# OPERATIONALISING THE INCREASE OF WATER-USE EFFICIENCY AND RESILIENCE IN IRRIGATION (OPERA)

Report to the
**Water Research Commission**

by

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# EXECUTIVE SUMMARY

Stellenbosch University Water Institute partnered with seven European partners in a Water-JPI project entitled "Operationalising the increase of water-use efficiency and resilience in irrigation (OPERA)", aimed at better understanding farmers' use (or non-use) of irrigation technology, and investigating ways to practically improve water efficiency. The Water-JPI (Water Challenges for a Changing World Joint Programme Initiative) is an initiative of the European Union aimed at promoting inter-governmental collaboration to address the global challenge of water availability. The Water Research Commission (WRC) joined the Water-JPI network as a funding partner in 2015 and as a full member in November 2017 (WaterJPI, 2019). The OPERA project is one of the first projects funded by the WRC as part of this international agreement. The WRC and Stellenbosch University entered into a normal WRC contracting agreement for the South African part of the OPERA project. As such, a reference group was appointed and a mid-term and final meeting of the reference group to review the work, took place.

The aims of the international OPERA project consortium was to identify:

1) User demands of farmers, farmer associations, extension services as well as water management organisations
2) Best possible combinations of information technologies (sensors, models, remote sensing)
3) Innovative service models to realise a practical transition towards an increased use of precision irrigation in practice

Each country had one case study site and each case study developed and tested a different technology. The innovation of the OPERA project lies in the overlap and comparison of approaches in the different case studies. The end project is a guideline based on the lessons from the different approaches, as well as an econometric model to better understand drivers behind technology uptake.

South Africa's contribution to the project was collecting data for a survey on technology uptake, and – based on the outcome of this survey – investigate whether it would have been beneficial for farmers to use more than one technology available to them. Focusing on the technology already available to farmers, instead of developing a new model, was the chosen approach as South Africa has numerous crop models that have been developed (many funded by the WRC), and the Western Cape also has a free remote sensing service called FruitLook, which is funded by the Western Cape Government and developed by Dutch partners.

The aims of the South African case study within the international project context was to:

i. Better understand farmers' perception of technology and their appetite for risk and trying new technology
ii. Determine the uptake and use of FruitLook as remote sensing service in the study area
iii. Evaluate the usefulness of FruitLook as remote sensing service and/or other technologies or models that farmers use

Aim iii) was further developed based on the results of aims i) and ii), in order to ensure the applicability and usability of results generated in the study. The following two sub-aims were added to aim iii) after conclusion of aims i) and ii):

a. Compare the outputs of technologies used for irrigation, to determine if it would have been beneficial for the farmers to use more than one technology (with a particular focus on FruitLook as remote sensing product)
b. Using the results of aim iii-a), use field-level data to develop a water budgeting approach for the catchment

For aims i) and ii), the research team used the questionnaires that were developed and also used by the international team, in order to produce comparable results across the countries. However, a decision was made to answer the questionnaires through individual interviews rather than workshops (as done in the other countries), in order to obtain as much data as possible.

The interviews revealed a high uptake (83%) of technology amongst farmers, but also that mainly one type of technology is being used in the area, namely soil water probes. Unlike many international studies, farmers' age and farm size did not have a significant link to technology uptake. It was concluded that post-installation service offering, as well as perceived ease of use and usefulness (value for money) are the main drivers behind farmers' uptake of the soil water probes. Significant efforts have to be made by the developers of new technology to simplify and personalise the product and service offering for farmers to adopt it in the long-term, which contributed to its success. A total of 88% of interviewees have heard of FruitLook and there is interest in the service, but only five out of 33 persons interviewed reported to actively use it. Only one of these five reported to use it for irrigation purposes, the rest used it to identify weak spots in their orchards or vineyards, or to better understand their farms. Based on farmers' detailed responses, the lack of uptake of FruitLook can be mainly attributed to the programme being time-consuming at the start, the fact that it provides results without advice on how to act on those results, and perceived inaccuracies. The case of FruitLook shows that cost-effectiveness does not guarantee technology uptake.

The interviews also revealed that one key reason behind farmers' use of only one technology is that it would be too time-consuming and too much effort to use additional technologies that provide different types of output data, which also have to be interpreted and somehow linked together to inform decision-making. A general comment by farmers was that while information is important for decision-making, receiving too much scattered information is not useful, and that they would be more likely to use FruitLook (or any other new product) if it could be linked to their existing chosen technology. It is this point that the second part of this study aimed to address, by exploring whether it is at all possible to compare the outputs of three different technologies. Seeing the datasets of all three technologies in one document or graph could provide the farmers with an opportunity to cross-check the results to ensure accuracy and, as such, contribute to water saving.

Based on the outcome of the survey, the most popular technology used by farmers for irrigation scheduling was soil water probes. The other two technologies that are freely or affordably available to the farmers are FruitLook and weather station data, both of which provide a form of evapotranspiration data to interpret as irrigation requirements. Therefore, for aim iii-a) of the study, the water loss profile of a soil water probe was compared to FruitLook and weather station data and differences or similarities in the results were discussed. FruitLook is readily available to all farmers with internet, while there are numerous weather stations in the area that farmers can subscribe to at a relatively low cost.

Hourly data for six probes were obtained for the period of January 2015 to January 2019. Hourly weather station data ($ET_0$, rain) were bought for the corresponding time period from stations located between 1 km and 5 km from each probe. The FruitLook ET values for the corresponding blocks were downloaded. Data were aligned in Excel in order to compare weekly soil water loss with weather station $ET_0$, $ET_c$, as well as FruitLook $ET_{actual}$ and $ET_{ideal}$ values. Comparing the data was time-consuming as there were many gaps in the hourly soil water probe datasets. Due to the gaps in data, only one probe was used in further analysis. Although much work is needed to refine the approach, the results showed that soil water readings, weather station data and remote sensing data could in fact be aligned and compared. The comparison showed fair correlations (>0.75) between all values, except between FruitLook and weather station data, with FruitLook ET values being much lower. When compared to actual irrigation applied to this block, the farmer over-irrigates by approximately 30% according to FruitLook. Irrigation applied is closest to $ET_0$, with $ET_c$ and the soil water levels showing 13% and 16% over-irrigation respectively. The estimated over-irrigation compared to FruitLook ET values can most likely be attributed to the plum orchard being under net cover, illustrating that remote sensing cannot be used as a reliable estimate with shade netting. This is problematic seeing as the use of nets as water saving effort, is growing rapidly in the province.

The final aim of the study was to create a water budget approach for the catchment. During the interviews most farmers were critical of the manner in which they received water during the restrictions – wine farmers would have preferred receiving less water early in the season and more during the peak months of January and February. Instead, the 40% cut was implemented for all months. This suggests that the catchment could benefit by using field-level data on actual water requirements, rather than across-the-board rationing during restrictions, in order to minimise losses. With the calculation of water demand from the soil probes, FruitLook and weather station, as was done for the previous aim in this study, the next step was to calculate a monthly water budget for the catchment, for the chosen crop.

The total monthly ET values for all measurements were extrapolated to a regional level water budget for plums. Should the above approach be more refined, this could be done for all crops in the irrigation area to calculate the total monthly water budget for the region per crop type. This could then be compared to current allocations and be used to better inform decision-making regarding allocations in the irrigation scheme during times of restrictions. The monthly ET values of all measurements were also compared to the results calculated by SAPWAT – a programme funded by the Water Research

Commission to calculate irrigation water requirements. All SAPWAT values were much lower than field measurements. Possible reasons for this are unclear and should be investigated further.

The aims of the study were met and provided the following insights and innovation:

- A better understanding of South African farmers' personal preferences for certain technologies to inform their irrigation scheduling decision-making was produced. These findings should be considered by anyone wanting to introduce a new technology or model into the agricultural market.
- An independent assessment of the uptake of FruitLook was done. Although there is widespread awareness about it, it is not being actively used in this area as desired by the developers, which suggests that it could fail if government should start asking a registration fee for it. The reasons for the non-use of this service and the quotes provided in this report provides valuable feedback for the developers of the programme to consider to ensure future success of the service.
- A simple methodology that could be used by farmers to view the results of their soil probes together with results from FruitLook and a weather station in the same document, to obtain a holistic picture, was developed. This has not been done before and although more refinement is needed and the equipment used are not calibrated for scientific analysis, this approach would be very useful for management purposes, allowing farmers to cross-check results and thereby ensure better accuracy in their decision-making regarding irrigation scheduling and total water application. It also suggests that small farmers could be supplied with one technology and taught how to extrapolate it for water budgeting purposes.
- The water budget approach developed here is also new and would be useful for irrigation scheme managers to change their water allocations methodology during droughts, in order to minimise crop losses in the catchment.
- The results also shed light on the importance of developing a way to correct remote sensing data for shade nets.

The results of the South African case study were well received by the international partners, who are working on developing crop models and remote sensing products for their countries similar to those already available in South Africa. The reasons behind the non-uptake FruitLook, despite it being a free service, were of particular value to the international researchers.

The results will be presented to the participating farmers, FruitLook and the developer of the soil water probes upon completion of the international deliverables.

**This report should ideally be read together with the final WaterJPI-OPERA report, as much of the work of the South African case study (particularly part A of the report) were purposefully designed to be discussed in relation to the other countries' work.**

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| 3 | Evenor Tech (Evenor), Spain | Evenor |
| 4 | Instituto de Recursos Naturales y Agrobiologia de Sevilla (IRNAS – CSIC), Spain | IRNAS |
| 5 | French National Institute for Agricultural Research (INRA – EMMAH), France | INRA |
| 6 | University of Florence (UNIFI – DISPAA), Italy | UNIFI |
| 7 | Council for Agricultural Research and Economics (CREA) – Research Centre for Policies and Bioeconomy (CREA-PB), Italy | CREA |
| 8 | Institute of Technology and Life Sciences (ITP), Poland | ITP |

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## LIST OF ABBREVIATIONS

| | |
|---|---|
| ARC | Agricultural Research Council |
| DAFF | Department of Agriculture, Forestry and Fisheries |
| DEA | Department of Environmental Affairs |
| ET | Evapotranspiration |
| $ET_0$ | Reference evapotranspiration based on Penman-Monteith |
| $ET_c$ | Crop evapotranspiration |
| FAO | Food and Agriculture Organisation of the United Nations |
| JPI | Joint Programming Initiative |
| Kc | Crop factor as per FAO56 guideline |
| RS | Remote sensing |
| VSD | Variable Speed Drive |
| WARMS | Water use Authorisation and Registration Management System |
| WCDA | Western Cape Department of Agriculture |
| WRC | Water Research Commission |

# 1 INTRODUCTION TO THE OPERA JPI PROJECT

## 1.1 Rationale for South African case study

South Africa is one of the most water-scarce countries in southern Africa, with climate change expected to contribute to even more infrequent rainfall patterns (DEA 2019; DWA, 2013;). Parts of the country are still experiencing the worst drought in over a century. It is estimated that agriculture accounts for approximately 60% of all of South Africa's water use (Bonthuys, 2018; DAFF, 2015; DWA, 2013), with DWA's Water use Authorisation and Registration Management System (WARMS) database for registered water uses putting this figure at 64.8% (CSIR, 2019). Water is considered to be one of the most limiting factors for agricultural expansion (WWF, 2015). Therefore, in order to stay productive, farmers will need to adopt methods or technology to use their water more efficiently.

Extensive research has been done, internationally and locally, to improve on-farm water-use efficiency. Interventions include changes in irrigation types (i.e. micro or drip irrigation vs flood irrigation), pressure control to prevent leaks and optimise application, as well as numerous technologies and crop models to inform irrigation scheduling. Irrigation scheduling – originally defined as "*a planning and decision-making activity that the farm manager or operator of an irrigated farm is involved in before and during most of the growing season for each crop that is grown*" (Jensen, 1981), is considered an important method for improving water-use efficiency, as well as yield quality (Annandale et al., 2011; Fessehazion et al., 2014; Montagu and Stirzaker, 2008; Stevens and Van Heerden, 2013). The Water Research Commission has invested in the development of many irrigation scheduling applications, including: ACRU, BEWAB, MyCaneSim, PUTU, SAPWAT, SWB and Wetting Front Detector (Annandale et al., 2011; Singels et al., 2010; Stevens and Van Heerden, 2013). However, ensuring uptake of these and other technologies have proven more difficult than anticipated (Annandale et al., 2005; Annandale et al., 2011; Botha et al., 2000; Stevens, 2006), similar to international experience (e.g. Montagu and Stirzaker, 2008; Parker, 2005).

In the Western Cape, the Provincial Government has invested a significant amount of money in developing a remote-sensing service for farmers in the province, offering it to them for free in an attempt to improve water efficiency. The service, called FruitLook, was developed in partnership with Dutch firm eLEAF, Hortgro and the Integrated Application Promotion Programme for the European Space Agency. It is an open-access online platform, using satellite and weather information, to monitor vineyards and orchards in terms of crop growth, crop water-use and leaf nitrogen content. The programme uses eLEAF's Pixel Intelligence technology (PiMapping®) which combines meteorological, biophysical and satellite data (WCDA, n.d.). Data components are based on the Surface Energy Balance Algorithm for Land (SEBAL). FruitLook has been online since January 2012 and covers approximately 200 000 hectares of crops.

A FruitLook survey conducted in 2015 attributed a 10-30% water saving to the use of the tool (FruitLook, 2017). An independent study, however found that FruitLook overestimates ET at the start of a season and underestimates it at the end (Myburgh, 2018). Furthermore, although it has been reported that FruitLook is widely used (e.g. Myburgh, 2018), the actual use of this free service by farmers has not been determined, at least not by a third party. All these points require further investigation.

Since a remote sensing service as well as numerous crop models were already available to South African farmers at the start of this project, new technology was not developed as part of this project, as was set out to do by the European partners. Instead, an effort was made to evaluate the usefulness and challenges of FruitLook as remote sensing service, and/or other technologies or models that farmers use. South Africa's evaluation of existing technologies would provide lessons to the European partners who are now developing such products for their local farmers.

The South African study aimed to achieve the following:

i. Better understand farmers' perception of technology and their appetite for risk and trying new technology
ii. Determine the uptake and use of FruitLook as remote sensing service in the study area
iii. Evaluate the usefulness of FruitLook as remote sensing service and/or other technologies or models that farmers use

Aim iii) was further developed based on the results of aims i) and ii), in order to ensure the applicability and usability of results generated in the study. The following two sub-aims were added to aim iii) after conclusion of aims i) and ii):

a. Compare the outputs of technologies used for irrigation, to determine if it would have been beneficial for the farmers to use more than one technology (with a particular focus on FruitLook as remote sensing product)
b. Using the results of aim iii-a), use field-level data to develop a water budgeting approach for the catchment

The purpose of aim iii) was to assess how the outputs from different technologies available to the farmers relate and whether they could be combined into one comparable dataset, which would make it possible for farmers to consider the results together as one management tool to improve irrigation. Table 1 provides a summary of how the South African aims relate to the international project aims.

**Table 1**: Outline of how the South African aims contribute towards the international project aims

| SA aim | Contributes towards international aim: |
|---|---|
| i. Better understand farmers' perception of technology and their appetite for risk and trying new technology | 1) Identify the user demands of farmers, farmer associations, extension services as well as water management organisations |
| ii. Determine the uptake and use of FruitLook as remote sensing service in the study area | 2) Identify the user demands of farmers, farmer associations, extension services as well as water management organisations |
| iii. Evaluate the usefulness of FruitLook as remote sensing service and/or other technologies or models that farmers use | 2) Identify the best possible combinations of information technologies (sensors, models, remote sensing)<br>3) Identify innovative service models to realise a practical transition towards an increased use of precision irrigation in practice. |
| a. Compare the outputs of technologies used for irrigation, to determine if it would have been beneficial for the farmers to use more than one technology (with a particular focus on FruitLook as remote sensing product) | 2) Identify the best possible combinations of information technologies (sensors, models, remote sensing)<br>3) Identify innovative service models to realise a practical transition towards an increased use of precision irrigation in practice. |
| b. Using the results of aim iii-a), use field-level data to develop a water budgeting approach for the catchment | Upscaling project results from field level to regional level for improved regional water management. |

Through these aims, South Africa contributed towards the international work packages 1 (Identifying sector needs to increase resource use efficiency), 3 (Guidance for optimal irrigation water strategies), 4 (Conceptualisation of practical service models) and 5 (Dissemination) – see information box starting on page 5 for details on the international project aims and work packages.

The study area was chosen as the Central Breede River Valley in the Western Cape, between Worcester, Robertson, Ashton and Bonnievale (see Figure 2). The reason for choosing this area is because farmers in this region have had a lot of exposure to technological developments through the ARC experimental farm situated in the area, as well as numerous WRC-funded studies on irrigation and salinity management that have been conducted there over decades. There are also a number of weather stations in the area, and FruitLook was activated for the area in 2015 already.

The report is divided into two parts, namely Part A, which deals with the analysis of farmers' uptake of technology (aims i and ii), and Part B, which is the technical comparison of data from the different technologies that farmers use (aims iii-a and iii-b). This will be followed by an overall conclusion.

First, the purpose of the report will be clarified in section 1.2, followed by an information box to provide the background and context to the international work (the text of this information box was written by the international consortium, not by the South African project team).

## 1.2 Purpose of report

Stellenbosch University partnered with seven European partners in a Water-JPI (Joint Programming Initiatives) project entitled "Operationalising the increase of water-use efficiency and resilience in irrigation" (OPERA). The Water-JPI is an initiative of the European Union, launched in 2011. There are 23 member countries, with South Africa, Israel and Turkey the only non-European partners (WaterJPI, 2019a). The JPI facilitates inter-governmental collaborations to address the global challenge of water availability. In these international collaborations, each national funding organisation funds their country's research in the projects (WaterJPI, 2019a).

The international JPI OPERA project is scheduled for completion in **December 2019**. This report contains results on the **South African case study only**, since the international results are still being processed and are therefore not available to be presented yet. **This report should ideally be read in conjunction with the final international JPI project report, as much of the research (particularly regarding technology uptake) were specifically done to be discussed as a whole with the other countries' results.**

***Information box***

### International project background

***Introduction***

Extreme climatic events have negatively affected crop productivity during the first decade of the 21st century in Europe and this is expected to further increase yield variability under climate change (EEA, 2014). Information is needed on when and where water shortage is to be expected and if there are alternative market opportunities for drought tolerant crops. Sustainable agricultural water management requires the best fitting of water supply to the actual demand in a more flexible way. Precision irrigation must be realised both at field scale, but also at the territory scale. Actual water demand is not only dependent of the growth stage of the plant, but also on the remaining soil water availability.

Recent decades provided massive developments in remote sensing products, soil water sensors, plant-based sensors, and models to analyse soil water dynamics and crop growth. For individual products operational services have been also established in the market. However, there is a significant gap in applying the necessary combination of such techniques in order to predict the upcoming water demands within a region. In contrary to technological driven research projects, OPERA set out to apply a transdisciplinary approach (Scholz et al., 2015) to identify jointly:

1) The user demands of farmers, farmer associations, extension services as well as water management organisations,
2) Best possible combinations of information technologies (sensors, models, remote sensing), and
3) Innovative service models to realise a practical transition towards an increased use of precision irrigation in practice.

***State-of-the-art and relation to the work programme***

Worldwide significant progress has been made to utilise precision irrigation as a mean to increase water use efficiency or decrease the water footprint in irrigated agriculture. The progress is mainly restricted to advances at the plot scale and individual systems such as installations for drip irrigation or central pivots. Specifically, closed systems (greenhouses) reached a very high level of maximising water use efficiency. Overall this progress is restricted to application at field scale. Integrating precision irrigation in the planning of water resource use at territory scale is still a challenge. Point information, such as resulting from sensors, is difficult to be transferred to a larger spatial unit. Remote sensing algorithms to estimate evapotranspiration are available but often not at sufficient resolution to obtain operational data at field scale.

New market opportunities may allow farmers to shift more flexible to alternative water saving crops. More experience needs to be gained in combining these technologies and scales so that they can serve the practical adaptation of water consumption: direct mapping of soil water as done with in-situ observations, air- or space-borne radar, crop water stress mapping by thermal infrared sensors and/or modelling of the crop/soil/atmosphere continuum. When adequately fused with terrestrial measurements these mapping tools offer decision support for agricultural water management. Up to now the advance is often restricted to academic and experimental data collection and solutions are mostly supply driven.

***Originality and innovative aspects of the research (ambition)***

Currently decisions in irrigation are based on experience, current status of the crop and sometimes soil water content and perhaps a farmer's interpretation of the weather forecast as presented in the media. Current remote sensing products are used to monitor the crop growth status and the evapotranspiration. Opportunities to use remote sensing products in order to verify continuously field scale prediction and the quality of modelling in response to practical user demands is less exploited so far. Overall the strive of OPERA was to elaborate a practical concept that can support future service providers in delivering more robust decision-making support, particularly under the anticipation of climate variability and critical moments of water scarcity. On a larger scale, this information can be used to support drought management decisions.

The main ambition of the OPERA research group was to demonstrate how a combined use of mechanistic models (soil + crop) of crop response to water stress, meteorological data (short and long term predictions), soil and crop sensors (at local scale), and remote sensing data (at larger scale) can be realised to better determine crop water needs, and to transfer research results into an operational practice for irrigation scheduling. Both (i) the application of a full transdisciplinary process and (ii) the mature processing of high-resolution Sentinel information are a real breakthrough, which is expected to contribute to innovative services in irrigation.

***Clarity and quality of transfer of knowledge for the development of the consortium partners in light of the proposal objectives***

Historically, irrigation has been practised mainly in southern Europe. In light of predicted climate change more drought spells may occur in other parts of Europe, e.g. the more northern countries. Current knowledge in the South can thus be transferred to other parts through project initiatives like OPERA. Making use of newly available information, such as weather forecast and sensor information (soil and crop sensors, remote sensing), irrigation can be further fine-tuned to spatial and temporal demands. Currently this information is locally available at the partners' organisations, and through the OPERA initiative, this can be further shared among the partners. Although experiences exist in the linking of meteorological data, remote sensing and crop models to assess vegetation production and water need, improvement is foreseen, for example, by incorporating improved information from the new Sentinel 1 and 2 satellites. Sentinel images can help to detect irrigation failure and to evaluate plant development and possible water stress feedback.

Vulnerability to climate change is a key aspect in all case studies and transfer of knowledge and data among partners will be important to develop adaptation plans to ensure resilience of irrigated agriculture areas under climate change.

OPERA brought together research units from different countries with complementing contributions and disciplines, such as specialists in crop modelling, in soil water modelling, and in remote sensing. Despite the fact that each case study had its own focus, interchange of information and knowledge led to better understanding the situation in the case studies. The diversity of partners and case studies contributed to the development of a shared understanding and a new mind-set regarding water management problems and solutions among the different stakeholders. The diversity of problems and contexts in the different study areas showed the impossibility of thinking in terms of 'one size fits all' approaches to the use of smart and precision technologies for irrigation management in agricultural areas.

***Research methodology and approach***

OPERA built upon complementary experience across Europe and South Africa advancing sensors, remote sensing and crop growth modelling to evaluate the soil and crop water status to support irrigation planning. This was done for short-term situations (e.g. based on weather forecasts), as well as for the effects of climate change. A combination of soil and crop models, soil and crop sensors and high-resolution remote sensing (RS) imagery were implemented in different test sites. The project will finish with guidelines on the most adequate combination of sensors, RS, weather forecast and simulation models that allow the better consideration of rainfall, evapotranspiration and soil water in irrigation scheduling. The approach involves the following three transversal research lines which will be tested in six study sites and communicated with local stakeholders (Figure 1).

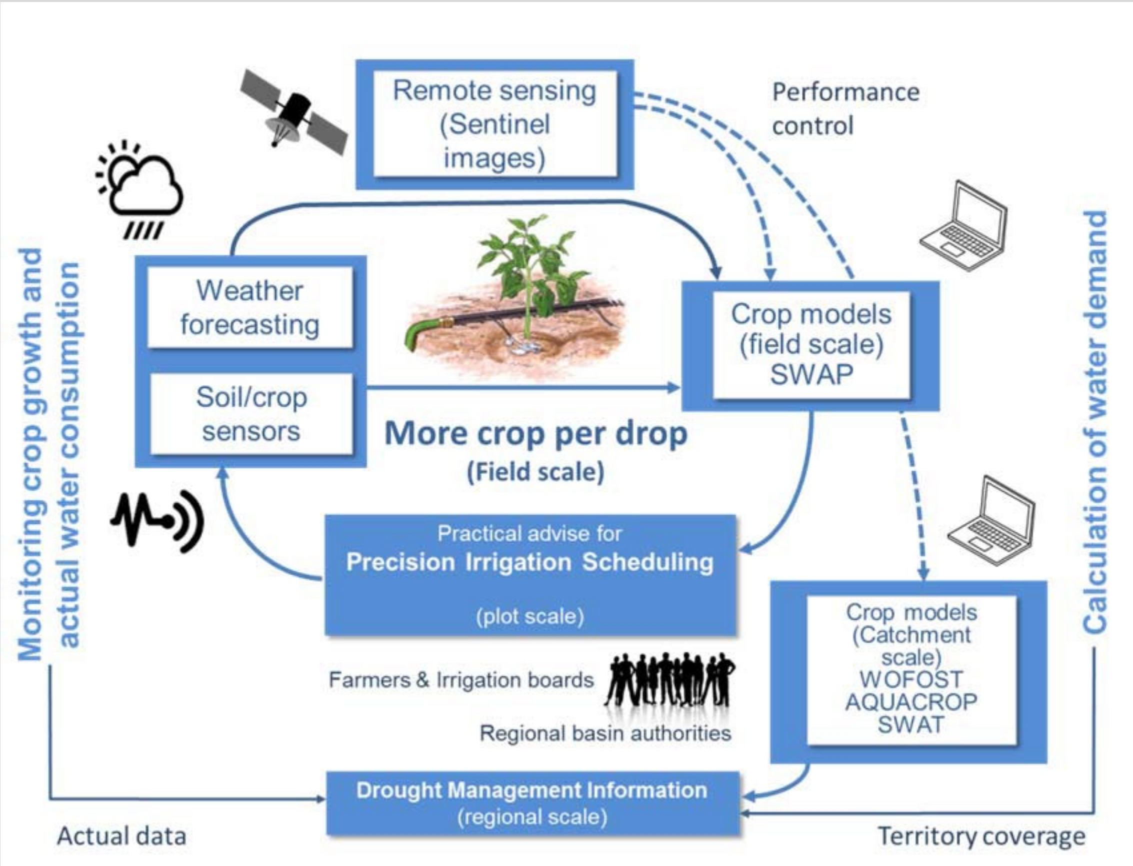


**Figure 1**: Linking weather, remote sensing, in-situ crop and soil sensors, crop and soil models, and stakeholders to synthesise case study results in a concept for an operational support of precision irrigation at field scale and water saving at catchment scale

*a) The use of RS data at high spatial and temporal resolution for water demand (case studies Italy, France, Spain)*

Focus was on the use of high-resolution Sentinel 1 and 2 and Landsat 8 remote sensing data to monitor evapotranspiration and vegetation status, and to determine crop water stress. This information was then used, in combination with climate and soil-crop models, to optimise irrigation practice: 1) Indicator on irrigation efficiency to detect non-efficient irrigation system and give feedback on water reduction strategies and thus revise them. 2) Mapping irrigation water needs at various spatial scales (field, irrigation sector, irrigation area, river basin) and temporal term (multi years to size infrastructure and define general sharing rule using future climatic scenarios, real time monitoring to manage the water distribution between users according to the water availability.

*b) Improving soil water content knowledge using in situ sensor and upscaling (case studies Poland, Netherlands, Spain)*

The focus was on a telemetric system of weather, soil water and crop growth monitoring at field scale and the upscaling to the regional scale. Local soil water content and plant-based sensors were used together with regular measurements of physiological variables to determine details of the soil water status. The sensors were used to calibrate the crop simulation models (e.g. the Soil, Water, Atmosphere and Plant model SWAP). Special attention was paid to the upscaling of point/field information to the regional scale, using mathematical modelling complemented (occasionally, in special drought events, supported) with RS. The aim was to identify ways for upscaling allowing a better management of water scarcity and drought.

*c) Ensemble weather forecast and decision making under water uncertainties with farmers (case studies Netherlands, Poland, Spain, France, South Africa)*

The focus was on the possibility to use weather forecast ensembles (e.g. ECMWF or MeteoGroup) in order to predict the temporal dynamics in the root zone water content up to 15 days ahead. This information could then be used by the farmer to better adapt irrigation planning, to anticipate climate variability and critical moments of water scarcity in practice. A concept was defined on how to make info available to the farming community for decision making. The flexibility of stakeholders to adapt (alternative crops) was also considered for guiding precision irrigation in such a way that these crops can actually be grown. Increased awareness of water use through water demand prediction was be raised through co-learning in the OPERA programme. The insights from the case studies will be used to integrate experience from various climatic zones in Europe and South Africa.

The OPERA project is scheduled for completion in December 2019. Table 1 on the next page provides a summary of the work packages and activities in the consortium.

Table 2 provides a summary of the work packages.

<table>
<tr><td colspan="5">Table 2: Outline of work packages of international project</td></tr>
<tr><th>Work package title</th><th>WP lead</th><th>Duration (months)</th><th>Starting month</th><th>End month</th></tr>
<tr><td>WP1: Identifying sector needs to increase resource use efficiency</td><td>Evenor/CSIC, Spain</td><td>30</td><td>1</td><td>30</td></tr>
<tr><td colspan="5">WP1 is dedicated to the involvement of stakeholders, both in the case studies and at national/ European level. Stakeholder involvement will play a key role to identify market-driven needs and to increase water-use efficiency. The WP1 will work closely together with other WPs: With WP2, stakeholders will be closely involved in the evaluation of the (innovative) management strategies; With WP3, stakeholders will actively participate in the monitoring and demonstration activities at the sites, and with WP4, stakeholders will be involved in defining and fine-tuning OPERA’s services to the irrigation sector.<br><br>Description of tasks<br>1.1 Stakeholder and institutional analysis (needs assessment). Identify key stakeholders for involvement. Assess how farmers and irrigation organisations can react more flexible in crop selection and production for markets in each case.<br>1.2 Establishment of a stakeholder platform. Partners will be responsible for setting up stakeholder platforms for communication throughout the project in their respective national languages.<br>1.3 Organisation of stakeholder workshops relating to other WPs.<br><br>Deliverables (D) and milestones (M)<br>D1.1 Report: Assessment of user requirements of the sector (month 8)<br>D1.2 Report: Outcome of the two stakeholder workshops (month 30)<br>M1.1 Establishment of a stakeholder platform (month 6)<br>M1.2 Stakeholder workshops 1st round – with WP4 (month 6)<br>M1.3 Stakeholder workshops 2nd round – with WP4 (month 24)</td></tr>
<tr><td>WP2: Forecasting water availability and critical water demand</td><td>INRA, France</td><td>30</td><td>1</td><td>30</td></tr>
<tr><td colspan="5">Objectives of WP2 are to develop innovative methods to assess water availability, irrigation needs and the impact of water stress on production. Methods must be suitable for water management and implementable in operational context. Innovation will take profit of technical progresses as provided by the Sentinel satellite mission, progress in low cost sensors, weather forecast and data assimilation in crop models.<br><br>Description of tasks<br>2.1 Establishment of a common reference framework to translate user requirements in terms of method functionalities (with WP1 and WP3), to define implementation conditions (with WP3 and WP4) and provide a common evaluation procedure to be used for the demonstration in the different case study areas.</td></tr>
</table>

2.2 Integration of different sources of information and models. Methods will integrate different sources of information and models
2.3 Coupling RS data and models. Use of HRST satellite images (Sentinel and LC8) and Landsat 8 with crop model (data assimilation, model input, model calibration) to provide spatialised soil water content, plant requirements and assess the quality of irrigation implementation.
2.4 Use of in-situ sensors to monitor vegetation status and development of upscaling strategies to account for heterogeneities at the field and the farm scale using models and remote sensing.
2.5 Implementation of ensemble weather forecast in crop models and errors assessments.
2.6 Development of portfolio of methods which present, in a harmonised way, the target, their rationale, the data requirements and the evaluation on use case. A special emphasis will be devoted to error assessment which will be a key characteristic to be considered in irrigation strategies (WP3) and service design (WP4).

*Deliverables and milestones*

D2.1 Reference framework (Report) defining requirements, implementation condition and evaluation procedure (month 9)
D2.2. Portfolio of methods (report, website) (month 30)
M2.1 Reference framework shared with all case study sites (month 10)
M1.2 Stakeholder feedback on method concept – with WP1 (month 6)
M1.2 Stakeholder feedback on the results – with WP1 (month 24)

| | | | | |
|---|---|---|---|---|
| **WP3: Guidance for optimal irrigation water strategies** | **ITP, Poland** | **18** | **12** | **30** |

Objective of the WP is to synthesise results and testing of practical guidance in the field as proof-of-principle (case studies). Testing will be carried out during two growing seasons in several case studies.

*Description of tasks*

3.1 Installation of soil and crop sensors for monitoring of actual conditions. In-situ soil water monitoring will be complemented in some cases with remote sensing observations. Activities in this task will be in cooperation with WP2.
3.2 Field operational works (cooperation between farmers and researchers).
3.3 Collection (in real time as often as possible) of results from all case studies and elaboration of results.
3.4 Verification of the system for optimal irrigation scheduling based on results from the case studies. Activities in this task will be in cooperation with WP2 and linked to activities of WP4.
3.5 Elaboration of practical guidance for optimal irrigation strategies.

*Deliverables and milestones*

D3.1 Results of field measurements, weather forecast and simulation models that allow elaborating more precise irrigation scheduling based on actual conditions (month 24).

| | | | | |
|---|---|---|---|---|
| D3.2 Draft version of practical guidance for optimal irrigation strategies for farmers, farmer associations, local policy makers (month 26).<br>D3.3 Final version of practical guidance (month 28).<br>M3.1 Installation and launching of a measurement system in all case studies (month 4).<br>M3.2 Practical guidance document discussed with stakeholders (month 27). | | | | |
| **WP4: Conceptualisation of practical service models** | **CREA, Italy** | **12** | **18** | **30** |
| This WP aims to investigating the roles, institutions and potential markets for operationalising services to the irrigation sector capable of providing benefits to the user community.<br>*Description of tasks*<br>4.1 Framework for socio-economic assessment and business development. This includes the definition of an overall methodology for socio-economic assessment of irrigation schemes applicable to different contexts/situations.<br>4.2 Business models. Elaboration of a business model by identifying business roles of the system, defining the relationships and building the overall business model framework to establish operative and self-supportive downstream service activities with the user community of irrigation water management.<br>4.3 Assessment of willingness to pay. Analysis of the importance of technological innovation in the agricultural water management, use of choice experiment (CE) for preferences of the farmers, and the analysis of marginal willingness to pay for the service.<br>4.4 Socio-economic assessment of service scenarios. It includes cost-benefit analysis for a range of users, economic valuation and an assessment of socio-economic impacts.<br>*Deliverables and milestones*<br>D4.1 Report on socio-economic assessment (month 26)<br>D4.2 Report on feasible service models for the irrigation sector (month 29)<br>M4.1 Framework for business development and portfolio of business models established (month 24) | | | | |
| **WP5: Project management and dissemination** | **Alterra, Netherlands** | **30** | **1** | **30** |
| This work package involves project management, the organisation of transdisciplinary approach, co-learning and evaluation during the project period. The general objective of this work package is to coordinate and administer the project smoothly and to disseminate the project results to a wider audience.<br>*Description of tasks*<br>5.1 Project management<br>5.2 Project meetings (physical attendance all partners). Three all-partner progress meetings will be organised: Kick off meeting in Wageningen, The Netherlands; Mid-term progress meeting (at one of the test sites) and final project meeting to present final results and dissemination materials (at one | | | | |

of the test sites). In addition, monthly skype/WebEx will be organised with the WP leads to discuss progress. The 3 meetings organised by the Water JPI will be attended.

5.3 Dissemination activities. Preparation of factsheets, presentation of results at conferences, events, press releases.

5.4 Consortium Agreement and progress reports

*Deliverables and milestones*

D5.1 Inception report (month 3)

D5.2 Consortium Agreement signed by all partners (month 4)

D5.3 Midterm Progress report (month 16)

D5.4 Final progress report (month 30)

D5.5 OPERA scientific booklet and peer-reviewed paper(s) (month 30)

M5.1 Kick off meeting (month 2)

M5.2 Midterm meeting (month 16)

M5.3 Final dissemination meeting (month 30)

# 2 PART A: TECHNOLOGY UPTAKE

## 2.1 Introduction

It is estimated that the prolonged drought in the Western Cape between 2015 and 2018 cost agriculture in the province R5,9 billion, an estimated 300 000 jobs were lost, and exports dropped by up to 20% (WWF, 2018). Such conditions are forcing farmers to adapt in order to remain profitable or grow their businesses. Numerous technologies have been developed locally and internationally to support water-use efficiency, but the uptake thereof remains limited (Annandale et al., 2011). In 2006, a survey revealed that approximately only 18% of farmers in South Africa used technology to inform their irrigation scheduling, with the rest relying solely on intuition and experience (Stevens, 2006). Twelve years later it can be assumed that uptake would be higher, especially in the Western Cape after the droughts in 2004-2006 and 2017 until now (Koopman and De Buys, 2017).

Numerous studies have been done on technology uptake in agriculture, many with contradictory results. Characteristics of farmers commonly mentioned as drivers behind uptake are farm size, level of education, economy (income and access to market) and technical skills (e.g. Aubert et al., 2012; Parvan, 2011; Pierpaoli et al., 2013). Aspects of tools that make it more successful include ease of use and usefulness (e.g. Aubert et al., 2012; Parker, 2005), but the characteristics of the farmers again influence their perceived ease of use and usefulness (Aubert et al., 2013).

Various questions related to crops, markets and willingness to change were asked in order to investigate possible drivers behind technology uptake (or the lack thereof). **Many of these questions were meant for the analyses in combination with the other countries' results in work packages 1 and 4, led by the Italian and Spanish partners as work package leaders. All answers were provided, but only the results deemed most relevant to South Africa are discussed in more detail in this report, as at this moment the analyses by the work packages leaders are still under way.**

## 2.2 Methods

Two questionnaires were prepared by work package leaders (international partners to the project). Each country had to customise the questionnaires for local conditions and conduct a workshop during which the questionnaires can be completed. A decision was made to hold individual interviews with stakeholders, rather than a workshop, for the South African case study. The reasons for this decision include:

1) From previous experience the researchers know that workshops are generally poorly attended by farmers. They have too many other commitments and do not like this type of environment. Getting them all in one room at the same time is also difficult, given different harvesting times of their crops.

2) Similarly, we have found that in such workshops, one or two people would dominate discussions (even in small groups), while the opinions of the majority of attendees are not documented.

3) The researchers wanted to use the interviews for both completion of the questionnaires, as well as information gathering for the other work packages for which much more detail is required. It made sense to gather all the necessary information from each farmer during one meeting, rather than to meet them at a workshop and see them again later to collect more information.

4) Such an approach allowed the researcher to build relationships with each of the stakeholders interviewed, which is useful should further information be required from them throughout the project.

## 2.3 Results

The customised questionnaire used for the South African interviews is presented in Appendix 1. Interviews were conducted between 15 May and 1 August 2018. Chain referral (snowball) sampling was used as sampling technique (Biernacki and Waldorf, 1981). The first two farmers interviewed were known to the researchers and were used to test the questionnaire and make necessary adaptations (only minor adaptations were needed). These two farmers were asked for names and contact details of more farmers to interview. Each farmer interviewed was asked for references. By around the 20$^{th}$ interview, the names provided by the farmers were either already on the contact list, or they were already interviewed. The researchers collected 44 names, of which 33 persons agreed to be interviewed.

A total of four agricultural advisors (two viticulturists of cellars, one consultant viticulturist and one consultant soil scientist) and 29 farmers were interviewed. All interviewees work in the Breede River Valley around the town of Robertson, stretching towards Worcester, Ashton, Bonnievale and McGregor (see Figure 2). Traditional sample size calculations using a percentage of the total population could not be done, because the number of farmers and farm managers are not known – only the total population size for the area, which includes farmers and all other residents. In addition, many of the farmers own more than one farm, therefore the number of farms as an estimate of the number of farmers would also not be accurate. It was therefore decided to aim for 20% of the total cultivated area as sample size, instead of a population size. According to a 2017 crop census by the Western Cape Department of Agriculture (WCDA, 2017), approximately 23 000 hectares of crops are planted in the study area. Interviewed farmers' land represents 17 566 ha (4 864 ha under production). This represents 21% of the total planted area and was deemed to be a satisfactory sample size. When including the land of the farmers that the viticulturists advise, 25 966 ha (8 864 ha under production), representing 50% of planted land.

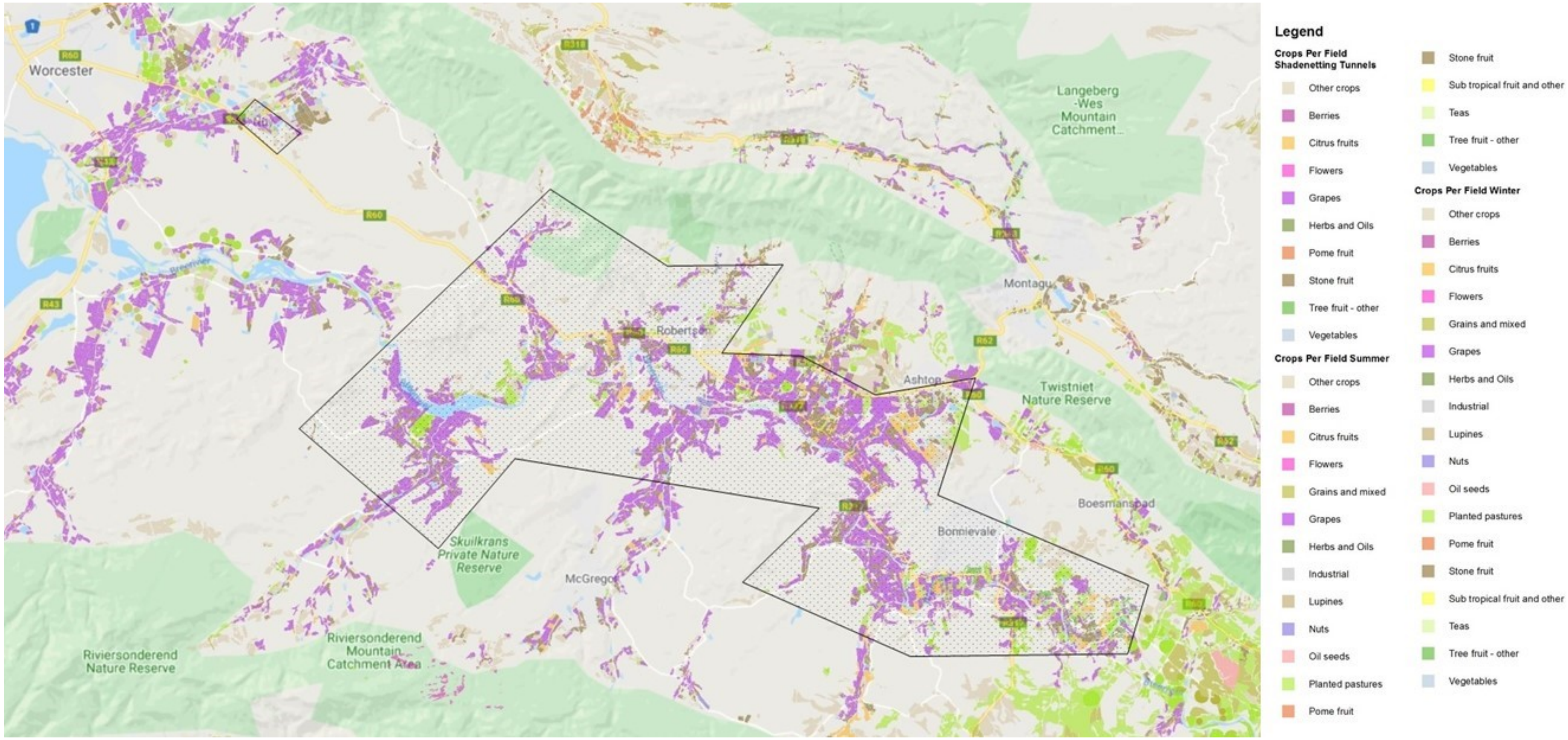


**Figure 2**: All farms visited lie within the shaded area (Map adapted from Cape Farm Mapper®).

**It is important to note that although 33 people were interviewed, not all of them answered all the questions, therefore the number of responses in the questions differ throughout the reporting of the results.** The questions regarding risk were, for example, not applicable for a farm manager who is only responsible for viticulture. Questions regarding what persons would like to see in advice tools were not relevant/answerable for those who are not interested in such technology at all. How to become more water efficient was also difficult to answer for some, seeing as the farmers have become incredibly efficient over the past two seasons and they couldn't envision what more they could have done/could do. More explanations are provided in the relevant sections.

### 2.3.1 Overview of interviewees and farms

*Age*

Ages of persons interviewed ranged between 26 and 79 years. In total, 24 of the 33 people interviewed were aged between 30 and 49 years (Figure 3). Some of the younger farmers have recently taken over from their fathers or are in the process of doing so. All interviewees were male, apart from one soil scientist agricultural consultant.

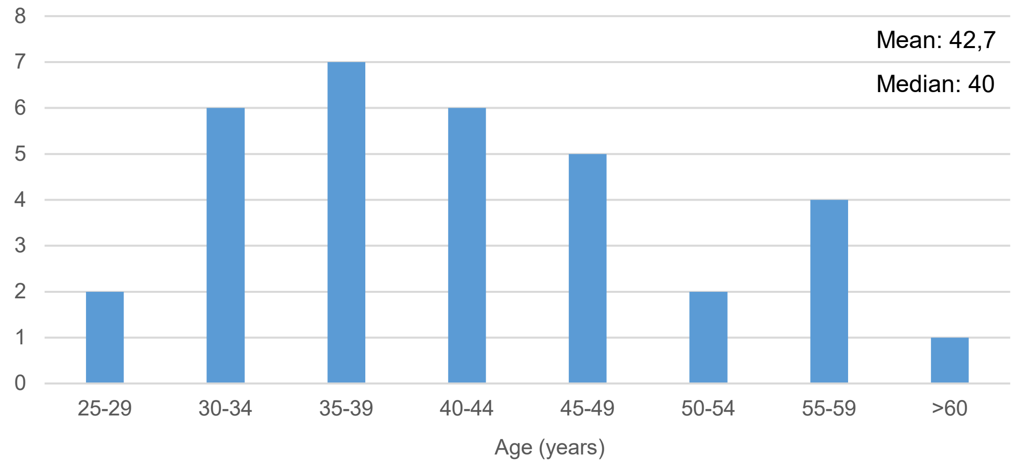


**Figure 3**: Age of persons interviewed (n=33)

*Position on farm*

Most of the interviewees (24) were the owners or co-owners who also farm themselves. Three were farm managers (with different levels of responsibility), two were viticulturists for cooperative cellars and two were consultants (Figure 4).

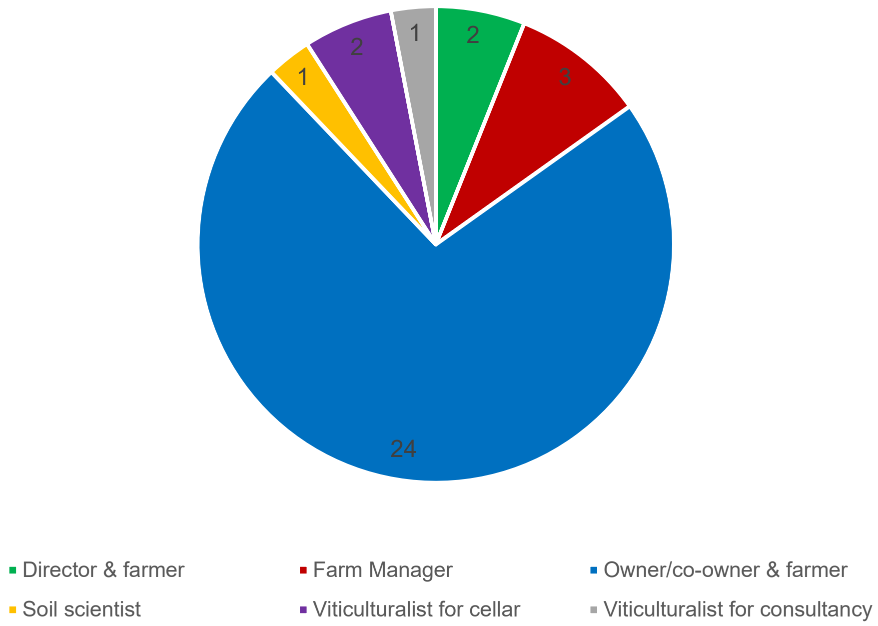


**Figure 4**: Position of interviewees on farm (n=29)

*Farm size*

Farms (excluding the cooperative cellars) ranged in size between 96 ha and 3500 ha (median 350 ha, average 605 ha), while area under production ranged from 32 ha to 700 ha (median 140 ha, average 160 ha).

### 2.3.2 Market analysis and competitiveness

The questionnaire (Appendix A) contained questions to determine the market of the farmers, and also what they believe they could do to increase their competitiveness in the market.

Farmers were asked which percentage of their produce goes to wholesalers, retailers, food processing industry, e-commerce, food exchange or other – as per the international questionnaire. Table 2 shows the results.

**Table 3**: The market share for grapes, fruit and vegetables produced by the farmers interviewed

| **GRAPES/JUICE** | | **FRUIT** | | **VEGETABLES** |
|---|---|---|---|---|
| Bulk, local cellar | 77,9% | Export | 70,3% | 100% local market |
| Own label* | 21,8% | Preserves | 28,2% | |
| Local market | 0,3% | Local market | 1,5% | |

**Not all farmers were sure of percentages of export vs local market for own labels, so it was grouped as one.*

The next question was regarding which actions the farmers see as important to increase their competitiveness in the market (*According to your experience, which actions could be important to increase the competitiveness of your farm into the market?).* Interviewees were asked to score 9 questions on a scale from 1 to 7 (7 being strongly agree). Figure 5 shows the mean for each category and the range of answers to each category.

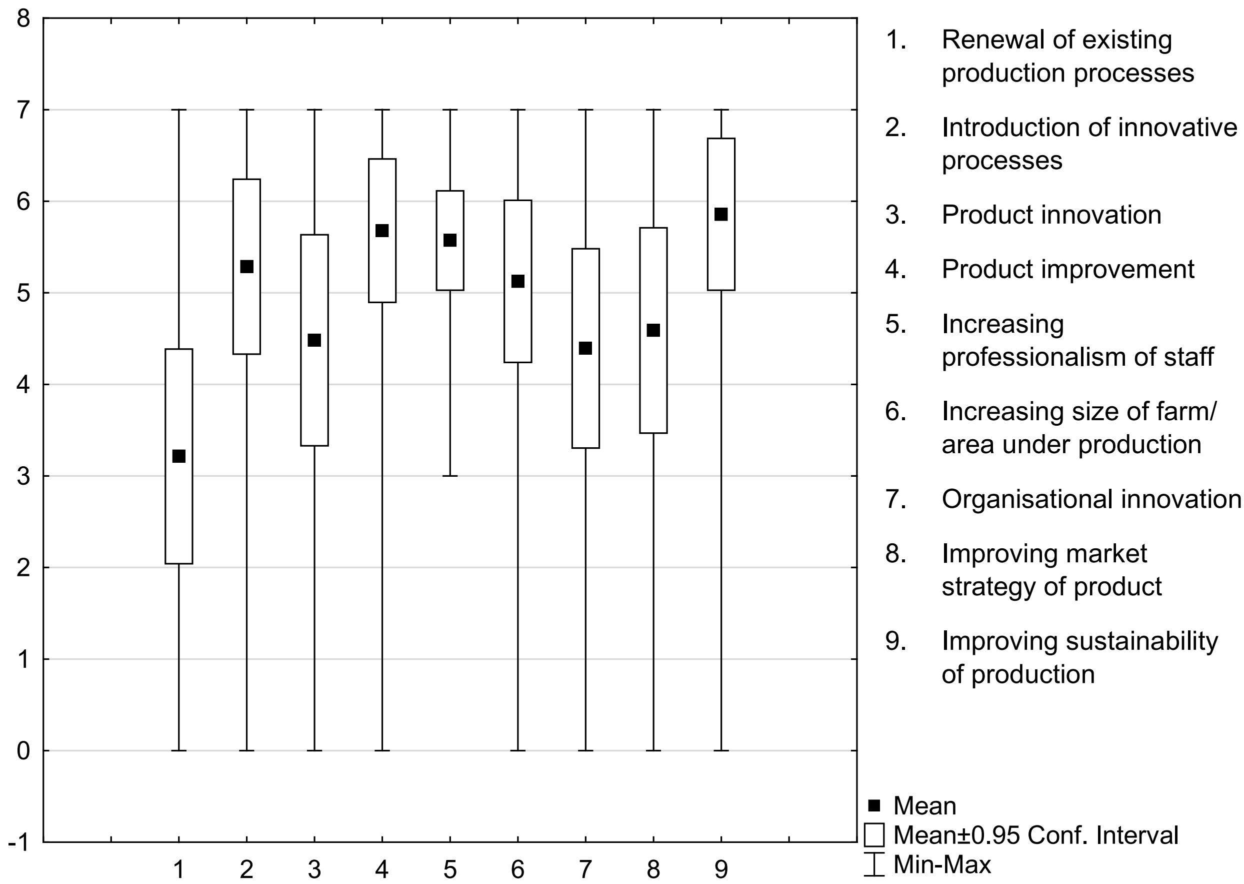


**Figure 5**: Preferred ways to improve market competitiveness (n=27)

The results showed that innovative processes, product improvement, training and sustainability were most important to the interviewees to increase their competitiveness. However, answers to all questions, ranged from 0 (not applicable) to 7, which shows that all categories were somewhat relevant to the farmers. It was clear at the end of the interviews that cellars and those farmers with their own production facilities (pack houses, cellars), had different opinions in what could increase their competitiveness, than those farmers who sell their products in bulk to cellars or exporters. The following two graphs (Figures 6 and 7) show the results for these two groups separately.

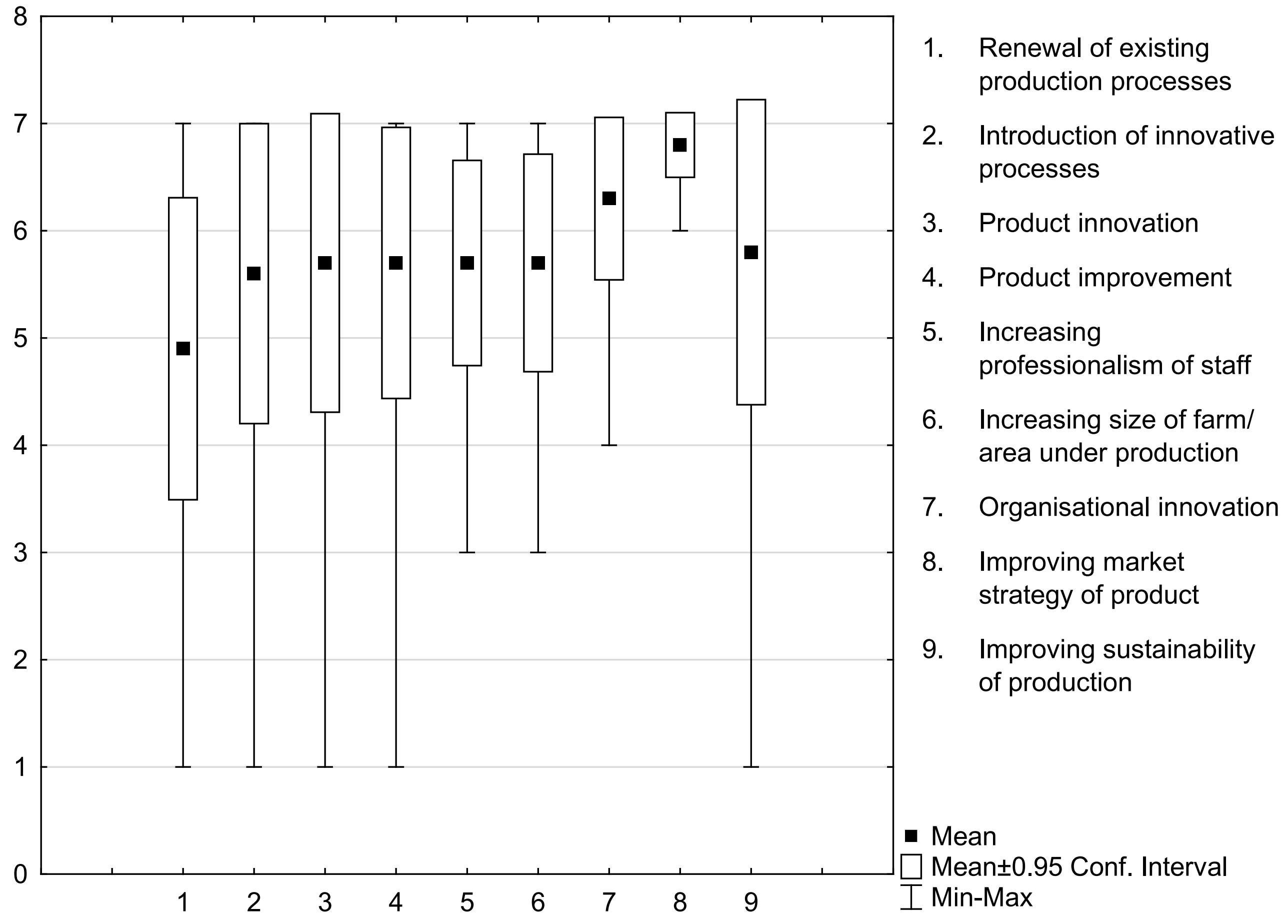


**Figure 6**: Private producers' preferences to improve competitiveness (n=27)

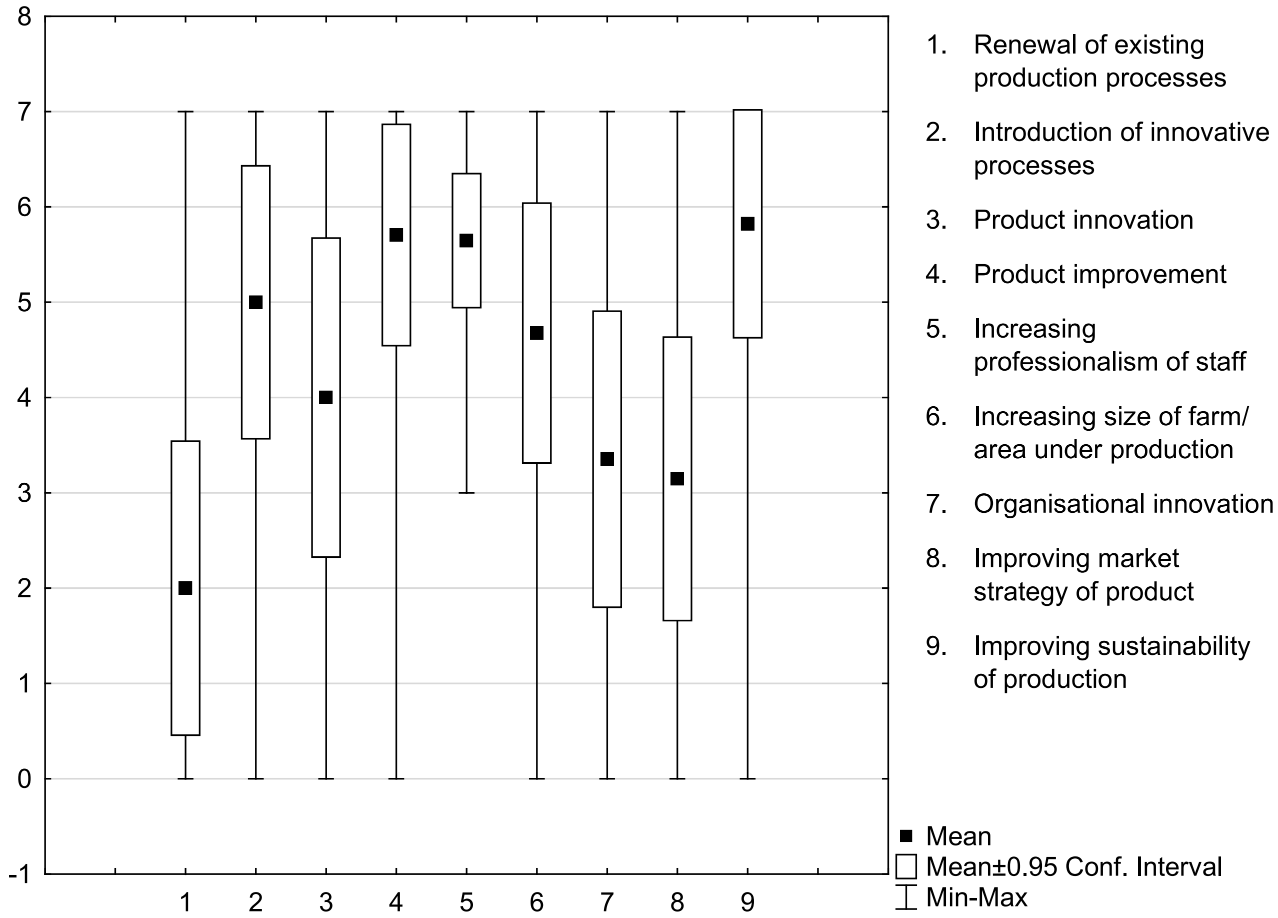


**Figure 7**: Bulk suppliers' preference to improve competitiveness (n=27)

This separate analyses showed that priorities for increasing competitiveness differ between those farms with own cellars or brands (labels, Figure 6), and the farms selling their produce in bulk (no production facilities, Figure 7). This is further illustrated in Table 4. The researchers were of the opinion that the separate analysis, present a more accurate result. For the farms with own labels, expanding their farms/area under production, organisational innovation and marketing, were the three most important factors. Innovation and sustainability were also important to these farmers. For the bulk suppliers, product improvement, training for their staff and sustainability, were the three most important factors. Table 5 summarises some key comments made by interviewees with regards to the nine categories.

**Table 4**: Comparison of mean values for Figures 5-7

| | Overall | Own cellar/ label | Bulk suppliers |
|---|---|---|---|
| Renewal of existing production processes | 3,5 | 4,9 | 2,1 |
| Introduction of innovative processes | 5,3 | 5,6 | 4,9 |
| Product innovation | 4,8 | 5,7 | 3,9 |
| Product improvement | 5,7 | 5,7 | 5,8 |
| Increasing professionalism of staff | 5,7 | 5,7 | 5,6 |
| Increasing size of farm/area under production | 5,2 | 5,7 | 4,7 |
| Organisational innovation | 4,8 | 6,3 | 3,3 |
| Improving marketing strategy of product | 4,9 | 6,8 | 2,9 |
| Improving the sustainability of production | 5,8 | 5,8 | 5,8 |

**Table 5**: Comments of interviewees regarding preferred methods to improve competitiveness

| | |
|---|---|
| Renewal of existing production processes | Those farmers with cellars and pack houses regarded this as important. It was emphasised that keeping machinery in the cellar has a big impact on the amount of juice that can be extracted from the grapes; pack houses give farmers a competitive advantage over those who have to sell everything to cooperative pack houses; and many said that continuous upgrading is essential to stay ahead in the market. |
| Introduction of innovative processes | Farmers described their efforts to constantly try to improve irrigation, fertiliser and equipment to farm optimally. The point was also raised this is expensive and not affordable/profitable for all farms. |
| Product innovation | Farmers are looking at new clones and cultivars to improve production. |
| Product improvement | Most farmers agreed that it is important to always try to improve the product they deliver to the market and they are continuously looking at ways to achieve this. |
| Increasing professionalism of staff | All farmers offer training to their farm workers and believe that this is important. Training is also required by industry standards (e.g. Wieta, Siza). However, some raised the point that the application of what they learned is often lacking. |
| Increasing size of farm/area under production | Most farmers mentioned that economy of scale is important and that they would like to expand, but that water is the limiting factor. It was also mentioned that there's a "tipping point" at which it makes more financial sense to farm more intensively than to acquire more land. |
| Organisational innovation | Farmers who ranked this high mentioned the need to "think outside the box" and "try new things" in order to move forward. |
| Improving marketing strategy of product | This was very important to all farmers with their own cellars or labels, and not at all important to the bulk suppliers who depend on exporters for marketing (they have no control over it). |
| Improving the sustainability of production | Most farmers rated sustainability very high, particularly ensuring the soils stay healthy. |

### 2.3.3 Crop preference and climate change

Farmers were asked why they grow the fruit crops that they currently have on their farms. Vineyards, apricots and peaches are traditional to this area, although wine grapes are the most predominant crop (Figure 8). Over the past few years there appears to have been significant diversification in the area, the main reasons being a good international market (favourable exchange rate for export), as well as stretching the season – and thereby labour use, water use, and importantly the cash flow for the farmers. Citrus (lemons, naartjies, clementines) is particularly popular, with most farms now having at least a small amount (e.g. around 5 ha) of citrus. Other crops include blueberries, pomegranates and prunes.

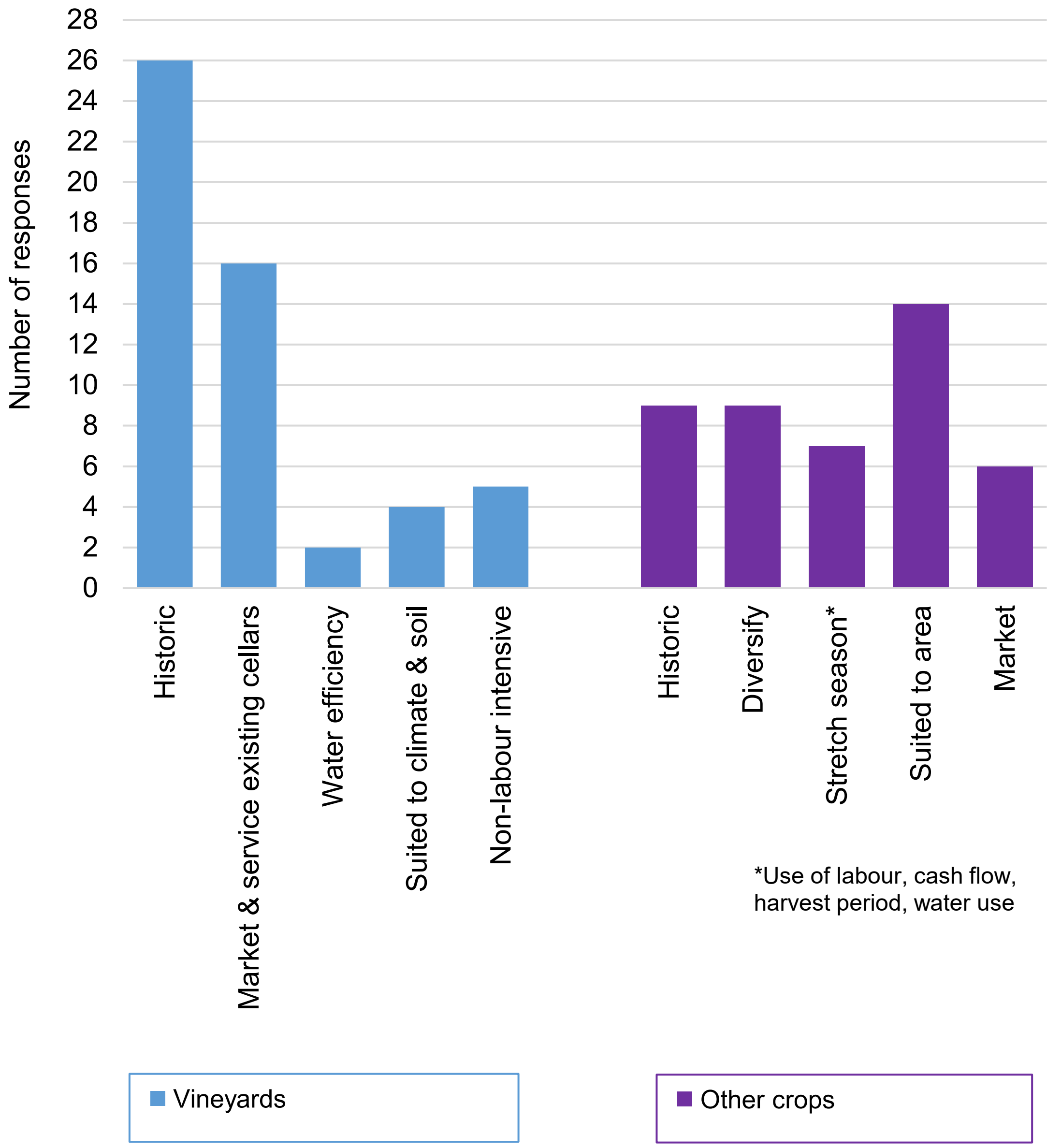


**Figure 8**: Farmers' and consultants' reasons for farming with their current crops (n=33)

When asked how likely they were to consider changing crops based on climate change predictions, farmers overwhelmingly answered that they were unlikely to switch (Figure 9). The reasons for this will be become clear in the analyses of the next two follow-up questions.

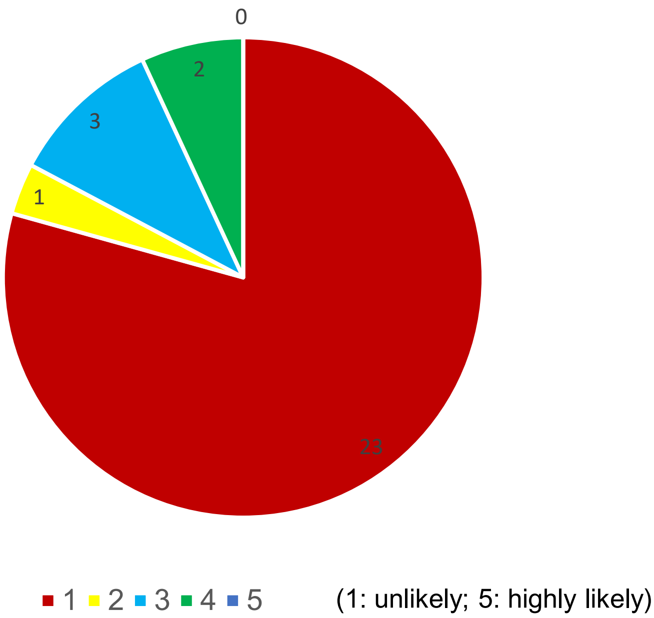


**Figure 9**: Farmers' and consultants' likelihood for changing crops based on climate change predictions (n=33)

*Q1: What factors would influence you and convince you to switch to crops more suited to the area's climate?*

Most farmers considered vineyards to be the best suited crop for the area, being the most water-efficient (Figure 10). Water availability was seen by most in light of the other crops that need more water (fruit), not vineyards. Climate change did not play a big role in farmers' decisions about the crops they planted and will plant in the foreseeable future – they planted according to market needs and will rather try new cultivars and clones of wine grapes than to switch crops.

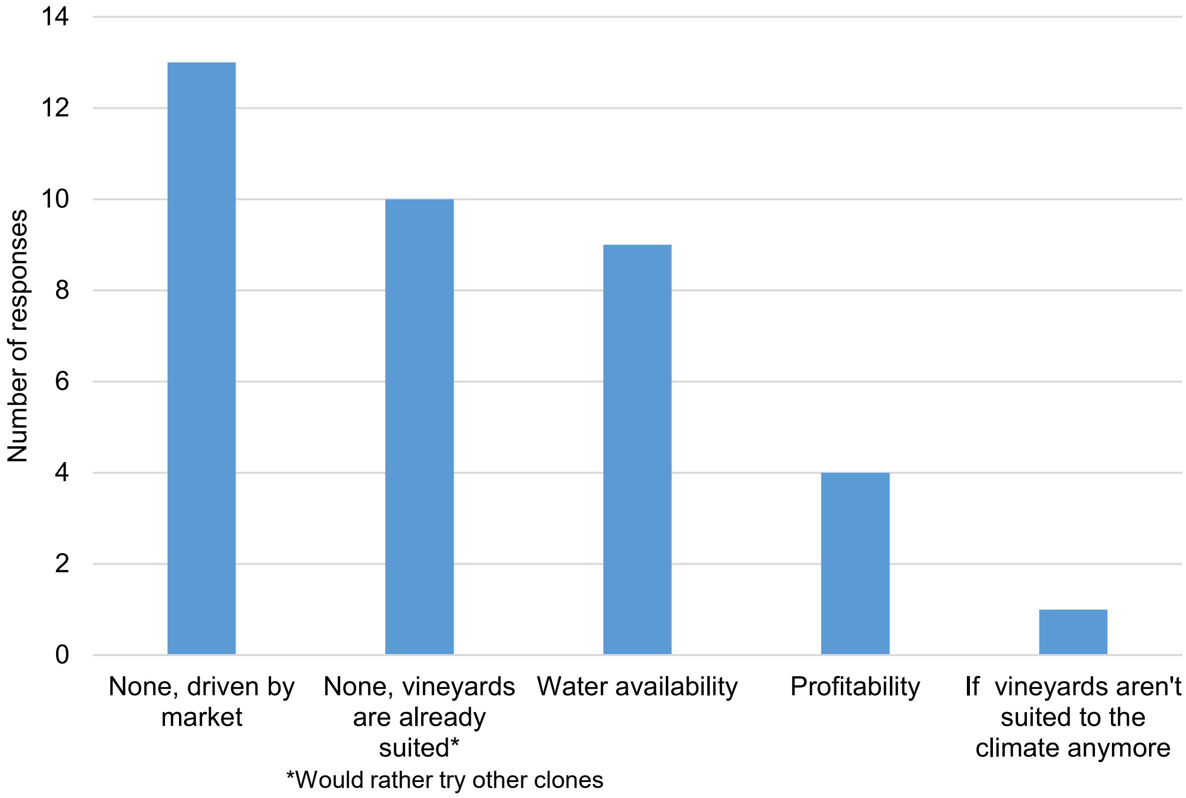


**Figure 10**: Factors that would convince farmers to switch crops due to climate change impacts (n=33)

*Q2: What are the main limitations for adopting alternative crops?*

Interviewees were asked to rate the factors they consider to be the main limitations for planting new crops, on a scale of 1 to 5 (5 being very important). They were given three limiting factors to rate, but there were three additional limiting factors that were raised by most farmers. Answers given for the three factors posed were mostly "yes, somewhat, no", therefore the analysis was done on this scale, rather than 1 to 5. The first half of the graph (Figure 11) shows this analysis, while its second half shows the number of times the other factors were mentioned.

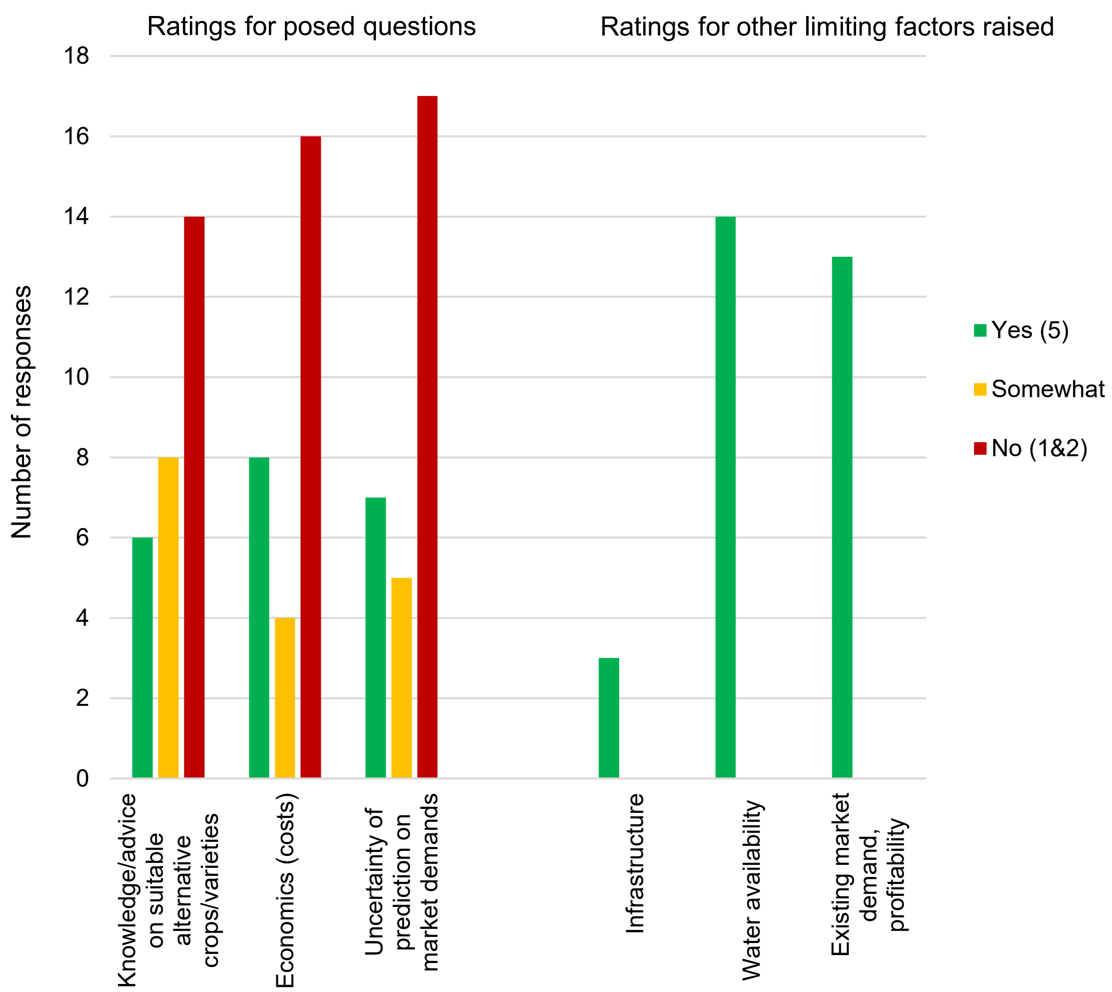


**Figure 11**: Factors farmers perceive as limitations for planting different crops based on climate change predictions or impacts (n=29)

Most farmers saw water availability as the key limiting factor for the type of crops they can plant. There was also a strong emphasis on the current (foreseeable future) market demands and profitability as being a limiting factor to planting new crops, much more so than an uncertainty about the predictability in the market. Infrastructure as a limiting factor relates to the fact that most farms are historically designed (pump houses and irrigation) for vineyards, with a bit of orchards. To change crops might mean that all infrastructure would need to be changed too, which would be too expensive. Figures 12 to 13 illustrate the crop diversification of the region.

**Figure 12**: Citrus is a fast-expanding crop being planted in the area. Peaches and apricots are still traditional to the area. These crops are well suited to the climate, have a good export market and stretch the harvest season in terms of labour and cash flow.

**Figure 13**: An increasing amount of farmers are planting blueberries, for which there is a good export market

#### 2.3.4 Water sources, irrigation and scheduling

This section covers the type of irrigation used on farms, an analysis on what tools farmers use for scheduling, as well as a look at how farmers think they could become more water efficient. It also contains a section on what farmers changed during the recent drought.

*Water sources*

Farmers, as well as the two viticulturists of the cellars, were asked what their main sources of water are. Most farmers receive their water either from the Brandvlei Dam canal system or pumps from the river, or a combination of both (Figure 14).

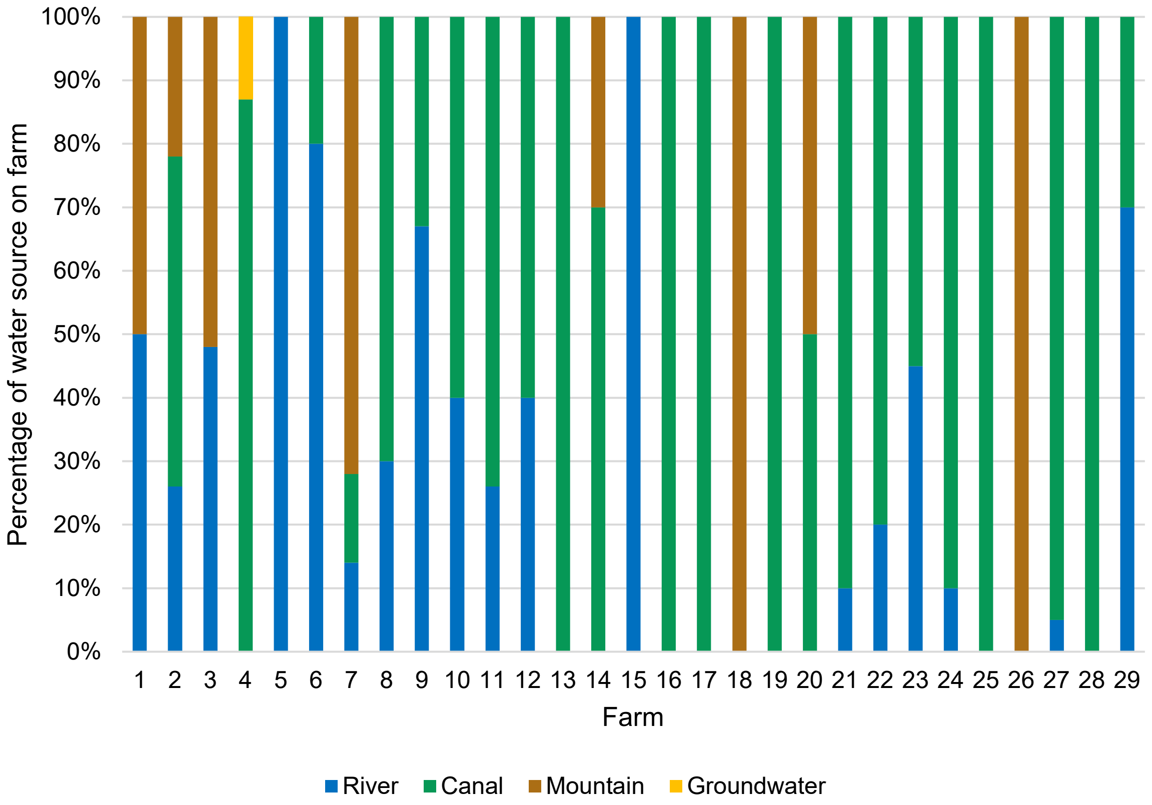


**Figure 14**: Percentage of different water sources on each farm (only farmers' responses) (n=29)

*Irrigation types*

The predominant irrigation type was drip (Figure 15). The micro irrigation used was mostly in orchards, with some farmers still having a little micro irrigation in their vineyards. One farmer used only micro irrigation in his vineyards and other crops. Reasons for the change from micro to drip were mainly improved water-use efficiency and easier management (less labour-intensive). Surface irrigation was mainly used by farmers with lucerne, while one farmer indicated the use of a water canon (when water is available) to deep wet the soils.

Only one farmer has sub-surface irrigation. He estimated his water savings with this type of irrigation at around 10%; however, the management costs of this system do not make it worthwhile for him to further expand this type of irrigation (e.g. one cannot see when there's a leak – "by the time you see that the vineyard struggles it's too late"; have to use pesticide to ensure the roots don't damage the pipes; difficult to flush the system clean; use more pipes so much more expensive).

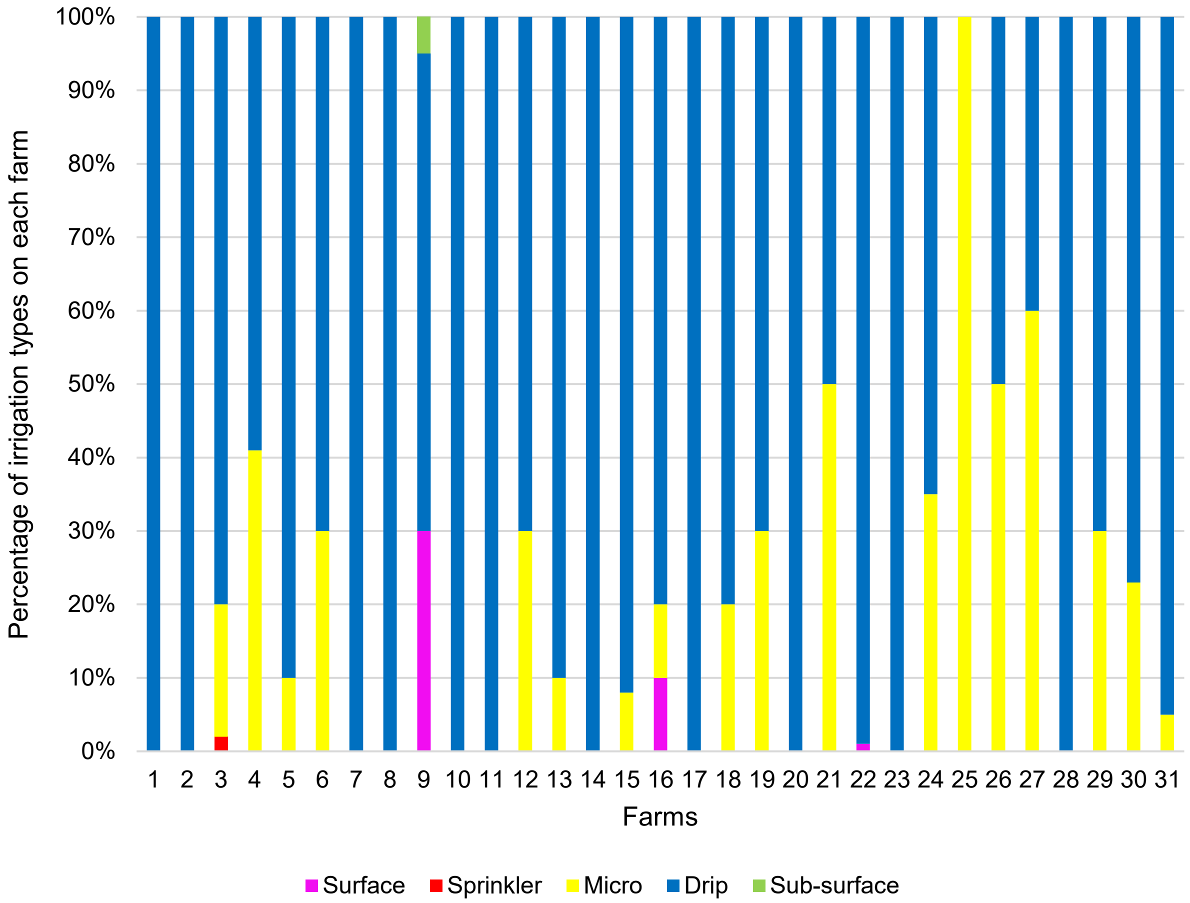


**Figure 15**: Percentage of each irrigation system per farm (including consultants' responses on the averages of their cooperatives' farms) (n=31)

*Irrigation scheduling*

Interviewees were asked to explain how they irrigate; how they determine their schedule and what tools or methods they use to adapt the schedule (if any). In total ,100% of people interviewed said that experience (some over generations), as well as knowledge of your farm, and particularly soils, were the most important factors behind setting an irrigation schedule for their farms. They use this, historical data, crop types and (some) consultants' advice to compile a set schedule.

While some have used technology to fine-tune their schedules, as will be discussed in more detail below, all farmers agreed that they would not use technology to replace field measurements and experience when it comes to scheduling decision-making. Some mentioned that "technology makes you lazy", and one "doesn't need technology if you know your farm and soils".

The following are phrases that were repeatedly mentioned in interviews (just in different wording):

> "I still have to get to each block, but these technologies help … to manage your time optimally, particularly to move between the different crops and sizes of blocks."

"We rely a lot on technology but it's critical to still go out and use your own experience in decision-making."

"Computers make your life easier, but you still have to go look yourself."

"I feel one should use technology as far as you can, but anything can go wrong, for example a tap can stay closed. You have to go look for yourself."

"The computer only helps because you can't be everywhere on your farm at the same time. You need eyes, ears and footprints to farm successfully."

"If you look at too much data, you're going to spend all your time behind a computer. You need to drive around, look at the plants."

The researchers led the farmers with questions regarding the above tools if they did not mention it themselves. At the end of this interview section, all of the interviewees were specifically asked if there was anything else, they used that we have not yet discussed in an attempt to not miss any information.

As the data are qualitative, each interview was analysed to distinguish between the importance of the tools the interviewee mentioned, and a value was accordingly assigned to the tool as presented in Table 6.

**Table 6**: Analysis of responses given regarding preferred approach to irrigation scheduling

| **Words used to describe use of tool** | **Category assigned** | **Number assigned for analysis** |
|---|---|---|
| Mentioned immediately; "adapt accordingly/based on", "daily", "best", "very good", "important" | Most important, check daily | 1 |
| Mentioned second; "Regularly", "weekly", "often", "use it", "do it", "good", "important" | Important, check regularly | 2 |
| "At start of season only", "sometimes", "only if there's a problem" | Use/do it, but not regularly | 3 |
| "No", "don't use/do it", "haven't heard about it", "used to use/do it, but not anymore", "doesn't work" | Not at all | 0 |

The analysis was done at least four times and when the same result was reached three times in a row, the researcher accepted the accuracy of the number assigned to the person's answers. When all numbers were finalised, the totals for each category were tallied to compile graphs. Farmers and consultants' answers were analysed separately (Figures 16 and 17).

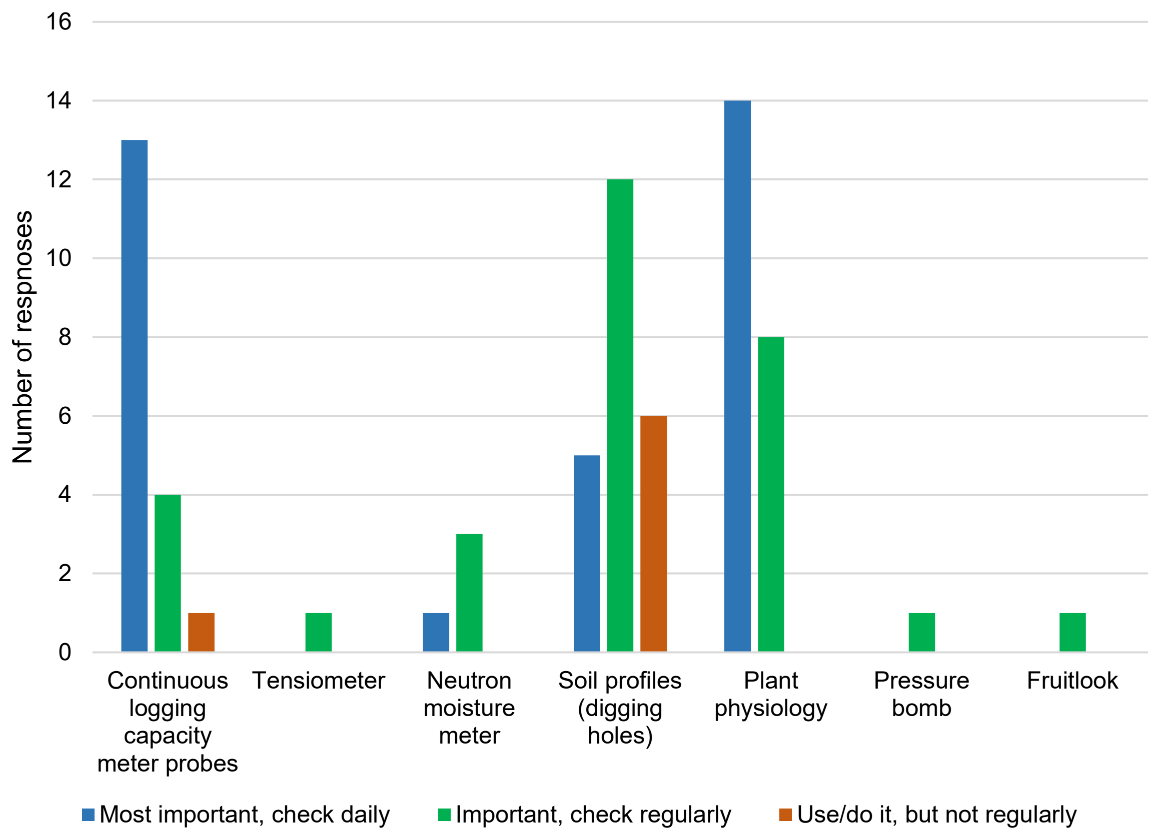


**Figure 16**: Decision-making tools farmers use for irrigation scheduling (n=29)

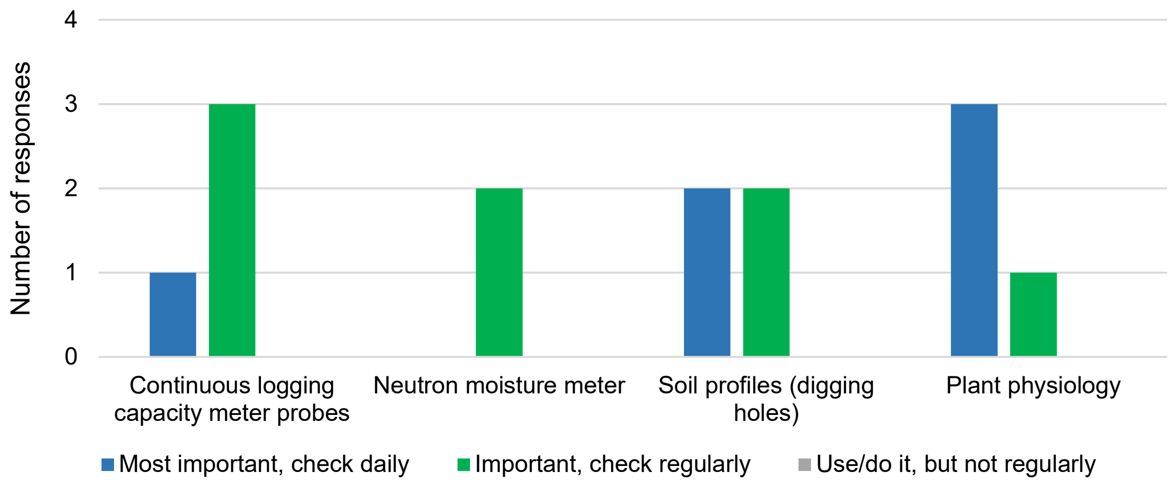


**Figure 17**: Decision-making tools consultants advise their farmers to use (n=4)

In total, 17 people were actively using continuous logging probes (13 Irricon, 3 DFM and one Mobi-Probe), while an additional person was busy with the installation of Irricon probes, and three people used to have Irricon probes, but now (after better understanding their farm with the probes) only use their experience. An additional four persons used Neutron measurements and one used tensiometers.

This amounts to 24 out of 29 farmers (83%) actively using some form of soil water measurement for scheduling (including the person who is installing the probes). When considering the responses of the consultants as well, this percentage is 85% (28 out of 33 persons).

There was no significant relationship between the age of the farmer and his use of technology for scheduling (Table 7), nor between the farm size (utilised land) and the use of technology for scheduling (Table 8).

**Table 7**: Statistics on relationship between farmers' age and their use of technology for scheduling

| **Statistic** | **Chi-square** | **df** | **p** |
|---|---|---|---|
| **Pearson Chi-square** | 20.82 | df=18 | p=0.29 |
| **M-L Chi-square** | 20.07 | df=18 | p=0.33 |

**Table 8**: Statistics on relationship between farm size and the use of technology for scheduling

| **Statistic** | **Chi-square** | **df** | **p** |
|---|---|---|---|
| **Pearson Chi-square** | 24.59 | df=22 | p=0.32 |
| **M-L Chi-square** | 23.5 | df=22 | p=0.37 |

### 2.3.5 Water-use efficiency

As briefly mentioned in the introduction, farmers struggled to answer questions relating to how they can improve their efficiency, as most of them have done all they can, considered themselves highly efficient and would not change anything further.

Regarding the limitations to improving water-use efficiency, there were very diverse answers to the questions, beyond the options contained in the questionnaire that had to be answered on a scale from 1-5. Each farmer only had one or two factors he felt was a limitation to his water-use efficiency. For this reason, it was decided to rather add the different answers and illustrate how many people raised each point (Figure 18). Only 21 interviewees answered this question, while six said they believed they are as water efficient as they can possibly be and therefore cannot improve anymore. The rest could not think of limiting factors for improving their efficiency (but also were not of the opinion that they cannot improve anymore).

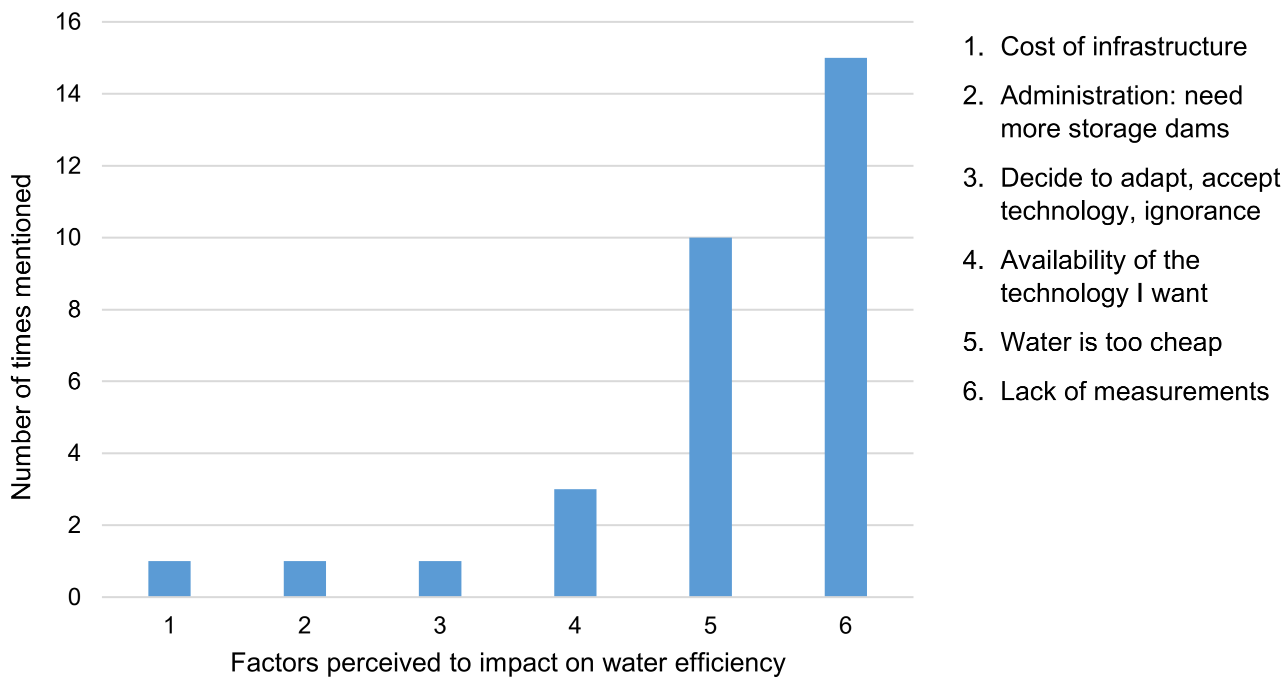


**Figure 18**: Factors that farmers' perceive as limitations for improving their irrigation efficiency (n=21).

The cost of infrastructure and the need for dams were most mentioned as limitations to improve efficiency.

Three farmers mentioned how the lack of private storage dams leads to inefficiency. Reasons include:

- "If we didn't have a dam, we would have to over-irrigate to get our allocation otherwise it flows into the ocean"
- "People have the fear that 'if I don't use it, I'll lose it'. People will then rather use their water out of fear that it will be taken away."
- Due to old laws, existing dams are too shallow, "this means that there's high evaporation because the dam is shallow. We're a water-scarce country and need deep dams with lower losses."
- Eight farmers mentioned the lack of private dams for winter storage water as a major issue when asked what they would change in the area. Although not mentioned during the water efficiency part of the interview, their concerns about not having dams to store winter water is directly related to efficient and effective use of water and therefore these comments were included in this question's analysis.

When asked about their preferred options for improving water efficiency, most farmers were of the opinion that improving field infrastructure and adapting their irrigation strategies were the best ways to improve efficiency (Figure 19). Seven farmers mentioned the value of adding mulch to their vineyards, and particularly orchards, but also mentioned the cost implications makes this a difficult option. Cost implications are also the reason for farmers who said that improving infrastructure is not helpful.

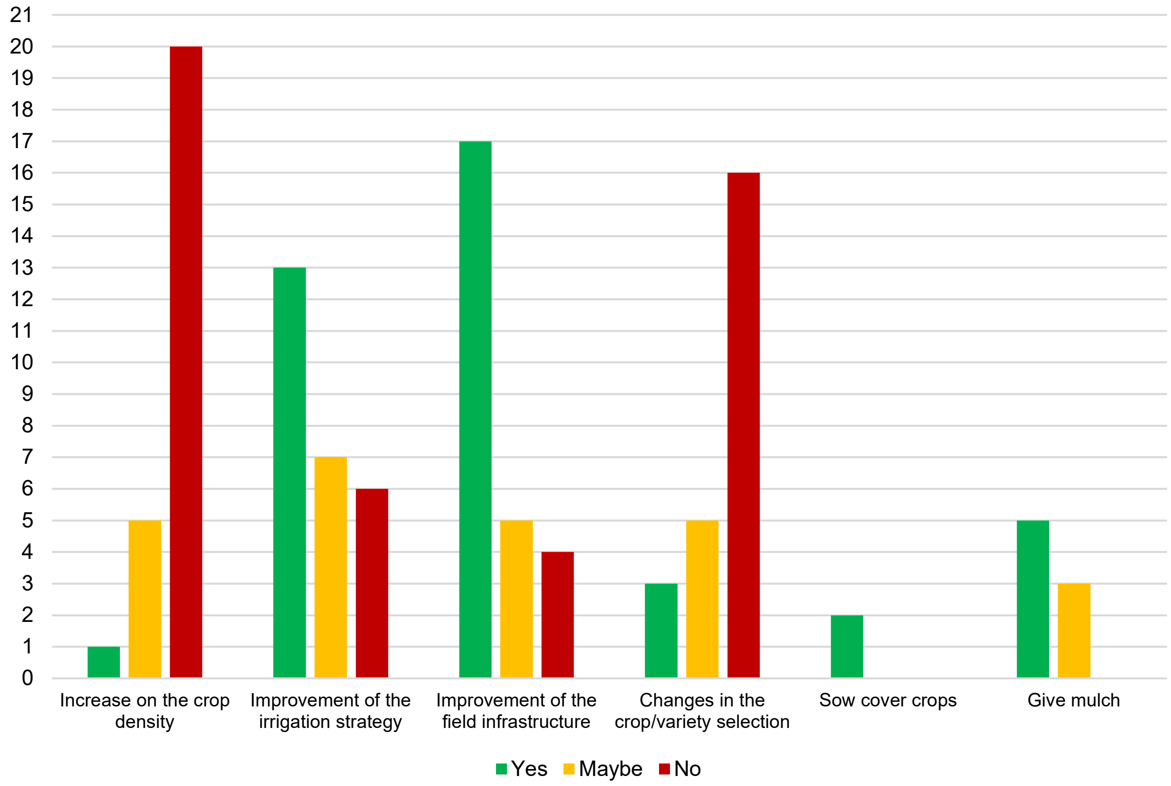


**Figure 19**: Preferred options for improving water efficiency (n=29)

Measures taken by farmers to improve their water efficiency with infrastructure include (illustrated in Figures 20 to 24):

- Switching from micro to drip irrigation
- Installing VSDs (Variable Speed Drives), or slow starter pumps
- Applying mulch (very expensive, mostly used for orchards)
- Self-compensating drippers
- Changing spacing of drippers
- New inventions

**Figure 20**: Farmers have switched most of their crops to drip irrigation, replacing micro irrigation in vineyards and most orchards as well, in order to improve their efficiency (less evaporation, targeted water application)

**Figure 21**: Many of the farmers have installed Variable Speed Drives (VSDs) to their pump stations. These automatically ensure that the right amount of pressure is used per block. This saves a significant amount of energy, as well as water.

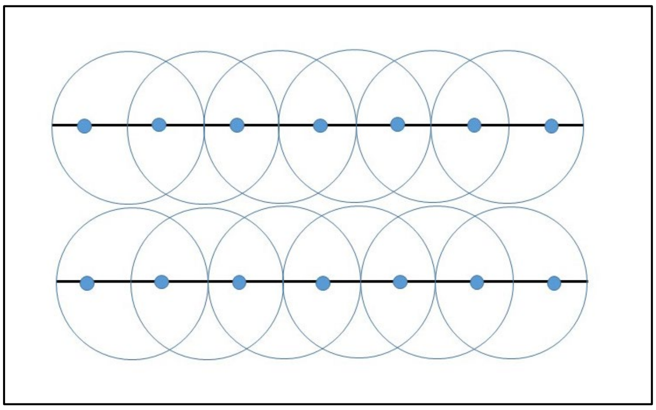

**Figure 22**: One farmer designed spacing between his micro heads to water the ridges optimally. The blue circles are the micro heads, and the large circles are the areas where the water falls. He used between 17 and 38% less water with this new design.

**Figure 23**: One farmer invented a new, now-patented, product for his lemon trees, called TreeHog™. This invention ensures that the micro irrigation is also targeted, while creating a favourable environment for the tree, saving water up to 70% of water.

**Figure 24**: Experiments have shown that trees grown with the TreeHog (right side of picture) are 1,5 years physiologically more mature than trees planted at the same time (left side of picture)

### 2.3.6 Drought adaptations

Farmers in this region, who are reliant on the Brandvlei dam (river and canals), only received 50% of their allocations throughout the 2017-2018 season. Although not part of the international questionnaire, the researcher asked farmers about how they made it through the season and what the impacts of the drought were. Individual farmer responses are shared in Table 9 (in no particular order).

**Table 9**: Adaptations farmers made during the 2017/2018 drought season and lessons they learned from it

| | **Adaptations** | **Impact** | **Lessons learned** |
|---|---|---|---|
| 1 | "**I gave shorter periods of irrigation**, daily, instead of my regular longer irrigation times. **I** mainly **irrigated during the night** and gave **higher impulses**. Had to adapt to get through the irrigation schedule/cycle. I would also switch on the micros to avoid frost." "We also tried to make our soils loose to keep water better. We put **mulch** where we could, mostly on the trees. It's too expensive for vineyard too." | "The entire Robertson had an **above-average harvest.** The nights were cold, so the soil took up less water. We also didn't have long heatwaves. I'll maybe **struggle a bit next y**ear. | |
| 2 | "We **couldn't sow cover crops**. We also made a big effort to save household water use – we realised that the amount of water used over weekends for laundry is significant, we had to **educate** our workers." | | |
| 3 | "We checked the dam level every day to see what we have to work with. We **watered what we could, when we could**." | "Vineyards are quite tough, but I suspect that the **roots could have had some damage**. We did have a very good harvest, could perhaps have been a record if had a bit more water." | |
| 4 | "I gave a little less water to our lower-producing blocks. **We cut water from the older blocks to properly irrigate the high-producing blocks.** We started irrigating earlier this past season to get the soil properly wet." | "The **harvest was still very good**. The old vineyards died because of **salt build-up**, but we would have removed them now anyway. | "I won't continue giving so little water if I don't have to. I realised that we actually irrigated a bit too much at places and I will adapt, I know now how much I can push the plants." |
| 5 | "I **didn't irrigate at all during the winter**, because it was so dry and we didn't have enough water in our dams. I **also gave less** | **Smaller yield** for the season. | Not giving water during winter and at the start of the season was a mistake as the groundwater levels couldn't recover. |

| | Adaptations | Impact | Lessons learned |
|---|---|---|---|
| | **water at the start of the season**. We had some good rains by mid-season and I could then irrigate as normal.<br>I didn't take away irrigation of the lemons, I just wouldn't plant anymore and use boreholes to keep them going." | | |
| 6 | **Adapted scheduling** to irrigate mostly at night (drip), micros late afternoon/early morning, to prevent evaporation. Installed a **VSD** to manage pressure. Used **probes** to manage carefully. | "By irrigating at night this year during the drought we got an **8% bigger harvest**, with half the water." | "We were all spoilt with water. Only people that were water-savvy before the drought made it through. The days are over where you can simply give water, people in the past over-irrigated hopelessly too much." |
| 7 | "I had to give less than half the amount of water than usual, but groundwater was low. Now I'm irrigating to fill soil for next year for a buffer." | "The plants look OK, but we'll see next year whether there was any damage." | "I will give less water going forward, but not as little as we had now." |
| 8 | "I gave **longer irrigations**." | "Here and there at a weak spot I had **some damage** but there wasn't much that I could change with regards to irrigation to fix that. Some brackish spots showed damage. | "I've now documented my irrigation precisely for the past two seasons, **we've been using less and less water, but our harvests are drastically higher**. I'm therefore now using less water and expanding my farming area. I'm also in the process of building a dam." |
| 9 | "I gave less water, reduced from 12 hours to 6 hours irrigation. We got through with **shorter irrigation cycles**. I also had no frost damage, which saved me." | "Despite the little water and everything we had a **very good harvest**." | "I learned how much less water the vineyard can actually survive by. |
| 10 | | | "It was stressful, but overall positive. We were **forced to see how much you actually need**. I'm happy to have gone through this season, it |

| | Adaptations | Impact | Lessons learned |
|---|---|---|---|
| | | | forced me to test the extremes. I'll definitely give less water going forward, I can actually use that water to expand." |
| 11 | "We don't use our full allocation yet because we're still expanding, so we JUSt had enough to get through the season. I **gave a bit less water to the peaches and managed it with pruning**. I **gave some nitrogen as reserves** for next year." | "Some of the **vineyards did stress**, but it was still a very good harvest. Some of the vineyards and orchards had some visible damage, but they seemed to have recovered quickly after harvest." | "I'm **not going to change anything** with my irrigation scheduling based on the drought. I have my neutron water meters which I believe work. I'll **rather just not expand as much as planned** to have reserve water. The mountain water is always a gamble." |
| 12 | "This year we **managed weeds more intensely** to save water… as a more holistic approach to manage the drought, it is not for the long term." | "People lost about 5% of their harvest to frost. Apart from this, the harvest was up by 9.8%, with half of the water allocations available. They had a surprisingly good harvest." | |
| 13 | "We had to decide this year where to stop and give what we had. Some people removed old peach orchards, some removed old vineyards, and people also didn't plant new vineyards.<br>We put **mulch** on the problem spots – it's too expensive to use widely." | "We only had a **6% loss in harvest**, and that can mostly be attributed to **frost**. It was also **difficult to plant cover crops,** because we didn't have winter water. We just kept the ridges clean. | "People learned a lot this year, management has improved a lot. A year like this is actually good to see where you can improve your practices." |
| 14 | We don't have any storing capacity and have too little water (only 80% of what I need optimally). I had to **irrigate before season to wet the soils**. Got to a block once every 6-7 days instead of the usual once in 4 days.<br>We **postponed planting** an additional 7 ha and **pulled out 5 ha of fruit that uses a lot of water**. We rather kept our tomatoes going." | | |

| | Adaptations | Impact | Lessons learned |
|---|---|---|---|
| 15 | “We **checked carefully** which blocks had the highest need and irrigated just before the plants’ stress levels got too high (probes). We also put **mulch** on the very poor patches. Although this is efficient for water saving, it’s too expensive to apply everywhere.” | We expect to see the impact of this year’s drought during the next season, because the vineyards did suffer and get hurt a bit. We also had a smaller harvest this year. | |
| 16 | “We **replaced micros with drip**. We also used our ridge water more effectively – laid pipes to get the **water back into the dam**. We **gave shorter impulses;** the roots were shallower and showed sooner when they were dry.<br>We **kept a very close eye on our scheduling**, we couldn’t plan too far ahead. We used **skins and wood chips on the young orchards and vineyards**.”<br>“**We didn’t plant cover crops**. We tried to **manage weeds at the right time**, using it as cover crop at the right times.” | “The prunes had 50% heat damage and we also had frost damage. Our harvest was quite normal, we’ll see the effect of the drought next year.” | “I **learned that I can give less water**, but I’ll would have given more if I could. I **don’t know what the long-term effect of giving such little water will be** on the plants, so I would rather not test it.” |
| 17 | “There were weeks where we would have liked to have more water, but we had to scale down. Before summer we gave heavy irrigation to increase the water table, because we saw the drought coming. We only have two levelling dams, not storage dams. So, we only have two weeks’ worth of storage water.” | | |
| 18 | | “We lost our lucerne. The grapes were still a good quality.” | “We learned that we’ve actually been over-irrigating some of the blocks. |

| | **Adaptations** | **Impact** | **Lessons learned** |
|---|---|---|---|
| 19 | “Some plants I gave less, some more. The **probes** helped a lot to do corrections.” | “With 50% less water I only had 20% less harvest.” | “I realised one can actually get quite more from your water, some plants can get by with far less. Everything changed this year, everyone things differently about water.” |
| 20 | “We work on a weekly schedule so we gave a little less where we thought we could.” | “We had 20% less water but **would have had the second highest harvest if it wasn’t for the frost**. The climate was good, we didn’t have real, long heat waves and the plants recovered quite quickly. The **water quality was also fantastic**, because there was little salt that flowed back into the system (because we irrigated less).” | “Everyone here learned more about water. Everyone realised you can actually get further with the water you have. The challenge is to not expand your area under irrigation too much, you have to think about the next drought.”<br>“You have to think about what your optimum production per hectare is. Nets, for example, saves a little water per fruit but overall not so much.” |
| 21 | “People **didn’t plant much vegetables**, they used that water for their vineyards.” | “We still had a good harvest, although some farmers had some losses. **Lost** around 3000 tonnes to frost, and **perhaps about 1000 tonnes to the drought**.” | “I hope farmers realised that they’re over-irrigating. I hope there will be less water used from now on.<br><br>Will have to see if plants were damaged but don’t think so, could irrigate at end of season still. |
| 22 | “We **didn’t cut water for the profitable blocks** at all. We rather cut for the older, less profitable blocks, but only a little bit. We **mixed good and bad quality water** (we used ridge water) and this way we stretched our water with a week or two to get us through the season.” | “We just made it through the season and our **harvest was average**. We had quite a bit of frost, so we did quite well under the circumstances.” | “You have to be very aware of what you have available in your dams (quality and quantity).” |

| | Adaptations | Impact | Lessons learned |
|---|---|---|---|
| 23 | "I gave a lot less water." | | "We saw with how little we can actually come by – where and where not. I've learned a lot and will give less water this next season." |
| 24 | "We had enough water to JUST make it through the season. The dams could take the knock to allow us to get through our full schedule (only just)." | "Despite this we had a good harvest." | |
| 25 | "I was lucky to have enough water and still have some left. The mountains get South-East rains which provides enough for our valley (5 farmers). I store winter water in my dams. In the summer I pump from the Breede River and store surplus." | | |

### 2.3.7 Technology

This section deals with farmers' desire to have and use remote-sensing or modelling products for farming. The section starts with answers to questions relating to farmers' appetite for risk, followed by what they would like to see in a remote-sensing or modelling product that would perhaps convince them to use it, and ends with a summary of perceptions of advantages and disadvantages of FruitLook in particular, as this is the only such product that the farmers know of and could comment on.

Interviewees were asked whether they see themselves as risk-averse, risk-neutral or risk-seeking. The majority of people answered that they are risk-neutral, noting that they prefer to take "calculated risks" (Figure 25).

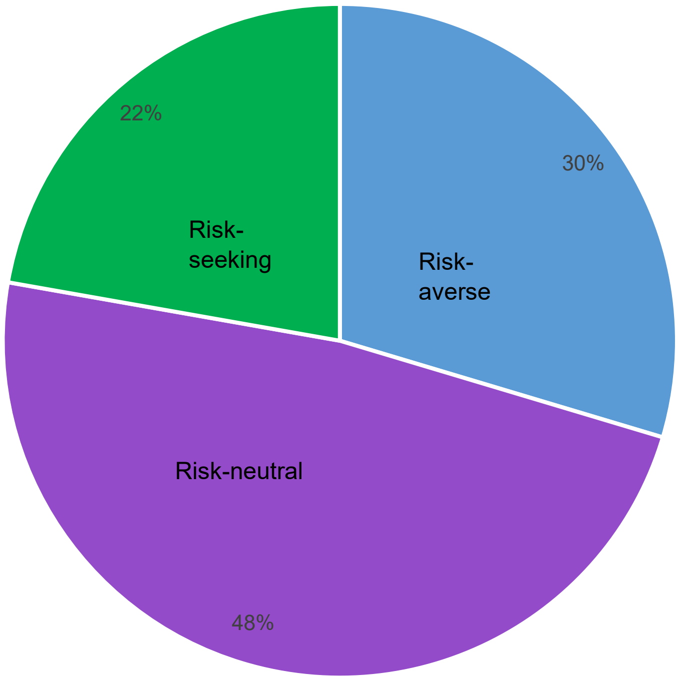


**Figure 25**: Farmers self-reflection on their appetite for risk (n=27)

Farmers and advisors were asked about their desire to experiment with new technologies. They generally indicated that they like new technology, with all three variables scoring on average between 4 and 5 out of 7 (Figure 26). Most farmers indicated that they like to try new technologies, but "only if it works", or that they "first what to check what others do" (particularly what the large farmers do), or that the new technology "has to warrant the cost". There is no significant relationship between farmers' interest in technology and age (Table 10).

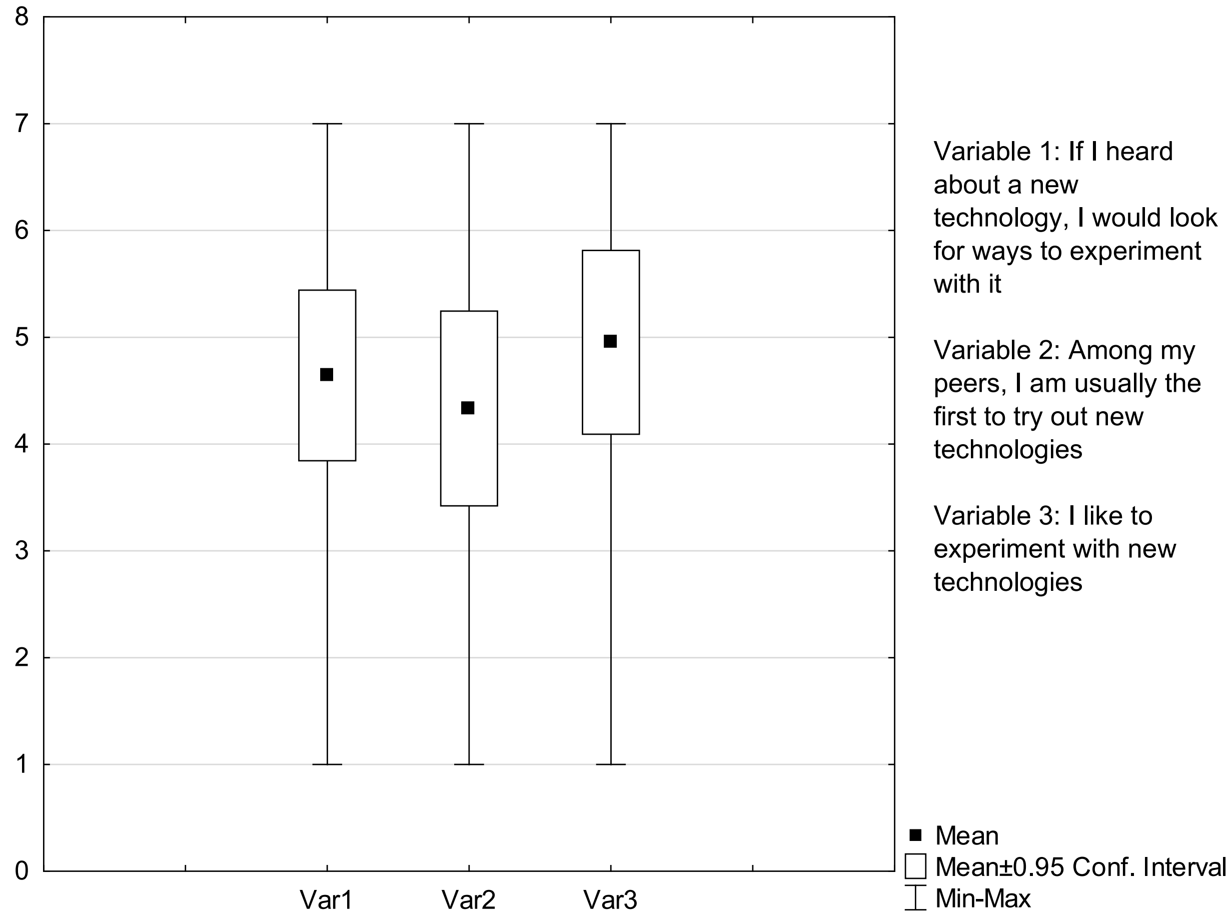


**Figure 26**: Farmers' keenness on experimenting with new technology (n=27)

**Table 10**: Statistical relationship between farmers' interest in technology and age

| **Statistic** | **Chi-square** | **df** | **p** |
|---|---|---|---|
| **Pearson Chi-square** | 63.08 | df=68 | p=0.65 |
| **M-L Chi-square** | 47.30 | df=68 | p=0.97 |

***Services and technology available to study group***

In order to put the analysis into perspective, a summary of advice services and technologies available to the farmers is included:

*a) Consultants*

All farmers make use of the services (products and advice) of chemical sales reps for spraying. These reps also supply the farmers with weather information to help them plan when to spray. Many farmers, particularly those with soil probes, make use of irrigation experts' services (for example *BreëRivier*

*Irrigation* (advisors), and the suppliers of the probes (e.g. *Irricon*, or individuals offering Neutron probe measuring services).

The company which is most widely used for advisory services in the area is *VinPro*. They hold numerous information days for the farmers, offer accredited training courses for farm workers, as well as a full suite of individual consulting services, such as establishing new vineyards or orchards, soil analyses, irrigation scheduling, problem management, etc. Numerous farmers make use of their services, and/or attend their open days.

*b) Information days*

Farmers can attend information days offered by VinPro and (less frequently) other farming organisations like Agri-Western Cape. The large cooperative cellars, Robertson Winery, Roodezandt Cellar, Rooiberg Cellar, Ashton Cellar and Bonnievale Cellar, as well as the export fruit pack houses, offer information sessions for their producers. The Farmers Associations also have regular meetings for their members. All these events serve as platforms for farmers to interact and learn from one another.

*c) Soil probes*

Although no climate modelling or remote sensing products in use, some of the probes used by many of the farmers are coupled to a computer programme that shows the wetness of the soil, twice a day (before and after irrigation). The most widely used continuous logging probes are Irricon (14 Irricon, 3 DFM and one Mobi-Probe). It allows the farmers to adapt their scheduling according to the wetness of their soil, and to investigate if soil seems too dry or wet after an irrigation.

Four interviewees use Neutron water meters. This is still considered to be the most accurate tool to determine soil wetness, but has become unpractical for most farmers. Some advantages and disadvantages of probes that were mentioned (Table 11).

**Table 11**: Perceived advantages and disadvantages of soil water technology

| **Continuous logging probes (Irricon, DFM)** | | **Neutron water meter** | |
|---|---|---|---|
| **Advantages** | **Disadvantages** | **Advantages** | **Disadvantages** |
| Improves water efficiency and more accurate scheduling | Still have to go to field to check, can't rely 100% on it | Most accurate | Still have to go to field to check, can't rely 100% on it |
| Accurate | Expensive | Time-intensive | Not regular enough (weekly service) |
| Makes irrigation easier to manage | Takes about 3 years to get right picture | | |
| Can monitor irrigation and adapt | Soil not homogenous, need many probes (wrong soil type, inaccurate readings) | | |

*d) iLeaf*

This programme is linked to weather stations. With a subscription, clients get 10-day weather forecasts, hourly humidity, $ET_0$, rainfall and wind data. The programme also contains climate modelling to predict risk for diseases (based on temperature, wind and rainfall), as well as reports on cold units, dew and frost risk, amongst others. The farmers who use this product are mostly interested in the predictions to plan for spraying, preventing frost and adapting their irrigation schedules based on the weather forecast.

*e) FruitLook*

FruitLook is a free remote sensing product that provides 20 m x 20 m resolution images for most of the Western Cape. Data provide are biomass index, leaf area index, evaporation deficit, actual evaporation and plant nitrogen levels. More details on the use of this tool are provided in the next section.

### 2.3.8 Use of remote sensing or climate modelling products

In total 88% of farmers and consultants interviewed said that they have heard about FruitLook and some have played around with it a bit, but only three farmers and two advisors have actually used the programme.

No one had any knowledge of other similar products available. Three farmers indicated that they would like to have drones that provide these types of images, but the technology is not at a suitable standard in South Africa yet. Farmers who use iLeaf are mostly interested in the weather forecast (rain and wind) to plan for spraying.

Because FruitLook is the only such tool known to the study group, interviewees were asked to think about a “programme like FruitLook” when thinking about what features they would find useful. Many of the questions proposed in the template were not relevant for South African farmers (it was tested on the first few farmers and judged to be of little relevance), or had to be combined into one. For example, energy costs related to pumping is important, but all farmers know this (there is also only one electricity service provider in South Africa). There are no incentives related to water in South Africa (farmers receive their allocation and pay a set price). The cost of different irrigation options (drip vs micro) is known to the farmers, they do not need this in an advice tool.

It was decided to ask questions that are more related to test the shortcomings or potential additions to the existing FruitLook (and iLeaf) programmes, as these and their contents are known to the participants and the results would provide valuable insights for the developers of this free, government-funded service. Figures 27 to 30 illustrate farmers’ opinions of the potential features of a remote sensing or similar decision-support system. The results show farmers are willing to pay for a service with a known track record of value for money (Figure 27); they prefer the resolution of data to be per block (Figure 28) and prefer to receive daily information (Figure 29).

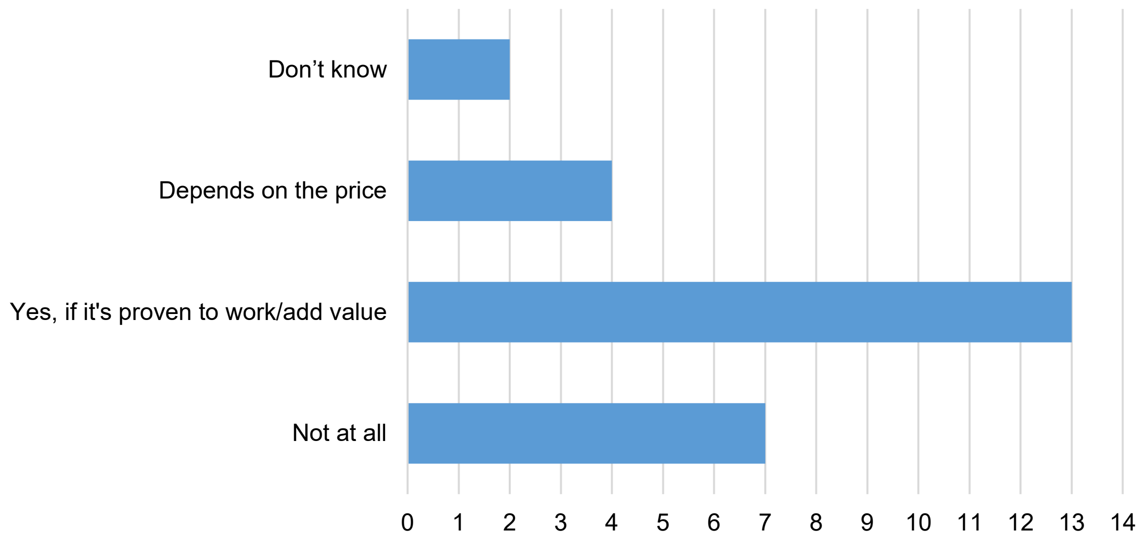


**Figure 27**: Farmers are willing to pay for remote sensing or similar products if it has been proven to work and be of value to them (n=27)

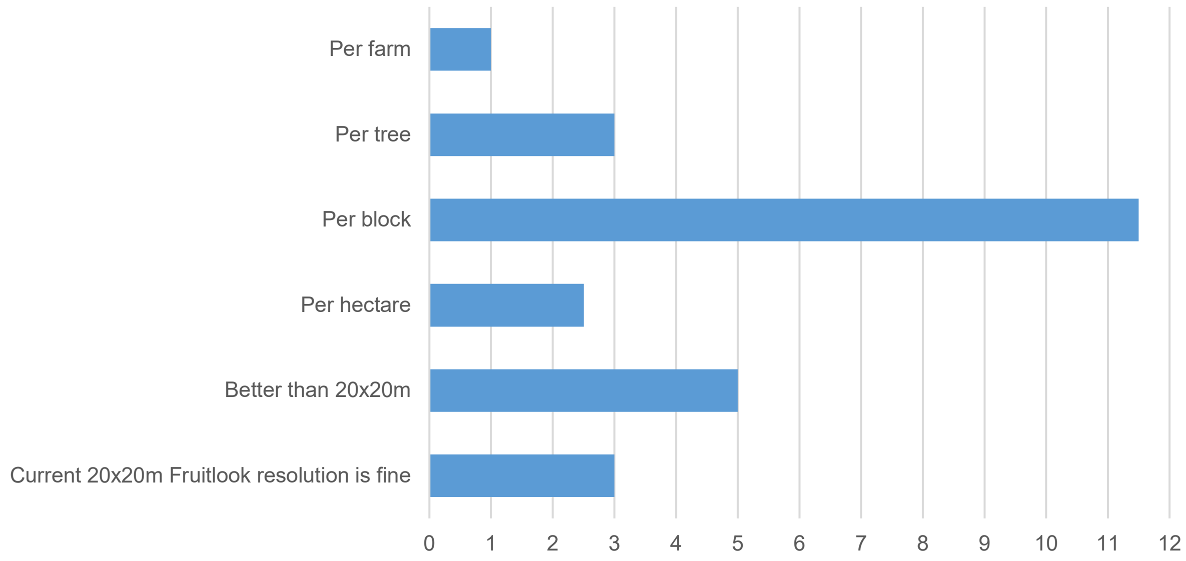


**Figure 28**: Farmers prefer products that are highly accurate, preferably per block (n=27)

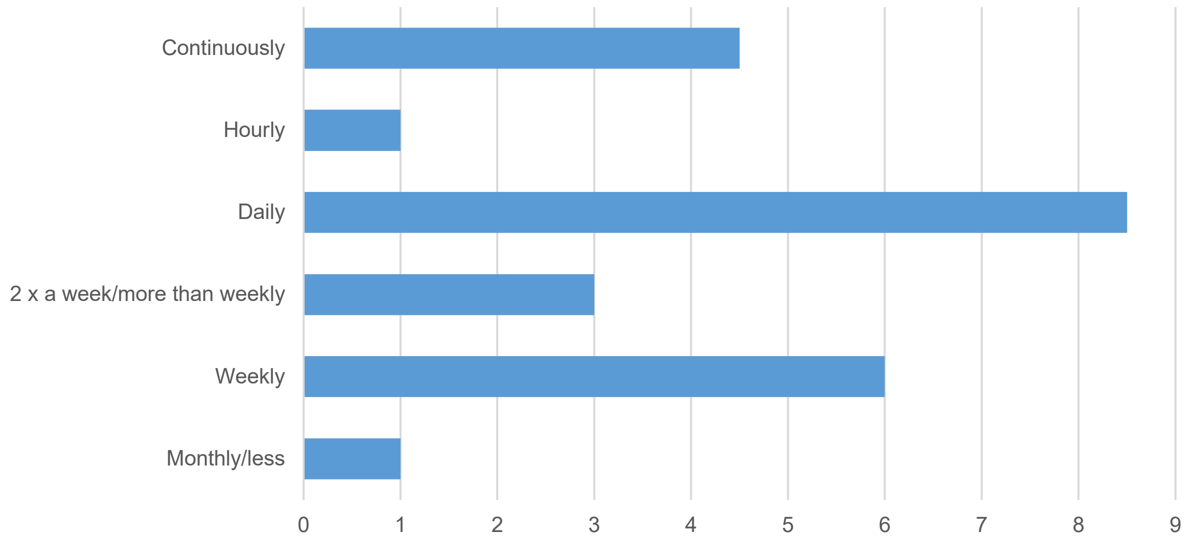


**Figure 29**: Farmers' opinions on the timeliness of information from a remote sensing service differs, but most prefer to receive daily information which can be used to adapt decisions in the field (n=27)

Farmers are not keen on receiving additional information to what they already have for their farms (Figure 30). Seventeen persons interviewed use continuous logging soil probes (plus one farmer is busy installing probes), according to which they adapt their irrigation scheduling (in combination with using experience and instinct). An additional four farmers use Neutron water meters, with only five not using this technology, relying on topsoil samples and visual plant physiology only. It was clear from the interviews that the farmers trust their probe information and do not see the need for receiving much more information than this. The probe data (after approximately three years) give farmers an accurate understanding of the crops' water use patterns and thereby the accuracy of their scheduling. It was quite clear that farmers would prefer personal advice from consultants rather than to rely on an advice tool or modelling product.

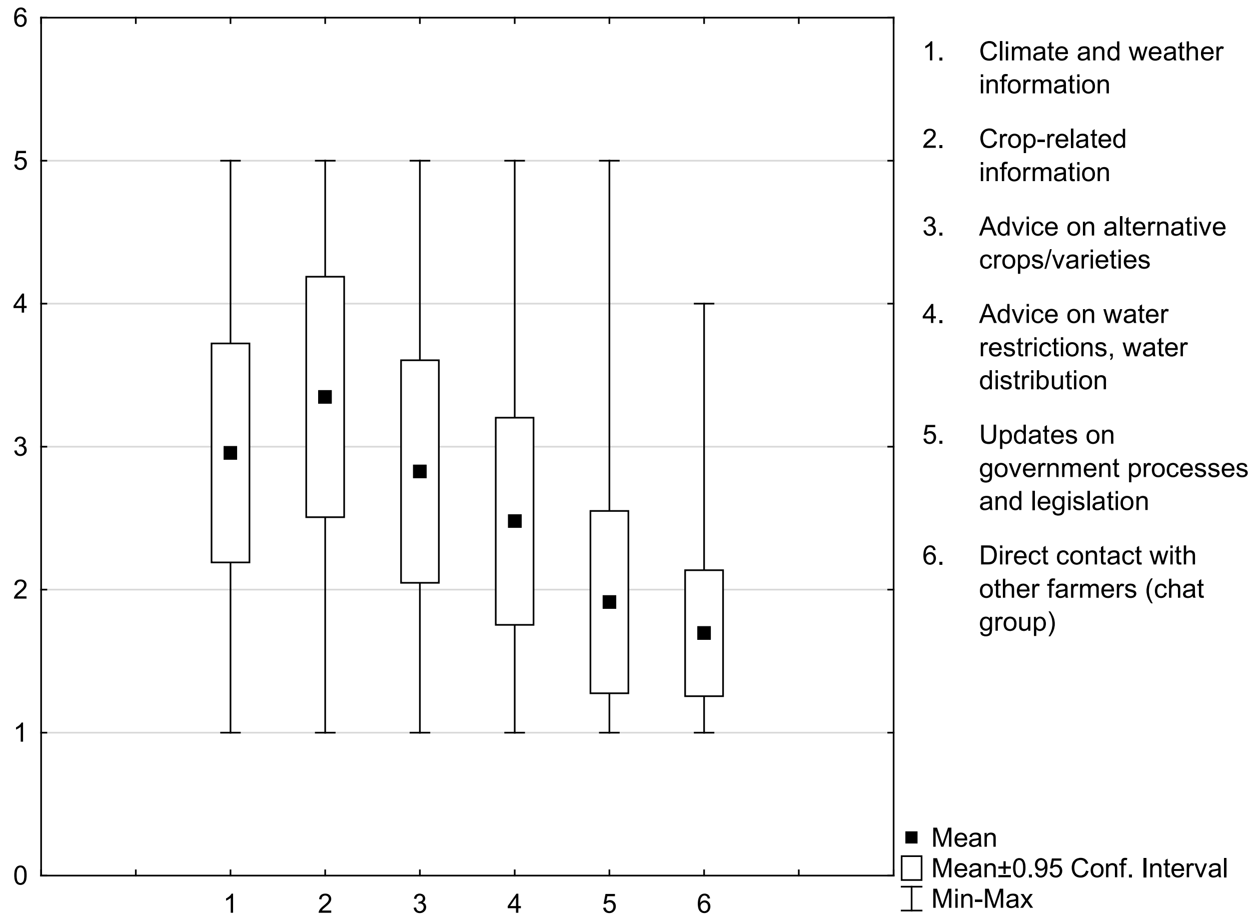


**Figure 30**: Farmers' opinion on how important (ranked 1-5) elements of a remote sensing or decision-support system are for them (n=27)

With regards to climate data, eight interviewees reported to receive climate data (forecasts, humidity, wind, $ET_0$, etc.) either from their own weather stations or from the cellar, or from chemical reps. The rest relied on weather websites and are happy with this approach. The need for climate modelling products are thus not high – farmers were mainly interested in wind and precipitation forecasts. Crop-related information, as well as information on alternative varieties, are received at open days, information sessions or from consultants and reps. Farmers do not see the need to have these in an advice tool.

All farmers were very satisfied with the information they received from the Water Users' Association regarding water availability for the season, restrictions and other regional information. About half of the farmers did indicate that it would be nice to receive dam levels and other water-related information on an advice tool.

### 2.3.9 The use of FruitLook

As mentioned before, only three farmers and two consultants interviewed used the programme, even though 88% of interviewees have heard about it, received training or started to play around with it a bit. One farmer used to use the programme but stopped due to perceived inaccuracy. Table 12 provides feedback on how these people reported to use the programme.

**Table 12**: Comments from the five persons interviewed who have used FruitLook

| | |
|---|---|
| 1 | "I was one of the first ones here to register and use it. It's a bit easier by now. But you have to spend a lot of time to actually understand all of it."<br>"I use the weekly summary that gets emailed. I also go into the history when I have time to compare my irrigation for the last couple of months (usually 3 months)."<br>"It's a lot like Irricon, I want to learn more about how my crops work (growth rate, biomass index) and compare blocks. I want to understand my blocks better."<br>"It shows the bad patches very well. You've got the advantage of seeing your farm from above, whereas you might not have noticed the stopped dripper FruitLook would show you the stress. I could look between 2016 and 2018 what the vineyards' weakening looked like."<br>"I would like to know if FruitLook can be calibrated to be closer to reality (for example biomass – it picks up weeds too)."<br>"I don't and won't make decisions based on FruitLook". |
| 2 | "I look at historic data on FruitLook to identify weak spots, particularly on new blocks."<br>"I screen through all the biomass readings once a week to check for anomalies, looking mostly for weak spots, so this way I use FruitLook as a problem-solving tool. I also use the water part to see if a block is too wet or too dry, it helps to identify probes that are dysfunctional."<br>"You have to look at it carefully and really understand. Then it can show you if you over-irrigate. But you have to go yourself and check what's going on in the field." |
| 3 | "I look at the start of season a lot and thereafter only now and then."<br>"Can see how effective you irrigate, particularly where it's wet and if you've been using your water efficiently. Use ET, biomass, water, etc."<br>"It's fantastic, but it picks up weeds in the orchards and vineyards too. So, when we spray, the biomass reduces." |
| 4 | "I experimented with it a bit before the drought and chatted to friends about it."<br>"The biggest problem is the effect that weeds and cover crops have on your biomass index."<br>"I drew in a lot of blocks and checked biomass, water stress, but the pixels are too coarse. I want to see 5x5 m at least, and the roads in between your blocks have a huge impact on the calculations.<br>"I know my blocks and what I see in the field doesn't correlate with the FruitLook images, so I'm not going to use it. I can't base my decisions on it." |
| 5 | "I use FruitLook to look at spots in blocks. 90% of the time it's water-related issues."<br>"In the high season it's useful to see where the plants stress, but then when you drive to that part of the farm you see it's the soil type, not the water. It's very rare that a block will have homogenous soil composition, which means there will be parts of the block that will be over-irrigated and parts that will stress and show on FruitLook." |

Table 13 contains the perceived advantages and disadvantages of all people who have heard about FruitLook (or remote sensing and climate modelling programmes) and have looked into it a bit or went on training (i.e. they knew enough about it to provide a comment on perceived advantages and disadvantages).

**Table 13**: Perceived advantages and disadvantages of FruitLook, as mentioned by all interviewees

| **Advantages** | | **Disadvantages** | |
|---|---|---|---|
| | **# people** | | **# people** |
| Can help you irrigate more accurately (indication of whether you're on the right track) | 5 | Still have to go into the field and check for yourself, can't rely on it as management tool and won't replace probes | 13 |
| Can identify problem spots in blocks | 8 | Time-intensive to set up | 8 |
| Could help with prevention (pick up problems before you see them) | 2 | Difficult to understand what all the data means and how to apply it | 6 |
| Have 5 years of history | 2 | Not accurate enough | 5 |
| It's free | 2 | Get information a week later | 4 |
| Can help bring production costs down | 1 | Picks up biomass | 2 |
| Can inform spraying programme | 1 | Only for technologically advanced | 2 |
| Can help adapt farming holistically (not just water) | 1 | Can't update when cloudy | 1 |
| Can help with fertiliser application | 1 | Can't make small adjustments to entire irrigation plan | 1 |
| Learn how your crops work, understand farm and plants better | 1 | Doesn't give solutions so doesn't add value for farmers | 1 |
| Comparison between different years help you improve your strategy | 1 | | |
| Can increase marketing value for estates with their own labels | 1 | | |
| Problem-solving tool | 1 | | |

The following advantages and disadvantages were mentioned specifically by the persons who use or have used the programme:

*User-friendliness:*

"FruitLook is aimed at about 20% of farmers that are technologically advanced, most farmers are still very old-school. It's aimed at the mega farmers, 5%. The rest of the farmers are small."

“Farmers want someone to do FruitLook for them. They don’t have the time, especially now with all the diversification on the farms. Labour is a massive issue. It takes a long time to draw the shapefile for each block.”

“Not everyone is keen on technology. There’s also so many other tools to support farmers.”

“It takes time to load your blocks onto the programme, but once you’ve gone through that and you understand then it’s quickly to use the programme. When people realise the benefits of FruitLook I believe they’ll use it more.”

“Just like probes, and all other tools, it’s not the silver bullet. You still have to go out and check if the probe is working, or even in the right place to take the reading.”

*Outcome/results:*

“FruitLook only shows you that there is a bad spot, it doesn’t actually tell you why and what to do about it. You still have to drive out to investigate for yourself and maybe get a specialist in to come help you fix the issue.”

“With vineyard, the size of the berry doesn’t matter, it’s about the sugar content. Fruit has to be more perfect, but fruit farmers generally know what they’re doing so they don’t need all the extra information that FruitLook gives.”

“A farmer knows exactly happens on his farm. He knows where the weak spots are and why. He only needs a specialist to, for example, advise on a disease, or to manage old vineyards that weren’t planted correctly many years ago.”

“We need an app in which you can put all your information and it throws out a solution for you, for example which clone suits which soil type, how to treat a disease, etc. Climate, weather, diseases, shortcomings – the WHY and HOW is needed. They need a ‘consultant on their computers’ – the technology has to be as simple and easy as possible for farmers to take it up.”

*Accuracy:*

“FruitLook is climate-driven (ET values), but you have to manage the micro-climate on your farm. FruitLook decides based on temperature, which is not practical on a farm. The weeds also impact on the programme’s calculations.”

“Irrigation wise it’s too high a risk (to use FruitLook for irrigation). There are too many factors that have an impact on energy radiation. You have to be careful and only use it in combination with other tools.”

“FruitLook’s grid is still a bit coarse. But it’s another tool in your toolbox to use to improve your farming.”

*Other:*

“You can only look in hindsight with FruitLook and make changes accordingly. But our irrigation system uses 12 computers, it will be half a day’s work to make slight adjustments to the entire schedule if FruitLook shows something’s wrong. If I had an irrigation system that I can manage from my phone, then I might use FruitLook more.”

“Government thought that FruitLook will be taken up much faster and that many farmers will use it. But there’s a massive gap, the developers and farmers are worlds removed from each other.”

“Probes already do what FruitLook does so farmers will rather trust their probes than to spend time on FruitLook. It is handy if there is a problem that he doesn’t know of already.”

“The problem is that FruitLook only shows you that there is a bad spot, it doesn’t actually tell you why and what to do about it. You still have to drive out to investigate for yourself and maybe get a specialist in to come help you fix the issue.”

“Vineyards are not so precise. It might be more useful for people with fruit. It makes more sense; fruit farmers may use it more.”

“People just don’t understand the programme enough. We need “leader farmers” who use it, then the rest might catch on.”

## 2.4 Discussion and conclusion

The results relating to irrigation types and the uptake of technology are discussed in more detail in the following section. With regards to irrigation types, the results obtained are in accordance with industry research on irrigation types for vineyards. According to data collected by the South African Wine Industry Information and Systems (SAWIS), drip irrigation is by far the most widely used in vineyards (see Figure 31), (Myburgh, 2018).

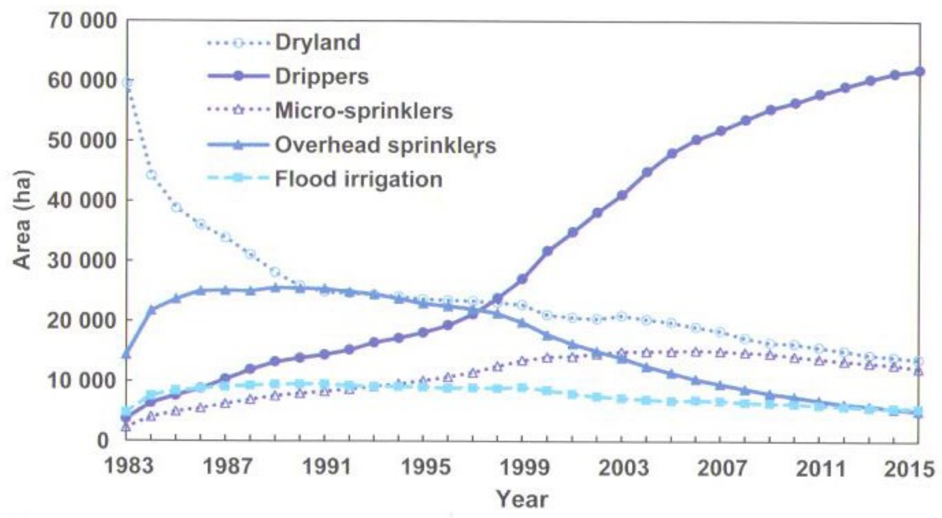


**Figure 31**: Irrigation systems used in vineyards between 1983 and 2015, according to SAWIS (graph taken from Myburgh, 2018, p73).

The questions on planting preferences and current crops confirm diversification occurring in this part of the Breede River Catchment. Citrus in particular is expanding fast. Despite widespread scientific concern for the future of agriculture in South Africa due to expected climate impacts, farmers interviewed in this study are highly unlikely to make changes according to predicted climate change impacts. Farmers realise that climate change is a problem, but they still prefer to plant for the near future predicted market-demands rather than longer term, predicted climate indications. Although water is a concern for most, they would rather plant less of a profitable crop, than more of a less-profitable crop with the water they have available. The current market is the main driver behind crops being planted – this is particularly evident in this region where farmers are rapidly replacing their water-efficient vineyards with soft citrus. Adapting an area's crops to be most suited for the climate in terms of water use can therefore not be considered by government as one possible intervention to save water in irrigated agriculture.

Furthermore, farmers' feedback on their adaptations taken during the drought revealed that most of them realised they can cope with less water, but they are too scared to take the risk to continue giving less water the next season in fear that there would be unexpected long-term impacts, and as such they will continue irrigating as normal should they receive their full allocations the next season. Studies on the long-term impact of less irrigation, and proper dissemination of the results, would help confirm or allay these fears.

The interviews revealed an interesting impact that diversification has on a local irrigation scheme. Many farmers raised concerns about the way in which the irrigation canal can be maintained – maintenance is done during winter when the vineyards are dormant, but citrus requires water throughout the year. It also led to conflict during the drought, as wine farmers required less water at the start of the season and more during peak months, but a set ration was distributed to accommodate the needs of other crops. This is an important point that requires further investigation in preparation for future droughts.

This study showed that 83% of farmers in the Central Breede River are using some form of technology to inform their irrigation scheduling. A national survey, undertaken in 2006, on technology uptake for irrigation scheduling revealed that only 18% of farmers use "objective" scheduling methods (i.e. technological methods, as opposed to intuition and experience only) (Stevens, 2006). It appears that at least soil water measuring has gained significant uptake in this region in particular. However, this is only one type of technology, while there are countless more technologies that are being ignored.

The farmers interviewed generally said that the probes are sufficient, as they still only use it as a guide to build on their experience and intuition and that they don't have time to sit behind computers to implement all the technology that has been developed. In other words, the technology is used as decision-support tools, and not yet for automation. The Irricon system was designed with recommendations for an automated schedule based on the history of the probe and some farmers did indicate that they would like to automate their irrigation accordingly, but they are not yet confident enough in the product to do so. Decision-support tools will have to be perceived as highly reliable before farmers will use it for automated irrigation. The heterogeneity of the soil in the region poses a challenge for automated irrigation as some spots will inevitably be over-irrigated while the rest of the block is irrigated perfectly – this adds to the challenge of turning decision-support tools into automated irrigation tools.

The successful uptake of the probes lie behind the product's perceived accuracy, ease of use, cost and perceived value for money. Other contributing factors are the high level of personalised support that comes with the product, in terms of in-field calibration, investigating potentially malfunctioning probes and general support with the use of the product.

These observations are somewhat in line with widely reported international factors that have been found to impact on irrigation technology uptake. In a review, Parker (2005) listed seven factors that are commonly reported in literature as being barriers to irrigation technology uptake. The results of this study are noted with each of the factors listed by Parker (2005):

- Computer use and specification: Parker (2005) noted that this is not such a big problem anymore, as was the case in this study. However, some farmers still felt that not having a state-of-the art computer is problematic for the new technology.
- Threat to the agronomist/consultant: Parker (2005) reported that many studies found consultants will deliberately not take new models or technology to their clients as the product may render their services void. This was not the case at all in this study, where farmers said they still prefer personal contact and the ease of just phoning a person for advice.
- Inappropriate models: This relates to the academic nature of many of the models or tools that are developed. This was not raised as an issue by the Robertson farmers, but relates to their comments that they want to "farm in the field", not behind a computer, and therefore are reluctant to try new tools.
- Data requirements, particularly weather: Parker (2005) listed cost, access and relevance
- Integration between systems: this was also found in this study, as most farmers noted they would only adopt additional technology if it was somehow aligned to their soil probes.
- Trust and understanding: This relates to the software and the concept behind the technology. This was also very relevant here – farmers trust the soil probes because of the level of support they get from the developer and because soil water reading builds on the traditional, well-known and long-used method of looking at topsoil water.
- Support and training: The interviews revealed that even with support and training, farmers would prefer to have someone else do the work for them, as they want to farm and not spend too much time behind computers.

A key issue raised by many of the farmers is that their scheduling is limited by when and how much water they can pump from the irrigation scheme or river, as per the instructions of the Irrigation Board. This was also found to be the case in a South African study by Stevens and Van Heerden (2013), where 47% of farmers interviewed responded that they can only schedule effectively if they have "full control over their water supply". Supporting farmers with the process of building larger storage dams should be considered by Government in an effort to improve on-farm efficiency.

Stevens (2006), as well as international studies (e.g. Parvan, 2011; Pierpaoli et al., 2013) showed a significant relationship between the use of objective scheduling and age or farm size. This was not the case here, where no significant relationship between these factors were found. There was also no relationship between farmers' age or farm size, and their interest in technology.

Based on farmers' feedback during the interviews, it can be concluded that the following are the main reasons for the successful uptake of soil water probes for irrigation scheduling:

1. Farmers believe in its accuracy, as it corresponds with their field observations.
2. It is affordable and they perceive it as good value for money. However, value for money is difficult to interpret, as FruitLook is a free service and is not being used.
3. The user interface is easy to navigate and use as an everyday management tool.
4. Post-installation, personal service is highly important to the farmers. They use this probe because they can phone the developer and ask for help when needed, and he will come to their farm if necessary.

The following factors are the main reasons for the poor use of FruitLook in the study area:

1. Weekly data is considered too sparse to inform irrigation decision-making.
2. It takes too much time to initially set up the fields.
3. One technology for decision-making is enough for farmers – using more than one with different timelines, a different interface and data that need to be interpreted separately from their probes is too time-consuming and not seen as worthwhile.
4. FruitLook data does not always correspond with what the farmers observe in the field; there are factors (such as weeds) that need to be corrected before farmers will believe the results.
5. It provides information that still needs to be interpreted and acted upon, it does not provide advice on how to solve the issues presented.
6. Similar to the conclusion regarding post-installation service of probes, farmers are more likely to use the programme if someone will interpret everything for them and send them summaries and advice on how to act on the data.

The reasons for use of probes and lack of uptake of FruitLook correspond with some of the findings of Annandale et al. (2011), who reviewed the success of some technologies launched in South Africa. Their similar conclusions are that:

- Farmers adopt technology where they are familiar and comfortable with the developer of the product and receive post-installation service and support.
- Technologies that have been locally tested and adapted for local conditions, fare better. FruitLook is too coarse for the farmers' liking.
- Price and user-friendliness does not naturally lead to uptake – it requires assistance and dedicated service as well.

Some researchers (e.g. Mackrell et al., 2009; Rehman et al., 2006; Pierpaoli et al., 2013) have emphasised that technology developers do not place enough emphasis on users' personal characteristics and perceptions. This study found support for this notion, as perceived value-for-money and accuracy of soil water measurements are key drivers behind its uptake, while perceived inaccuracy and difficulty-to-use are some factors that prevent farmers from using FruitLook.

The poor uptake of technology could also be related to farmers' perceptions of their current levels of water efficiency. Most judge themselves to be highly water efficient with little room for improvement left, which means that they do not believe that they need any additional technologies to improve. When faced with severe water restrictions they actively look for practical ways to save water, such as checking for leaks, distributing water to most profitable vineyards or orchards, installing pressure regulators and adjusting drip spacing. And although yields were good with the little water applied during the drought, the farmers all hoped to be able to apply more water again in the next season as the uncertainty over long-term impacts of low irrigation is too high a risk for them. The fact that they managed to have a good yield with less water was only enough to convince about half the farmers to continue irrigating less during the next season.

# 3 PART B: ANALYSIS OF TECHNOLOGIES USED

## 3.1 Introduction

As stated in the Rationale for the South African case study, the following aim and sub-aims are to be addressed in this second part of the report:

Aim iii): Evaluate the usefulness of FruitLook as remote sensing service and/or other technologies or models that farmers use

- iii-a) Compare the outputs of technologies used for irrigation, to determine if it would have been beneficial for the farmers to use more than one technology (with a particular focus on FruitLook as remote sensing product)
- iii-b) Using the results of aim iii-a), use field-level data to develop a water budgeting approach for the catchment

The interviews reported in Part A revealed high uptake of technology for scheduling (83%) amongst farmers in the case study area. This is much higher than the reported 18% use of technology by a national study in 2006 (Stevens, 2006). However, farmers in this area only use soil water technology to inform their scheduling, together with the subjective methods of soil profiles and checking plant conditions. Only one farmer uses a pressure bomb, and one farmer uses FruitLook. No other technology is being used to inform scheduling by this group of farmers. Although there are numerous weather stations in the area, very few farmers have subscriptions to obtain this data. Only two farmers reported to use ET data to inform their scheduling.

The interviews also revealed that one key reason behind farmers' use of only one technology is because it would be too time-consuming and too much effort to use additional technologies that provide different types of output data that also have to be interpreted and somehow linked together to inform decision-making. A general comment by farmers was that while information is important for decision-making, receiving too much scattered information is not useful, and that they would be more likely to use FruitLook (or any other new product) if it could be linked to their existing chosen technology. It is this point that this second part of this study aimed to address, by exploring whether it is at all possible to compare the outputs of three different technologies. Seeing the datasets of all three technologies in one document or graph could provide the farmers with a management tool to cross-check the results and thereby ensure accuracy, and as such contribute to water savings.

Based on the results of the questionnaire, it was decided to investigate whether a comparison can be made between ET values derived from FruitLook (remote sensing) with local weather stations and with soil water loss, as measured by the farmers' operational probes. The weather station ET values were used as reference and the possible deviance between the ET values and soil water loss values are discussed. The probes could not be used as reference as these were not scientifically calibrated (they were installed and calibrated by the developer and serve as a management tool, not to achieve a highly accurate soil water reading). This should give farmers an indication of whether it would have helped them to look at FruitLook and/or the weather station, in addition to their probes. **The intention was not to do a technical comparison on the accuracy of any of these technologies, but rather to explore whether they can be compared in a simple manner by farmers themselves, based on the information and data they have readily available.** Nearly a decade ago researchers already called for the coupling of technologies for combined approaches in irrigation scheduling, particularly remote sensing and volumetric soil water (e.g. Annandale et al., 2011), yet this is still not being done in practice. It is hoped that this study will contribute towards the understanding of whether technologies can complement one another.

It was also decided to investigate water budgeting techniques at farm and catchment level, with the technology farmers are already using (soil probes), or that are readily available to them at little to no additional cost (FruitLook, climate data). We attempted to use field-level information to arrive at a farm-level or region-level prediction, based on the technology and information that is already used by farmers in the Central Breede River area. Using field-level data to inform catchment water needs has not been done and could be a useful management tool for the irrigation board to allocate water, particularly during droughts. During the interviews, wine farmers raised concerns about the allocation of water during restrictions – most of them do not have dams and therefore cannot save their allocations for the two months in which the vineyards have the highest water needs. A water budget for the catchment, based on field-level measurements, could support decision-makers to optimise water distributions based on plants' actual needs. Water budgeting with the already widely used technology could also be useful for small farmers who could not afford numerous technologies for their irrigation planning.

One model has been developed in South Africa, with WRC funding, to serve as catchment water budgeting tool. The programme, SAPWAT 4, uses the FAO guide (Allen et al 1998) for calculation on reference ET, combined with climate data, to calculate irrigation water estimations. It provides monthly total crop water requirements, which can be compared to the water requirements as calculated here for the soil probes, weather station and FruitLook data.

## 3.2 Approach

To address the above aims, the following steps were followed:

- Compared the ET values derived from FruitLook (remote sensing) with local weather stations and with soil water loss, as measured by the farmers' operational probes. The weather station ET values were used as reference.
- The possible deviance between the ET values and soil water loss values were discussed. This should give farmers an indication of whether it would have helped them to look at FruitLook and/or the weather station, in addition to their probes.

- Using the farmers' irrigation records, determined over- or under-irrigation in relation to FruitLook, weather station and soil water data.
- Used all measurements to calculate a water demand budget for the irrigation area (based on hectares of crops).
- Compared all measurements with SAPWAT 4.

In order to relate soil water loss to ET and FruitLook, the following data were required:
- Hourly or daily soil probe data over at least two seasons
- Hourly or daily weather data (rain, $ET_0$) from nearby weather stations
- FruitLook $ET_{actual}$ for the same blocks as the probes

To compare soil water loss with ET, a continuous soil water loss profile (loss over time) had to be developed for each probe. This was achieved by deleting irrigation and rain events and replacing these hours with average values for the hour.

A correlation was made between:
1) Weather station ET ($ET_0$ and with Kc) against soil water loss
2) Weather station ET ($ET_0$ and with Kc) against FruitLook $ET_{actual}$
3) Soil water loss against FruitLook $ET_{actual}$

Because FruitLook only has weekly totals, the correlations were done with total weekly values for ET, FruitLook ET and soil water loss. The results were compared to that generated through the SAPWAT4 software.

For the water budget, monthly water requirements based on FruitLook ET, weather station ET and water profiles are compared. Actual irrigation records for at least one block (with a probe) were obtained and the differences to applied water and predicted water are discussed.

## 3.3 Methodological development

### 3.3.1 Data gathering

FruitLook has been available for the Robertson area since 2015, therefore an effort was made to gather soil probe and climate data between 2015 and early 2019. In addition, FruitLook is only available for the growing season, September to April, and therefore all comparisons were made for these months only.

*Soil probes*
Of the 22 farmers that use probes for scheduling, 16 of them specifically use Irricon's G100 continuous logging probes, therefore these probes were used in this study. Permission was obtained from six

farmers to access their probe data. All six were used at the start of the analysis, but only the most accurate one was used for further development, comparisons and discussions. Problems and shortfalls of the other five probes are discussed.

The Irricon probes are continuous logging capacitance meters. The probe logs soil water at five levels. The operating system then combines it into an average for management purposes. The farmer sets his full and refill lines on the system, where after he can see four management categories, from red being too dry and blue being too wet (see Figure 32).

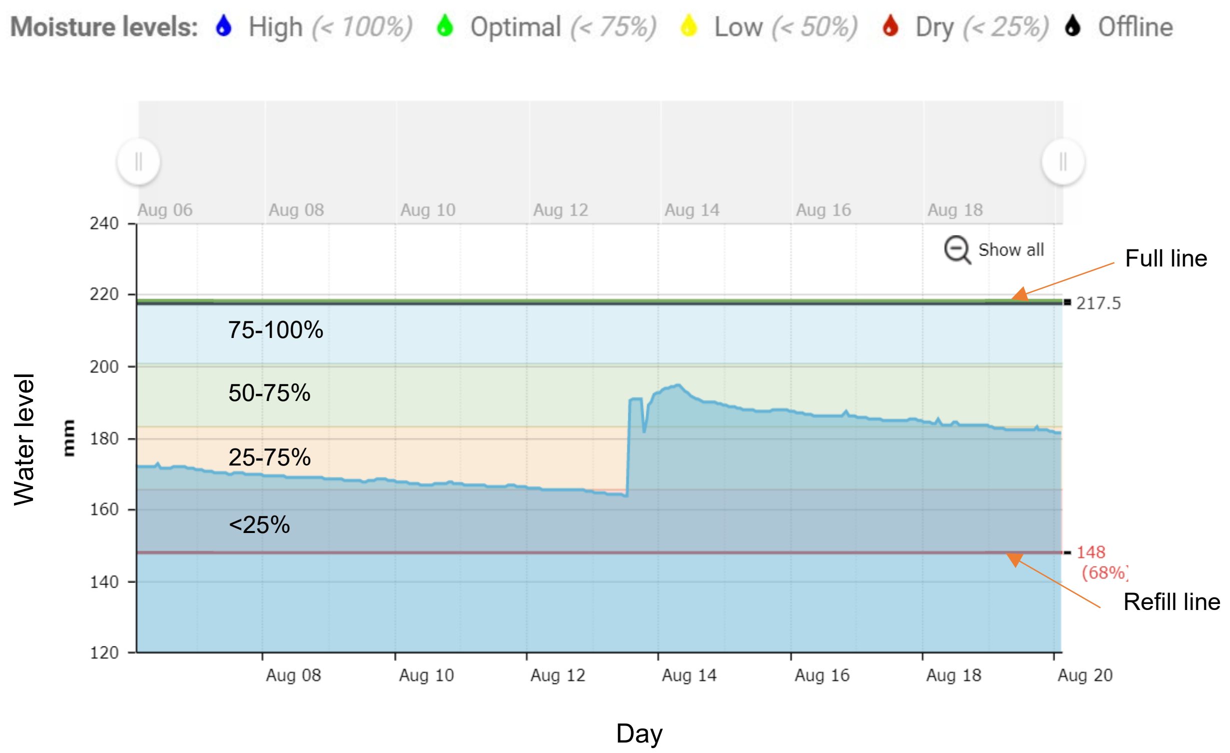


**Figure 32**: What the Irricon interface looks like, with saturated zones for management. Farmers and the developer set the refill line together.

While the logger is accurate, it amplifies the water level to make it visually readable to the farmer as per the graph below. The factor by which the water levels are multiplied depends on the soil type. This was further explored in the analysis in order to make the readings comparable to ET and FruitLook water values.

*Irrigation data*

Irrigation records were obtained from two of the farmers for the blocks corresponding to the probe data.

*Weather data*

There are numerous automatic weather stations in the Robertson area. Most are owned by Hortec (Pty) Ltd, some by the Agricultural Research council and only a few privately-owned stations. Hourly data were purchased from the two institutions from 2015 to January 2019 to correspond with the six probes and FruitLook data. The weather stations were all between 1km and 5km away from the probes.

*FruitLook data*

All FruitLook information is freely available to everyone. Data from the same field as the selected probes were found on the map function of FruitLook and downloaded (see Figure 33). FruitLook provides two ET values: $ET_{actual}$ is the actual evaporation and transpiration of the field, including that of the weeds; $ET_{deficit}$ is the difference between the potential ET (ideal condition) and the actual ET. $ET_{actual}$ plus $ET_{deficit}$ is therefore the ideal ET (i.e. $ET_{ideal}$) that a farmer should strive to achieve. Both $ET_{actual}$ and $ET_{ideal}$ are used for comparisons.

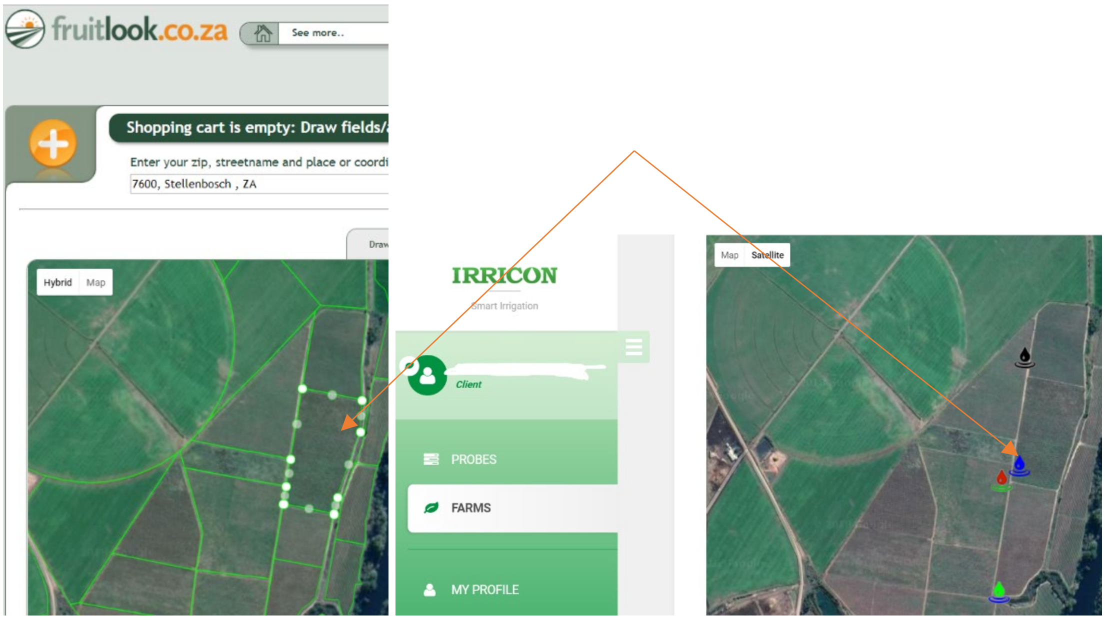


**Figure 33**: Using the map functions in FruitLook (left) and Irricon (right), the field on FruitLook that corresponds with the selected probe could be downloaded

### 3.3.2 Data consolidation

In order to make the data of the three chosen technologies comparable, the data had to be reworked so all three datasets could be presented in the same format and displayed next to each other for interpretation. The hourly soil probe and weather station data had to be aligned with the weekly FruitLook values. It was decided to use Excel for this, as farmers generally know the programme and would be able to use the template designed here.

<u>Creating soil water loss profiles:</u>

1. Using Excel, all soil water values for September to April, 2015 to January 2019, as well as $ET_0$ values were added to the same sheet.

2. Due to missing data points in the soil probe data, it had to be screened in order to align it with weather station hourly data, which had no or limited missing data points.
3. Soil water loss per hour was calculated.
4. In order to obtain a soil water loss profile over time, irrigation events (plus 5 hours after the event to compensate for peak infiltration) were removed from the hourly readings. Figure 34 illustrates the data points that were used to obtain the water loss profile.

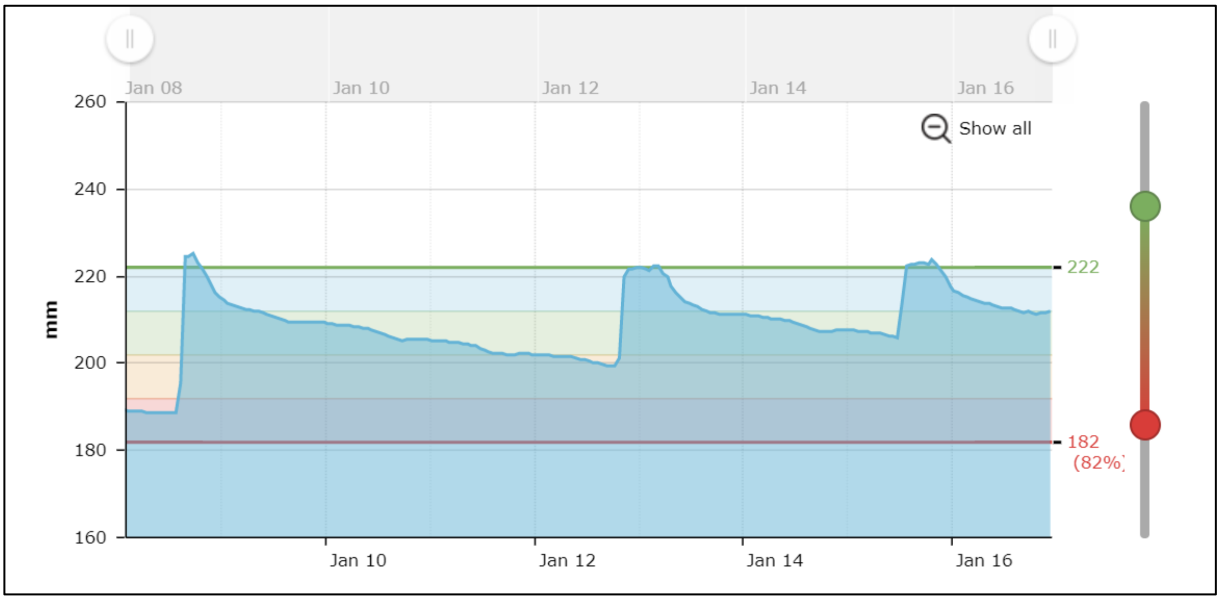


**Figure 34**: The red arrows illustrate which data points were used to calculate a continuous soil water loss profile over time

5. All negative values (i.e. water additions) in the soil water loss profile were removed, together with an additional 5 hours after the irrigation event to compensate for the peak infiltration (see Table 14, column *"Avg loss – irrigation").*
6. Averages for each hour per month were calculated (see below pivot table) and returned to all the empty cells of the soil water loss profile (see Table 15, column *"Averages returned").*

**Table 14**: Excerpt of Excel sheet to calculate continuous soil water loss profile

| Hour | Month | Date/time | Rain mm | Avg mm | Avg loss (mm) | Avg loss - irrigation | Averages returned | ETo mm |
|---|---|---|---|---|---|---|---|---|
| 3 | 12 | 2015/12/14 03:00 | 0.00 | 157.525 | 0 | 0 | 0.00 | 0.00 |
| 4 | 12 | 2015/12/14 04:00 | 0.00 | 157.425 | 0.1 | 0.1 | 0.10 | 0.00 |
| 5 | 12 | 2015/12/14 05:00 | 0.00 | 157.45 | -0.025 | | 0.15 | 0.00 |
| 6 | 12 | 2015/12/14 06:00 | 0.00 | 157.3 | 0.15 | | 0.14 | 0.00 |
| 7 | 12 | 2015/12/14 07:00 | 0.00 | 157.225 | 0.075 | | 0.20 | 0.07 |
| 8 | 12 | 2015/12/14 08:00 | 0.00 | 161.825 | -4.6 | | 0.41 | 0.19 |
| 9 | 12 | 2015/12/14 09:00 | 0.00 | 175.075 | -13.25 | Irrigation event | 0.67 | 0.33 |
| 10 | 12 | 2015/12/14 10:00 | 0.00 | 189.6 | -14.525 | | 0.86 | 0.45 |
| 11 | 12 | 2015/12/14 11:00 | 0.00 | 190.025 | -0.425 | | 1.07 | 0.58 |
| 12 | 12 | 2015/12/14 12:00 | 0.00 | 190.125 | -0.1 | | 1.16 | 0.66 |
| 13 | 12 | 2015/12/14 13:00 | 0.00 | 190.475 | -0.35 | | 1.22 | 0.71 |
| 14 | 12 | 2015/12/14 14:00 | 0.00 | 189.425 | 1.05 | | 1.24 | 0.73 |
| 15 | 12 | 2015/12/14 15:00 | 0.00 | 188.2 | 1.225 | | 1.28 | 0.68 |
| 16 | 12 | 2015/12/14 16:00 | 0.00 | 187.325 | 0.875 | | 1.23 | 0.58 |
| 17 | 12 | 2015/12/14 17:00 | 0.00 | 185.825 | 1.5 | | 1.08 | 0.49 |
| 18 | 12 | 2015/12/14 18:00 | 0.00 | 184.9 | 0.925 | 0.925 | 0.92 | 0.40 |
| 19 | 12 | 2015/12/14 19:00 | 0.00 | 184.25 | 0.65 | 0.65 | 0.65 | 0.24 |
| 20 | 12 | 2015/12/14 20:00 | 0.00 | 183.825 | 0.425 | 0.425 | 0.43 | 0.11 |

**Table 15**: Pivot table of hourly averages

| Hours: | Jan | Feb | March | April | May | June | July | Aug | Sept | Oct | Nov | Dec | Grand Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0.13 | 0.16 | 0.13 | 0.12 | | | | | 0.18 | 0.14 | 0.12 | 0.14 | 0.14 |
| 1 | 0.14 | 0.16 | 0.13 | 0.10 | | | | | 0.17 | 0.15 | 0.10 | 0.15 | 0.14 |
| 2 | 0.13 | 0.15 | 0.12 | 0.11 | | | | | 0.17 | 0.15 | 0.09 | 0.15 | 0.14 |
| 3 | 0.14 | 0.16 | 0.12 | 0.11 | | | | | 0.13 | 0.12 | 0.11 | 0.16 | 0.13 |
| 4 | 0.15 | 0.16 | 0.13 | 0.10 | | | | | 0.12 | 0.14 | 0.12 | 0.14 | 0.13 |
| 5 | 0.14 | 0.14 | 0.12 | 0.09 | | | | | 0.13 | 0.12 | 0.12 | 0.15 | 0.13 |
| 6 | 0.16 | 0.16 | 0.09 | 0.11 | | | | | 0.10 | 0.12 | 0.13 | 0.14 | 0.13 |
| 7 | 0.17 | 0.17 | 0.12 | 0.10 | | | | | 0.10 | 0.11 | 0.15 | 0.20 | 0.15 |
| 8 | 0.28 | 0.21 | 0.12 | 0.12 | | | | | 0.08 | 0.21 | 0.33 | 0.41 | 0.23 |
| 9 | 0.51 | 0.47 | 0.21 | 0.10 | | | | | 0.10 | 0.38 | 0.58 | 0.67 | 0.42 |
| 10 | 0.78 | 0.72 | 0.39 | 0.27 | | | | | 0.13 | 0.50 | 0.69 | 0.86 | 0.60 |
| 11 | 1.04 | 0.87 | 0.52 | 0.42 | | | | | 0.17 | 0.58 | 0.84 | 1.07 | 0.76 |
| 12 | 1.13 | 1.04 | 0.62 | 0.50 | | | | | 0.18 | 0.54 | 0.94 | 1.16 | 0.84 |
| 13 | 1.18 | 1.14 | 0.65 | 0.61 | | | | | 0.13 | 0.59 | 1.01 | 1.22 | 0.90 |
| 14 | 1.29 | 1.15 | 0.68 | 0.55 | | | | | 0.21 | 0.63 | 1.03 | 1.24 | 0.93 |
| 15 | 1.26 | 1.15 | 0.69 | 0.58 | | | | | 0.21 | 0.64 | 1.00 | 1.28 | 0.93 |
| 16 | 1.11 | 1.13 | 0.67 | 0.55 | | | | | 0.24 | 0.63 | 0.97 | 1.23 | 0.88 |
| 17 | 1.00 | 1.03 | 0.61 | 0.54 | | | | | 0.27 | 0.55 | 0.85 | 1.08 | 0.79 |
| 18 | 0.79 | 0.79 | 0.45 | 0.38 | | | | | 0.24 | 0.38 | 0.53 | 0.81 | 0.59 |
| 19 | 0.55 | 0.58 | 0.29 | 0.22 | | | | | 0.17 | 0.25 | 0.35 | 0.51 | 0.39 |
| 20 | 0.33 | 0.31 | 0.18 | 0.17 | | | | | 0.20 | 0.18 | 0.21 | 0.29 | 0.24 |
| 21 | 0.19 | 0.20 | 0.15 | 0.11 | | | | | 0.19 | 0.15 | 0.15 | 0.17 | 0.17 |
| 22 | 0.14 | 0.17 | 0.14 | 0.16 | | | | | 0.17 | 0.16 | 0.12 | 0.15 | 0.15 |
| 23 | 0.14 | 0.17 | 0.15 | 0.13 | | | | | 0.16 | 0.17 | 0.12 | 0.14 | 0.15 |
| **Grand Total** | **0.52** | **0.50** | **0.31** | **0.24** | | | | | **0.16** | **0.32** | **0.45** | **0.55** | **0.41** |

7. At this point, the soil water loss profiles were checked against the $ET_0$ data to determine the accuracy and usability of the probe data. The hourly averages of the soil water loss were compared with the hourly averages of the weather station ET values (see Figure 35 below).

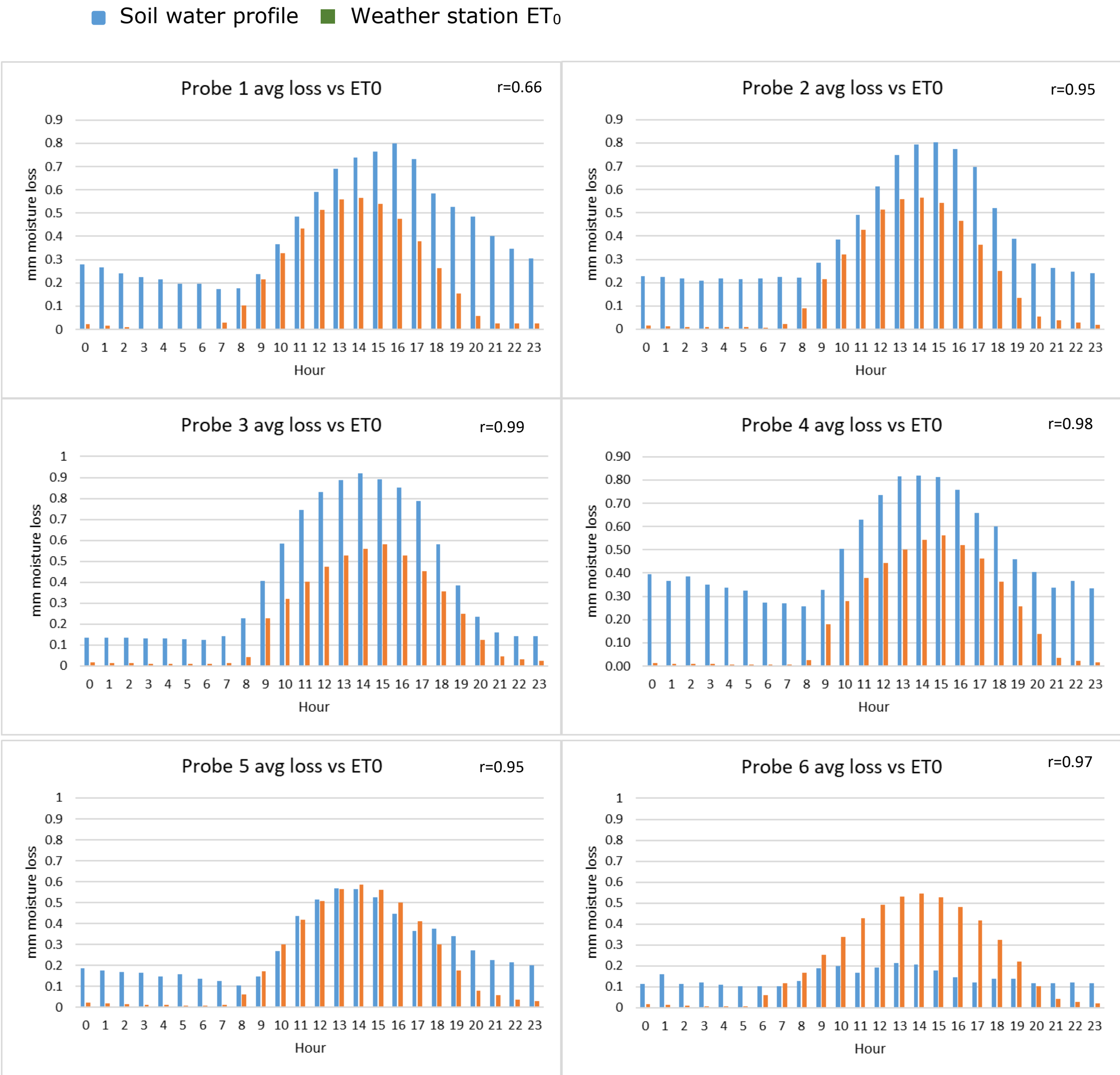


**Figure 35**: Results of plotting the continuous water loss profiles of the probes against weather station $ET_0$

Probe 3 is the most accurate in relation to the weather station ET and has the least amount gaps in the dataset. Therefore, only this probe was chosen for further methodological development. The reasons for the inaccurate data of the other probes are unclear – it could be faults with the probes in the field, or a fault on the server of Irricon. This will be discussed with the developer.

Probe 3 is situated in a block of plums, approximately 5 km from the nearest weather station for which data could be obtained. Irrigation data for this block in particular was not available, but data for an adjacent block with the same cultivar and soil type were available, and were therefore deemed adequate for the analyses. The block is covered by nets, which is expected to impact on the FruitLook readings. It is irrigated with mountain water, not water from the river or irrigation scheme.

$ET_c$ and FruitLook data preparation:

8. For the $ET_c$ values, FAO 56 Kc (Allen et al., 1998) values for plums were used as per Table 16.

**Table 16**: FAO56 Kc values for plums

| | | |
|---|---|---|
| September | 0.55 | Kc ini |
| October-March | 0.90 | Kc mid |
| April | 0.65 | Kc end |

9. Weekly $ET_{actual}$ and $ET_{ideal}$ ($ET_{actual}$ + $ET_{deficit}$) values from FruitLook were added to the dataset. The hourly soil water loss and weather station ET values for the week preceding each FruitLook reading were added to correspond to the weekly FruitLook data points (Tables 17 and 18).

**Table 17**: Excerpt of calculation of weekly values for the hourly soil water and ET values. The blue line represents the weekly FruitLook values in relation to the hourly soil probe and weather station data

| Hour | Month | Date/time | FL ETactual | FL ETdeficit | FL# | Averages returned | SUM avgs | ETo mm | ET o sum | ETC | ET c sum |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 11 | 12 | 2015/12/18 11:00 | | | | 1.400 | | 0.650 | | 0.585 | |
| 12 | 12 | 2015/12/18 12:00 | | | | 1.350 | | 0.760 | | 0.684 | |
| 13 | 12 | 2015/12/18 13:00 | | | | 1.650 | | 0.840 | | 0.756 | |
| 14 | 12 | 2015/12/18 14:00 | | | | 1.725 | | 0.860 | | 0.774 | |
| 15 | 12 | 2015/12/18 15:00 | | | | 1.650 | | 0.820 | | 0.738 | |
| 16 | 12 | 2015/12/18 16:00 | | | | 1.650 | | 0.740 | | 0.666 | |
| 17 | 12 | 2015/12/18 17:00 | | | | 1.300 | | 0.600 | | 0.540 | |
| 18 | 12 | 2015/12/18 18:00 | | | | 1.050 | | 0.440 | | 0.396 | |
| 19 | 12 | 2015/12/18 19:00 | | | | 0.400 | | 0.280 | | 0.252 | |
| 20 | 12 | 2015/12/18 20:00 | | | | 0.300 | | 0.150 | | 0.135 | |
| 21 | 12 | 2015/12/18 21:00 | | | | 0.025 | | 0.080 | | 0.072 | |
| 22 | 12 | 2015/12/18 22:00 | | | | 0.125 | | 0.080 | | 0.072 | |
| 23 | 12 | 2015/12/18 23:00 | 22.090 | 8.440 | 1.000 | 0.200 | 97.601 | 0.040 | 41.390 | 0.036 | 37.251 |
| 0 | 12 | 2015/12/19 00:00 | | | | 0.000 | | 0.030 | | 0.027 | |
| 1 | 12 | 2015/12/19 01:00 | | | | 0.200 | | 0.010 | | 0.009 | |
| 2 | 12 | 2015/12/19 02:00 | | | | 0.075 | | 0.000 | | 0.000 | |
| 3 | 12 | 2015/12/19 03:00 | | | | 0.050 | | 0.000 | | 0.000 | |
| 4 | 12 | 2015/12/19 04:00 | | | | 0.138 | | 0.000 | | 0.000 | |
| 5 | 12 | 2015/12/19 05:00 | | | | 0.151 | | 0.000 | | 0.000 | |
| 6 | 12 | 2015/12/19 06:00 | | | | 0.142 | | 0.000 | | 0.000 | |
| 7 | 12 | 2015/12/19 07:00 | | | | 0.199 | | 0.080 | | 0.072 | |
| 8 | 12 | 2015/12/19 08:00 | | | | 0.407 | | 0.200 | | 0.180 | |

**Table 18**: Excerpt of dataset with weekly values

| Date/time | FL# | FL ETactua | FL ETdefic | FL ideal | SUM avgs | ET 0 sum | ET c sum |
|---|---|---|---|---|---|---|---|
| 2015/12/18 23:00 | 1 | 22.09 | 8.44 | 30.53 | 97.60134 | 41.39 | 37.251 |
| 2015/12/22 23:00 | 2 | 22.67 | 5.71 | 28.38 | 51.87345 | 23.35 | 38.952 |
| 2016/01/08 23:00 | 3 | 29.06 | 2.79 | 31.85 | 90.19351 | 40.64 | 36.576 |
| 2016/01/15 23:00 | 4 | 28.51 | 1.4 | 29.91 | 81.20624 | 38.53 | 34.677 |
| 2016/01/22 23:00 | 5 | 30.33 | 1.56 | 31.89 | 83.18503 | 39.67 | 35.703 |
| 2016/01/29 23:00 | 6 | 33.66 | 0.74 | 34.4 | 97.00331 | 37.75 | 33.975 |
| 2016/02/05 23:00 | 7 | 29.78 | 5.64 | 35.42 | 85.63816 | 35.64 | 32.076 |
| 2016/02/12 23:00 | 8 | 35.47 | 0.74 | 36.21 | 101.5493 | 40.61 | 36.549 |
| 2016/02/19 23:00 | 9 | 36.07 | 0.71 | 36.78 | 88.50699 | 38.59 | 34.731 |
| 2016/02/26 23:00 | 10 | 31.8 | 0.48 | 32.28 | 81.94922 | 34.23 | 30.807 |
| 2016/03/04 23:00 | 11 | 32.77 | 3.32 | 36.09 | 79.77712 | 39.41 | 35.469 |
| 2016/03/11 23:00 | 12 | 20.43 | 2.15 | 22.58 | 61.18389 | 25.2 | 22.68 |
| 2016/03/18 23:00 | 13 | 19.57 | 0.81 | 20.38 | 61.62542 | 27.66 | 24.894 |
| 2016/03/25 23:00 | 14 | 16.14 | 1.06 | 17.2 | 53.66432 | 22.97 | 20.673 |
| 2016/04/01 23:00 | 15 | 21.3 | 5.11 | 26.41 | 53.21344 | 31.3 | 27.195 |

## 3.4 Analysis

### 3.4.1 Comparison between ET, FruitLook and soil water loss

Correlations were done of the weekly values of FruitLook $ET_{actual}$, FruitLook $ET_{ideal}$, $ET_0$, $ET_c$ and soil water loss (Table 18).

**Table 19**: Correlation of all values

| **Correlations (r)** | FruitLook $ET_{actual}$ | FruitLook $ET_{ideal}$ | $ET_0$ | $ET_c$ |
|---|---|---|---|---|
| FruitLook $ET_{ideal}$ | 0.97 | | | |
| $ET_0$ | 0.85 | 0.86 | | |
| $ET_c$ | 0.83 | 0.87 | | |
| Soil water | 0.79 | 0.82 | 0.82 | 0.84 |

As discussed earlier, the probe's system amplifies the mm with a factor to visually show the effect of irrigation for management tool. All the soil water readings have to be multiplied by this factor in order to obtain the actual water level (not adapted for visual management purposes). To determine an estimate of this factor, weather station data was used. Based on weekly correlations between soil water loss measurements and the other values, the highest correlation with the soil water factor, is $ET_c$. Dividing $ET_c$ by the soil water readings gave a factor of 0.46. The soil water readings were corrected accordingly (Table 20 and Figure 36). The "soil factor" therefore represents the actual soil water loss data.

**Table 20**: The weekly averages of all measurements, also showing the corrected soil water reading (soil factor)

| *(mm/week)* | **FL $ET_{actual}$** | **FL $ET_{ideal}$** | **Soil** | **$ET_0$** | **$ET_c$** | **Soil factor** |
|---|---|---|---|---|---|---|
| **Sept** | 12.983 | 13.472 | 23.621 | 21.887 | 13.28242 | 10.912 |
| **Oct** | 20.543 | 22.824 | 50.174 | 32.600 | 27.7685 | 23.180 |
| **Nov** | 24.591 | 25.580 | 75.774 | 40.250 | 35.70943 | 35.006 |
| **Dec** | 29.432 | 31.317 | 87.160 | 40.240 | 37.3266 | 40.266 |
| **Jan** | 31.594 | 32.868 | 91.955 | 41.981 | 37.5336 | 42.481 |
| **Feb** | 32.486 | 33.781 | 90.019 | 38.377 | 34.53943 | 41.587 |
| **Mar** | 23.069 | 24.246 | 56.149 | 29.573 | 26.61525 | 25.940 |
| **April** | 16.660 | 18.059 | 44.028 | 26.181 | 18.25844 | 20.340 |

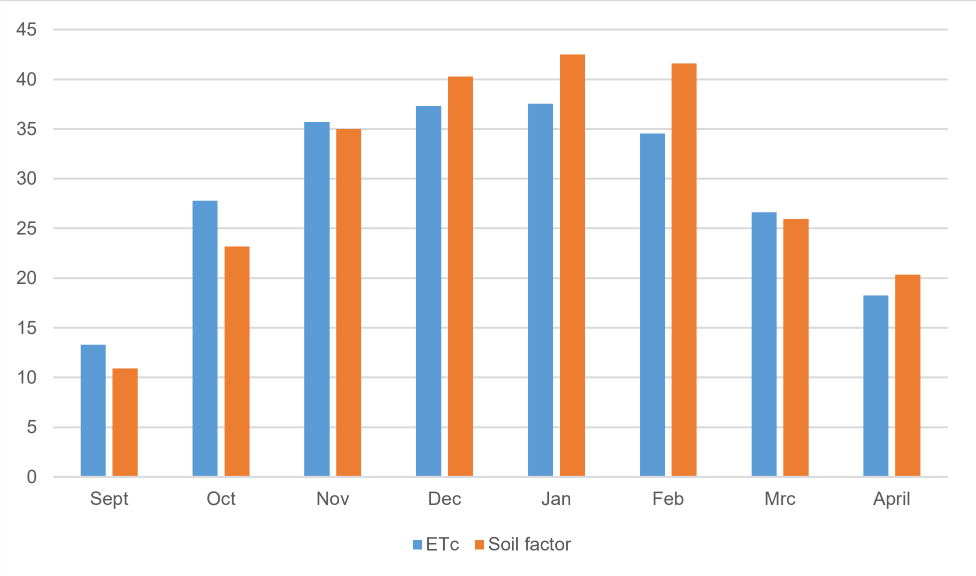

**Figure 36**: The correlation between the soil water factor and $ET_c$

Correlations were done between FruitLook $ET_{actual}$, FruitLook $ET_{ideal}$, $ET_0$, $ET_c$ and the soil water readings (corrected and original) (Table 21 and Figure 37). Table 20 shows fair correlations (>0.75) between the soil water readings and the other measurements, but not between FruitLook and the weather station. Figure 37 shows that FruitLook readings are much lower than the weather station and soil water data.

**Table 21**: Correlations of weekly values (65 weeks' data)

| *(r)* | **FL $ET_{actual}$** | **FL $ET_{ideal}$** | **$ET_0$** | **$ET_c$** |
|---|---|---|---|---|
| **$ET_{ideal}$** | 0.970575 | | | |
| **$ET_0$** | 0.737011 | 0.728775 | | |
| **$ET_c$** | 0.695039 | 0.712877 | | |
| **Soil** | 0.750655 | 0.778051 | 0.816379 | 0.769384 |
| **Soil factor** | 0.750655 | 0.778051 | 0.816379 | 0.769384 |

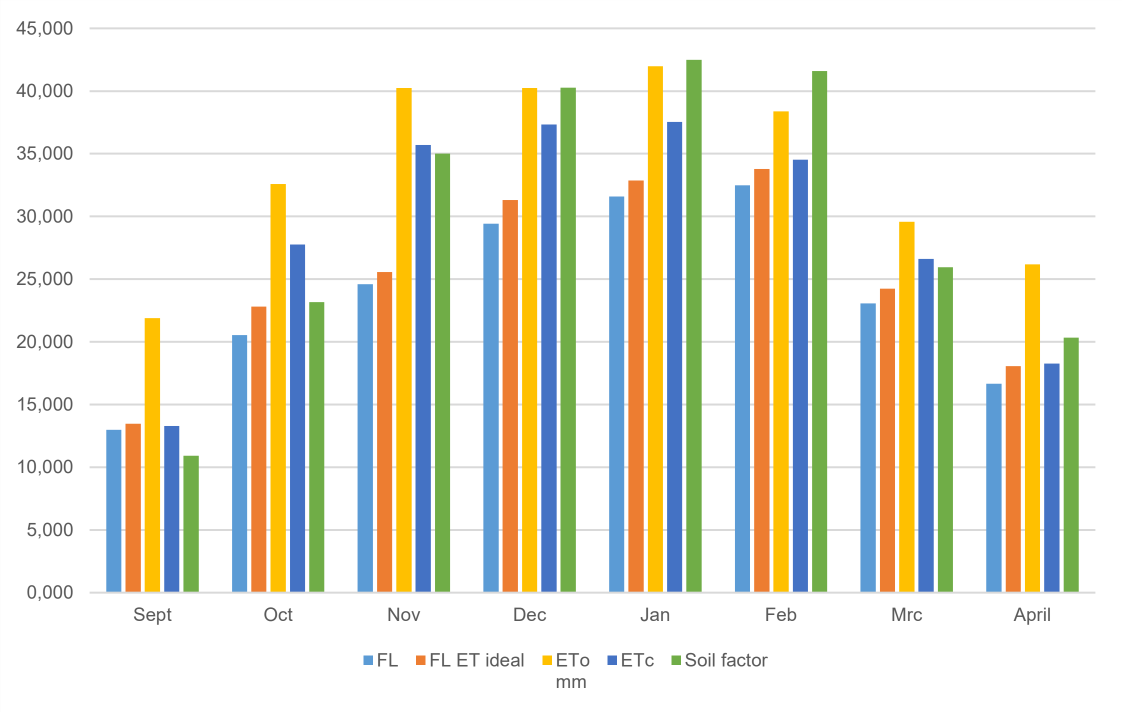


**Figure 37**: Comparison of the average weekly water loss per month for all measurements

### 3.4.2 Comparison of ET, FruitLook and soil water loss, with actual irrigation applied

The farmer's irrigation records are of total volume applied ($m^3$) per month per block, therefore all measurements had to be converted from weekly to monthly totals. The average weekly values per month, used in previous analysis, converted to average monthly values, which were then converted to $m^3$ per hectare (Table 22). Tables 22 and 23 show the correlation and comparison of each measurement against actual applied water, with an illustration of the differences in Figure 38.

**Table 22**: Monthly water loss ($m^3$ per hectare), together with the actual applied amount of water as per the farmer's irrigation record

| **($m^3$/1 ha)** | **FL $ET_{actual}$** | **FL $ET_{ideal}$** | **Soil water** | **$ET_0$** | **$ET_c$** | **Soil factor** | **APPLIED $m^3$/1 ha** |
|---|---|---|---|---|---|---|---|
| **Sept** | 556.429 | 577.357 | 1012.316 | 938.000 | 569.246 | 467.672 | **1300** |
| **Oct** | 909.776 | 1010.797 | 2222.008 | 1443.714 | 1229.748 | 1026.529 | **1500** |
| **Nov** | 1053.918 | 1096.286 | 3247.438 | 1725.000 | 1530.404 | 1500.260 | **1500** |
| **Dec** | 1303.417 | 1386.896 | 3859.945 | 1782.057 | 1653.035 | 1783.227 | **2000** |
| **Jan** | 1399.163 | 1455.583 | 4072.275 | 1859.159 | 1662.202 | 1881.320 | **2000** |
| **Feb** | 1299.429 | 1351.257 | 3600.766 | 1535.086 | 1381.577 | 1663.491 | **2000** |
| **Mar** | 1021.616 | 1073.763 | 2486.585 | 1309.639 | 1178.675 | 1148.759 | **900** |
| **April** | 714.000 | 773.946 | 1886.905 | 1122.054 | 782.504 | 871.717 | **900** |

**Table 23**: Correlation between all measurements and applied irrigation

| (r) | FL $ET_{actual}$ | FL $ET_{ideal}$ | Soil | $ET_0$ | $ET_c$ | Soil factor |
|---|---|---|---|---|---|---|
| **Applied** | 0.77 | 0.77 | 0.76 | 0.75 | 0.72 | 0.76 |

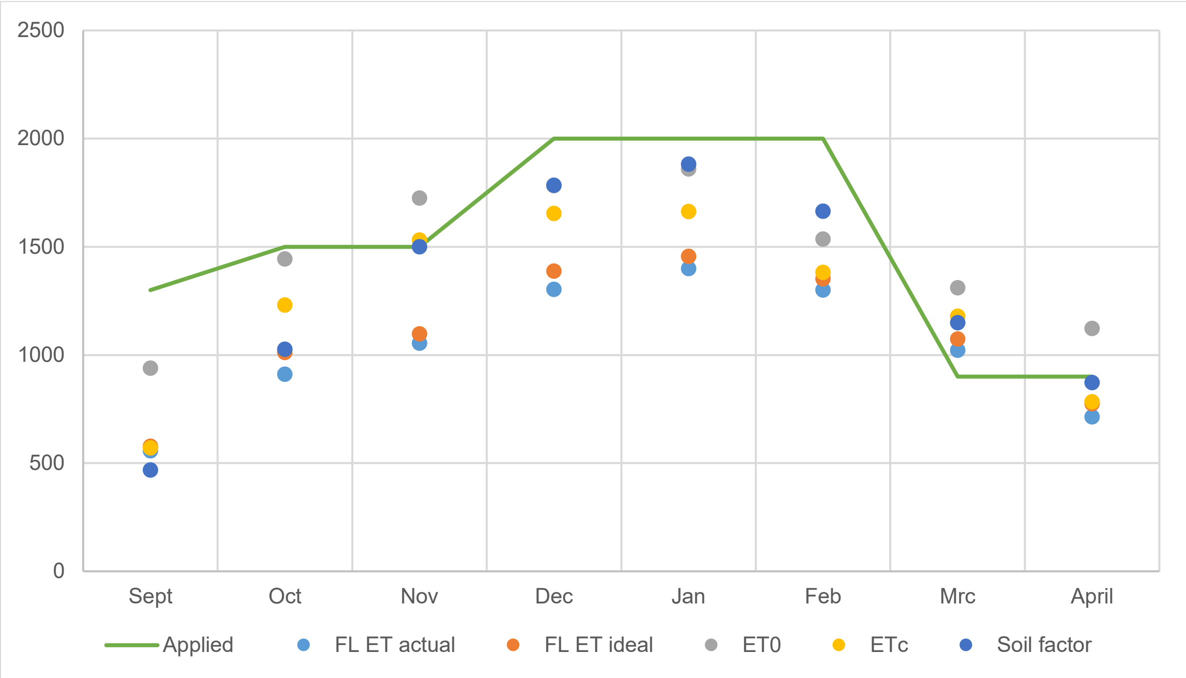


**Figure 38**: Comparison of all measurements (monthly m$^3$ per hectare) and applied irrigation

Although all values are fairly comparable (>0.75), except $ET_c$ and applied irrigation, Figure 38 shows that the FruitLook values are much lower than the applied irrigation. The farmer irrigates closer to $ET_0$. Table 24 presents the percentage over-irrigation in comparison with all the measurements.

**Table 24**: Percentage over-irrigation when compared to all measurements

| % | FL $ET_{actual}$ | FL $ET_{ideal}$ | $ET_0$ | $ET_c$ | Soil factor |
|---|---|---|---|---|---|
| **Sept** | 57.198 | 55.588 | 27.846 | 56.212 | 64.025 |
| **Oct** | 39.348 | 32.614 | 3.752 | 18.017 | 31.565 |
| **Nov** | 29.739 | 26.914 | -15.000 | -2.027 | -0.017 |
| **Dec** | 34.829 | 30.655 | 10.897 | 17.348 | 10.839 |
| **Jan** | 30.042 | 27.221 | 7.042 | 16.890 | 5.934 |
| **Feb** | 35.029 | 32.437 | 23.246 | 30.921 | 16.825 |
| **Mar** | -13.513 | -19.307 | -45.515 | -30.964 | -27.640 |
| **April** | 20.667 | 14.006 | -24.673 | 13.055 | 3.143 |

September and March present mixed results – September over-irrigation is possibly due to pre-season leaching, but the reason for what appears to be under-irrigation in March is unclear. When excluding these months, a peak season (October to February) average over-irrigation can be calculated as presented in Table 25.

**Table 25**: Peak season (Oct-Feb) average over/under-irrigation

| % | FL $ET_{actual}$ | FL $ET_{ideal}$ | $ET_0$ | $ET_c$ | Soil factor |
|---|---|---|---|---|---|
| Average % over-irrigation during peak months (Oct-Feb) | 33.80% | 29.97% | 5.99% | 16.23% | 13.03% |

According to FruitLook the farmer over-irrigates this block by approximately 30%. Irrigation applied is closest to $ET_0$, with $ET_c$ and the soil water levels showing 13% and 16% over-irrigation. **The lower ET values by FruitLook (and therefore higher over-irrigation by the farmer in relation to these values) can most likely be attributed to the orchard being under net cover**, illustrating that remote sensing cannot be used as a reliable estimate with shade netting. This is problematic seeing as the use of nets as water saving effort, is growing rapidly in the province.

Since this farmer receives clean mountain water and his orchard is under nets, it is possible that he over-irrigates and could cut his water consumption by at least 5% to correspond with $ET_0$.

## 3.5 Water budget for region

In order to determine the water budget for the irrigation area, each measurement used in the previous analysis has to be multiplied with the amount of plums in the study area. According to a 2017/2018 crop census conducted by the Western Cape Department of Agriculture (WCDA, 2018), there are 943 hectares of plums planted in the study area. Table 26 shows the water budget for plums in the catchment.

**Table 26**: Water budget for plums in the Robertson area

| $m^3$ water for 943 hectares of plums in Robertson valley | | | | | | |
|---|---|---|---|---|---|---|
| | FL $ET_{actual}$ | FL $ET_{ideal}$ | $ET_0$ | $ET_c$ | Soil factor | Applied |
| **Sept** | 524712 | 544448 | 884534 | 536799 | 441015 | 1225900 |
| **Oct** | 857919 | 953181 | 1361423 | 1159652 | 968017 | 1414500 |
| **Nov** | 993845 | 1033797 | 1626675 | 1443171 | 1414745 | 1414500 |
| **Dec** | 1229122 | 1307843 | 1680480 | 1558812 | 1681583 | 1886000 |
| **Jan** | 1319411 | 1372615 | 1753187 | 1567457 | 1774085 | 1886000 |
| **Feb** | 1225361 | 1274235 | 1447586 | 1302827 | 1568672 | 1886000 |
| **Mar** | 963384 | 1012558 | 1234990 | 1111491 | 1083280 | 848700 |
| **April** | 673302 | 729831 | 1058097 | 737902 | 822029 | 848700 |

The farmer whose probe and irrigation records were used in this study, irrigates closer to $ET_0$ than any other measurement. While this farmer is one of only a few that receive clean mountain water, most farmers in this area have to over irrigate to compensate for the highly saline water they receive from the irrigation scheme. This has to be incorporated in the planning for water distribution in the scheme. Therefore, it can be argued that $ET_0$ is a good reference to use as a conservative estimate for water budgeting at catchment level. Using FruitLook will only be possible should open blocks be used for these calculations, not blocks under shade netting. During water restrictions farmers need to receive at least the amount of water budgeted with soil water or $ET_c$ values.

## 3.6 SAPWAT analysis

SAPWAT 4 was developed to calculate irrigation water allocations, particularly for licensing of agricultural water use (Singels et al., 2010). It can also be used by farmers for pre-season irrigation planning (Van Heerden et al., 2001). According to Singels et al. (2010), there are 300 registered users in 14 countries, but none of the farmers or consultants interviewed in this case study have used this programme for their irrigation planning. The team had two researchers calculating the results for the farm independently. Both arrived at the same results, indicated in Figure 39.

Table 27 and Figure 40 show the SAPWAT results in relation to the other water requirement estimations. The results of the SAPWAT 4 analysis are much lower than all the other water requirement estimations. The reason for this could be found in the general shift in monthly ET calculated in the 1950 to 1991 data used in SAPWAT, to the recent climate data used form a new weather station in the region. This fact is highly debatable and the mismatch is placing a question mark behind the usability of SAPWAT. The result can also indicate a climate change impact, but finding the truth is perhaps a discussion for a follow-up project.

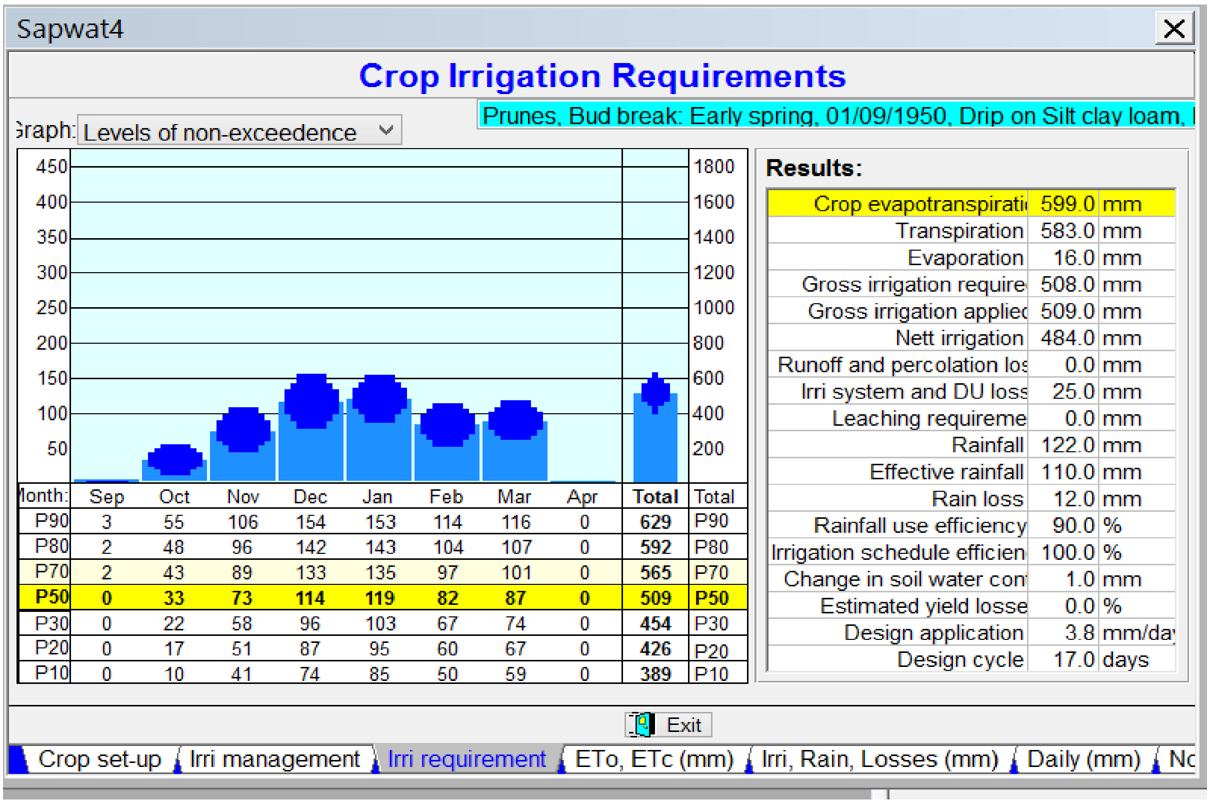


**Figure 39**: The results of the SAPWAT 4 water budget

**Table 27**: Comparison of SAPWAT 4 monthly mm results, with all measurements and applied irrigation (P= percentiles of total irrigation amounts to be applied)

| | | | | SAPWAT calculations | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **mm** | **$ET_0$** | **$ET_c$** | **Soil factor** | **P10** | **P20** | **P30** | **P50** | **P70** | **P80** | **P90** |
| **Sept** | 94 | 57 | 47 | 0 | 0 | 0 | 0 | 2 | 2 | 3 |
| **Oct** | 144 | 123 | 103 | 10 | 17 | 22 | 33 | 43 | 48 | 55 |
| **Nov** | 173 | 153 | 150 | 41 | 51 | 58 | 73 | 89 | 96 | 106 |
| **Dec** | 178 | 165 | 178 | 74 | 87 | 96 | 114 | 133 | 142 | 154 |
| **Jan** | 186 | 166 | 188 | 85 | 95 | 103 | 119 | 135 | 143 | 153 |
| **Feb** | 154 | 138 | 166 | 50 | 60 | 67 | 82 | 97 | 104 | 114 |
| **Mar** | 131 | 118 | 115 | 59 | 67 | 74 | 87 | 101 | 107 | 116 |
| **April** | 112 | 78 | 87 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

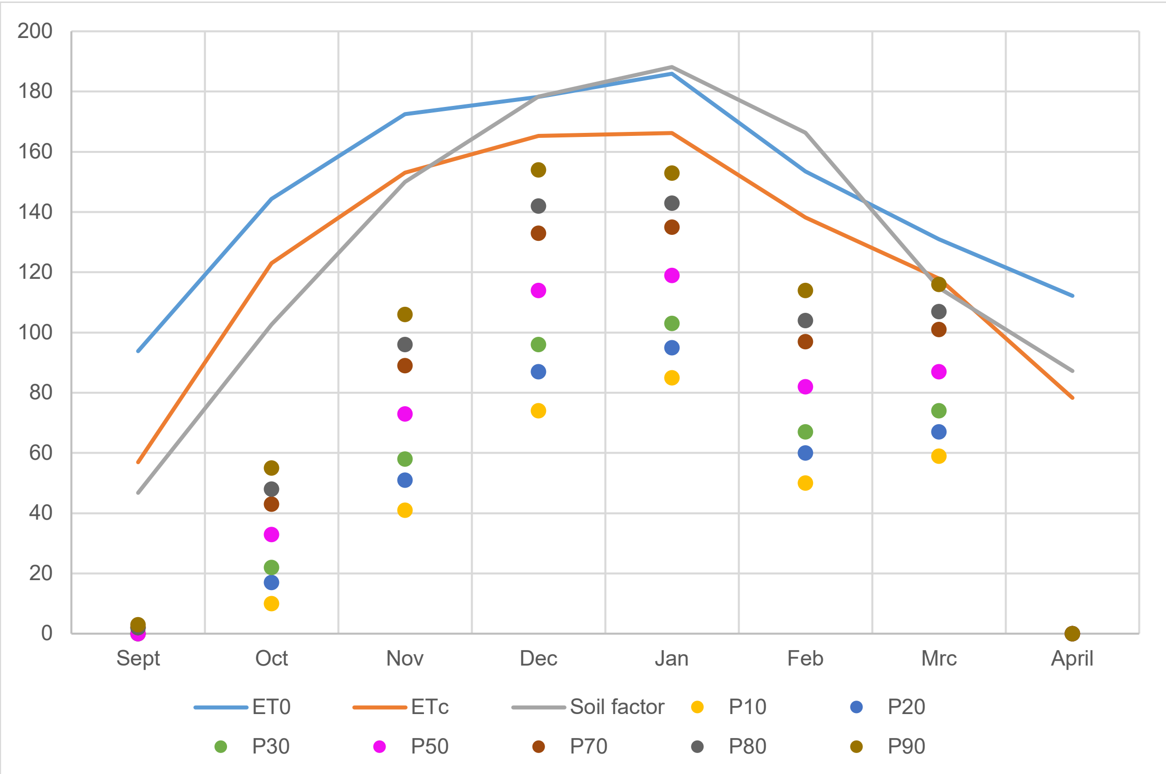


**Figure 40**: Monthly water mm water loss for all measurements, including SAPWAT4

## 3.7 Discussion

The first part of the discussion focuses on challenges experienced during the data analysis.

The first challenge is that the detailed, hourly probe data are not directly available to farmers – it has to be obtained from the developer, and it takes time for the developer to pull the data from the server. This could hinder farmers' interest in looking at the probe data in more depth as done in this study.

Aligning the hourly probe data with weather station data was challenging, as there were significant gaps in the probe datasets. Only one probe had sufficient continuous data to be deemed suitable enough for use in this study. It is not clear whether the probes are faulty, or the data are not being logged accurately on the server. Either way, this comparison showed that it will be useful for farmers to use weather station data to check the accuracy of the probe. Furthermore, it would be useful for farmers if the developer could provide them with the "soil factor" used to amplify the soil water readings on the user interface to ensure better accuracy in the analyses (instead of using $ET_c$ to make the correction).

Aligning the hourly weather station and probe data with weekly FruitLook data was also time-consuming. However, now that it has been done once, it would be possible to programme an Excel sheet for easy use by farmers, saving them many of the data management steps should they want to use this approach.

The analyses showed that soil water readings, when corrected, can be compared to remote sensing and weather station data. This comparison is by no means highly accurate, but it is representative of what farmers have available on their farms for decision-making and it illustrates that – with a slightly more refined approach – famers could be able to use one of the technologies to extrapolate to another, or to check accuracy against one another. Based on the results, the researchers would recommend to the farmers that they make the effort to use weather station and/or FruitLook data to cross-check their probe data (and vice versa), as it could improve their efficiency.

In 2010, the Department of Agriculture, Forestry and Fisheries published production guidelines for plums (DAFF, 2010), which includes recommendations for monthly irrigation. Comparing this recommended amount with all the measurements of this study (Tables 28 and 29, and Figure 41), the soil water and ETc values are closest to this recommended amount.

**Table 28**: All measurements compared to the DAFF (2010) recommended irrigation amount for plums

| $m^3$ | FL $ET_{actual}$ | FL $ET_{ideal}$ | $ET_0$ | $ET_c$ | Soil factor | Applied | SAPWAT P50 | Recom-mended |
|---|---|---|---|---|---|---|---|---|
| **Sept** | 556 | 577 | 938 | 569 | 468 | 1300 | 0 | 415 |
| **Oct** | 910 | 1011 | 1444 | 1230 | 1027 | 1500 | 330 | 840 |
| **Nov** | 1054 | 1096 | 1725 | 1530 | 1500 | 1500 | 730 | 1260 |
| **Dec** | 1303 | 1387 | 1782 | 1653 | 1783 | 2000 | 1140 | 1821 |
| **Jan** | 1399 | 1456 | 1859 | 1662 | 1881 | 2000 | 1190 | 1938 |
| **Feb** | 1299 | 1351 | 1535 | 1382 | 1663 | 2000 | 820 | 1627 |
| **Mar** | 1022 | 1074 | 1310 | 1179 | 1149 | 900 | 870 | 1185 |
| **April** | 714 | 774 | 1122 | 783 | 872 | 900 | 0 | 332 |

**Table 29**: Over or under estimation compared to the DAFF (2010) recommended irrigation amount

| % | FL $ET_{actual}$ | FL $ET_{ideal}$ | $ET_0$ | $ET_c$ | Soil factor | Applied | SAPWAT P50 |
|---|---|---|---|---|---|---|---|
| **Sept** | 34 | 39 | 126 | 37 | 13 | 213 | -100 |
| **Oct** | 8 | 20 | 72 | 46 | 22 | 79 | -61 |
| **Nov** | -16 | -13 | 37 | 21 | 19 | 19 | -42 |
| **Dec** | -28 | -24 | -2 | -9 | -2 | 10 | -37 |
| **Jan** | -28 | -25 | -4 | -14 | -3 | 3 | -39 |
| **Feb** | -20 | -17 | -6 | -15 | 2 | 23 | -50 |
| **Mar** | -14 | -9 | 11 | -1 | -3 | -24 | -27 |
| **April** | 115 | 133 | 238 | 136 | 163 | 171 | -100 |
| **Peak season average:** | **-16%** | **-11%** | **18%** | **5%** | **6%** | **18%** | **-42%** |

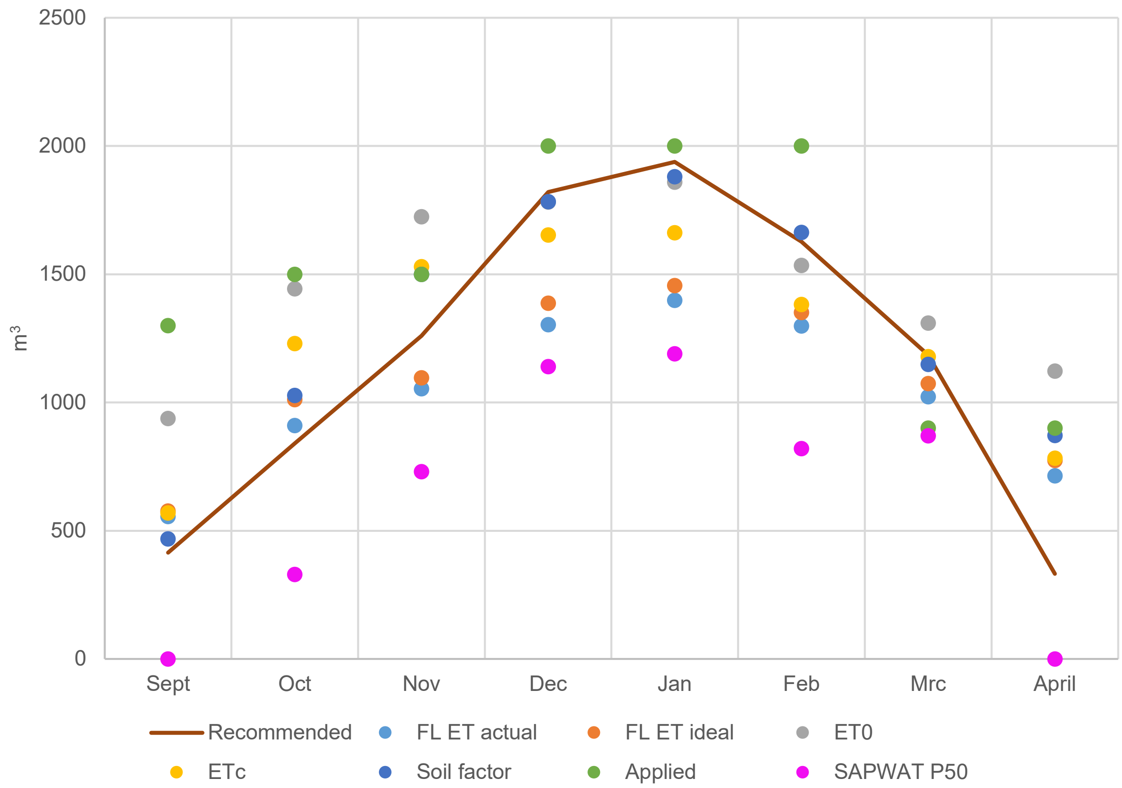


**Figure 41**: The DAFF (2010) recommended irrigation monthly amount plotted against all measurements of this study

The low FruitLook values obtained are most likely caused by the shade netting that covers the orchard. No literature could be found of a study looking particularly at this issue and it should be explored. As it stands, FruitLook cannot be used for water budgeting at a farm or regional level because of this issue and since the use of nets are increasing across the province, the issue would need to be addressed to keep FruitLook relevant.

For small farmers in South Africa that do not have access to much technology, it would be best to give free access to weather station ET data for water budgeting.

To compensate for salinity, it is recommended that $ET_0$ be used for water budgeting at catchment scale. At farm level, soil water probes and $ET_c$ can be used for budgeting conservatively, depending on the salinity of irrigation water received.

# 4 OVERALL CONCLUSION

As part of an international JPI project consortium, this study investigated technology uptake amongst farmers in the Central Breede River. It also compared their chosen irrigation technology with remote sensing and weather station data to explore whether it would have been beneficial for them to use more than one technology.

Results showed that 83% of the farmers use some form of technology for irrigation scheduling, with the majority preferring soil water measurements. The most widely used type is the Irricon probes. In contrast to the results of many international studies, there is no relationship between technology uptake and age or farm size. The Western Cape Government's free remote sensing product, FruitLook, is widely heard of, but only 5 out of 33 persons in the study area have used it.

Based on farmers' feedback during the interviews, it can be concluded that the following are the main reasons for the successful uptake of soil water probes (specifically the Irricon probes) for irrigation scheduling:

- Farmers believe in its accuracy, as it corresponds with their field observations.
- It is affordable and they perceive it as good value for money. However, value for money is difficult to interpret, as FruitLook is a free service and is not being used.
- The user interface is easy to navigate and use as an everyday management tool.
- Post-installation, personal service is highly important to the farmers. They use this probe because they can phone the developer and ask for help when needed, and he will come to their farm if necessary (the service is localised).

The following factors are the main reasons for the poor use of FruitLook in the study area:

- Weekly data is considered too sparse to inform irrigation decision-making.
- It takes too much time to initially set up the fields.
- One technology for decision-making is enough for the farmers – using more than one with different timelines, a different interface and data that need to be interpreted separately from their probes is too time-consuming and not seen as worthwhile.
- FruitLook data does not always correspond with what the farmers observe in the field; there are factors (such as weeds) that need to be corrected before farmers will believe the results.
- It provides information that still needs to be interpreted and acted upon, it does not provide advice on how to solve the issues presented.
- Similar to the conclusion regarding post-installation service of probes, farmers are more likely to use the programme if someone will interpret everything for them and send them summaries and advice on how to act on the data.

These findings are important for the developers of new technology as it highlights that good quality and affordability are not guarantees for uptake – post-installation service (localisation) and perceived ease of use and usefulness are important factors that need to be investigated and targeted to enable uptake.

Based on the outcomes of the technology uptake survey, it was decided to compare soil water readings, FruitLook and weather station data. The purpose was not to do a scientific accuracy test, but rather to explore what farmers can do more with the technology already available to them, in a way that they will be able to do themselves.

Hourly probe data were obtained from six farms. The corresponding FruitLook data were downloaded and weather station data were purchased from six stations that are located closest to each probe (between 1 and 5 km away). The probe data were problematic as there were large gaps in the data. When comparing it to $ET_0$, data from only one probe was deemed good enough for use in further analyses. The reason for the poor-quality data is not clear, but will be discussed with the developer. With FruitLook providing weekly total ET values, all hourly data were added to get to weekly totals. The weekly comparison showed that data are comparable, however FruitLook values were much lower than the weather station and soil water readings. This could be attributed to the fact that the block being investigated is under shade nets. This analysis highlighted the importance of investigating in detail the impact of shade nets on FruitLook values, as an increasing amount of farmers are investing in nets for their orchards and as such are making FruitLook less usable for the wider region.

Further comparisons with applied irrigation, as well as DAFF recommended irrigation amounts for the crop, confirmed that soil water readings could be used as a water budgeting, planning tool, even at a regional level. However, the gaps and inconsistencies in the probe data suggest that it would be beneficial for farmers to use weather station data to check the accuracy of their probes. FruitLook could also be used for this, should the orchard not be covered with nets. It is the researchers' recommendation that farmers use this type of comparison to cross-check their chosen technology with others in order to ensure accuracy. In follow-up research, the comparative exercise could be done with more probes and for different crops to see how the field-level calculations differ from irrigation boards' water budgeting volumes.

This exercise showed that, should the approach be refined, it could be useful to use field-level measurements to extrapolate to an irrigation scheme level as it may create a more realistic picture of farmers' actual irrigation needs for the management of the scheme. This will be particularly important during times of restrictions, when different crops have different water requirements and a more refined approach in allocation could support farmers to manage better with the water available to them.

Lastly, despite numerous efforts the researchers could not reach results in SAPWAT that are comparable to that of the weather station or soil water readings. It is not certain what the reason for this difference is and this should perhaps be investigated further in a follow-up project.

# 5 SHORTCOMINGS AND RECOMMENDATIONS

Although a large percentage of farmers of this region was interviewed, results cannot be extrapolated across South Africa. As farmers alluded to, there is a measure of using the technology that their neighbours have tested and have found to work – it is possible that each sub-catchment could have a technology preference based on this principle. The results of technology uptake should, however, be a fair indication for the Western Cape. Repeating relevant parts of the survey in other regions will be useful for comparison and validation of the results. Nevertheless, the study provided important evidence of farmers' personal preferences for technology uptake and it could be assumed that the main findings (i.e. comparability of data, post-installation service, perceived usability and value) should be applicable to most farmers in the country.

There were large gaps in the probe data which led to only one out of the six probes being used in the comparative analysis with FruitLook and the weather station. This means that the approach could not be refined to the extent that was hoped for. The reasons for the data gaps and discrepancies will be discussed with the developer, as these will need to be addressed in order for farmers to adopt a template of the spreadsheet created in this study as a management tool.

Future research should be done with more probes to refine the approach into a usable management tool, although the work done here will already be useful for any farmer to evaluate his water application in relation to his probes, FruitLook and weather station information. Adding more probes to the analysis, placed in fields of different crops, will also be necessary to refine the catchment-level water budget approach. The analysis should be done for all the main crops planted in the area and the results compared to the water allocations and the distribution procedure of the irrigation board. Once this has been done, important recommendations could be made regarding water distribution during drought periods, to address the conflict that arose during this drought in the area regarding the distribution of water for crops' needs.

Another shortcoming was that the only usable probe was situated under shade nets. The research could, therefore, not show the real relation between FruitLook and the other two measurements. The study was useful in providing some evidence of the effect that shade nets has on remote sensing outputs and highlighting the importance of having this addressed in order to ensure the future success of the service.

It is important that the SAPWAT results be further investigated in a future study to determine why the results differed so much from the field measurements, FruitLook and weather station data. One possibility is the outdated climate data contained in SAPWAT as it ends in 1998. It could be useful to add a function in SAPWAT to import one's own local weather station data.

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# APPENDIX 1



## SECTION 1. General information

***Information is strictly confidential – names are only important for the researcher to organise and collate information.***

Name of interviewee:

Position of interviewee:

Farm/company name:

**Gender:** M ☐ F ☐

**Age:**

**Highest level of education:**

- Primary School ☐
- High School ☐
- Bachelors degree ☐
- Honours degree ☐
- Masters degree ☐
- PhD or equivalent experience ☐
- None ☐

**Farm location:** Nation: RSA Region: Bonnievale-Robertson

**Farm surface:** Total Agricultural Area (ha):

Utilized Agricultural Area (ha):

**What is the form of management of your farm?**

Direct management of the farmer ☐

- ✓ Are only family components involved? ☐
- ✓ Are you involving part of the family? ☐
- ✓ Are you involving professional workers? ☐

Salaried personnel 8

Management of the farm in rent

Other: ☐

**Sales channels and their percentage** (Please define % in one box)

- Wholesalers __________
- Retailers __________
- Food processing industry __________
- E-Commerce __________
- Food exchange (commodity exchange) __________
- Others: __________

**According with your experience, which actions could be important to increase the competitiveness of your farm into the market?**
*Please mark your answer (1-7) in the corresponding empty box:* **1** = Unimportant; **4** = Not so important; **7** = Very important.

- Renewal of existing production processes ____________________
- Introduction of innovative processes ____________________
- Product innovation ____________________
- Product improvement ____________________
- Increasing professionalism of management (course, stage, study visits) ____________________
- Increasing the size of farm (merge with other farms, rent or purchase) ____________________
- Organizational innovation ____________________
- Improving the marketing strategy of the product ____________________
- Improving the sustainability of the production process ____________________

**Do you have livestock activities?**

Yes ☐ No ☐

1.6.1 Which type & how many?

1.6.2 Reason:

Are you member of any environmental association (e.g. WWF, Cape Nature biodiversity stewardship) and/or do you take part in funded actions for environmental protection?

Yes ☐ No ☐

Has your farm obtained any kind of certification?
(Environmental impact on soil, air and water)

Yes ☐ No ☐

Which one/s?

Are there any other certifications you are striving to accredit with? Which one/s?

## SECTION 2. Groundwater and soil information

**GROUNDWATER**

| | |
|---|---|
| Depth of water table (m) | |
| pH of groundwater | |
| Groundwater salinity (mS/m) | |

| | |
|---|---|
| Groundwater used for irrigation (L/season) | |

**SOILS**

| | |
|---|---|
| Type of soil/s on farm | |
| Effective depth (m) of irrigated soil | |
| Visible signs of salinity? If yes, please describe how you manage it | |

## SECTION 3. Crop selection

**What are the most important cultivated crops on your farm?**

Crop: (ha)
Crop: (ha)
Crop: (ha)
Crop: (ha)
Cultivar: (ha)
Cultivar: (ha)
Cultivar: (ha)
Cultivar: (ha)
Cultivar: (ha)

What are our reasons for planting these crops in particular?

Would you consider switching to other crops based on predicted climate changes? Please rate your flexibility to switch crops from 1 (not likely) to 5 (highly likely): What factors would influence you and convince you to switch to crops more suited to the area's climate?

What are the main limitations for adopting alternative crops/varieties?
*Scale of 1 (not relevant) to 5 (highly relevant)*

| | |
|---|---|
| Knowledge/advice on suitable alternative crops/varieties in relation with plant physiological requirements, soil and climate characteristics | |
| Economics (costs) | |
| Uncertainty of prediction on market demands | |
| *Other (Specify):* | |

## SECTION 4. Irrigation information

**What are your sources of water? (rough percentage for each)**

Groundwater (borehole):

River/stream:

Irrigation canal:

**Main irrigation systems** (Please select from the following list)

- Surface Irrigation ☐
- Sprinkler Irrigation ☐
- Micro ☐
- Drip or Trickle Irrigation ☐
- Sub-Surface Irrigation ☐

What irrigation scheduling techniques do you use? (please describe). What drives your decisions behind irrigation management? (e.g. intuition, crop requirements, consultants' advice etc.)

Did you change your irrigation practices during the drought?

Yes ☐ No ☐

**What are the main limitations for improving water efficiency in irrigation?**

| | |
|---|---|
| Economic/costs | |
| Administrative/legal limitations? | |
| *Other (Specify):* | |

**What are your preferred options to increase water efficiency?**
*Scale of 1 (not relevant) to 5 (highly relevant)*

| | |
|---|---|
| Increase on the crop density | |
| Improvement of the irrigation strategy | |
| Improvement of the field infrastructure | |
| Changes in the crop/variety selection | |

| | |
|---|---|
| *Other (Specify):* | |

## SECTION 5. Information technology

Among the following alternatives, **which <u>one</u> would you choose to define yourself**?

- ☐ I am a risk-averse person
- ☐ I am a risk-neutral person
- ☐ I am a risk-seeking person

**Please indicate how much you agree with each of the following statements:**

**1** = Strongly disagree (very untrue about me); **7** = Strongly agree (very true about me).

| | |
|---|---|
| ▪ "If I heard about a new technology, I would look for ways to experiment with it" | |
| ▪ "Among my peers, I am usually the first to try out new technologies" | |
| ▪ "I like to experiment with new technologies" | |

Have you been exposed to remote sensing/climate modelling information products?
*If yes, please describe*

| |
|---|
| Benefits/risks? |

Do you use any remote sensing or modelling products to inform your irrigation scheduling?

If you were to use remote-sensing or modelling products for information, how important are the following features to you in such a product?
*Please score on a scale of 1-5:*
1 = not important at all
5 = very important

| **Feature** | **Score (1-5)** | **Comments** |
|---|---|---|
| Price per hectare | | |
| Accuracy | | |
| Immediacy of information | | |
| Climate and weather information | | |
| Crop-related information (e.g. tolerances, diseases etc) | | |

| | | |
|---|---|---|
| Advice on water restrictions management/water distribution adjustments and predictions for season demand | | |
| Advice on alternative crops/varieties | | |
| Advice on costs associated to energy used for irrigation | | |
| Updates on government processes and legislation | | |
| Direct contact with agricultural extension officers | | |
| Direct contact with other farmers in the region (e.g. chat group) | | |

Name the main advantages and disadvantages of the information services you use/have used:

| Name | Main benefits/ advantages | Main problems/ disadvantages |
|---|---|---|
| | | |
| | | |
| | | |
| | | |

If you could start over with an irrigation strategy – on your farm and in the area – what would you do differently?

| |
|---|
| *In irrigation area:*<br><br>*On farm:* |

## SECTION 5. Collaboration

To which Water Users Association and/or Irrigation Board do you belong?

Do you participate in any formal or informal groups to collaborate on addressing shared challenges in the area?
*If yes, please describe*

Do you have regular or irregular contact with the Catchment Management Agency?
*Please describe your interaction with them*

What do you understand the role of the Catchment Management Agency to be?

Are you open to the idea of collaborating with other parties in your area (farmers, government, communities etc) to address shared water risks as a collective? YES / NO

What would you like to gain from such a collaboration if there was one?

# APPENDIX 2

## CAPACITY BUILDING

This work forms part of the PhD of Marlene de Witt, co-author of this report.

Mrs De Witt is in the process of registering for her PhD at Stellenbosch University. Additional funding to continue this work was secured mid-2019, at which point her topic could be finalised. As such the University advised her to register at the start of the 2020 academic year and not halfway through 2019.

# APPENDIX 3

**KNOWLEDGE DISSEMINATION**

1. **Conferences**

Some of the results of the South African case study was presented by Dr WP de Clercq at the following conference:

***Name of conference**:* GVSA congress 2019

***Date***: January 2019

***Title***: Conservation farming in irrigated agriculture

***Abstract***:

The largest problem in South Africa in most irrigated regions is that the demand for water is exceeding the supply, as surface water in most catchments are fully, or even over-allocated. Recent, prolonged droughts across most of South Africa since 2014 has been forcing water users to relook the efficiency of their farming systems. At a farm scale we need efficient irrigation on the correct soil type. We need farmers that measure irrigation volume and irrigation demand. We further need to measure water and soil water quality during irrigation. Farmers need to plan for irrigation during warm dry periods that may exceed the design criteria of their irrigation systems. In a regional context, we need water suppliers to optimally manage the quality of water distributed to farmers. The information of water quality supplied or available must also be available to the farmers for planning purposes. The concept of conservation farming in irrigated agriculture is often seen as a community-based approach, but the understanding by individual farmers are the key to the success of conservation farming. To be successful, farmers need a good knowledge base related to their soils and the plant water requirements. A recent survey among farmers in the Central Breede River Catchment found that farmers are interested in irrigation technology and most have made significant investments to improve their on-farm water efficiency, but willingness to change based on climate change predictions and water availability is still very low. . Farmers still mostly focus on short-term market demands rather than on long-term strategies to cope with declining water availability. Their investments in water-use efficiency are also mainly driven by the desire to expand their production ("more crop per drop"), rather than to save on actual water application. Although these farmers do to some extent follow the principles of conservation agriculture, the assumption that behavioural change in terms of water saving for long-term sustainability is occurring on farms, does not stand – at least not in this catchment. Still, research suggests that agriculture in the Western Cape will be most adaptable to predicted climate change impacts owing to (amongst other factors) the widespread infrastructure investments that have been made.

## 2. Publications

In addition to this conference presentation, the researchers are in the process of preparing papers for publication. The following abstracts are of papers that will be submitted to journals soon. **It is expected that the researchers will also contribute towards an additional one or two papers on the overall international work.**

### a) <u>Draft paper 1</u>

***Aimed date of submission**:* December 2019/January 2020

***Draft title**:* Testing the uptake of technology for irrigation scheduling amidst recurring drought conditions in the Central Breede River Valley, South Africa

***Authors**:* M. de Witt[a], W.P. de Clercq[a], F.J. Blanco Velazquez[b] and F. Altobelli[c]

[a] Stellenbosch University Water Institute (SUWI), Stellenbosch University, Western Cape, South Africa

[b] Evenor-Tech, Spain

[c] Council for Agricultural Research and Economics (CREA) – Research Centre for Policies and Bioeconomy, Italy

***Draft abstract**:*

The agricultural sector in South Africa has suffered tremendously under recurring droughts over the past decade, costing the economy billions of Rands. In semi-arid country where irrigation uses 64% of all surface water and the climate is drying, commercial farmers are expected to use the technology at their disposal to improve their irrigation efficiency. However, studies in the past decade suggested that technology uptake remains low, but the reasons for this have not been studied. The uptake of a free, government-funded remote sensing service in the Western Cape, called FruitLook, has also not been independently tested. This study sought to determine the personal reasons behind farmers' adoption or non-adoption of technology to improve their irrigation water-use efficiency and to discuss the outcomes in the context of international case studies and conceptual work on the topic. Better understanding South African farmers' reasoning in particular would be valuable in an international context given the current great need for water saving amidst recurring droughts. The case study area was chosen as the Central Breede River valley in the Western Cape, as farmers here have a long history of irrigation and exposure to technology, as well as access to FruitLook since 2014. In-depth interviews were conducted with 29 farmers, using the snowball sampling technique to identify interviewees. Technology uptake was high with 83% of the farmers using technology to inform their decision-making for irrigation scheduling. However, the only type of technology used is soil water measurement, and 75% of these persons using technology use the same type of soil water probe. While 88% of farmers have heard of FruitLook, only one farmer uses it for irrigation, with an additional two use it seasonally to understand their farms better and to look for bad spots in their fields. This study revealed four key reasons behind farmer' use of technology: 1) Too much information that come in different software packages and need

to interpreted separately are not practical. Developers who wish to introduce a new technology need to look at ways in which this new technology can integrate with and complement existing technologies in a specific area. 2) Farmers still place a high value on their personal experience and intuition. Any new product will have to be of very high perceived value and usefulness in order to be adopted successfully. 3) The personal interaction between the developer and his local client base plays a significant role in the success of a new product. 4) The management of an irrigation scheme and the availability of storage dams play a significant role in farmers' need for additional technology.

**b) Draft paper 2**

***Aimed date of submission**:* December 2019/January 2020

***Draft title**:* Conservation farming in irrigated agriculture

***Authors**:* W.P de Clercq and M. de Witt

***Abstract**:* *(paper from conference presentation)*

The largest problem in South Africa in most irrigated regions is that the demand for water is exceeding the supply, as surface water in most catchments are fully, or even over-allocated. Recent, prolonged droughts across most of South Africa since 2014 has been forcing water users to relook the efficiency of their farming systems. At a farm scale we need efficient irrigation on the correct soil type. We need farmers that measure irrigation volume and irrigation demand. We further need to measure water and soil water quality during irrigation. Farmers need to plan for irrigation during warm dry periods that may exceed the design criteria of their irrigation systems. In a regional context, we need water suppliers to optimally manage the quality of water distributed to farmers. The information of water quality supplied or available must also be available to the farmers for planning purposes. The concept of conservation farming in irrigated agriculture is often seen as a community-based approach, but the understanding by individual farmers are the key to the success of conservation farming. To be successful, farmers need a good knowledge base related to their soils and the plant water requirements. A recent survey among farmers in the Central Breede River Catchment found that farmers are interested in irrigation technology and most have made significant investments to improve their on-farm water efficiency, but willingness to change based on climate change predictions and water availability is still very low. . Farmers still mostly focus on short-term market demands rather than on long-term strategies to cope with declining water availability. Their investments in water-use efficiency are also mainly driven by the desire to expand their production ("more crop per drop"), rather than to save on actual water application. Although these farmers do to some extent follow the principles of conservation agriculture, the assumption that behavioural change in terms of water saving for long-term sustainability is occurring on farms, does not stand – at least not in this catchment. Still, research suggests that agriculture in the Western Cape will

be most adaptable to predicted climate change impacts owing to (amongst other factors) the widespread infrastructure investments that have been made.

c) **Draft paper 3**

***Aimed date of submission****:* February/March 2020

***Draft title****:* Towards the integration of irrigation technology outputs

***Authors****:* M. de Witt and W.P de Clercq

***Abstract****:*
With the impacts of climate change that is already being felt, the need for irrigation is increasing in areas where farmers' used to be able to rely on rainfall alone. Still, technology adoption for irrigation remains poor internationally. Recent work in South Africa, where 64% of all surface water is used for irrigation, revealed that adoption is over 80%, but that farmers choose to use only one type of technology, despite having had exposure and even free access to numerous good technologies. A key reason for this is that the different technologies offer different types of information, in different computer packages with different data outputs. Interpreting all this information separately and attempting to understand the different results in relation to the different technologies for in-field decision-making is considered too time consuming and therefore adopting a new technology – how useful it may be – is not worthwhile for the farmers. In order to get farmers to adopt new technology, the data outputs of the new products have to somehow talk to the data from the farmers' existing chosen technology so it can be interpreted collectively for decision-making. This study aimed to investigate whether the outputs from the most widely used technology in a chosen study area could be combined in a simple manner with two other technologies that are free and/or readily available to farmers, but that are not widely used. This was not a scientific exercise to compare the accuracy of any of the technologies, but rather an effort to explore whether and how these technologies can complement one another as decision-making tools. In the Central Breede River Valley in the Western Cape, South Africa, farmers widely use one specific type of soil water probe as scheduling tool. They also have affordable access to numerous weather stations in the area, as well as free access to a government-funded remote sensing service called FruitLook. The data from these three products from the same field over a four-year period was compared in a simple approach that could be replicated by farmers themselves. Data compared were hourly soil water readings from the soil probe (water loss over time), hourly $ET_0$ data from the nearest weather station ($ET_0$ using Penman-Monteith), and weekly $ET_{actual}$ data from FruitLook, derived from Sentinel 2 imagery and regional weather station data. The results showed a correlation in the data from the three technologies. This suggests that the tools could be used to cross-check accuracy of the products and create a better understanding of possible over- or under-irrigation, which could lead to water savings. Using in-field data in the proposed manner could also improve irrigation scheme management (crop-specific water allocation) during periods of water restriction.

**d) <u>Popular article</u>**

***Aimed date of submission***: February/March 2020

***Draft title***: Can farmers do more with the technology they already have?

***Authors***: M. de Witt and W.P de Clercq

***Topic***: Combination of articles a) and c) above.