measured very wet conditions throughout the entire crop growing season, with 100% blue patterns for all three soil layers. This was, however, not the case for the DFM probes, especially for the last two thirds of the growing season (from about 20 September onwards), which generally measured moderate to dry soil conditions, with the exception of a few cases when rainfall occurred (e.g. 24 Oct and 6 Nov).

Crop: **Potato**, Planting Date: **18 Jul 18**, Harvest Date: **27 Nov 18** Sensor: **KD East**

Figure 7.12: Chameleon sensor data for three soil layers (15, 25 and 40 cm) (top graph) and DFM soil water contents (bottom composite graph) for the total root zone (top pattern), top roots (middle pattern) and buffer zone (bottom pattern) of field KD2 East.

The drainage lysimeter that was installed in this field showed no drainage beyond 1 m soil depth (data not presented), which also confirms that this field was not over irrigated, and the DFM probe results were probably reliable.

Figure 7.13: Chameleon sensor data for three soil layers (15, 25 and 40 cm) (top graph) and DFM soil water contents (bottom composite graph) for the total root zone (top pattern), top roots (middle pattern) and buffer zone (bottom pattern) of field KD2 West.

7.3 Conclusion

Potato is a high value, shallow-rooted and drought sensitive crop. Growers, therefore, tend to maintain their soils relatively wet to avoid risk of water stress that may negatively affect yield and quality. In the Sandveld, the risk for water stress is especially high due to the very low water holding capacity of their sandy soils. Plant available water (PAW) in the root zone is often as low as 50 mm/m soil. The implication thereof is that typically only 7 mm of water can be depleted in the early stages of crop growth, when the roots are about 25 cm deep (assuming 50% allowable depletion of PAW), and 15 mm when the roots are 50 cm deep. It is, therefore, obvious why growers tend to refill their soil profiles every one to two days, and there is thus limited opportunity to leave room for rain, taking into account the high risk of water stress. Yields in the Sandveld study were generally acceptable for the specific growing seasons, ranging from 41.5 to 53.9 t/ha.

From the results presented, there is a general trend that Chameleon sensors tended to continuously indicate very wet soils. This was probably mostly true, given the explanation above for the management style typically adopted by most Sandveld growers. However, there is also evidence that the Chameleons generally responded poorly to sudden changes in soil water content, and that they did not point out short periods of dry conditions, which may have resulted in incorrect management decisions. The slow sensor response to sudden changes in soil water content is probably related to the rapid drop in unsaturated hydraulic conductivity of the sandy soils as they dry out. The drying soil may therefore not be able to effectively “suck water” out of the sensor matrix, resulting in the sensor remaining “wet”, while the surrounding soil has already “dried out” to different water content. This hypothesis should be tested in a laboratory study to assess the change in hydraulic conductivity with a decrease in soil water potential for these sandy soils.

Contrary to the poor response in sand, the Chameleon sensors generally responded well to changes in soil water content of sandy loam and loamy soils of Limpopo. The Chameleon sensors therefore provided useful irrigation management information, especially after the blue-to-green switch points were altered to -18 kPa. This was confirmed by the good comparison between Chameleon colour patterns and those provided by capacitance probes installed in the same field.

Chapter 8: Commercial pecan grower in Cullinan, Gauteng

The following part of the report is reflecting on the experiences of a part time commercial farmer on the farm Pecandale, Cullinan, Gauteng with Chameleon sensors installed in pecan orchards (growing season 2018/19). According to the farmer, as a part time farmer he needs all the help he can get to keep an eye on the pecan crop. Monitoring stations were installed in two blocks of mature trees that are at a stage that they now need hedging or selective limb pruning for better solar radiation management. The two blocks where monitoring tools were installed are labelled Andre Block and Langry.

Andre Block was planted in 1997 and trees are now 22 years old. Cultivars include Ukulinga, Mohawk and Mahan, with lower lying parts of this 2 ha block filled in with shorter season cultivars to avoid damaging cold like Pawnee and Wichita. Rows are east-west oriented, with 7 m between trees and 10 m between rows. This is a higher density than the usual 10 X 10 m spacing, and the original thinking was to come into production earlier than the standard spacing, and to eventually thin out every second tree to end up with a N-S oriented 10 X 14 m orchard. The trend with many tree crops has been to move to higher densities and manage canopy size, and he has decided to leave the orchard as is. This block is irrigated with dragline sprinklers running down every second row with stand positions 12 m apart – giving a 12 X 20 m spacing, or 240 m^2 per sprinkler position Stand times are typically 12 hours.

The **Langry** block was planted in 2001, with tree spacing also 10 X 7 m, but rows are N-S oriented. Cultivars are predominantly Choctaw with a few rows of Wichita which is a good cultivar, but has proved to be sensitive to pecan scab. Draglines are also used in this 4 ha block, but they run perpendicular to the rows between every second tree, giving a 10 by 14 m spacing, or 140 m^2 per sprinkler position. Stand times are also 12 hours (Figure 8.1).

Chameleon sensors were buried at 30, 60 and 90 cm depths, with soil temperature measured at 45 cm. The deep sensor positions are to cater for a deep-rooted crop receiving large infrequent irrigations. Sensors are typically read on Mondays, Wednesdays and Fridays by his labourer who works in the homestead and is also responsible for shelling and packaging of nuts. On occasion, he will also read them on a Saturday or Sunday, especially if the labourer has skipped a reading for some or other reason. Cell phone reception is very poor or absent on the farm. The readings are uploaded at the homestead where internet is available. Especially useful for the specific farmer is the VIA website, as he is able to see what is happening in the orchard during the week when he is not on the farm. This makes it easy to call the workers and start or stop irrigation. The worker on the farm also sends him SMS messages when it rains.

Figure 8.1: Drag line sprinkler in the Langry block at Pecandale.

Water supply on Pecandale is not guaranteed, and is the largest risk factor for production. There are two small ephemeral streams running through the property, the Malanspruit and Moutonspruit, which is more of a vlei than a stream. If running, it supplies water to a small storage dam that holds about two weeks water (around 8400 m^3). His irrigation strategy is to refill the profile in winter if there is water, as flow is especially unreliable in spring before the rains come. It takes more than a week to irrigate a block with the pump running nonstop, so he estimates from Chameleon readings (the line within colours is very useful) and weather forecasts, when to start irrigating and when to hold back. This has been difficult during the 2018 season as forecasts have not been that reliable.

The 2018 season started well as the Malanspruit was running and hey could fill the profile before the trees came into leaf. They apply about 100 kg N/ha, 45 kg P/ha and 100 kg K/ha early in the season (October) and topdress with another 100 kg N and K per ha in January 2019. The Chameleons have been very useful to avoid over irrigating at these times to minimise the chance of leaching. The farmer has not installed wetting front detectors, but will do so later this year. Low rainfall in October (41 mm) and November (67 mm) during 2018 made it difficult to keep the profile wet at depth, especially in Andre Block (Figure 8.2).

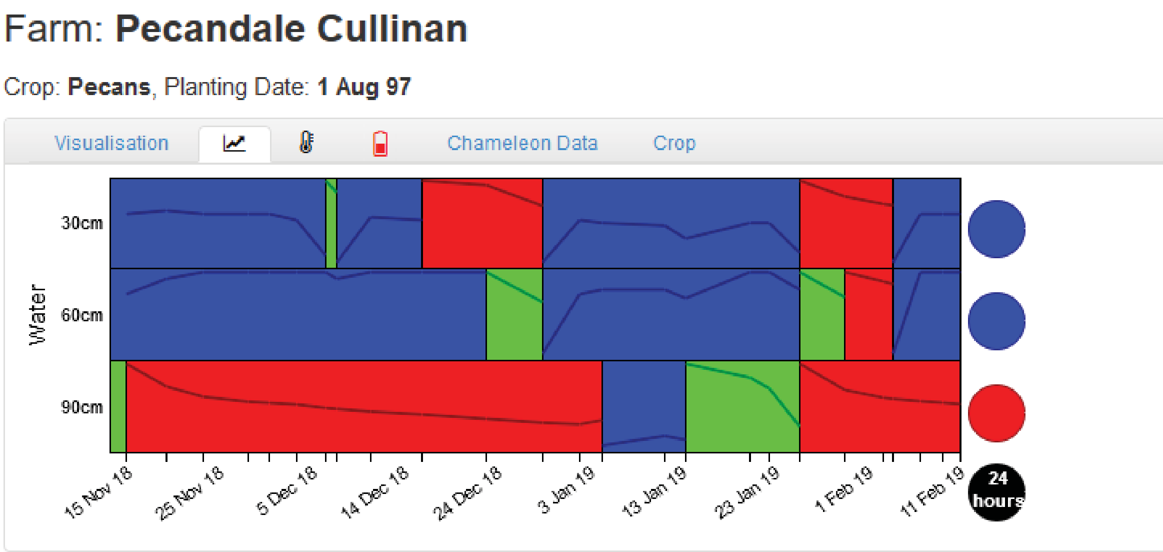


Figure 8.2: Chameleon soil water patterns for Andre Block at Pecandale

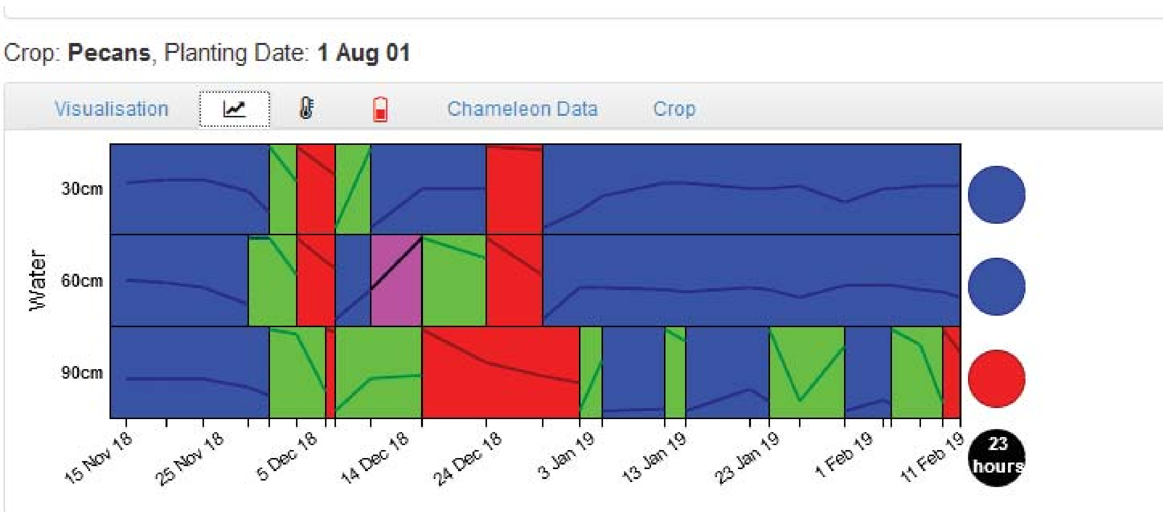


Figure 8.3: Chameleon soil water patterns for Langry block at Pecandale

The farmer was running into trouble at the end of December, which together with November were very dry months (Figures 8.2 and 8.3). The dam was empty and streams had run dry. The soil water patterns indicated that the soil was dry at all three depths. This has serious implications on the nut size as it was during a very critical stage of nut filling. Small nuts or improperly filled nuts fetch a much lower price than well filled, large nuts. In addition, the risk of the tree shedding its crop is also very real at this time of year. Luckily the farm was blessed with a few wet days at the very end of December and into January, receiving 94 mm soaking rain over four days. However, surprising for the farmer was that this rain did not bring the soil profile back to blue on all three layers, which shows us how dry the soil was, and how much the profile can store when wet up at the beginning of the season. The whole orchard is around

12 ha, and with 100 mm water storage in the profile, the opportunity is to store around 12 Ml, more than the farmer can store in his dam. This worked out very well for the topdressing, as the bottom of the profile was not that wet.

The second lesson the farmer learned with the Chameleons installed in the orchard was that he needed to go up one row and back down the adjacent row for Andre Block, as the profile was always a lot drier than for Langry. Although this is obviously, because the sprinkler spacing is so much larger in Andre Block, he admitted that the penny only really dropped for him when looking at the Chameleon patterns. This irrigation practice was done in the past winter period in his attempt to fill the profile before the season starts. This will take longer to get through Andre Block (and Kortry) with his irrigation, but he is of opinion he will benefit with larger and better filled nuts.

The farmer is optimistic that with the Malanspruit flowing well, the dam is about 80% full. The crop is looking excellent and nut size much better than usual (Figure 8.4). The farmer is of the opinion that Chameleons have, without a doubt, improved his irrigation practices on the farm. This is especially important given his water limitations and the price and unreliable nature of electricity supply.

Figure 8.4: Large nuts in nut filling stage at Pecandale

Part 3: Syntheses of learning experiences using irrigation monitoring tools and the VIA

In its more than 45 years of existence, the Water Research Commission (WRC) has funded research aimed at improving the way irrigation water is managed. Starting from early studies which focused on allowable depletion, or the so-called 'profile available water capacity' (PAWC) concept, and models to derive PAWC values for different crop-soil combinations (Hensley and De Jager, 1982), many other research projects have followed, numerous reports and papers have been published, human capital has been developed and tools designed and/or refined. In a review of past WRC-funded research on irrigation management done by Annandale et al. (2011) it was noted that although these research projects produced many novel mechanisms successfully applied by the target end-users, the adoption by the irrigation industry as a whole was not as impressive. In fact, after a national survey covering 332 irrigation schemes and which included semi-structured interviews with irrigation professionals, and a survey of large- and small scale farmers, Stevens (2006) showed that only 18% of commercial irrigators used the products of science to help them schedule irrigation. This is in spite of these robust research projects which provide concrete proof of the advantages of irrigation scheduling using science-based tools.

This situation, however, is not unique to South Africa. Even in countries where use of soil water monitoring tools is more common and well-developed, many farmers still rely on their prior experiential knowledge or intuition when making irrigation decisions, rather than on monitoring tools (Stirzaker, 2006). Social scientists have helped to explain this conundrum. In interviews with Australian irrigators, Whittenbury and Davidson (2010) reported that irrigators admitted to using a shovel so they could see the soil 'wetness' for themselves, despite paying large sums of money for sophisticated equipment. Others expressed the view that the equipment is just a 'guide', is not always reliable and that the monitoring tools can 'lie'. These irrigators gave their prior experiential knowledge priority over the numbers coming from the science-based tools, and were reluctant to cede control to a technical device. These findings resonate with other studies that have tried to deliver Decision Support Systems or similar solutions to farmers. They found that the business of farm decision making was much more than manipulating some biophysical data (McCown, 2002; Matthews et al., 2008) and farmers often preferred simpler forms of information as an input into their own decision making frameworks.

The VIA combines novel research in soil water and solute sensors to digital platforms, so that data can be easily captured, visualised, shared and analysed. It is underpinned by a robust understanding of soil physics, electronics, data management and visualisation. This is coupled with a deep interest in social learning, particularly tacit to explicit knowledge conversion (i.e. farmers structuring their learning around their own colour patterns) and double loop learning (managers understanding the assumptions and belief structure underpinning their actions). The main research questions for this study were how did the Chameleon and VIA help farmers in South Africa to progress from data to information to knowledge to wisdom for irrigation water management? What did farmers or other users experience with the implementation of the Chameleon sensors and uploading of data to the VIA?

In this part of the report syntheses of some of the lessons learned from emerging commercial farmers at Nkomazi, Taung and citrus farmers in Limpopo, North West and Eastern Cape Provinces, as well as commercial potato and nut growers will be discussed.

Chapter 9: Lessons learned with emerging commercial farmers

The three case studies with emerging commercial farmers included in this study illustrate where private industry, public organisations (like the PDoAs) and farmers joined forces to ensure that small scale agriculture and especially farmer settlement within land reform programmes in South Africa, can be successful and taken to the next level. The key elements of this joint venture in the three cases illustrate where the emphasis was on supporting farmers within the value chain, and without this support efficient irrigation management could not be practised. The three private organisations RCL/TSGro; AB InBev/SAB and CGA/CRI focussed on the development of appropriate value chains for farmers; the dissemination of innovation and technology; agribusiness development and marketing of products through established markets.

9.1 Emerging commercial sugarcane farmer, Nkomazi

The Nkomazi Irrigation Expansion Programme (NIEP) was developed in the early 1990s as part of the Komati Basin Development Programme, giving particular attention to emerging commercial sugarcane cultivation. The area is 3 500 square kilometres, and the majority of sugarcane growers reside in the Nkomazi Local Municipality area. The NIEP was initiated from the fifth phase of the Farmer Support Program (Kirsten, 1994), and sugarcane was identified as an easy crop to cultivate (Brown &Woodhouse, 2004). The reasons included the fact there was water available from rivers in close proximity and also from the planned dams. Furthermore, the sugar price was high and favourable as potential source of income for farmers at the time of farmer settlement. A market was immediately available via TSB Sugar (currently known as RCL). About 7 200 ha was initially provided to the SiSwati's (local community) and was divided into farms of 7-10 ha each, which was a good farm size for sugarcane cultivation as shown by studies done by Development Bank of South Africa (DBSA) (DBSA, 1999). The NIEP provided an opportunity for the development of the rural community in this area. The SSG selected for this project was predominantly a person who lived in the tribal system in the region for generations, and they were given approval to cultivate the land through obtainment of a permission to occupy (PTO) from the local traditional authority.

The major advantage for these emerging commercial farmers were that the majority of operational farming activities requiring capital assets, such as tractors, rippers, transport to the mill and irrigation systems were provided either by contractor services or through soft loans provided by the mills (Slabbert, 2011).

Emerging commercial sugarcane growers are typically elderly women, and most of them are full time farmers who depend on the cane sales income. However, in some cases some of them are part-time farmers who have other full time jobs, which make it very difficult for development officers of TSGro to provide support services (Mavimbela, 2016). Owning a sugarcane farm is sometimes regarded as a status symbol by part time farmers, regardless of whether it is sustainable or not, since they have alternative income sources. This causes some friction between full time and part time farmers as there are many full time farmers who would like to expand their fields (Mavimbela, 2016).The farmers in the area are grouped into development projects (37 projects currently) with funding for inputs either from loans or a retention option provided by Akwandze Agricultural Finance. The irrigation system that is used by the majority farmers in these projects is a sprinkler irrigation system, specifically draglines. In a few cases, farmers use drip irrigation, where the water is delivered close to the sugarcane stems. Although this system is more efficient than sprinkler irrigation, regular maintenance of the system is required to ensure that pipes are not clogged. Any obstruction or leak in the pipe means the irrigation delivery will be influenced. Fieldwork in Nkomazi confirmed that very few of the farmers using drip irrigation are aware of maintenance requirements, including how to flush or repair the drip system. The capital cost, application efficiency and labour requirements for each system differs. The relative low technical knowledge and skills level of sugarcane farmers in the area means that development officers are required to assist growers with the necessary information and support.

In the Nkomazi irrigation scheme, 35 SSGs were purposefully selected by TSGro development officers and the management of TSGro Development Services to participate in the project (Table 5.7). Varying scales of operation, educational level and differences in gender were considered during the selection of participating farmers. The sizes of the farm plots range from 7-11.7 ha and a mixture of sugarcane varieties have been planted (N36, N41, N53, N19, etc.) of which N36 was the most popular. The irrigation systems used are sprinkler and drip, and farmers receive irrigation water from the Lomati and Komati rivers. TSGro is responsible for development or extension services including cane husbandry, training, bookkeeping, irrigation, and facilitates the marketing and financing of farmers (provided by Akwandze, Land Bank and other financing partners). The TSGro Development Service Division consists of seven development officers and two managers, all with tertiary agriculture qualifications. Each development officer is responsible for approximately 1 400 ha sugarcane and maximum of 200 farmers, through established project committees driven by farmers. Despite financial risk to RCL of SSGs who may not be able to pay back loans, RCL continues to support these farmers because the 10 000 ha cane produced by SSGs contribute to approximately 20% of the output of the mills.

The Bulk Water Supply division was introduced in 2015. The aim of this division is to support farmers with the maintenance of irrigation water supply systems at field edge. Farmers are facing challenges to maintain pump stations built with huge motors and pumps designed for projects and not for individual farmers. This has resulted in farmers not being able to maintain or repair pumps when required. Projects however have the choice to use this service at a monthly fee, or to take care of these responsibilities on their own. The cost mainly includes cost of material and consumables for repairs. The SSGs did not use any scientific method for scheduling apart from following a fixed recipe provided by TSGro.

The model that the project team selected in Nkomazi was to introduce the tools (Chameleon, VIA and wetting front detector) first to development officers and lead farmers. This was done through a workshop that was held on 15 August 2017 (Figure 9.1) after which development officers, lead farmers and the project team installed the equipment initially in Walda, Sibange and Langeloop. Initially eight lead farmers were selected with the support of TSGro staff to attend this workshop based on prior relationships with farmers and with the anticipation that these farmers will play an active role in the dissemination of technology in Nkomazi. The farmers selected comprised of four male and four female farmers with sprinkler and drip irrigation systems. The farmers initially selected were regarded by development officers as more progressive and were playing a leading role in the respective development projects. It was also decided at the first meeting with farmers and development officers held in Malelane that rather than indicating what pattern is recommendable or desirable, farmers were encouraged to irrigate according to their “traditional schedule” and watch the colour patterns and then after interpretation, align irrigation practices with the main lessons learned.

Figure 9.1: A cross section of farmers and development officers attending the on-farm training in 2017.

Initially it was envisaged that farmers will be able to take readings and upload data via their smartphones to the VIA website. However, the project team experienced unforeseen challenges namely that very few farmers participating in the project were able to upload data due to the lack of smartphones. Based on these experiences, a decision in collaboration with TSGro management staff was taken to make development officers responsible for the taking and uploading of data on a regular basis. All development officers received a company smartphone as part of their basic equipment to communicate regularly with farmers (Figure 9.2). It was expected that problems regarding data taking and uploading were settled, however there were certain areas where the Wi-Fi reception was very poor, and no uploading could take place. This necessitated the project team to install portable Wi-Fi router at the TSGro offices to help with regular uploading of data.

Initially the taking of data and uploading was a huge problem at all the sites at Nkomazi as been mentioned earlier. One of the problems that development officers experienced with soil monitoring tools during the early stages of the project was loose wires on the green plugs that connect sensors to the fielder reader. This problem could have easily been fixed if a very small and specific electronic screwdriver was available in the area. As a result of this experience, a small screwdriver was included as a standard item in every reader that left the ring facilities in Pretoria. Currently, the cabling system uses spring-loaded push-in connectors instead of screw terminals (as described in Chapter 2). Other improvements made to the tools are described in Chapter 2.

Figure 9.2: Development officers taking readings with farmers in Walda, Nkomazi

Despite the initial technical problems and challenges of using monitoring tools being addressed, poor data collection and uploading by development officers continued (as discussed in Chapter 5). This led the project team to request a meeting with TSGro management to discuss the situation. During this meeting the CEO and senior management reassured the project team of the importance of Chameleon sensor information for improving farmer irrigation management practices on the various development projects. Following this meeting, the project team decided to install more sensor arrays at several development projects. Participants in these selected sites were selected by the TSGro management on the basis that some of them experienced some challenges such as over irrigating, irrigation infrastructure problems or failure to meet certain production targets set by TSGro.

Chameleon patterns were discussed with the farmers by the respective development officers during monthly meetings held at the resource centres in the different projects. TSGro uses a "ticketing system" of three basic colours, green, yellow and red to help farmers to understand the importance of basic husbandry actions which should be practised timeously, for instance fertilisation, spraying and irrigation. Once a farmer attends to a specific action at the appropriate time, a green ticket is issued. However, if a farmer is late with a specific action or does not attend to it (i.e. irrigation management problems), a yellow ticket is issued. If a farmer completely fails, a red ticket is issued. This system helps development officers to communicate critical aspects of cane growing to farmers. Development officers thought there could be many advantages by including Chameleon soil water patterns as part of the ticketing system.

These monthly meetings between development officers and farmers were also used to introduce the tools and the VIA to farmers who were not selected to participate in the project. Although the Chameleon patterns did not directly influence the irrigation scheduling followed on the projects, it helped farmers to understand how their crops were being affected by the irrigation management practices and to learn more about sugarcane water use. The main lessons learnt were how irrigation influence the uptake of fertilisers and possible leaching of nutrients when over-irrigation occurs, and how to account for dry spells and rainfall. Development officers perceive that it was relatively easy for farmers to understand and associate with the Chameleon patterns once the visualisations were thoroughly explained. Some farmers were interested and curious about their patterns, while others were not and were even afraid the tools could be used to penalise them in an event where they are perhaps over irrigating. In Chapter 5, an example was presented where a farmer pulled out the sensors installed in her field for this very same reason. The use of triad diagrams to try and interpret irrigation patterns over a season were for some development officers and lead farmers not easy to understand. A possible reason may be that some of them wanted to read more into the triad than what was displayed.

Farmers at Nkomazi traditionally burn cane before it is harvested. This meant that sensors that were installed had to be removed before this action, to prevent the tools being damaged. Few farmers were successful in removing sensors in time, and in many of these cases, sensors were damaged during the removal process due to the dryness of the soil before harvesting (dry off period). Development officers were uncomfortable to test whether removed sensors were still operational, and requested the project team to take care of it. After two consecutive seasons, only 50% of the development officers participating in the project felt comfortable in troubleshooting problems. Whether this was because they lack experience or they wanted the project team to take care of this is unclear.

Development officers and farmers experienced several practical challenges with regard to use the monitoring tools in the field such as:

a. *Adjusting the sensor cable lengths:* The Chameleon sensors are connected to three cables which are red, white and blue in colour. The order that these sensors are buried is important. However, farmers have often confused the order in which the sensors should be buried. As a result, the lengths of the cables were adjusted, with the red cable lengthened and the blue cable shortened. This helped farmers to easily identify the depth at which each sensor should be buried. This was discussed in more detail in Chapter 2.

b. *Lodged sugarcane:* When Chameleon sensors are installed after harvesting in relatively young sugar cane, it was easy to locate monitoring tools in the field. However, after a few months, because of the growing pattern of sugarcane, it became a challenge to take readings (first difficulty in finding the sensors in the crop and second the danger of being bitten by snakes) (Figure 9.3).

c. *Cane rats:* Cane rats caused severe damage to wires and equipment that was above the soil surface.

Figure 9.3: Chameleon sensors installed in young (left) and matured (right) sugarcane

At the end of the project, participating development officers were asked about their recommendations to improve the uptake of Chameleon sensors amongst farmers. All of them indicated that Wi-Fi reception was perceived as the major stumbling block, which should be addressed. They also indicated that more training with regard to irrigation management was needed and training workshops were necessary.

9.2 Emerging commercial citrus growers

Participating emerging commercial citrus farmers in this project are all beneficiaries of the Land Reform Programme in South Africa. These farmers received or are renting land from government. They are either individual owners or are representing communities through legal entities like Batlhako Temo Coop or Community Property Associations (CPA) as in the case of Zebediela.

Only three farmers had any experience in farming, but not specifically in citrus farming. Two of them have employed irrigation managers who had the necessary irrigation management knowledge. Three of the farmers are part time farmers, and have other full time positions in mines or government. The biggest challenges these farmers experience is the lack of farming knowledge, especially farming with a high value crop like citrus. Furthermore, they received agricultural land (farms), but the post settlement support rendered by PDAs in the respective provinces is poor and not aligned to the needs of these farmers. The Comprehensive Agricultural Support Programme (CASP) is implemented in all provinces of South Africa and earmarked to build capacity and support development through provision of infrastructure. However, in the case of North West Province citrus farmers this support was received at a very late stage after farms were transferred, and therefore in most cases at an inappropriate time. Farmers complained about the low level of technical support PDAs can offer, and especially with regard to irrigation planning and management.

The model that was employed in introducing monitoring tools to citrus farmers involved the selection of farmers with the help of the CGA advisor. The advisor was firstly thoroughly trained in the use of the tools. He also attended all workshops that were arranged during the lifespan of the project. After these training sessions, monitoring tools were introduced to farmers (September 2017) to test on their farms. This approach showed significant benefits, namely handing over responsibility and ownership to farmers for taking data and uploading to the website. The CGA advisor helped to facilitate the process. In retrospect it was perhaps a very steep learning curve for especially farmers with little farming or irrigation experience, while it was much easier for the “trained” irrigation managers employed at Zebediela and Batlhako Temo Coop.

The role of the CGA was found to be crucial in the development of these farms, especially with regard to preparing farmers to export their fruit. However, the technical advisor of CGA acknowledged that he lacked the necessary skills and knowledge to help farmers with the planning and management of irrigation. This is the reason that CGA eagerly engaged in this project. All the emerging citrus farmers follow a fixed irrigation schedule based on the guidelines provided by CRI (CRI, 2007). It was only at Zebediela where weekly monitoring of the effectiveness of irrigation practices took place through the use of a spade to check if the soil was wet enough. These observations were manually recorded and submitted to the CEO for decision making. When Chameleon sensors were installed on Zebediela, they replaced this monitoring activity.

The use of Chameleon sensors and the VIA almost universally found that citrus farmers tended to over irrigate, for example in the cases of Ripplemead, Batlhako Temo Coop. and Zebediela. The main reason is that the traditional schedule that these farmers followed are rough guidelines that do not take into account different soil types and how the soil water status changes over time. When one of the irrigation managers was asked about the tendency of over-irrigation he said the following: *“I did not believe the blue colour pattern in the beginning of the project, and therefore ignored the message not to irrigate. However, after the workshop held at UP I followed the information provided by the Chameleons and increased our citrus yield by 60% and halved the fertiliser use. The quality of the fruit is also much better, and we can export for the first time since we started farming.”* This farm manager’s experience shows that where the Chameleons were used properly and frequent readings were taken and uploaded, irrigation management can be improved to enhance farm productivity.

What have we learned from the use of Chameleons and the VIA by these citrus farmers?

a. *Ability to troubleshoot:* Three of the six farmers really found it difficult to troubleshoot problems that occurred with regard to sensors and readers, notwithstanding regular interaction with the support desk at the University of Pretoria and attendance of training workshops.

b. Easiness of uploading: Some (2) farmers were able to upload data regularly to the VIA, while others experienced problems with the availability of Wi-Fi reception and pairing of smartphones. The help desk located at University of Pretoria played an important role in helping these farmers.

c. Easiness to understand and interpret data: Three farmers indicated that it was relatively easy to interpret the colour patterns for their specific farms. For the other three, poor data taking and challenges experienced with uploading meant that no substantial data could be provided to test their ability.

In the case of Zebediela and Batlhako Temo Coop, wetting front detectors were installed which helped the farm managers with decision making regarding irrigation practices. At Zebediela, the irrigation manager introduced the VIA and monitoring tools to his block managers but only 50% of them were able to understand and use the tools independently without his support.

d. Farmers are eager to learn and share experiences: Participating citrus farmers all belong to CRI/CGA study groups, which meet every month. On three occasions, the Chameleon and the VIA were discussed at these meetings and participating farmers were asked to provide feedback. An on-farm demonstration was also conducted at Batlhako Temo Coop during the 2018 production season, where farmers received practical experience on how to use the tools. These training and demonstration events created additional interest in the tools, and therefore more tools were deployed with citrus farmers at the end of the project.

e. Farmers expressed the need for frequent opportunities to engage with irrigation specialists and the provision of training workshops: Farmers expressed an urgent need for regular advice on irrigation and fertilisation management. They also would like to receive regular training workshops where the necessary capacity can be developed.

The irrigation systems that many of the participating farmers are using are in a very poor state, and urgently require replacement or repairing, before attention can be given to the monitoring of irrigation application. In these cases, the benefits of using the monitoring tools are not evident because these farmers have bigger problems that require their urgent attention.

At Zebediela twenty four Chameleon sensor arrays and 15 sets of Wetting Front Detectors were installed (Chapter 6). Initially both the CEO and the irrigation manager were very enthusiastic about the potential use of these tools to replace the fixed recipe applied on the farm, which was monitored through the hand feel method. After testing the Chameleons for nearly two years, they found the value of the visualisation patterns very helpful with decision making, but requested field readers with continuous logging capability to be left in the orchards.

9.3 Emerging commercial barley growers

In 1998, Southern Associated Maltsters began producing barley for commercial purpose in the Taung irrigation scheme. At the beginning of the project, 55 farmers were involved on 556 hectares of irrigation land (Kokome, 2004). Currently, 3 764 ha is developed for irrigation in Taung with 411 farmers participating. When the Taung irrigation scheme was initially developed, it consisted of small plots of between 1.5 and 1.7 hectares. Many of the plots are now between 7.5 and 10 ha. Water users are required to register the use of irrigation water for pricing purposes and for determining the annual irrigation water requirement. As mentioned previously (Chapter 4), SA Breweries (now Anheuser BuschInBev) and FARMSOL provide support to farmers which includes, among others, agricultural extension services and input supplies and crop financing. One extension officer from SAB Malsters provides agricultural support services to the barley farmers at Taung irrigation scheme. A private irrigation scheduling agent provides weekly irrigation recommendations using capacitance sensors.

Farmers with varying levels of education, both male and female participated in the project. During installation of the Chameleon sensors in the farmers' fields in January 2017, the project team experienced an unforeseen challenge. The extension advisor who was supposed to assist the farmers to upload their data onto the VIA platform was unable to do so. The reason for this was that the portable Wi-Fi hotspot on his company (SAB Malsters) smartphone was disabled by the company when it purchased the phone. Uploading data on the website can be done in one of two ways. It can either be recorded manually and the data captured on the VIA platform or electronically using a smartphone's mobile data and a portable Wi-Fi hotspot. The project team was aware that in certain areas poor cellular reception may be a problem but had not experienced a situation where reception was good and a smartphone was available but it was not suitable for the purpose of uploading data. Of the twelve farmers who would be participating in the project, only one farmer had a smartphone which could be used. This lead farmer from Pudimoe and the SAB extension officer visited the various sites every week to take Chameleon readings and upload data to the VIA platform. However, this was not successfully done in the first two seasons (the summer of 2017-2018 and the winter of 2017).

Most of the farmers in the Taung irrigation scheme live within the Taung area, although some of the farmers also have other off farm jobs like teaching and running businesses. The villages are widely dispersed. Irrigation is important for farmers because it allows the production of two concurrent crops per year, which is the sole income for some Taung farmers. Four famers share a 40 ha centre pivot at project sites such as Pudimoe, Tshidiso, Ipelegeng and Bosele, each planting 10 ha. Only one crop is planted under the centre pivot so farmers need to agree on the crop to be planted. Farmers discuss how to irrigate the crop and follow the recommendations given by the agricultural advisor, however some farmers reluctantly cooperate.

The lead farmer at Pudimoe has three plots at Taung under different centre pivots. He was involved with the project from the beginning and consistently collected data and uploaded it to the VIA platform during one summer production season (2016-2017) and one winter production season (2018) when barley was planted. His perceptions about the VIA and the lessons he learnt from using the Chameleon and the observations of the researchers are discussed.

As mentioned previously, Pudimoe farmers experience problems with poor water availability as the site is supplied by Dam 7, which is the last dam served by the Vaalharts Water User Association. It is situated in the lowest area of the irrigation scheme and the canals feeding this project are old and leaking, and in general are too small to supply the irrigation project as well as the municipality. According to the farmer, the shortage of water has been a problem at Pudimoe for many years and continues to be so. As a result, farmers use three instead of all six pivots when irrigating. The farmers control the running of the pivots. In winter they irrigate twice per week for 12 hours (7:00 am to 7:00 pm) applying 12 mm and in summer (during September and October when it is hot), they irrigate for 24 hours applying 22 mm. Sometimes water arrives very late at the pump-house dams. The capacity of some dams is too small to supply the pivots in the area, and the sluices are sometimes not functioning properly, affecting farmers downstream.

Regularly visiting a centre pivot that is irrigating crops is most important, as there are a number of potential problems that can occur (Kokome, 2004). However, some of the farmers visit their plots only once or twice a month, meaning that they are not able to manage the application of irrigation water effectively and are unable to notice and repair breakages in time. Other farmers do not adequately monitor the centre pivots and farmers with sprinkler irrigation systems (at Rethuseng) sometimes allow the sprinklers to remain in one place for longer than necessary. There are also absent farmers who spend much of their time sourcing other forms of income, because they feel that the income from crop production which only occurs at the end of the season is not sufficient.

Taung farmers use contractors with mechanical equipment to plant and harvest their crops. This meant that Chameleon sensors had to be installed in the fields at the beginning of each season and removed at the end of the season. Although the sensors were installed at Taung in four different seasons, the extension officer only felt comfortable to install the sensors when the project team was present. Whether this was because he was still unsure of how to install the sensors properly or he wanted the project team present to motivate the farmers is unclear. At the end of the final season of the project the sensors were removed from the fields as before but have not been installed in new crops. This is despite the officer being extremely supportive and enthusiastic about the use of the Chameleon throughout the project.

The patterns from the VIA were shared with some of the famers from the different project sites (Figure 9.4). According to the lead farmer and the extension officer, famers benefitted from observing the patterns. Farmers from the different project sites showed an interest in the Chameleon patterns.

Figure 9.4: Farmers at Tshidiso discussing Chameleon patterns

The benefit from seeing the patterns mostly likely did not influence their management of irrigation water but it did help them to understand how their crops were being affected by their irrigation practices and to learn about crop water use. The challenge for both the lead farmer as well as the extension officer was that they found it difficult at times to interpret the soil water patterns. Although the farmers had the benefit of using the Chameleon and the recommendations of the private irrigation scheduling agent, they still used a spade to check if the soil was wet. The lead farmers at Taung stressed the need for training in irrigation water management.

At the beginning of the project the plan was for the extension officer to collect data and upload it to the VIA platform. Unfortunately, during the course of the project the work schedule of the extension officer changed such that he was not a position to visit every farmer participating project every week to collect data. This resulted in poor data collection in two seasons as mentioned before. The project team therefore decided to recruit two lead farmers, one from Pudimoe and another from Tshidiso, to collect data at the different sites and upload it to the VIA. This model was implemented during the 2018 production season and it worked well as is evident from the data collected during the second season of winter barley production. These two farmers were paid a nominal amount of money in order to cover their expenses such as fuel, costs of data and their time. Both famers concluded that this is a better model (using lead farmers) to apply in order to collect data from other sites at Taung. However, the best model to follow would be to provide farmers with their own readers so that they could monitor their irrigation practices whenever they wanted to. This approach is supported by the finding that famers involved in the project expressed an interest in having their own readers so that they could monitor the irrigation water applied. At a cost of R2100 for a sensor array and a Chameleon reader, farmers thought that the tools were affordable.

The private agent who is scheduling irrigation at Taung visits the scheme every week. He forwards his recommendations to the SAB extension officer who in turn informs the famers of the recommendations via SMS messages. The farmers are informed how much water to apply but it is up to them to follow the recommendations. The farmers do not learn about irrigation water management and what is happening in their individual plots but a given a recipe to follow. It was evident during the project that some famers are satisfied with this arrangement, however, there are others who want to learn and better understand how to manage their irrigation.

After the first year of the project, the extension officer at Taung presented some of the data from the Chameleon patterns at one of the SAB meetings where, according to him, senior managers in the company expressed a keen interest in the tools and the VIA. Following that specific meeting, the project team decided to install many more sensor arrays at the different sites at Taung. However, no further interest was shown after the additional installations. In fact, towards the end of the project one of the senior managers noted that SAB will continue to follow its previous practice and use their current irrigation scheduling method because the agent who assists with the irrigation scheduling is readily available and provides a service.

Chapter 10: Lessons learned with commercial farmers (macadamia and potato)

Chapter 10 is discussing some of the valuable lessons that were highlighted where the Chameleon and VIA was used by commercial potato and macadamia growers.

10.1 Commercial potato growers

Chameleon sensors were evaluated on-farm in the fields of commercial potato growers in Limpopo and the Sandveld regions. The following lessons were learned from observations during the study, as well as feedback from individual growers:

a. Need for adjustment in switch points

During initial evaluations on loamy soils in Limpopo, Chameleon sensor colour patterns remained mostly blue, suggesting too wet soils. At closer investigation, it was realised that the original switch point of about -25 kPa for colour change from blue-to-green was probably "too dry" for decision making of potatoes produced under centre pivots, where the soil profile is managed relatively wet to limit risk of water stress. The blue-to-green switch points were then changed to -18 kPa, which resulted in more colour variation in following evaluations. After the improvements, growers were generally satisfied with the usefulness of Chameleons for irrigation management decision of potatoes on loamy soils.

b. Field readers should have memory capability

Some growers experienced problems to upload data from early version field readers to the VIA using their cell phones in areas without or with poor cell phone reception. They suggested that readers should have memory capability to store data in areas with poor reception, for later uploading when Wi-Fi or cell phone reception is available. Later generation readers were modified accordingly.

c. Field readers with continuous logging capability

Some growers requested field readers with logging capacity that could be left in the field (connected to a sensor array set) in order to collect continuous data at regular intervals. This modification was made and currently all field readers have this capability.

d. Re-use of sensors in annual crops

Farmers realised the potential of digging up sensors at the end of a crop growing season, for re-use in a next annual crop. Early versions of the sensors tended to disintegrate after a season or two. The design of sensors has since been changed in order to make them more robust for re-use.

Furthermore, the re-use of sensors required functionality in the VIA to transfer such sensors to new fields (irrigation bays). Modifications were consequently made to the VIA to allow for such transfers.

e. Usefulness of Chameleons on sandy soils

The accuracy and usefulness of Chameleon sensors on very sandy soils, such as the Sandveld sands, was evaluated in this project. Chameleon sensors mostly showed blue response patterns throughout the growing season, suggesting very wet conditions for almost all the fields. However, DFM capacitance probes installed alongside the Chameleons showed that the fields were not continuously wet. Drainage lysimeters, which were also installed in some of the fields, confirmed the capacitance probe readings (that soils were not very wet). The Chameleons thus responded poorly to sudden changes in soil water content of these sands and could not alert growers to the sudden development of dry periods in the season. The use of Chameleons in these sandy soils is thus not recommended at this stage, as management decisions may not be reliable. This can probably be attributed to a sudden drop in hydraulic conductivity of these sands, resulting in the sensor matrix to remain relatively wet, while the soil had already dried out. We, therefore, conclude that Chameleon sensors are at this stage not sensitive enough for the management of irrigation in the very sandy soils of the Sandveld region.

f. Hardware improvements for better reliability

Growers made suggestions to improve reliability of sensors, such as to replace the green sensor connectors with a more durable solution, as these are not robust and bad connections are a frequent problem. Current developments are underway to solve these issues.

10.2 Commercial macadamia growers

Chameleon sensors were also used by a private consultant working with commercial macadamia growers in Mpumalanga. He indicated that over-irrigation of macadamias is common, and one of the reasons he posed is that very few guidelines are available with regard to how much water macadamias require. One of the major problems that the majority of macadamia growers are grabbing with is that specific data suitable for growing macadamias is scarce. The crop has an inherent ability to flower for extensive periods of time under very dry conditions. By over irrigating trees, more damage is done than letting the trees stress for a week or more. His view is that the Chameleon is excellently positioned to answer many of these questions.

He is convinced after testing Chameleon sensors in the orchards of Mayo Mac, a multi-faceted South African company consisting of various shareholders within the macadamia supply chain, that the Chameleon sensor is a useful way to calibrate the refill point for capacitance probes. While many experienced users of capacitance probes use a slowing of rate of water use as a means of identifying the refill point, it is also possible for the capacitance probe to reinforce the point that the irrigator thinks the crop needs water.

He is of the opinion that farmers were in general very positive and optimistic about the use of the monitoring tools. However, they were concerned about the many wires that are used with the sensor arrays and therefore were of opinion that the hardware requires some changes and attention. They were however confident they will be able to apply these tools on their farms.

Although he found the Chameleon easy to use and understand, the uploading of data was challenging, due to poor Wi-Fi reception and the technical knowledge required. He also stated that farmers will find the use of Chameleons challenging because many growers are relatively old and functions like the activation of a hotspot, which seems simple for younger farmers, can be challenging.

Chapter 11: Concluding remarks and key messages

The aims of this project were to:

- Deploy farmer-friendly monitoring tools that measure soil water, nutrients and salt.
- Develop a system of quick data sharing through on-line visualization of data from the monitoring tools linked to a virtual discussion, learning and teaching space with skilled facilitators.
- Further refine simple monitoring tools to address on-farm farmer experiences.
- Determine how this combination promotes learning that improves irrigated farm productivity.

The project successfully achieved its objectives. Monitoring tools (Chameleon sensors) measuring soil water were installed in numerous farms in six provinces in the country, namely; North West, Mpumalanga, Limpopo, Gauteng, Eastern Cape and Western Cape. These tools were installed in barley, maize, sugarcane and potato fields as well as citrus, pecan and macadamia orchards. Wetting Front Detectors were also deployed in a few farms with the intention of measuring nutrients and salts in the soil. A system of sharing data quickly through on-line visualization of data from the monitoring tools was developed, the Virtual Irrigation Academy (VIA) (https://via.farm/). Major improvements were made to the VIA during the course of the project by the developers of the VIA platform with input from researchers, project team members and other users, not only in South Africa but also in other countries which are part of the VIA community. As stated in Chapter 2, this project benefitted enormously from substantial developments made in the larger and more comprehensive ACIAR project that is running in Malawi, Tanzania and South Africa.

The central approach to developing and refining the monitoring tools is "User-led design". That means the developers of the Chameleon provides users with equipment for testing and feedback as early in the development process as possible. The objective was to identify what users want before it was tried at a larger scale. Farmers and other users of the monitoring tools reported challenges or problems that they experienced and their input was, where necessary, incorporated into fine-tuning the tools. Some of these improvements are noted in Chapter 2. The project team successfully addressed various issues raised by users whilst others are still receiving attention. Feedback from users played a major role in the refinement of the tools and continues to do so. Although the WRC project has come to an end, the ACIAR project will continue for a further four years.

In order to address the fourth objective of the project, the researchers followed the Mode 2 production of knowledge. Mode 2 aims to bring together shared knowledge production where the knowledge producers in the field of academic research together with the knowledge produced and used by practitioners allow the two sides to work together. It attempts to include the users of the knowledge (farmers) in its generation and address real-world problems by using a combination of disciplines. It tries to foster dialogue between academic research and the applicants of the knowledge, the farmers. This was done through the introduction of the Chameleon water monitoring tools and the on-line visualisation of data (Chameleon soil water patterns). Farmers were not told how they should irrigate or how much water they should apply; rather they were informed what the red, green and blue colours of the Chameleon mean and encouraged to learn-by-doing (experiential learning). The project primarily focussed on introducing user-friendly tools to irrigation farmers to see whether the tools identified obvious problems, such as fields that were too dry, nitrate deficient or salty and whether farmers could understand the information and act on it.

The results of this work are reported in Part 2 of this report for different crops where the Chameleon had been installed. Some of the findings include:

- Given the limited timeframe to implement the project, the project team could only observe how the tools were received and tested. The team could not meaningfully document the adoption process that leads to improved farm productivity, but could reflect on the learning experiences in testing monitoring tools on irrigation plots. Learning is a journey which takes time, and the project has shown benefits of the Chameleon pattern helping to empower farmers and development officers to co-learn about root zone soil water content.
- The project team could not clearly establish a direct relationship between learning as a result of using the monitoring tools and VIA platform and improved farm productivity. There were emerging commercial farmers who changed their irrigation practice as a result using the Chameleon and the VIA platform, for example Batlhako Temo Coop and Ripplemead farm but this project was not able to determine whether this change improved crop productivity.
- A commercial part time pecan grower is using the Chameleon to manage his orchards. A private consultant, who advised commercial macadamia farmers, found the Chameleon to be very useful and has actively promoted its use among growers.
- Although not all farmers at the project sites used the information from the Chameleon and acted on it to manage their irrigation, they did benefit from seeing their soil water patterns and the change in the soil water status during the development of their

particular crops. This helped them to get a better understanding of the water use of their crops. This learning journey of looking at Chameleon patterns changing over time is, according to the team, a huge achievement, since it encourages farmers (perhaps for a first time) to reflect, start to rethink the patterns and encourages a deeper level of learning.

- In some cases, the relation between soil water patterns generated by the Chameleon during the crop growth period and yield were evident and problems were identified, whilst in other cases the link between the patterns and yield were not apparent and further investigations are needed.
- A major problem at many of the project sites was the poor collection of data and uploading to the VIA platform. Often development officers and others tasked with collecting data were occupied with other responsibilities.

Part 3 of the report documents the lessons learnt by the users of the monitoring tools as well as researchers:

- The model implemented in this project of primarily using development or extension officers as in the cases of Nkomazi and Taung to collect data was not successful. A better approach in future is to give field readers to the farmers as in the cases of emerging commercial citrus farmers. Development officers can upload the data once or twice a month when they visit the farmers. This will ensure that more readings are taken and more accurate records of soil water patterns are captured because Chameleon readers have the capacity to store a significant quantity of data. In addition, farmers will have easy access to readers and can monitor their crops regularly and not wait for someone who visits occasionally.
- Managing irrigation water remains a major challenge for many emerging commercial farmers. Development officers and farmers agreed that skills training in irrigation water management were necessary. Some private organisations, i.e. RCL/TSGro and AB InBev/SAB provide training in irrigation management for their development officers. The experience of this project illustrated that the VIA can only expand with the necessary support of skilled people that are able to undertake troubleshooting in the field after monitoring tools are installed. Therefore, there is also an urgent need that irrigation farmers should receive appropriate training.

  Other private organisations responsible for agricultural support services also need to provide training for their agricultural advisors. For example, the agricultural advisor from CGA/CRI responsible for assisting emerging commercial citrus farmers in several provinces is a specialist in citrus crop production but admitted his limited knowledge of irrigation water management. Therefore, the emerging citrus farmers receive limited support with regard to managing their irrigation.

- Large commercial farmers often have a wide selection of scientific irrigation scheduling tools to choose from, so the competitiveness among the companies that manufacture these tools is high. Providing a service to clients is one way of attracting big clients. In contrast, smallholder and emerging commercial farmers often do not use any irrigation scheduling tool but follow fixed recipes that are provided to them.
- Large scale commercial farmers like Zebediela and macadamia growers indicated they favour irrigation scheduling advice based on continuous logging capacitance probes, since this category of farmers do not have the time to take data and do the higher level of analytics of Chameleon patterns showing a three-layer time series of an irrigation plot or orchard. The irrigation scheduling advice usually includes a history of the soil water status of a specific irrigation plot plus recommendations for multiple fields in a user-friendly manner.
- The level of irrigation management by emerging commercial farmers is at a very basic level, where in the majority of cases standard recommendations by development officers or other advisors are followed without measuring of the soil water content on the irrigation plot. In many cases, this approach led to over-irrigation and the leaching of nutrients. One reason for using this approach is because these farmers are usually resource poor and do not have resources to buy smartphones or sophisticated irrigation scheduling tools. The deployment of the VIA and monitoring tools encouraged farmers to irrigate and watch the coloured lights and then interpret their own patterns, instead of farmers being told what pattern is desirable. Furthermore, small scale irrigation systems are complex socio-ecological systems with many different role players and subsystems (Van Rooyen et al., 2017), which influence the deployment of technologies like the Chameleon and VIA.

Important observations were noted by the project team during the course of the project which not only relate to the use of the tools and the learning experiences but also the wider issues regarding irrigation water management and the emerging commercial farming sector.

- Large private organisations such as RCL/TSGro; AB InBev/SAB and CGA/CRI play a key role in the development of these farmers, but could even play a more crucial role in ensuring that agricultural water is used more efficiently both at a farm and scheme level. This fact is particularly important because of the water situation in the country. South Africa is a water scarce country and the situation is expected to become more severe with the changing climate. The responsibility for managing agricultural water use efficiently should not only be the responsibility of farmers but also those who have an influence on water use in an entire irrigation scheme.

- Several emerging commercial citrus farmers had little knowledge of farming prior to receiving their land and are finding it difficult to manage their orchards productively, let alone run their farms as a business. These farmers are struggling to survive.
- At Taung irrigation scheme, emerging commercial farmers have access to land, financial services, extension support and established markets. The initial challenges of being established have been overcome, but now these farmers face the reality of producing on a sustainable basis in a commercial market environment where the exposure to external drivers is very high. Since these farmers do not own land or the irrigation equipment, the fixed cost component is very low. However, a general trend is that these farmers do not re-invest to a great extent in farming operations, apart from sporadic addressing of repairing farm machinery and tools. In the case of emerging citrus farmers, farmers do not own land which means they do not have the necessary incentives to re-invest their profits, which influence the long term sustainability of these farms.

Recommendations

The following recommendations should be considered:

- Conventional approaches to agricultural development have often focussed on "hard" technologies to improve the functionality and efficiency of infrastructure and irrigation application technologies. However, since many examples exist in South Africa where small scale irrigation schemes are trapped in a negative cycle of infrastructure provision, unprofitable farming, lack of investment and infrastructure degradation, transitioning these systems into profitable and economically sustainable schemes requires a mind shift. Investment in technologies like the Chameleon and VIA is as important as investing in farmers (human capacity), institutions, social capital and the building of aligned value chain networks.
- It is unrealistic to think that emerging commercial or small scale irrigation can be sustainable in the medium- to long term if they remain dependent on government or private sector support. Multiple interventions are required to transform these irrigation systems to a more sustainable and profitable state.
- For a learning system like the VIA to be sustainable in the longer term, farmers need to take their level of learning to a deeper level (i.e. exploring their seasonal patterns), and here the support of technically competent extension or development staff is

required.

- The report recommends that further research is needed to explain some of the results that were observed.
- Further work also needs to be done on Chameleon responses in potato production

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Appendix A

1. Capacity building

Project: K5/2557/4: Improving on farm irrigation water and solute management using simple tools and adaptive learning

The nature of this project is different from most WRC assignments, as it included the users of the research knowledge (farmers) in its generation and addressed of the challenges irrigation farmers' experience. The aim was to encourage dialogue between academic research and the applicants of the knowledge.

Capacity building or development for the purpose of this project was defined as a "process that improves the ability of a person, group, organization or system to meet the objectives or to perform better". The capacity building took place at several levels during the lifespan of the project, namely human, social, organisational and institutional levels.

1.1 Capacity building among students and project members

Through this WRC project capacity was in the first place built amongst the project team members who gained a lot of experience and insight into the challenges small scale, emerging commercial and commercial farmers experience in the application of the monitoring tools and the uploading of data to the VIA website. The interaction and exchange of information between the project team, development/extension officers, academia, researchers and irrigation water management staff in the industry contributed to a better understanding of the challenges and options that these role players face with the implementation of irrigation monitoring tools and use of the VIA website. This feedback was used to improve the monitoring tools and the VIA website over the project lifespan. It furthermore highlighted the challenges that exist amongst irrigation farmers to achieve high irrigation water use efficiency and profitability in irrigated agriculture.

Students gained a lot from the involvement in the project, not only financially but also through the development of new analytical skills to interpret the data generated by the VIA and how to communicate it to farmers. The project supported one master student from University of Pretoria directly with a student bursary and through the co-funding received from ACIAR/CSIRO another six students were registered. These post-graduate students appreciated being supported by the project, especially the financial support.

- Ms N Mente assessed the factors which have an influence on irrigation management decisions in Taung Irrigation Scheme, North West Province amongst emerging commercial barley and maize farmers. Ms Mente is finalizing the examination copy of her dissertation with the title *“Factors influencing irrigation management decision making: The case of Taung Irrigation Scheme, North-west Province* “ to finalise her study for the degree of Masters in Agricultural Extension (M Agric Extension).The student will finalise the study during the 2019 academic year and graduate early 2020.

- Three students from Malawi successfully finished their studies during 2018 and graduated in April 2019 in biophysical science:
  - Mr N Sichali finalized his research with the title: “*The use of simple soil water and nutrient monitoring tools to improve maize productivity in Bwanje Valley irrigation scheme, Dedza district, Malawi.”*
  - Mr T Kandinga finished his study with the research title: *“Understanding the effects of shallow groundwater movement for water and salinity management at Kasinthula irrigation scheme, Southern Malawi.”*
  - Ms T Chinula finished her study with the research *title:” Utilization of water in the soil profile after flooded rice by beans: The case study of Bwanje Valley irrigation scheme, Malawi. “*
- An additional three master students in crop production are busy finalising their research:
  - Title of Mr A Motshweneng’s dissertation is: “*Water stress response of pecan (Carya illoinensis Wangenh.C.Koch)”*
  - Mr P Thakali’s dissertation is: Improving water and nitrogen use efficiency of green maize using simple tools and the Soil Water Balance model”
  - Mr K Deane’s dissertation is: *“Irrigation scheduling of potatoes using Chameleons of different switch point sensitivities”*
- A seventh post-graduate student, Mr K Dlamini is finalizing his master study in horticulture with the research title: *“Utilizing simple tools to schedule irrigation and monitor nutrients in commercial evergreen subtropical orchards.”* and will also finalise his study during 2019, to be able to graduate early 2020.

1.2 Capacity building amongst development or extension officers and farmers

The VIA and Chameleon sensors offered various levels of capacity building to extension staff and irrigation farmers. The first level (level 1) offered measurement tools to farmers to be used through instantaneous reading and interpreting of soil water content status of their irrigation plot. The second level (level 2) offered a coloured time series of three layers of a single Chameleon reading, while level three is representing the higher analytical level of interpreting Chameleon sensor and WFD data over a production season(s), where skilful support staff are required.

The first level of capacity building among farmers was relatively easy where farmers have to interpret the readings in the field (blue, green, and red) at the three reading levels. Various workshops and in-field training sessions have been offered during the project lifespan. Some farmers initially perceived that "blue" was the best option to aim for, but after several training opportunities like the workshop held in March 2018 at the University of Pretoria, changed practice. Farmers did not only learn how to install monitoring tools correctly, but also to use the three-layer coloured pattern to interpret irrigation practices and to answer irrigator's questions through observation, reflection and adjusting their actions by using the tools.

The second level of capacity building were found to be more challenging as it requires skilful technical people to help with the analysis of colour patterns (visualisations) and interpreting of visualisations to help farmers in their learning about irrigation.

Very few of the development/extension staff involved in the project (AB InBev/SAB, TsGro and CGA) had the required knowledge and skills to help farmers with the interpreting of Chameleon visualisations and interpreting of WFD data. Apart from the project helpdesk that was situated at the University of Pretoria and available to support staff, various training opportunities were offered like workshops, personal face-to-face training and tutorials developed for the VIA website. The development of triads in the second half of the project was a result of the feedback received from development officers who expressed the need to evaluate Chameleon patterns over different seasons in order to make certain adjustments to irrigation practices.

The third level of capacity building was not addressed in this project, but will require the training of skilful technical support staff to be able to do more complicated analyses of patterns, which will require basic training in crop production and soil physics. These specialists will be required to serve on the "help desk" to support farmers and development officers with meaningful interpretation of colour visualisations and the effect on crop productivity and profitability.

1.3 Capacity building with other stakeholders

The project team was successful in active collaboration and outreach with various stakeholders (national and international) through the participation in various conferences, symposia and workshops. Papers were delivered at the following workshops, conferences and symposia during the project period:

a. 51st Annual SASAE/3rd AFAAS combined international conference held in Durban (October 2017)

b. NIRESA workshop held at Loskopdam , Mpumalanga (April 2018)

c. SARIA workshop held at Pietermaritzburg, KwaZulu-Natal (May 2018)

d. SANCID symposium held at White River, Mpumalanga (November 2018)

e. Potato SA symposium held at Klein Kariba, Limpopo (July 2019)

Apart from participating in above mentioned events, the project team also published widely through a number of popular articles in Landbouweekblad (May 2017 and July 2019) as well as Farmers Weekly (May 2017). The final results will also be used for publication planned in accredited journals.