Irrigation of potatoes

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Foreword

Although the potato is one of the crops that most effectively convert water into food, the plants are sensitive to water shortages from the time when the tubers are initiated, throughout the growing season until the fully-grown tubers are harvested. Over irrigation, on the other hand, is also not desirable because valuable water drains away, expensive nutrients leach from the root zone and the quality of the harvested product can be adversely affected.

Consequently, producers must have the necessary knowledge in order to decide when to irrigate, and how much to irrigate to produce the highest yield of quality potatoes. In addition, it is important that the irrigation system be optimally designed so that electricity is used efficiently to keep the cost of irrigation under control and so that water is applied optimally to promote the responsible use thereof.

This publication contains a number of short articles that discuss the principles of irrigation and irrigation scheduling. The articles were compiled by Prof. Martin Steyn of the University of Pretoria. Since the 1990s Prof. Steyn has been pioneering research on water requirements and irrigation scheduling of potatoes in South Africa. Although the research is to a large extent completed, he remains passionate about the role irrigation scheduling can play in South Africa to use our most scarce resource in a most sustainable way. He is consequently still involved in knowledge transfer about irrigation scheduling.

As the cost of electricity increases more than the rate of inflation, Potatoes South Africa is conducting case studies in different production regions to improve the efficiency of electricity and water use. Two articles in this publication illustrate what can be done to limit electricity costs.

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How big is the water footprint of potato?

Prof. Martin Steyn, University of Pretoria

South Africa in general is a dry country with poor rainfall distribution throughout the season and consequently water is one of our scarcest resources. Currently nearly 60% of all our fresh water is used to irrigate crops.

The local potato industry is also extremely dependent on available irrigation water, as potato is one of the most sensitive crops to water shortages, and any water stress will lead to yield and quality losses. As a result of the drought sensitivity and extremely high input cost of potato production, the risk of dryland production is very high in most areas of the country. Consequently, more than 80% of all potato plantings are currently irrigated.

We can expect that in future, agriculture will increasingly come under pressure to use less water and that more water will be allocated to other industries and household users. Farmers will therefore be expected to use less water, but continue to produce food for a growing population.

How is water use efficiency measured?

The efficiency with which water is used to produce any product or foodstuff can be expressed in different ways. In scientific terms, the water use efficiency of crops is expressed as the millimetre of water necessary to produce a kilogram of grain or product (kg/ha/mm). Another

Table 1: Average international water footprint for some foodstuffs*

Foodstuff	Unit	Water foot print (litre of water per unit)	Foodstuff	Unit	Water foot print (litre of water per unit)
	150 g Medium potato	43.5 L		150 g Orange	80 L
	125 ml Glass of wine	110 L		125 ml Cup of coffee	130 L
	150 g Peach	140 L		150 g Portion of chips	156 L
	60 g Egg	196 L		250 ml Orange juice	255 L
	725 g Margarita pizza	1260 L		300 g Steak	4620 L

* *Source: http//www.waterfootprint.org/?page=files/productgallery*

method that is generally used to compare the water use efficiency of different commodities (grains, fruits, meat, fibre, etc.) with one another is the so-called water footprint of products. This normally takes into account all the water that was used to deliver the final product to the end user. In the case of potatoes, for example, it includes all the water used to produce the crop (from soil preparation, irrigation and spraying throughout the season, up to the washing plant), or to further process the tubers (e.g. the water used in the chip factory). Table 1 provides examples of the volume of water that is typically required (direct and indirect usage) to produce a number of foodstuffs. From this it is evident that there is a significant variation between products, and that potato is one of the foods that requires the least water to produce. Processed products require more water, and animal products such a meat have the biggest water footprint.

Water footprint of potato production in South Africa

The water requirement information for potatoes in Table 1 is based on average international figures, and the question then arises as to how South African farmers

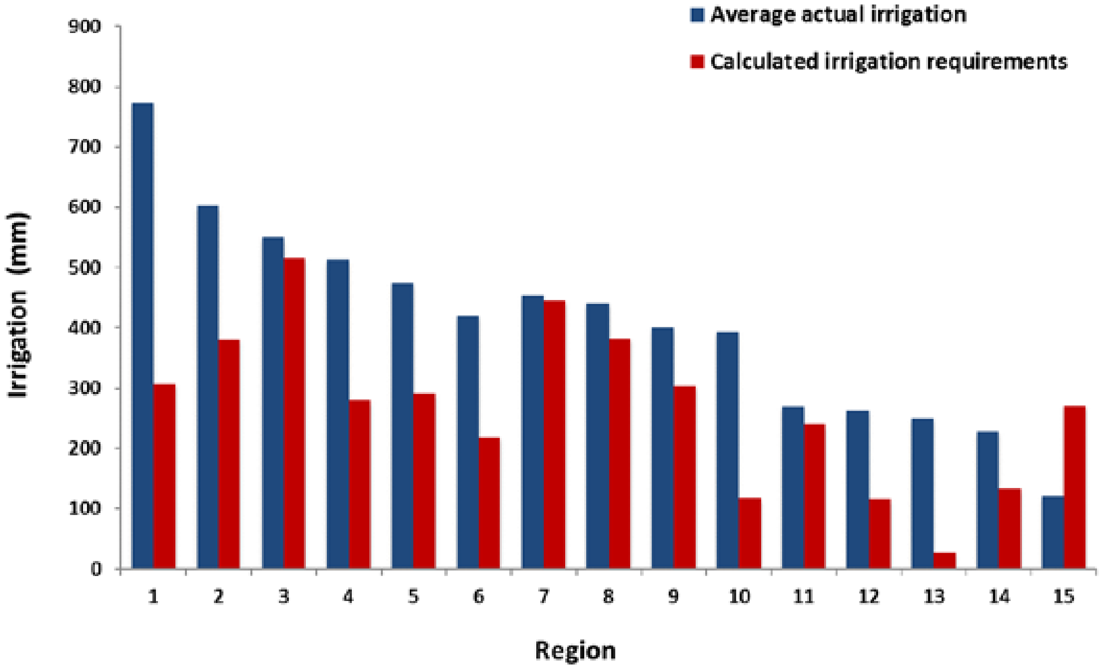


Figure 1: Average actual irrigation amounts and calculated irrigation requirements of potatoes in different South African production regions. Note: codes are used to protect the identity of production regions.

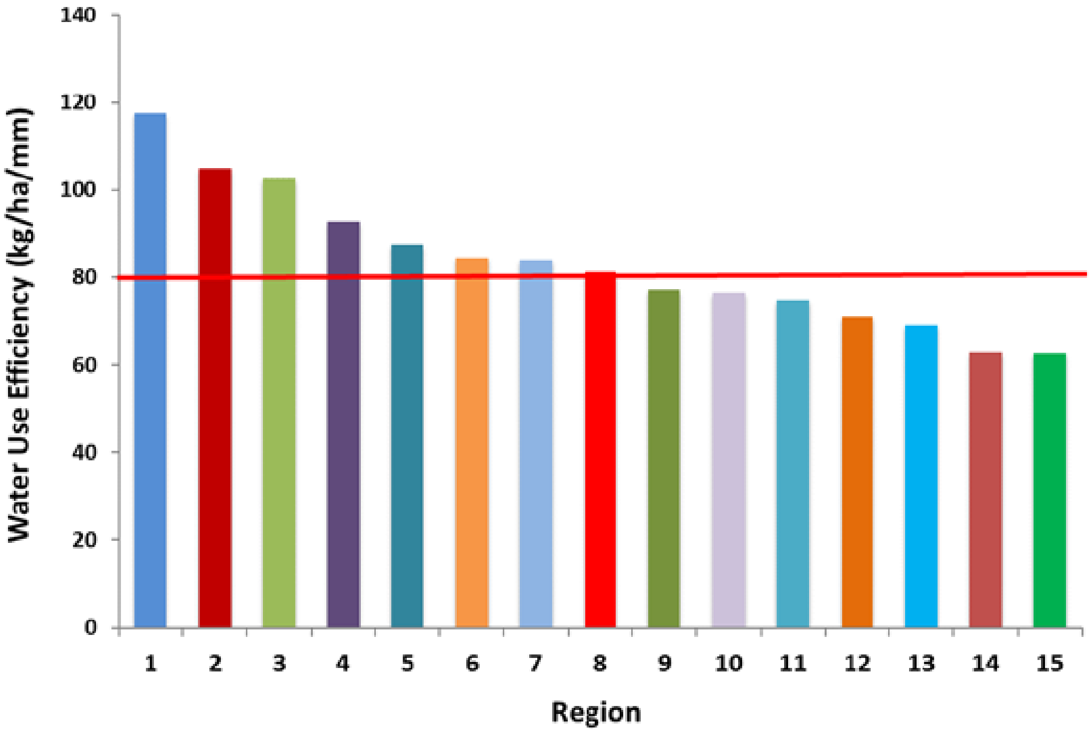


Figure 2: Water use efficiencies of potatoes in different South African production regions. Total rainfall and irrigation are used and it only includes direct water usage during production. Note: codes are used to protect the identity of production regions. The horizontal red line indicates the average.

compare therewith. A survey was recently conducted to study resource use efficiencies in the South African potato industry. About 100 producers throughout the country participated in the survey, representing 15% of the total number of commercial potato producers. As part of the survey, producers were asked how much they irrigate to produce their potatoes. The irrigation requirements for each region were also determined by taking into account the average evaporation demand and long-term rainfall. This was then compared with the actual average irrigation amount reported per region.

Figure 1 indicates the actual average irrigation volumes (blue bars) and calculated irrigation requirements (red bars) per region. According to this, it is clear that regions vary significantly in the actual irrigation volumes they apply. However, this is expected, as the climate and production practices differ considerably between regions. It is, therefore, more correct to compare the actual irrigation amount of each region with its calculated irrigation requirements. When such a comparison is made, there are four regions that perform very well (actual and calculated requirements are nearly the same). For most of the other regions, actual irrigation is significantly more than the requirement, which possibly points to inefficient water usage.

Various factors can complicate irrigation management or negatively affect irrigation efficiency, e.g.
- Soil type: sandy soils are more difficult to manage effectively and leaching can easily occur, especially if rain occurs during the growing season.
- Climate: high evaporation losses in areas with extremely high summer temperatures and strong winds.
- Poor irrigation management: producers do not apply proper irrigation scheduling.

The aforementioned soil and environmental factors definitely play a role in some regions, but in other regions the low water use efficiency can probably be ascribed to poor or no irrigation scheduling being applied.

The average irrigation, rainfall and yield data per region were also used to calculate how much water is used in each region to produce one kilogram of potatoes (Figure 2). As with irrigation quantities, there were substantial differences between regions in respect of calculated water use efficiency. It varied from 63 to 118 kg/ha/mm, with an average of 80 kg/ha/mm, which equates to 18 litres of water used for the production of one medium (150 g) potato. This average value is lower than the figure for potatoes in Table 1 because it excludes the indirect water usage (e.g. the washing of potatoes), but potatoes definitely compare extremely well with most other food crops. Thus, although potatoes are highly dependent on water, it can unequivocally be said that it is one of the crops that is most effective in the conversion of water into food.

The actual irrigation of region 15 in Figure 1 is lower than the calculated requirement because this is primarily a dryland region and irrigation is mostly only supplementary. Figure 1 also indicates that about half of the production regions have efficiencies higher than the average of 80 kg/ha/mm, whereas the other half are below the average. It is also important to note that within regions, significant variation in efficiency occurs between producers, which indicates that in most regions there is an opportunity to save water by introducing better irrigation management.

Effective irrigation management addressed

Various aids are available today to assist producers in their decision-making process as to when and how much should be irrigated at any given point in time. These are discussed in more detail later in this document.

Factors that affect irrigation water management

Prof. Martin Steyn, University of Pretoria

Potatoes are drought sensitive, and economical potato production, with the exception of a few production regions in our country, is nearly impossible without supplementary or full irrigation. However, South Africa is a water-poor country and agriculture must compete with various other sectors for water resources. Unfortunately, irrigation is regarded as the most ineffective of all water users and in addition agriculture is regularly accused of wasting water. Although this is a generalisation, we unfortunately have to acknowledge that irrigation water is not always used optimally. If the agricultural sector wishes to change this negative perception, it will have to make constructive efforts to use irrigation water more effectively.

How can irrigation water be used more effectively?

Various aspects of irrigation management are involved. Firstly it is very important to ensure that the irrigation system is in good working condition and that a uniform application is delivered across the whole field. The system should be tested regularly to ensure that it applies the intended quantity evenly across the field. In addition, the watering should be scheduled effectively so that the crop is not over- or under-irrigated. Under-irrigation can lead to drought stress, which can adversely affect yield and quality. Over-irrigation will lead to wastage of water and electricity and the leaching of valuable nutrients from the crop's root zone, and yield and quality can also be affected negatively.

Irrigation scheduling is the decision-making process to determine when and how much to irrigate to ensure optimum and sustainable production. However, in order to apply effective irrigation scheduling, it is important to understand which factors influence water use and management.

Example

For a loamy soil with 120 mm m^{-1} plant available water (PAW), 50% allowable depletion, and a root depth (RD) of 25 cm, irrigation must take place as soon as the following amount of water has been withdrawn from the root

Allowable depletion
= 50% x PAW x RD
= 50% x 120 mm m^{-1} x 0.25 m
= 15 mm

Later in the growing season, when the roots reach a depth of 45 cm, the allowable depletion amount between irrigations increases significantly:

Allowable depletion
= 50% x PAW x RD
= 50% x 120 mm m^{-1} x 0.45 m
= 27 mm

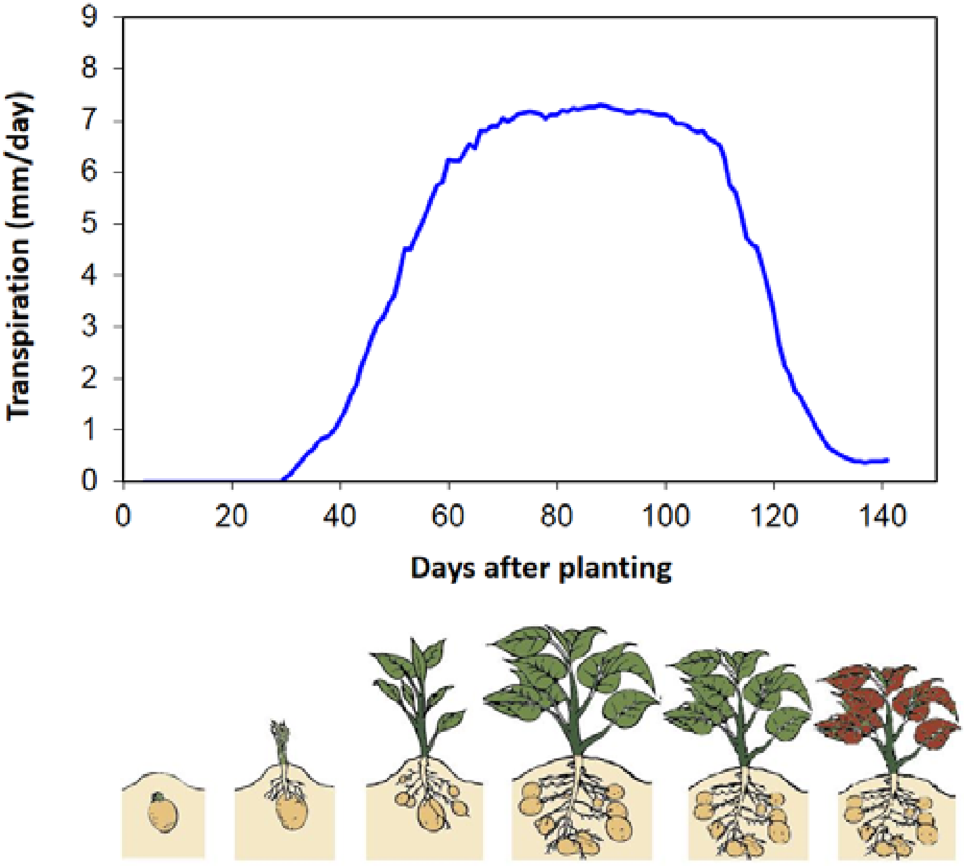


Figure 1: Typical daily water use graph of potatoes with a growing season of 120 days.

Factors that influence water use

Various factors influence the water use or irrigation requirement of a crop, including the *soil type, crop growth stage, weather conditions, type of irrigation system* and *management practices.*

The ***soil type*** determines how much plant-available water (PAW) a soil profile can hold. PAW is defined as the quantity of water between field capacity (so-called "full point") and wilting point (the point where plants can no longer take up water and die). The quantity of available soil water is primarily determined by the texture class of the soil and the profile or root depth. Sandy soils retain less PAW than loamy and clay soils. Typical PAW values vary from as low as 30 mm water per m soil depth (mm m^{-1}) for coarse sandy soils to 120 mm m^{-1} for loamy soils and 100 mm m^{-1} for clay soils. Water stress sets in and production can be hampered when the soil water content drops below the critical value, expressed as a percentage of plant-available water (PAW), and known as the allowable depletion.

A ***crop's*** sensitivity to water stress in different growth stages will determine how much water may be depleted before water stress sets in. As potatoes are very sensitive to water stress, we assume that water stress sets in when more that 50% of PAW is depleted in any growth stage. Any over- or under-irrigation of potatoes can lead to losses in yield and/or quality.

The ***crop growth stage*** also gives an indication of the crop's potentiall water use. When the canopy cover is still small early in the growing season, less water is required, but later in the growing season the daily water requirement rises as the canopy cover increases (Figure 1).

Furthermore, the growth stage determines the root depth of the crop, which is an indication of the soil volume from which the roots can extract water (Figure 2). Early in the season, the roots are still shallow and can only exploit a small portion of the soil reservoir. The risk of over-irrigation and leaching is highest during this stage and irrigation events must therefore be limited to small quantities at a time. Later in the season, the roots are deeper and therefore less frequent and heavier irrigations can be applied, but the allowable depletion amount may still not be exceeded (see example).

The prevailing ***weather conditions*** determine the atmospheric evaporative demand, which is the driver for water use (transpiration and evaporation). The temperature, wind speed, solar radiation and relative humidity are of importance and influence the evaporative demand (and thus the crop water use) as follows:

Figure 2: The root depth of the crop gives an indication of the soil volume from which the roots can take up water.

- Temperature – evaporation increases with an increase in temperature.
- Solar radiation – high light intensity and long days increase evaporation.
- Humidity of the air – evaporation rate is higher at low relative humidity.
- Wind speed – on a windy day the transpiration can be significantly higher than on a windless day.

According to this, it is clear that the water requirements of potatoes will differ between seasons, as well as between localities with differing climates.

The ***type of irrigation system*** used will determine the optimal irrigation quantity per irrigation event and the length of the irrigation cycle. For example, with a centre pivot system 10 to 20 mm will typically be irrigated every two to three days, whereas with a drip system more frequent, smaller irrigation amounts are possible. The frequency of irrigation influences the evaporation losses and thus also the total water requirement. Ⓒ

Water requirements during different growth stages

Prof Martin Steyn, University of Pretoria

Earlier in this series the factors that play a role in the water use of potatoes were discussed. Although potato is one of the most effective crops to convert water into food, it is also very dependent on sufficient water supply to ensure optimum yield and quality.

Most crops have a sensitive growth stage during which water stress can adversely affect yield and quality. In the case of grains the vegetative period is normally less sensitive to water shortages, whereas the flowering and grain filling stages are the most sensitive to water stress. In contrast, potatoes are sensitive to water stress in nearly all growth stages of the crop (from tuber initiation until just prior to senescence) and yield or quality can be seriously affected. It is, therefore, extremely important that soil water is managed optimally to ensure good yields and quality.

How does irrigation management affect yield and quality?

The effect of water management on the potato plant's growth, tuber yield and quality depends on the growth stage of the crop. The effects of over- or under-irrigation during each growth stage on the final yield and quality are subsequently discussed.

Period from planting to emergence

During this stage, evaporation is the only water loss and if the soil profile is close to field capacity at planting, it is normally not necessary to irrigate until the potato plants have emerged. However, a soil that is too dry can lead to poor root development and fewer sprouts, with subsequent uneven stand. If it becomes necessary to irrigate, it should be limited to small irrigation events.

Extremely wet soils with accompanying warm weather may cause seed potatoes to rot, which will lead to a poor plant stand. Wet, cold soils can also lead to sprouts being infected by *Rhizoctonia* and the development of stem canker (Figure 1).

Period from emergence to tuber initiation

This is the only stage of the potato plant when it can tolerate some degree of water stress without adversely affecting yield or quality. Because the root system is still shallow during this early stage, over-irrigation will lead to the wastage of water and nutrients, especially nitrogen, which leaches easily.

Tuber initiation period

Water stress during this growth stage leads to the initiation of fewer tubers, which will influence the final yield and tuber size distribution. Dry soils can also lead to common scab infection (Figure 2) of the newly initiated tubers, which will later develop into full-scale common scab lesions.

Over-irrigation during the tuber initiation stage will lead to wastage of water and leaching of nutrients. It can also lead to the development of internal brown spot (Figure 3), especially in cold, wet conditions. In addition, wet and poorly drained soils are favourable for the development of powdery scab (Figure 4) on the tubers.

Tuber bulking period

The tuber bulking period is the longest stage in the plant's lifecycle, and water management during this stage has the


Figure 1: Wet, cold soils between planting and emergence can lead to *Rhizoctonia* and stem cancer infection of the sprouts (Photo: Jacquie van der Waals).


Figure 2: Dry soils during tuber initiation can lead to common scab infection of the tubers (Photo: Jacquie van der Waals).


Figure 3: Over-irrigation and cold soils during tuber initiation can lead to internal brown spot development (Photo: Chantel du Raan).

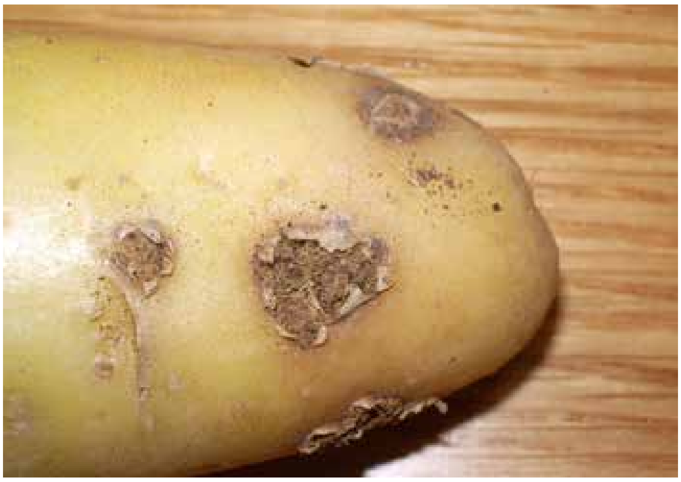


Figure 4: Powdery scab infection is promoted by extremely wet soils during tuber initiation (Photo: Jacquie van der Waals).

Figure 5: Malformation of tubers occurs because of variable and irregular irrigation (Photo: JM Gravoueillo).

Figure 6: Hollow heart occurs as a result of irregular irrigation (Photo: Chantel du Raan).

biggest effect on final tuber yield and quality. Serious water stress will lead to plants dying off earlier and tubers not bulking properly. This will result in a high percentage of small and less large tubers, with an accompanying lower total yield. Water stress, and especially fluctuating wet and dry periods (as with poor rainfall distribution or irregular irrigation), can also lead to undesirable physiological tuber disorders, such as secondary growth, malformation (Figure 5), hollow heart (Figure 6) and growth cracks (Figure 7). These disorders occur because tubers stop growing when it becomes too dry and then start to regrow when the water stress is relieved. Irregular irrigation can also lead to the build-up of sugars in tubers, which cause chip defects such as browning (Figure 8) during processing. Conditions are aggravated when water and heat stress occur simultaneously.

Over-irrigation once again results in the wastage of water and leaching of nutrients from the root zone, as well as excessive foliar growth, which can lead to higher foliar disease pressure, such as late blight (Figure 9). Extremely wet, poorly drained soils can also lead to the development of enlarged lenticels on the tubers. Such enlarged lenticels facilitate soft rot bacteria infection (Figure 10) and result in unsightly lesions on the tubers (Figure 11).

Maturation

Serious water stress in this late stage leads to tuber dehydration, causing them to easily incur mechanical damage during harvesting. Discolouration of the vascular ring of tubers can also occur and sugars can build up in the tubers. When the tubers are processed into chips, these undesirable disorders will cause brown discolouration of the chips (Figure 8).

Over-irrigation is often a problem during maturation. During this stage, extremely wet soils can lead to lower tuber relative density (or specific gravity, SG), which is undesirable as it adversely affects the keeping and processing quality of tubers. In addition, wet soils also lead to delayed maturation and skin set, which can lead to mechanical damage of the tubers during harvesting (Figure 12). Wet, cold soils (soil temperature <10 °C) during the period immediately prior to harvesting can lead to a build-up of sugars in tubers (so-called "cold sweetening"), which in turn will cause browning of chips during processing (Figure 8).

Figure 7: Growth cracks develop as a result of irregular irrigation (Photo: Martin Steyn).

Figure 10: Enlarged lenticels promote infection of tubers by diseases such as soft rot (Photo: Jacquie van der Waals).

Figure 8: Over-irrigation and cold soils prior to harvesting can lead to a build-up of sugars in tubers, which can cause chip defects such as browning
(Photo: www.giantbomb.com)

Figure 11: Extremely wet, poorly drained soils can lead to enlarged lenticels, which can result in lesions on tubers (Photo: Martin Steyn).

Figure 9: Over-irrigation stimulates excessive foliar growth, which can lead to increased leaf disease pressure such as late blight (Photo: Jacquie van der Waals).

Figure 12: Extremely wet soils just prior to harvesting lead to delayed skin set, which can result in mechanical damage of the tubers during harvesting.
(Photo: www.potato-tubers-blemishes.com)

Strategy for optimum yield and quality

From the above discussion, it is evident that effective soil water management is extremely important to ensure optimum yield and quality potatoes. The following general guidelines are recommended as a strategy for optimum tuber yield and quality:

- Prevent significant soil water deficits, and therefore water stress periods, throughout the growing season.
- Aim to maintain the water content of the root zone between field capacity and 50% depletion of plant-available water.
- For most soils tensiometer readings should not exceed 30 to 40 kPa in the upper 30 cm soil layer between irrigations.
- Ensure uniform growing conditions by irrigating regularly, e.g. 12 to 15 mm every two to three days, depending on the growth stage and prevailing weather conditions.
- Use scheduling tools to monitor soil water content and ensure effective water management.
- If water is limited, save water during the vegetative growth stage (between emergence and tuber initiation) and then distribute the available water uniformly throughout the remainder of the growing season.
- Avoid over-irrigation at any stage, as it can promote disease development, leaching of nutrients and wastage of water and electricity.
- Prevent extremely wet soils, especially during the last month prior to harvesting. ©

Scheduling tools - Atmospheric methods

Article and photos: Prof. Martin Steyn, University of Pretoria

The factors that play a role in the water use of potatoes, how the water use efficiency of potatoes compares with that of other crops, and that optimum water supply during all growth stages is necessary to ensure optimum yield and quality, we discussed earlier. In this section we start looking at the various irrigation scheduling methods and tools available to producers to assist them in making decisions on when and how much to irrigate.

Various approaches can be followed to estimate or calculate the water use of a crop. Most methods measure or estimate one or more components of the soil-plant-atmospheric system. Scheduling methods are therefore usually based on soil, plant or atmospheric measurements. In practice, soil and atmospheric methods are mostly used. Producers should preferably use a combination of more than one method to lower the risk of making mistakes.

Water uptake of crops is determined by the following factors:

- Atmospheric evaporative demand, i.e. how "dry" is the air.
- Size of the foliage, i.e. canopy cover.
- Root depth, i.e. size of the soil reservoir.
- Availability of soil water for uptake by plant roots.

The atmospheric evaporative demand is the driving force for water use and depends on the prevailing weather conditions on a given day. Atmospheric evaporation will be higher on a warm, sunny, windy day compared to when it is cool, cloudy and windless. It is, therefore, clear that crop water requirements may differ significantly from day to day, depending on the prevailing weather conditions.

The following four factors influence atmospheric evaporative demand:

- Air temperature – provides energy for evaporation; higher temperature increases evaporation.
- Solar radiation – supplies most of the energy for evaporation; high light intensity and long days therefore increases evaporation.
- Humidity of the air – determines the "drying ability" of the air; evaporation is higher at lower humidity.
- Wind speed – wind transports humid air away from the leaves; consequently evaporation can be significantly higher on a windy day compared to a windless day.

Atmospheric methods are handy to estimate the maximum potential water use of a crop. If we can measure the abovementioned weather variables (e.g. with a weather station), the atmospheric evaporative demand (or reference evapotranspiration, ETo) can be determined from that. The formula that is generally used for this is the so-called *Penman Monteith* equation. A typical ETo value on a warm, windy summer's day can easily reach 8 mm per day. This ETo value can now be used to estimate the actual crop water usage. Crop water use can never exceed the atmospheric evaporative demand. For example, if the ETo on a given day is 4 mm, it will not be possible for the crop to use 7 mm water, since there is only enough energy to evaporate 4 mm. In addition, it should be taken into account that as soon as more than 50% plant-available water is extracted from the root zone, the crop will start to experience water stress. The crop water use will then be lower than the atmospheric demand, since water uptake cannot meet the demand.

The most basic atmospheric scheduling methods and tools are briefly discussed below.

Atmospheric irrigation scheduling methods

Evaporation and crop factors

In the past, pan evaporation (Epan) was often used to calculate atmospheric evaporative demand. The assumption was made that the evaporation from the open water surface of an evaporation pan (Figure 1) integrates all the weather variables (radiation, temperature, wind and humidity) and it therefore gives a good indication of atmospheric evaporative demand. Today evaporation pans have to a large extent become obsolete. We also know now that although the method gave relatively good results, it had numerous limitations.

Figure 1: In the past Class A pan evaporation (Epan) was commonly used as estimation of atmospheric evaporative demand and used together with crop factors to calculate crop water usage (ET).

Notwithstanding the fact that evaporation pans are no longer commonly used, due to the simplicity of the method, it is applied in the following example to explain how atmospheric measurements can be used for scheduling.

The assumption is made that ET = Epan * f where ET is the crop water use or evapotranspiration (evaporation plus transpiration), Epan is the daily pan evaporation, and f is the so-called crop factor. The crop factor depends on the size of the crop foliage canopy. The crop factor starts low early in the growing season and increases as the season progresses and the size of the canopy increases. As soon as the leaves start to die off and the canopy becomes smaller again, the crop factor drops. Figure 2 depicts a typical crop factor graph.

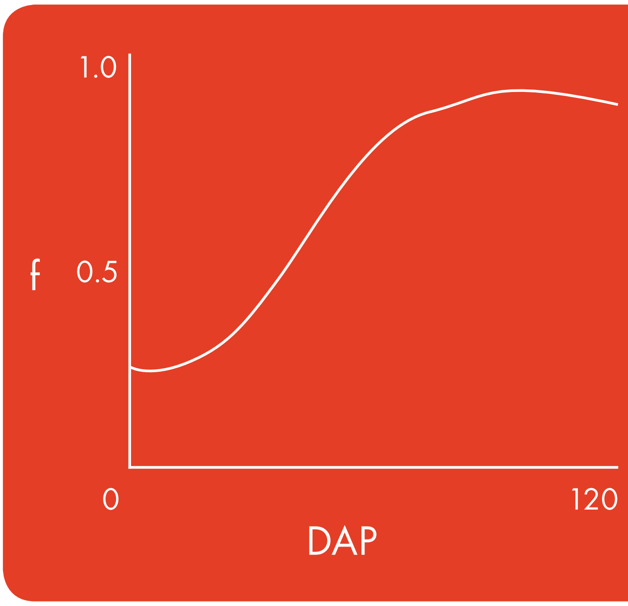


Figure 2: A typical crop factor (f) graph for annual crops such as potatoes (DAP = days after planting)

The pan evaporation and crop factor approach assumes that only atmospheric demand determines crop water use, in other words the higher the demand, the higher the crop water use. However, this assumption is only true if the soil is wet enough so that water uptake through the roots can meet the atmospheric demand. If the soil becomes dry, water use will decrease and the assumption will no longer be valid.

Example 1: Calculation of allowable soil water depletion

Potatoes are cultivated in a loamy soil with 120 mm m^{-1} plant-available water (PAW) and 50% depletion of PAW is allowed. We assume that the potatoes are now at 90 days after planting (DAP) and the root depth (RD) is 50 cm. To prevent stress the crop must be irrigated as soon as the following amount of water has been extracted from the profile:

Allowable depletion = 50 % x PAW x RD
= 50 % x 120 mm m-1 x 0.5 m
= 30 mm

Nowadays automatic weather station data (Figure 3) is in general readily available (*see note at the end of the article) and weather stations can be programmed to calculate atmospheric evaporative demand (ETo) directly from the data.

Example 2: Calculation of daily water usage (ET) from pan evaporation and crop factors

Assume that at 90 DAP the pan evaporation is 8 mm and the crop factor (f) is 0.8. That day's water usage is then calculated as:

ET = Epan x f
= 8 mm x 0.8
= 6.4 mm

The same calculation is then made for every following day and the water usage is accumulated until the allowable depletion value is reached, when the crop must be irrigated. If it rains at any stage, the amount of rainfall is deducted from the accumulated deficit. In the example below the maximum allowable depletion of 30 mm is reached at 96 DAP.

Example of daily water use (ET) and cumulative deficit calculations from pan evaporation (Epan) and crop factors (f)

Days after planting	Epan (mm/dag)	Crop factor (f)	ET (mm)	Rain (mm)	Cumulative deficit (mm)
90	8	0.8	6.4		6.4
91	7	0.8	5.6		12
92	6	0.9	5.4	20	0
93	8	0.9	7.2		7.2
94	8.5	0.9	7.7		14.9
95	8	0.9	7.2		22.1
96	9	0.9	8.1		30.2
97					

We now already know that the growth stage of the crop gives an indication of the crop's root depth and size of the foliage (canopy) (see Figure 4, as well as the section on Factors that affect irrigation water management). Producers can make an estimate of the canopy cover (percentage soil covered by leaves if looking from above the crop to the soil; % canopy cover or CC). This estimate of CC can then, in combination with ETo, be used to calculate the water use of the crop, as indicated in Example 3.

Figure 3: Example of an automatic weather station for the collection of prevailing weather variables that can be used to calculate atmospheric evaporative demand (ETo).

Example 3: Calculation of daily water use (ET) from ETo and percentage canopy cover

Assume that at 90 days after planting (DAP) the atmospheric evaporative demand (ETo) is 7 mm and the canopy cover (CC) is 90%. The daily water use can then be calculated as follows:

$$\begin{aligned} ET &= ET_o \times CC/100 \\ &= 7\text{ mm} \times 90/100 \\ &= 6.3\text{ mm} \end{aligned}$$

The same procedure as for the pan evaporation and crop factor example above is then followed to calculate ET on the following days. Water usage is then accumulated until the allowable depletion level is reached, when the crop must be irrigated.

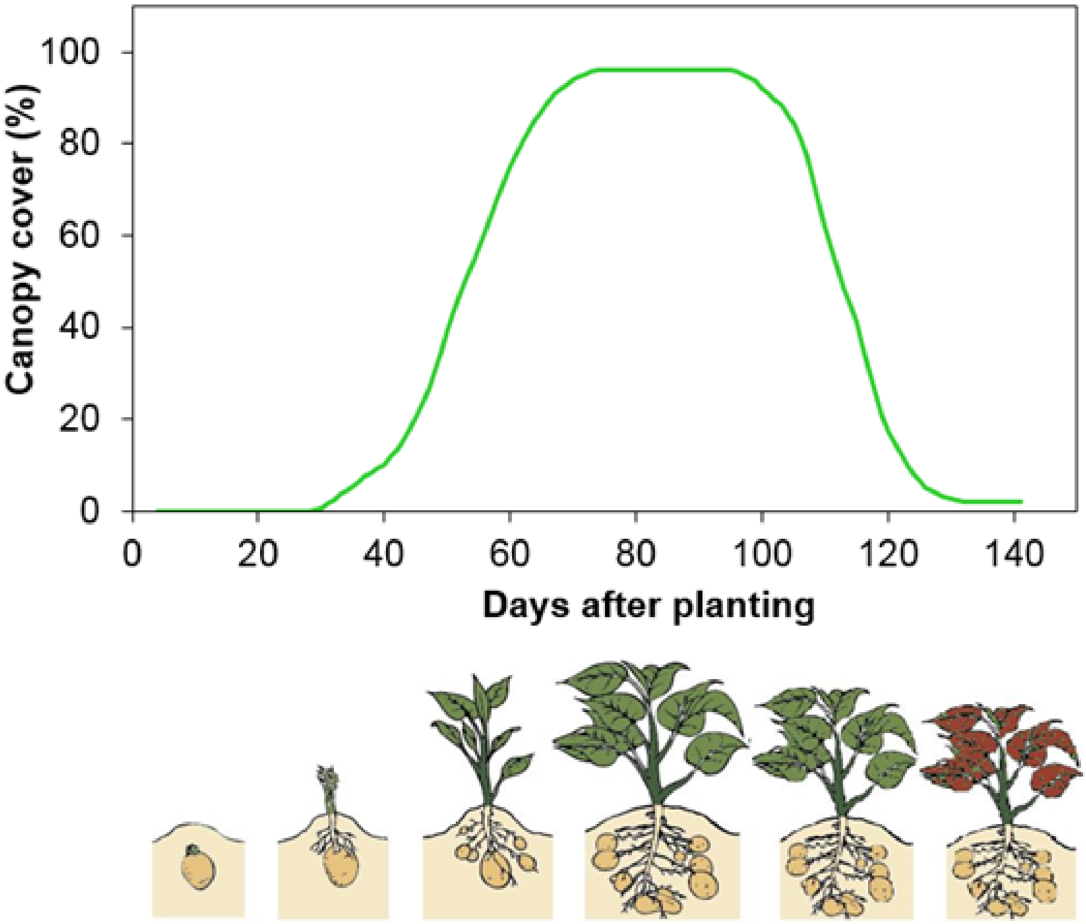


Figure 4: Graphic representation of changes in the crop canopy cover (% canopy cover or CC) during the course of the growing season.

Crop growth models

Computer simulation models for the estimation of crop water requirements have become more accessible to the public and are nowadays readily available. These computer programs usually use daily weather data to calculate crop growth and water use, similar to the method discussed in the above examples. Mechanistic models usually integrate variables such as water supply of the soil-root system, atmospheric evaporative demand and the crop growth stage to be able to make an accurate estimation of crop water usage. Models then usually make recommendations as to when the next irrigation should be applied. In cases where producers do not have access to daily weather data, irrigation calendars can be created, based on long-term historical weather data of the relevant locality.

Simulation models can be useful to reduce the frequency of field monitoring (e.g. taking of soil samples), but it is recommended that models should always be used in combination with another method (e.g. soil measurements). Soil Water Balance (SWB), BEWAB and SAPWAT are examples of freely available models in South Africa that can be used for water demand planning and irrigation scheduling. ©

* Producers can currently get free access to daily weather data from four Potatoes South Africa weather stations in the Limpopo region, one in the Eastern Free State and one in the Sandveld. Producers are welcome to send an e-mail to martin.steyn@up.ac.za for details as to where the stations are located and how to gain access to the data.

Scheduling tools – Soil water content measurements

Article and photos: Prof. Martin Steyn, University of Pretoria

Atmospheric scheduling methods were discussed previously. The next approach that can be followed to estimate the water use of a crop is soil water content measurements. In this section the most commonly used soil measurement methods are discussed briefly.

In any potato field there is a degree of spatial variation, whether in soil type, vegetation or uniformity of irrigation system application. This will consequently lead to a variation in the soil water content measured. The choice of the position in the field where soil measurements are made or sensors are placed is, therefore, extremely important in order to ensure that readings are representative for most of the field. Readings must be taken in the most representative soil type, not too close to the edge of the field or spray tracks, and where the vegetation is uniform.

Soil samples

This is a direct measurement and the simplest soil water measurement method. An auger (photo above) or soil sampler (Figure 1) with known volume is usually used to take soil samples. This method is labour intensive and slow and is therefore not used for scheduling purposes on a routine basis. Nevertheless, the method is discussed to help explain the basic principles of soil water content measurements. Soil samples are also often used to calibrate other soil measurement instruments.

Figure 1: Sampler with known volume for the collection of soil samples

Soil samples are taken to determine the gravimetric soil water content (mass of water per mass of soil). The volumetric soil water content (volume of water per volume of soil) can then be calculated if the sample volume is known. It is easier to determine gravimetric soil water content, but for soil water management we are rather interested in the volumetric soil water content (m^3 water per m^3 of soil, also expressed as % water). In practice soil water content is also often expressed in length units (or depth; mm water), similar to quantity of rain or irrigation.

Soil samples must be taken from at least two to three representative positions in every field. For each of these positions, samples are taken at different depths, depending on the crop's root depth, for example in 15 cm increments to a depth of 60 cm for shallow rooted crops such as potato – thus four samples per position. Each sample is placed in a separate marked container (e.g. brown paper bag) and then sealed in an airtight container (e.g. plastic bag) to prevent evaporation losses during transportation. After all the samples have been collected, they must be weighed as soon as possible and dried in an oven at 105 °C for at least 16 hours in order to evaporate all water from the soil. After drying, each sample is reweighed to determine its dry mass. The empty containers are also weighed and deducted from the dry soil mass.

Example 1 illustrates the calculation of gravimetric and volumetric water contents of a soil sample.

Example 1a: Gravimetric soil water content calculation

Suppose gravimetric soil samples were collected from a potato field using a sampler with a known volume of 390 cm^3. The samples were weighed before and after drying at 105 °C for 16 hours and the following masses were obtained:

Soil layer (cm)	Soil sample mass (g)	
	Wet	Dry
0-15	654.2	594.2
15-30	681.8	599.0
30-45	678.2	594.2
45-60	666.2	570.2

The gravimetric soil water content (Mw) of the 0-15 cm layer is then calculated as follows:

$$\begin{aligned} Mw &= \frac{\text{(wet mass-dry mas)}}{\text{(dry mas)}} \\ &= \frac{(654.2 - 594.2)\text{ g}}{594.2\text{ g}} \\ &= 0.101\text{ g water g}^{-1}\text{ soil} \end{aligned}$$

The same procedure is then followed to calculate the water content of the other soil layers.

Example 1b: Volumetric soil water content calculation

The volumetric soil water content is then calculated from the gravimetric water content. For this the bulk density (ρb) of each soil layer is required, and can be calculated as follows for the first soil layer:

$$\rho b = \frac{\text{dry soil mass}}{\text{sample volume}} = \frac{594.2\ \text{g}}{390\ \text{cm}^3} = 1.524\ \text{g cm}^3$$

Thereafter the volumetric soil water content is calculated:

$$\begin{aligned}\theta &= Mw \times \rho b \\ &= 0.101\ \text{g/g} \times 1.524\ \text{g cm}^3 \\ &= 0.154\ \text{m}^3\ \text{m}^{-3}\quad \underline{\text{or}}\quad 15.4\ \%\ \text{water}\end{aligned}$$

The volumetric soil water contents of the other soil layers are then calculated in the same manner:

Soil layer (cm)	Soil sample mass (g)		Gravimetric water content ($g\ g^{-1}$)	Gross density ($g\ cm^{-3}$)	Volumetric water content ($m^3\ m^{-3}$)
	Wet	Dry			
0-15	654.2	594.2	0.101	1.524	0.154
15-30	681.8	599.0	0.138	1.536	0.212
30-45	678.2	594.2	0.141	1.524	0.215
45-60	666.2	570.2	0.168	1.462	0.246

The volumetric soil water contents calculated above can now be used to determine how much water is required to refill the soil profile to field capacity, thus the irrigation amount, according to Example 2.

2. Neutron probes

The neutron probe (Figure 2) is one of the best-known instruments for the indirect measurement of soil water content. Although the instrument is no longer that popular for irrigation scheduling, it is still frequently used in research.

The water content of each soil layer is measured by lowering the instrument's radioactive source down the soil profile through pre-installed access tubes. Access tubes must be installed on at least two to three representative positions in each field. Measurements are usually taken at depth increments of 15 to 20 cm. For potatoes, a shallow rooted crop, measurements are usually taken to a soil depth of 60 cm. Measurements are taken by placing the instrument on top of the access tube and lowering the radioactive source to the first depth. A measurement is taken and the source is then lowered to the next depth. The process is repeated until all the soil layers have been measured.

Figure 2: The neutron probe is placed on top of an access tube and the radioactive source is lowered down the access tube to measure water content of the different soil layers.

Software applications are available to convert readings into soil water contents, using predetermined standard calibration functions for different soil types. For more accurate measurements, neutron probes can be calibrated for each individual soil. These calibration functions are then used to convert probe readings into soil water contents.

Example 2: Calculation of soil water deficit or irrigation amount

Suppose potatoes are cultivated on a soil of which the volumetric field water capacity (FC) has already been determined. A neutron probe is used to measure the water content of the root zone and the results are shown in the table below. The volume of water required to refill the first soil layer to field capacity (the deficit) can be calculated as follows:

$$\begin{aligned}\text{Deficit per soil layer} &= (\theta_{FC} - \theta) \times dz \\ &= (0.165 - 0.096) \times 150 \text{ mm} \\ &= 10.4 \text{ mm}\end{aligned}$$

where θ_{FC} is the soil water content at field capacity, θ is the actual measured soil water content and dz is the soil layer thickness (mm). The volume of water required to refill the soil profile to field capacity (deficit) is obtained by adding up the deficits of all the soil layers. In this case, 32 mm must be irrigated to refill the soil profile to field capacity.

Soil layer (cm)	Layer thickness (dz) (mm)	Measured volumetric soil water content (θ) ($m^3 m^{-3}$)	Field capacity (θ_{FC}) ($m^3 m^{-3}$)	Deficit per soil layer (mm)
0-15	150	0.096	0.165	10.4
15-30	150	0.124	0.183	8.9
30-45	150	0.145	0.195	7.5
45-60	150	0.169	0.204	5.3
Total soil water deficit for the profile				**32.1**

This can be done automatically with the accompanying software, or with a spreadsheet such as Excel. When the water content of each soil layer is known, it can be used to calculate the profile water deficit to field capacity or the irrigation volume. Example 2 explains how this is done.

Neutron probes have several advantages: measurements are less labour intensive and faster than gravimetric soil samples; they are non-destructive after the initial installation of the access tubes and repetitive measurements can be made on the same positions in a field. However, the instrument also has a few disadvantages such as high instrument cost; measurements in the top soil layer are problematic, and the instrument poses health risks due to its radioactive source.

3. Capacitance probes

Capacitance probes are currently quite popular, with several types and trademarks available on the market (Figures 3 to 5). Some types of sensors are lowered down the soil profile by means of an access tube (Figure 4), while others are installed directly into the soil (Figures 3 and 5), normally after a hole has been made in the soil with a rod or auger.

Capacitance probes operate on the principle that an electromagnetic pulse is transmitted into the soil, after which the dielectrical permittivity of the soil, which has a direct relationship with soil water content, is measured. Instruments may consist of a single sensor, or there may be several sensors that can measure the water content at different soil depths. These instruments are usually able to collect continuous data (e.g. hourly) that allows the user to monitor changes in soil water content over time. The data can usually be downloaded using a computer, radio logger or telemetry.

Figure 3: Examples of capacitance sensors that are connected to a datalogger (bottom right) for continuous data collection.

Figure 4: Capacitance probe with sensors at different depths (e.g. every 10 cm). The instrument is lowered down the soil profile through an access tube.

Figure 5: Example of a capacitance probe that is installed directly into the soil. It has sensors at five different depths (every 10 cm) and data can be downloaded with a radio logger (left on the photo).

Manufacturers of capacitance equipment normally also provide user-friendly software that presents data graphically and thereby assists users in interpreting the data. In many cases, the sensors are not calibrated for specific soils and readings are expressed in relative units (not absolute volumetric water contents). Users then follow trends in soil water content on the graphs in response to current management practices and adapt management accordingly. Rules of thumb are therefore developed over time to help users decide when and how much to irrigate.

"Full" and "Refill" lines are usually set on the graphs of every soil profile and the user should then ensure that the soil water content is kept between these two lines (Figure 6).

As with any other point measurements, capacitance sensors should be installed at representative positions in the field. Sensors are usually installed in the planting row between two plants. The measurement volume of capacitance sensors is very small and the soil disturbance during installation should therefore be as little as possible to ensure that reliable readings are obtained. When the soil settles and the structure changes after installation, sensor readings will be influenced and it may be necessary to adjust the "Full" and "Refill" lines on graphs to ensure that accurate management decisions are taken.

Capacitance sensors are currently quite popular because they are generally reliable and easy to use, continuous data can be collected (manually or via telemetry) and most of the locally manufactured equipment is relatively affordable. Some of the disadvantages are: the sensors give point readings that may not be representative of the entire field, they have a rather small measurement volume, are sensitive to installation errors, and management lines on graphs may require regular adjustments.

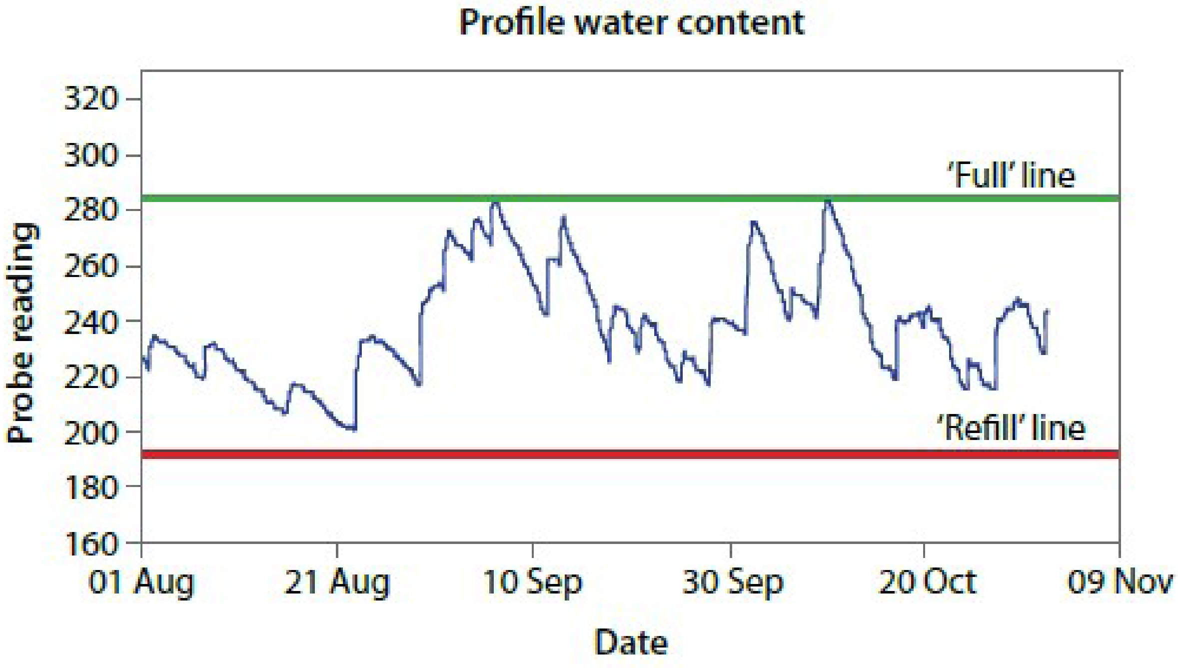


Figure 6: Typical output graph produced by capacitance probe software to illustrate soil water status. Irrigation amounts and frequencies are adjusted to keep readings between the set "Full" and "Refill" lines.

Photo: M Steyn

Soil water potential-based scheduling tools

Article and photos: Prof. Martin Steyn, University of Pretoria

Different atmospheric and soil water content measurement scheduling tools were discussed earlier in this series. In this section, the focus is on soil water potential measurement methods.

Not only is the volume of water in the soil important to plants, but also the energy status of the water. The energy status or water potential determines if soil water is available to plants or not, and also in what direction and at what rate water movement will occur. The units of water potential are J kg^{-1}, kPa or metres of water head.

Soil water potential consists of various components, but for irrigation management the matrix potential is the most important component. It gives an indication of how strongly water is attracted or "held" by soil particles. The drier the soil, the thinner the water layers surrounding soil particles, and the stronger the water is attracted. The water is then less available and it is more difficult for plants to take up water.

A soil of which all the pores are filled with water is at saturation point and the water potential is zero. When all excess water has drained from a soil profile under the influence of gravity, the soil is at field capacity and the water potential is between -10 kPa and -20 kPa, depending on the soil type. Wilting point is reached when plants have extracted all plant-available water from the soil and a water potential of about -1 500 kPa has been reached.

Measurement of soil water potential

The matrix potential of soils for irrigation scheduling can be measured with instruments such as tensiometers and electric resistance sensors. As with soil water content measurements, spatial variation in fields can influence the reliability of measurements, and therefore the proper selection of measurement positions is very important. Instruments must be installed at representative positions in fields with cognisance of soil type, uniformity of irrigation system application and plant growth. Measurements must also be taken at more than one position in the field to limit errors as a result of spatial variability as far as possible. The best known matrix potential sensors are subsequently discussed in brief.

1. Tensiometers

A tensiometer consists of a water-filled plastic tube with a porous ceramic tip (Figure 1). When a tensiometer is installed in the soil, the water in the instrument will move through the porous tip to reach equilibrium with the surrounding soil water. The part of the water-filled tube extending above the soil surface is connected to a mechanical or electric vacuum gauge, which is used to measure the matrix potential or "suction force" of the soil.

Tensiometers can only measure matrix potentials between 0 and -80 kPa. Higher readings (drier soil) cause air to enter the system and the meter could then give false readings of zero (which should not be confused with saturated conditions, when the readings are also zero). This 0 to -80 kPa measurement range may appear quite restrictive, considering that plants can extract water down to a soil water potential of as low as -1 500 kPa. However, since the relationship between soil water content and potential is not linear, the 0 to -80 kPa water potential range covers about 50% of the plant-available soil water in most soils (and up to 75% in sandy soils). Given the fact that soils under irrigation are normally managed reasonably wet to prevent crop water stress, tensiometers are very useful aids for practical irrigation scheduling.

Tensiometers give an indication of the difficulty plants experience to extract water from the soil, and therefore

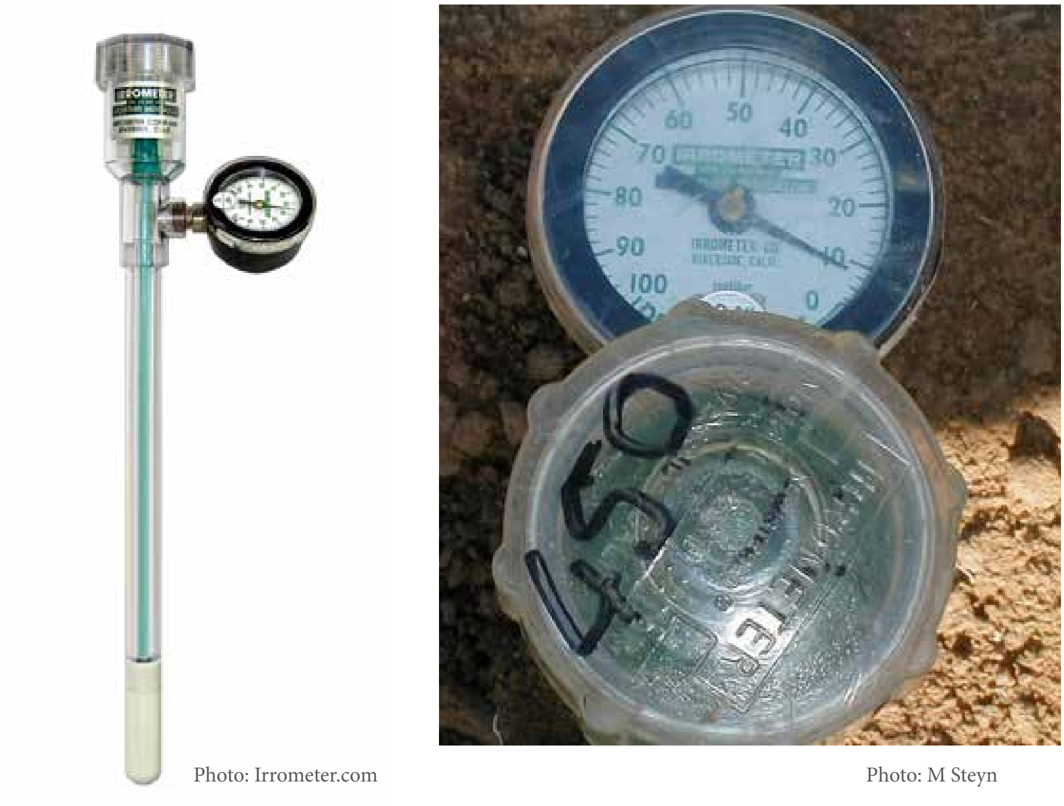


Photo: Irrometer.com

Photo: M Steyn

Figure 1: Tensiometer consisting of a water-filled tube, ceramic tip and vacuum meter (left); and tensiometer after installation in the soil – seen from above (right).

indirectly of how much water is present in the soil. The method only gives an indication of when to irrigate, and not of the irrigation amount. Usually at least one tensiometer is installed in the active root zone and a second tensiometer towards the bottom of the root zone. Irrigation is initiated when the tensiometer in the active root zone reaches a predetermined water potential value and the deeper tensiometer is used to monitor deep drainage.

Potato is a shallow-rooted, drought-sensitive crop and it is therefore recommended that the shallow tensiometer be installed at about 25 cm soil depth, whilst the deeper tensiometer is placed at 45 to 50 cm depth. The soil profile is then managed by irrigating to ensure that the reading of the shallow (25 cm) tensiometer is maintained above (or wetter than) -30 to -40 kPa. Users may initially not know how much to irrigate to refill the profile to field capacity. If the 25 cm tensiometer reading does not drop to zero after an irrigation event, the irrigation amount was possibly too little. On the other hand, if the reading of the deeper tensiometer remains at or near zero between irrigations, it may point to over-irrigation and drainage of water beyond the root zone. The next irrigation amount can then be reduced, or the cycle length (days between irrigation events) can be increased.

Correct tensiometer installation is important to ensure useful readings. The ceramic tip of the tensiometer must be in proper contact with the surrounding soil after installation. In addition, tensiometers must be serviced regularly (water level refilled and de-aired) to ensure accurate readings.

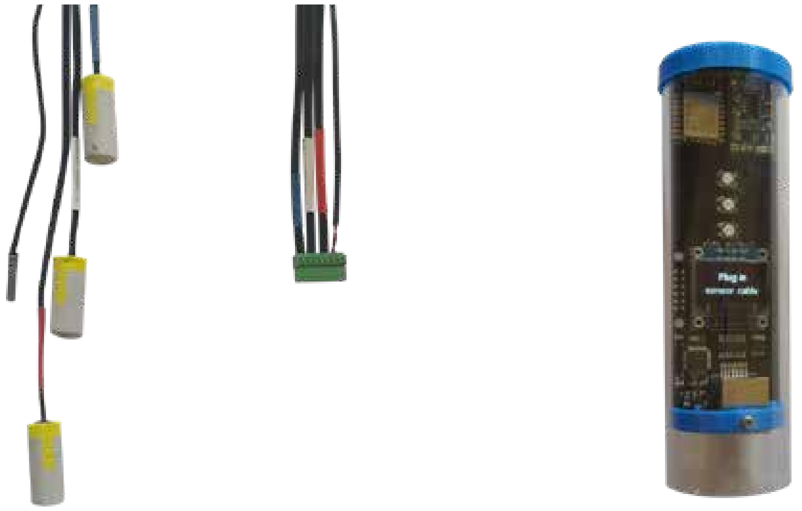
2. Electrical resistance sensors

The matrix potential of soils can also be estimated with sensors that can measure the electrical resistance of the soil solution in a porous medium. When the sensor is installed in the soil, the soil water reaches equilibrium with the water

Photo: forestry-supplies.com

Photo: copersa.com

Figure 2: Watermark® electrical resistance sensor (left) and digital gauge (right) for measuring soil water potential.



Photos: Luan Steyn

Figure 3: A set of Chameleon sensors for measuring soil temperature at one depth and matrix potential at three different soil depths (left); and LED reader (right).

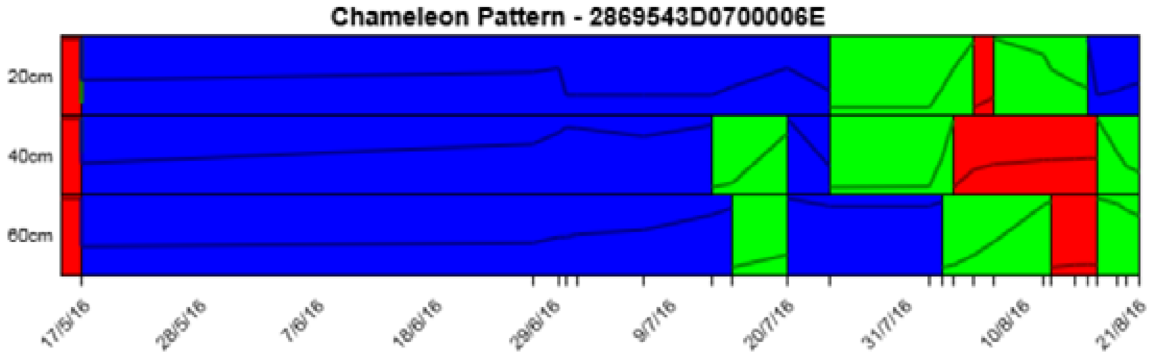


Figure 4: Graphic representation of changes in Chameleon sensor colours (and thus soil water potentials) at three soil depths throughout a crop growing season.

in the sensor, which influences the electrical resistance of the sensor medium. The higher the soil water potential (or water content), the lower the resistance for the medium to conduct electrical current. This resistance can be measured using a datalogger or resistance meter, which then gives an indication of the soil water potential at that stage. As an example of electrical resistance sensors, Figure 2 shows a Watermark® sensor with digital gauge that can be used to measure soil water potential.

These sensors, as with tensiometers, are installed at different depths in the soil profile, with at least one sensor in the active root zone and one sensor towards the bottom of the root zone. Readings are taken regularly and irrigation is initiated as soon as the matrix potential in the root zone reaches a predetermined value (e.g. -25 kPa). The deeper sensor (e.g. at 50 cm depth) is then used to monitor possible drainage.

The Chameleon sensor (Figure 3) is a new-generation electrical resistance sensor that operates on the same principle as the Watermark® sensor, except that the matrix potential is not measured with an analogue or digital gauge. The Chameleon reader uses LEDs that change colour when the soil water potential changes, just like a chameleon changes colours when its environment is changing.

Table 1 indicates the typical matrix potential ranges for different LED colours and the interpretation of each colour. The reader can also transfer data to a web server using the user's smartphone as WiFi hotspot. The data is then saved and displayed graphically on a webpage Figure 4 for later reference.

Table 1: Typical matrix potential ranges for the different LED colours displayed by a Chameleon sensor reader and interpretation of the different colours.

LED colour	Matrix potential range	Interpretation
Blue	0-25 kPa	Soil is "wet"
Green	25-45 kPa	Moderate soil water status
Red	>45 kPa	Dry soil

Reduction in electricity cost for irrigated potato production in Limpopo

Isobel van der Stoep: Bioresources Consulting, Prof. Bennie Grové: Department Agricultural Economics, University of the Free State and Prof. Martin Steyn: Department of Plant and Soil Sciences, University of Pretoria

According to a recent survey conducted by Mr Pieter van Zyl of Potatoes South Africa, the electricity cost for potato production in Limpopo varies between R5 100 and R18 500 per hectare. Participants had to provide Eskom account statements per power point for twelve months, as well as the number of hectares irrigated. The average cost per farming enterprise (numerous power points) varied between R6 000 and R12 000 per hectare. There are numerous reasons why electricity cost per hectare differs so much between farming enterprises, which is one of the reasons why Potatoes South Africa funded a project to conduct an economic evaluation of alternative strategies to reduce electricity cost, as well as to improve the water use efficiency of irrigation farming. If the latter is achieved, the profitability of irrigation farming can also be increased.

The project also included the development of an electricity cost calculation model, specifically for potato production under irrigation. The electricity cost calculation model is the direct outcome of research conducted by the University of the Free State's Department of Agricultural Economics for the Water Research Commission, titled "The optimisation

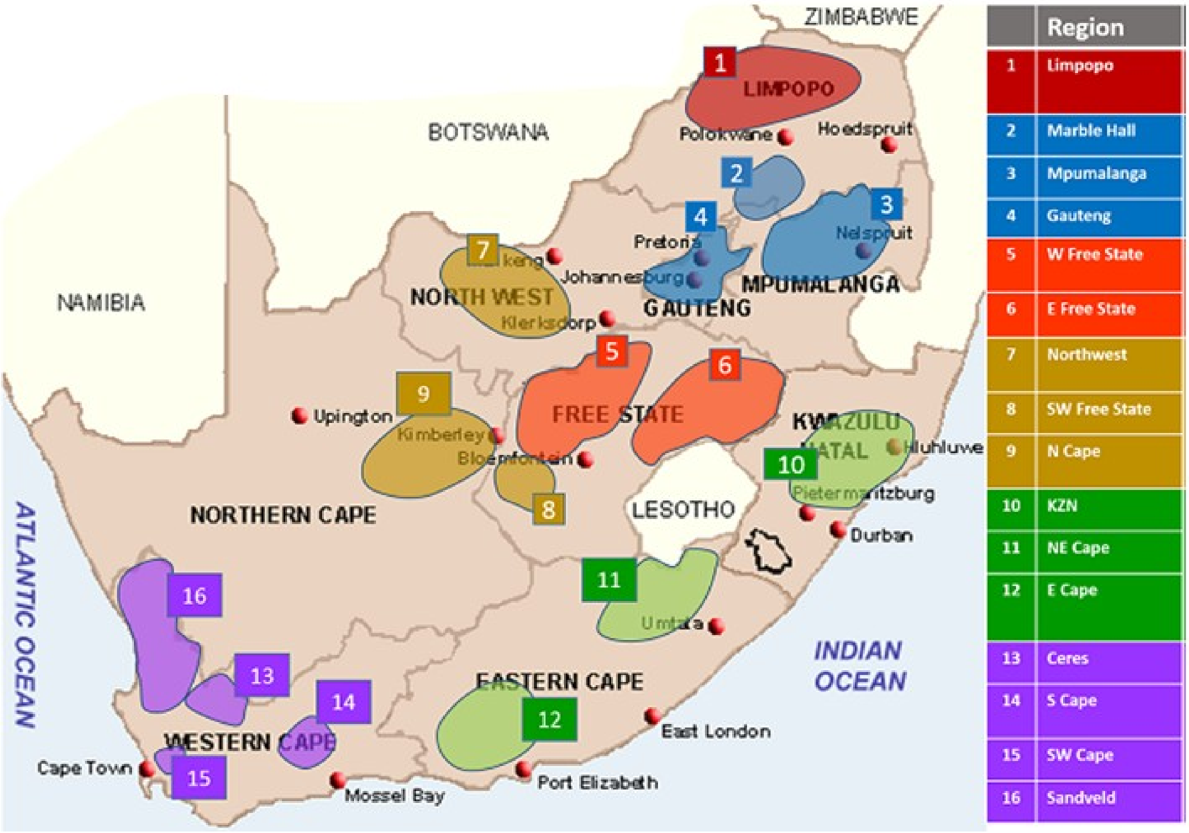


Figure 1: Potato production regions in South Africa

of energy and water use for sustainable management of irrigation farming enterprises"(Project K5/2279//4). The model was applied to compare the energy use for different scenarios on the basis of different case studies in the Limpopo production region, currently the biggest production region in South Africa (see Figure 1).

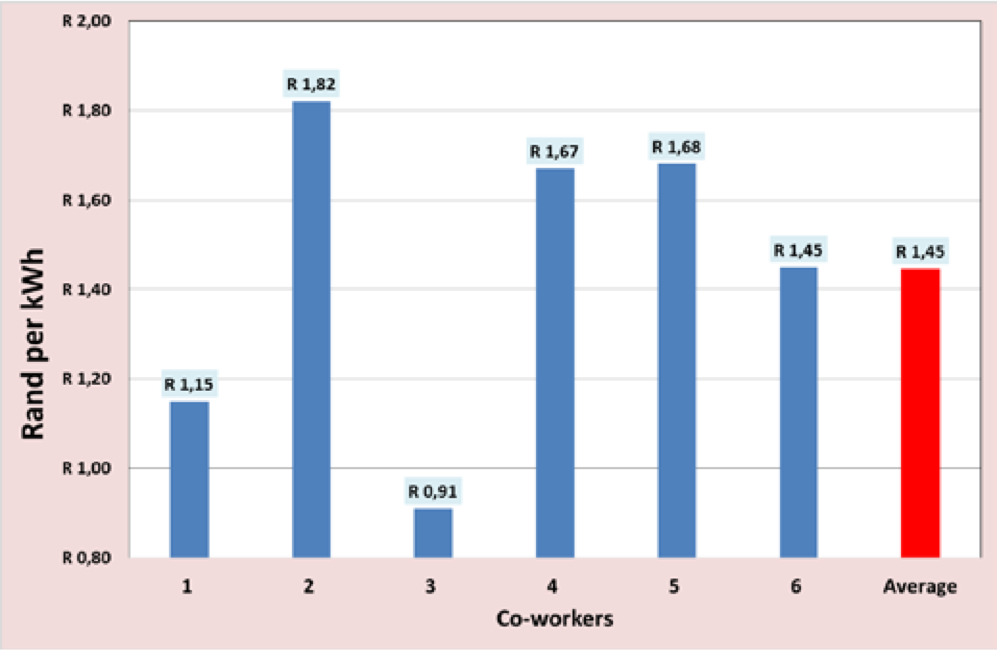


Figure 2: Average calculated electricity tariffs for 6 co-workers in Limpopo (Stones, 2016)

How do the average electricity tariffs for potato production compare with other crops in Limpopo?

To get the project started, a senior energy advisor at Eskom, Mr Roger Stones, conducted an energy audit at six potato producers in the region. The audit comprised, inter alia, a survey of all electricity uses on the farms. Energy use is measured in terms of kiloWatt-hour, which is determined by multiplying the number of hours that a specific device uses electricity with the kiloWatt rating thereof.

The results of the survey showed that the six participants' average calculated electricity tariffs (expressed in Rand per kilowatt-hour, or otherwise R/kWh) varied between R0.91/kWh and R1.82/kWh, with an average of R1.45/kWh (Figure 2). In essence, this means that the average calculated tariff participant 3 pays to Eskom is exactly half of that of participant 2. The significant variation found in the average calculated electricity tariff is the direct result of the various electricity tariff structures and the hours the different motors and devices with different kiloWatts utilised during the period. It was, therefore, part of the Eskom advisors' mandate to give advice to electricity users after the relevant surveys were conducted. Each participant thus received a report from Eskom with recommendations.

Table 1 depicts the results of similar studies conducted for other types of farming enterprises in Limpopo. Significant

Table 1: Comparison of calculated average electricity costs to produce different crops in Limpopo (Stones, 2016)

Crop type	R/kWh
Blue berries	1.04
Nursery	1.08
Nursey and subtropicals	1.85
Macadamias	1.76
Citrus	1.00
Subtropical crops:	
Co-worker 1	0.85
Co-worker 2	0.85
Co-worker 3	0.95
Co-worker 4	0.95
Co-worker 5	0.95
Co-worker 6	0.98
Co-worker 7	1.03
Co-worker 8	1.03
Co-worker 9	1.10
Co-worker 10	1.81
Average	1.05
Piggery	0.85
AVERAGE	1.13

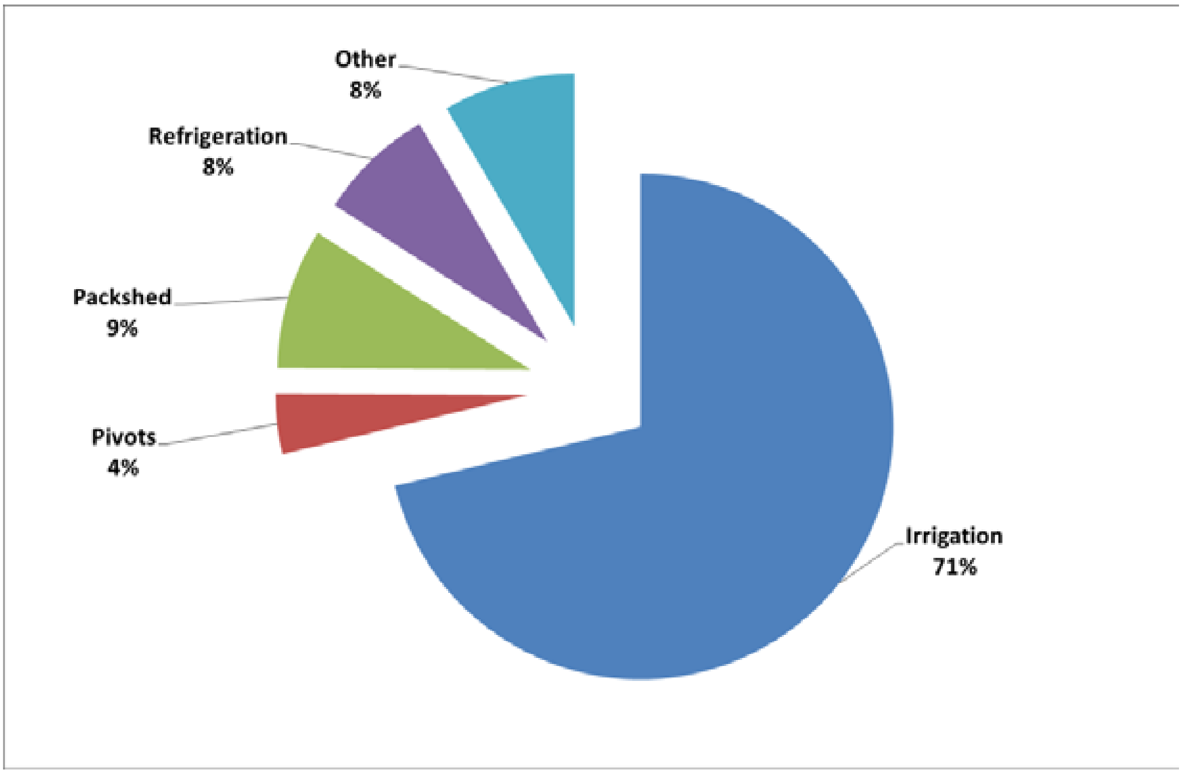


Figure 3: Distribution of the total annual electricity costs on potato farms in Limpopo (Stones, 2016)

variations in calculated electricity tariffs were also observed for other crops and the average of all the calculated tariffs was R1.13/kWh (see Table 1). It shows that the calculated electricity tariffs for potato production are relatively high in comparison with other production systems. Although one can speculate about the possible reasons, it emphasises the need for a calculation procedure of electricity costs for potato production under irrigation.

Figure 3 presents the energy audit results for the six participants. The pumping of irrigation water represents on average about 71% of the total electricity account, whilst cold storage rooms and pack stores combined account for a further 17% of the account. Most power supply points also have to provide electricity for other activities such as housing, which account for a further 8% of the total electricity cost.

The biggest potential for electricity cost savings, therefore, lies in optimising the water supply system and irrigation management on the farm. It consists of the following three aspects:

- The correct total seasonal irrigation needs must be applied.
- The irrigation water must be applied as efficiently, uniformly and economically as possible with a system that has been optimally designed and maintained.
- The irrigation scheduling must be optimally executed in accordance with the needs of the crop and the limitations of the Eskom tariff structure, if applicable.

These three aspects were investigated for the three case studies in the Limpopo region.

Irrigation requirements in Limpopo

Earlier research by the University of Pretoria has shown that the net irrigation requirement of potatoes that are planted on 15 June in Limpopo typically ranges between 450 and 480 mm. The net irrigation requirement represents the quantity of water that must infiltrate the soil to ensure that the crop does not experience water stress. Unfortunately, irrigation systems are not 100% effective and more water has to be applied to make provision for losses. The quantity of water that has to be pumped through the system is known as the gross irrigation requirement. Actual water applications are seldom measured by producers, and estimated figures for the three case studies were determined through interviews, as shown in Table 2. In two cases the actual gross irrigation applications were close to the gross irrigation requirement, whilst in one of the cases significantly more water was applied than was necessary (43% more water was pumped in Case study 1 than was needed by the crop).

According to Table 2, the actual yields were also lower than the yield potential, which was anticipated, as potential yields cannot necessarily be attained economically. Producers who utilise the available environment and their inputs efficiently should attain at least 66% of the environmental potential. In these case studies one of the producers (Case study 1) produced only 57% of the yield potential, which indicates that there is room for improvement in terms of increasing the efficiency of input usage.

Water use efficiency (WUE) gives an indication as to how efficiently water is converted into potatoes (i.e. how many

Table 2: Net irrigation requirements, gross irrigation amounts, potential and actual potato yields, and water use efficiency for three case studies in Limpopo with a planting date of 15 June

Parameter	**Case study**		
	1	2	3
Gross irrigation amount (GI) (mm)	650	475	450
Net irrigation requirement (NIR) (mm)	454	454	478
GI as a percentage of NIR (%)	143	105	94
Potential yield (t/ha)	88	88	65
Actual yield:			
t/ha	50	60	55
Actual yield as a percentage of potential yield (%)	57	68	85
Water use efficiency (kg potatoes / mm irrigation)	77	126	122

kg of potatoes were produced using 1 mm of water). Values above 80 kg/mm irrigated (8 x 10 kg bags) are regarded as acceptable, whilst good producers can easily attain values of 120 kg/mm and higher (Table 2). In this study WUE varied between 77 and 122 kg potatoes per mm irrigated. Case study 1 produced only 77 kg potatoes per mm of water irrigated, whereas the other two case studies performed significantly better. Unnecessary application of water does not contribute to higher yields, but it increases electricity costs, promotes disease incidence and also often lowers the quality of the potato crop. Scheduling tools and water measurement can be used to administer water more accurately (see the section on scheduling tools earlier in this series) in order to save water and increase WUE.

Application of irrigation water

The irrigation system (mostly pivots) and the water supply system (pump stations and main lines) make it possible for the producer to administer irrigation water according to the planned schedule, and are discussed separately.

A correctly designed irrigation system will administer water uniformly with the lowest possible losses. It is determined by conducting a system evaluation by placing rain gauges under a pivot in order to measure the actual application that is delivered to the soil surface.

The pivots at the three case studies were evaluated according to the prescribed methods of the Agricultural Research Council's Institute for Agricultural Engineering (ARC-IAE). The results are summarised in Table 3 and the distribution uniformities of the rain gauge readings are shown in Figure 4.

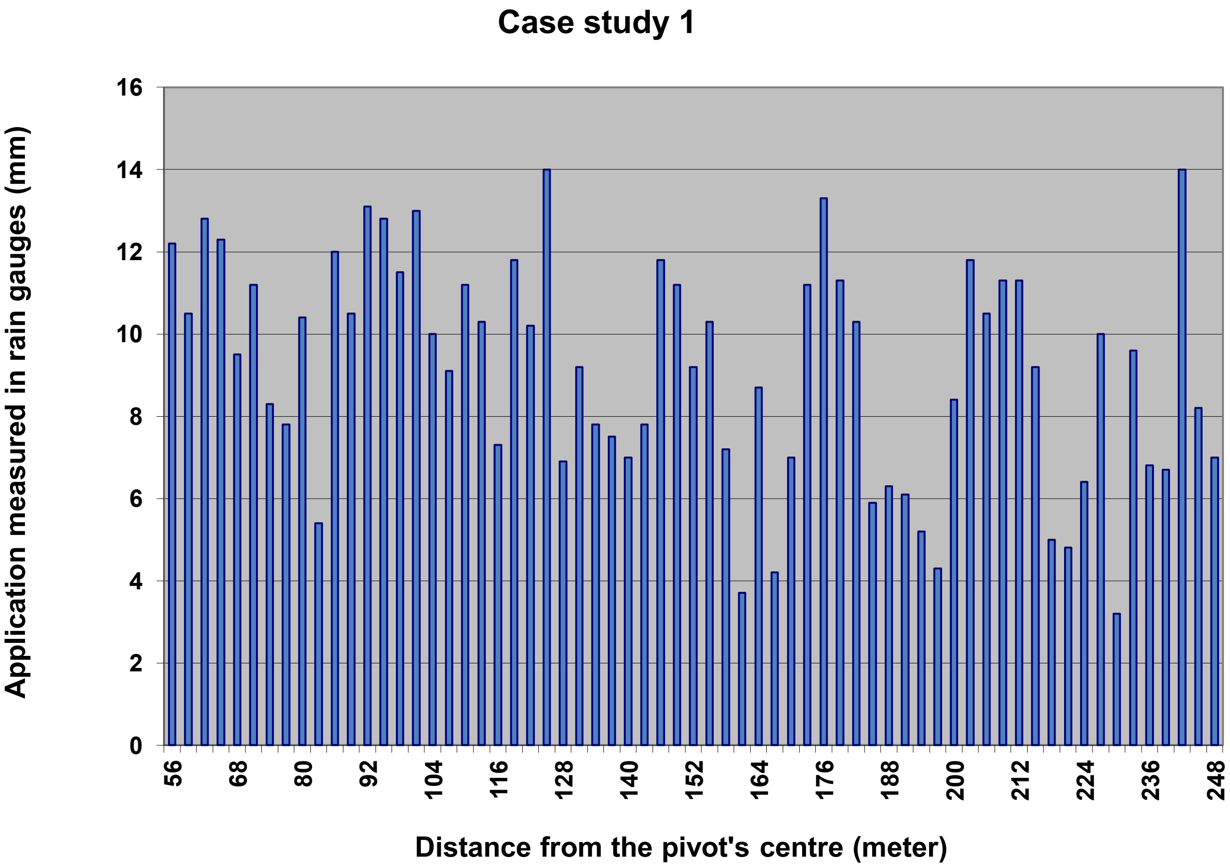
Application efficiency of pivots

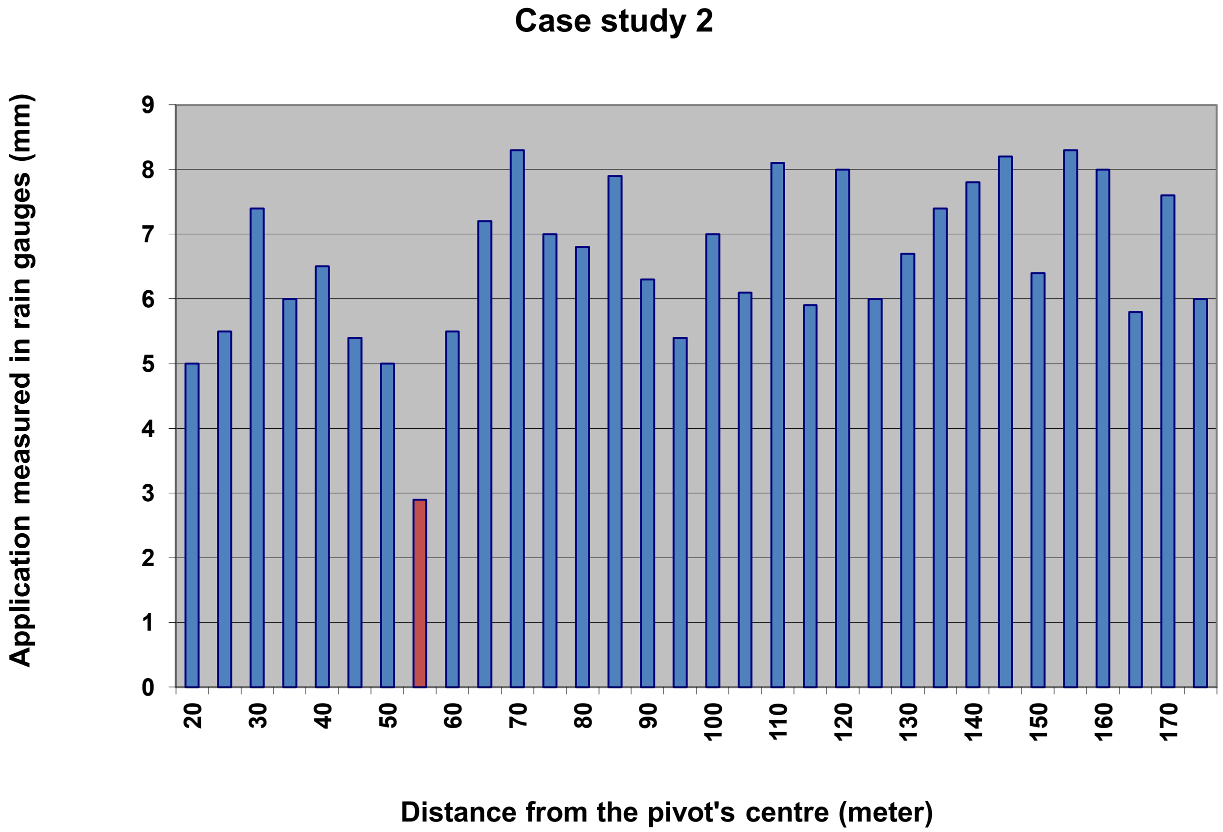
The application efficiencies in Table 3 show significant differences between the gross quantities of water administered, based on design data of the pivot and the amount of water measured on the soil surface (net application). There are numerous reasons for this. In Case study 1 the system pressure was too low (as measured at the pivot centre), and even though the measured application efficiency is good (97%), most of the sprinklers provided less water than they were supposed to. In Case study 3, where the lowest application efficiency (68%) was measured, the producer fitted all the sprinklers on the overhang with larger nozzles. This increased the system output to 7.2 mm, which is 2.9 mm above the design value of 4.3 mm. The performance of the pivot in Case study 2 was the best, with the lowest deviation from the original design parameters, as measured by the application efficiency, uniformity coefficient and distribution uniformity. This can be ascribed to the producer's positive approach towards infrastructure development and good maintenance practices on the farm. The average pivot application efficiency of all three case studies was 84.1%, which means that about 15.9% of the water emitted through the nozzles was lost between the sprinklers and the soil surface.

Table 3: Results of centre pivot evaluations for three case studies

Parameter	Unit	Case study			Norm	Average of case studies
		1	2	3		
Centre pivot area (hectare)	ha	20	10	13	-	14.33
Gross application according to design (mm)	mm	12.3	8.1	4.3	-	8.23
Gross application measured (A)*	mm	8.9	7.5	7.2	-	7.87
Net application – estimated by producer	mm	8	10	4	-	7.3
Net application – measured with rain gauges (B)	mm	8.6	6.6	4.9	-	6.7
Application efficiency (A / B x 100)	%	97	87	68	>80%	84.1
Uniformity coefficient (CU)**	%	71	83	82	>85%	78.7
Distribution uniformity (DUlq) ***	%	61	69	79	>75%	69.8

** A flow meter was used to measure the flow rate at the inlet of the centre pivot*
*** An indicator of the uniformity of water application over the length of the pivot*
**** Average net water application of the lowest 25% of rain gauge readings as a percentage of the average net application over the length of the pivot*


Case study 1


Case study 2

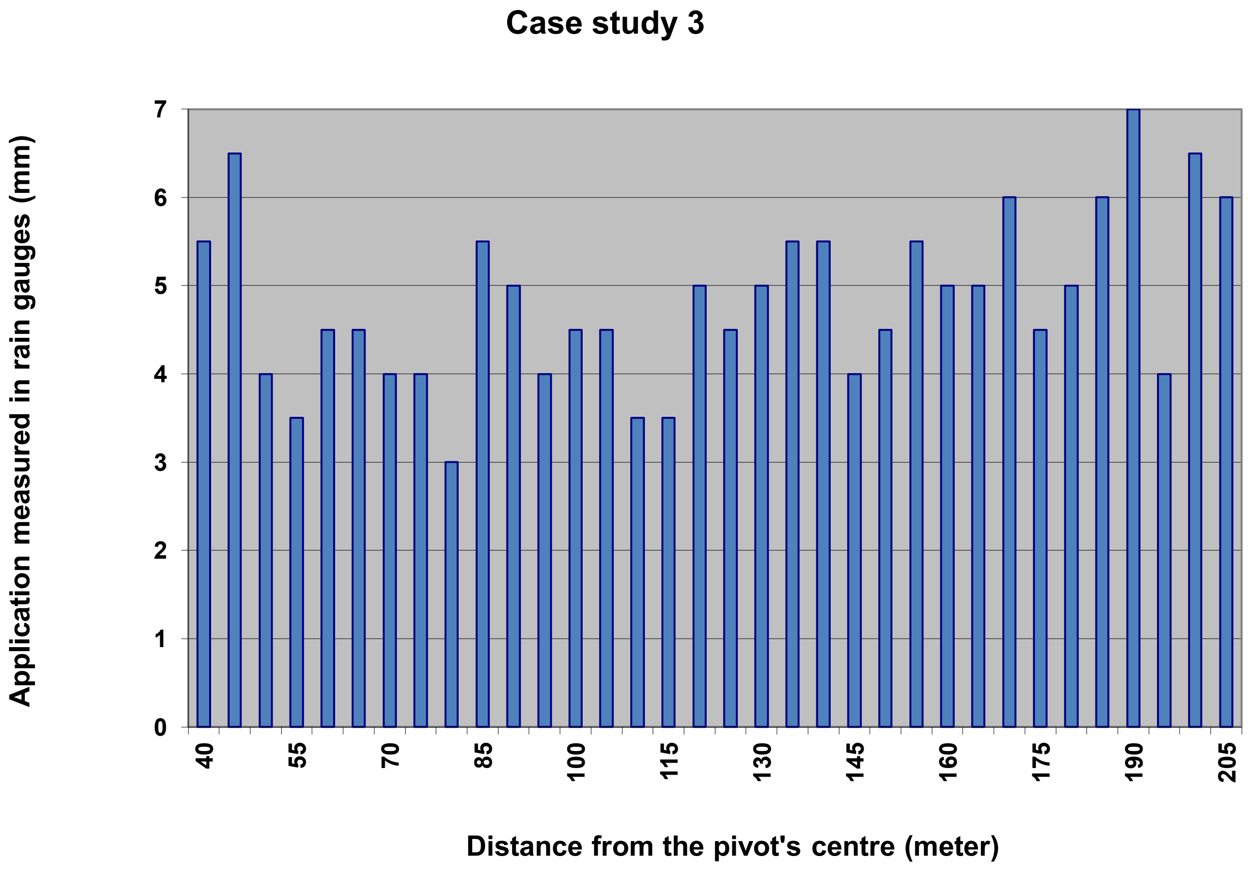


Figure 4: Distribution uniformity as measured for centre pivots of the three Limpopo case studies

Uniformity of pivots

Uniformity refers to the consistency of water application over the length of the pivot – in other words, whether all the plants received the same quantity of water during irrigation. This is evaluated on the basis of two indexes, i.e. the Heerman & Hein uniformity coefficient (CU) and the distribution uniformity of the lowest quarter of the readings (DUlq). Based on the uniformity values of the three case studies, none of them complied with the minimum required CU value of 85%, according to Table 3. The reasons are the same as described above (Case Study 1 – low pressure and Case Study 3 – changing of the nozzle package), as well as blockage of a sprinkler at approximately 55 m from the pivot at Case Study 2, as can be seen in Figure 4. Only Case Study 3 complied with the minimum DUlq value. The distribution of the rain gauge readings is shown in Figure 4. Note the significant variation in rain gauge readings, indicating that all plants do not receive the same quantity of water.

Water supply systems

Another part of the infrastructure that was investigated was the water supply system, consisting of the pump stations and main lines supplying the pivots with water. These components must be designed and selected to convey the water from the source to the irrigation system in the most economical way.

In addition, the producer must select the Eskom tariff structure that will be used at every power point (Landrate or Ruraflex). Although Ruraflex is a subsidised tariff with lower variable costs in comparison to Landrate, management is extremely important because specific peak times of the day must be avoided to benefit from the tariffs.

The following three typical water supply systems are used on farms in the Limpopo region:

- From a borehole directly to the irrigation system.
- From a borehole to a reservoir and then to the irrigation system.
- From a river to a reservoir, and then to the irrigation system.

These three system types were used as a guideline for selection of the three case studies. The electricity costs and management practices for the case studies are shown in Table 4. It is advisable to take note of the number of kW required per hectare to be irrigated – the most economical

Table 4: Cost of water supply for potato production in three case studies

Parameter	**Unit**	**Case study**		
		1	2	3
Average kW/ha (system capacity)	kW/ha	1.10	3.19	1.80
Eskom tariff		Ruraflex	Ruraflex	Landrate
Total number of pumping hours	Hours/season	1 651	1 226	1 395
Actual yield achieved	ton/ha	50	60	55
Irrigation applied (mm)	mm	520	530	537
Variable electricity costs:				
Per hectare	R/ha	1 274	2 659	2 670
Per mm water pumped	R/mm	2.45	5.02	4.98
Average calculated electricity tariff :				
Variable electricity cost	R/kWh	0.70	0.68	1.06
Variable and fixed electricity cost	R/kWh	1.14	1.23	1.66
Energy use efficiency	kWh/ton	726	482	594

systems have an average capacity of about 1 kW/ha. There are various factors that can unnecessarily increase the required capacity, such as when the irrigation system can only be utilised for a limited number of hours per day, if water must be pumped more than once in the case of long distances between the water source and the irrigation system, or if packhouses and/or processing plants must also be powered from the same power supply.

Although the first typical supply system (from borehole directly to system) is the most attractive because the water only has to be pumped once, it is seldom used owing to varying groundwater levels and general weakening of the boreholes in the relevant areas of Limpopo. In Case Study 1 the producer pumped directly from boreholes to the irrigation system, and although the electricity tariff was the lowest of the three case studies (R1.14 kWh), the water supply system contributed largely to the low pressure and flow problems experienced at this pivot. The effect was much longer pumping hours per season compared to the other systems, with lowest energy use efficiency (726 kWh/ton) as a result of the higher number of pumping hours.

The second type of supply system, as described above, is most common on farms where borehole water is used and usually comprises of long pipelines that transport water from a number of widespread boreholes (with relatively low yields per borehole) to the reservoir. The supply cost in these situations not only increase because the water has to be pumped twice or more, but also because multiple power supply points are often required, each with its own fixed cost component payable to Eskom. Case Study 2 uses dams to supply water to the irrigation system. The calculated electricity tariff is R1.23/kWh (Table 4), but the variable cost in terms of Rand/mm water applied more than doubles to R5.02/mm compared to Case Study 1 (R2.45/mm), because of the fact that water has to be pumped twice.

The third type of supply system is found on farms where water has to be drawn from a river. Normally the water also has to be pumped over long distances, but then from only one withdrawal point that is not deep below the soil surface. This type of system was investigated in Case Study 3. At a cost of R4.98/mm, the variable pumping cost is nearly the same as for Case Study 2 (Table 4). In Case Study 3 the Landrate tariff was used and not Ruraflex, which led to a higher electricity tariff (R1.66/kWh). With Ruraflex the farmer has the opportunity to manage his/her average calculated energy tariff (R/kWh) by avoiding certain time periods when the tariff is high. The variable cost tariff (R/kWh) for Landrate remains the same at any time of the day or week and is higher than the calculated

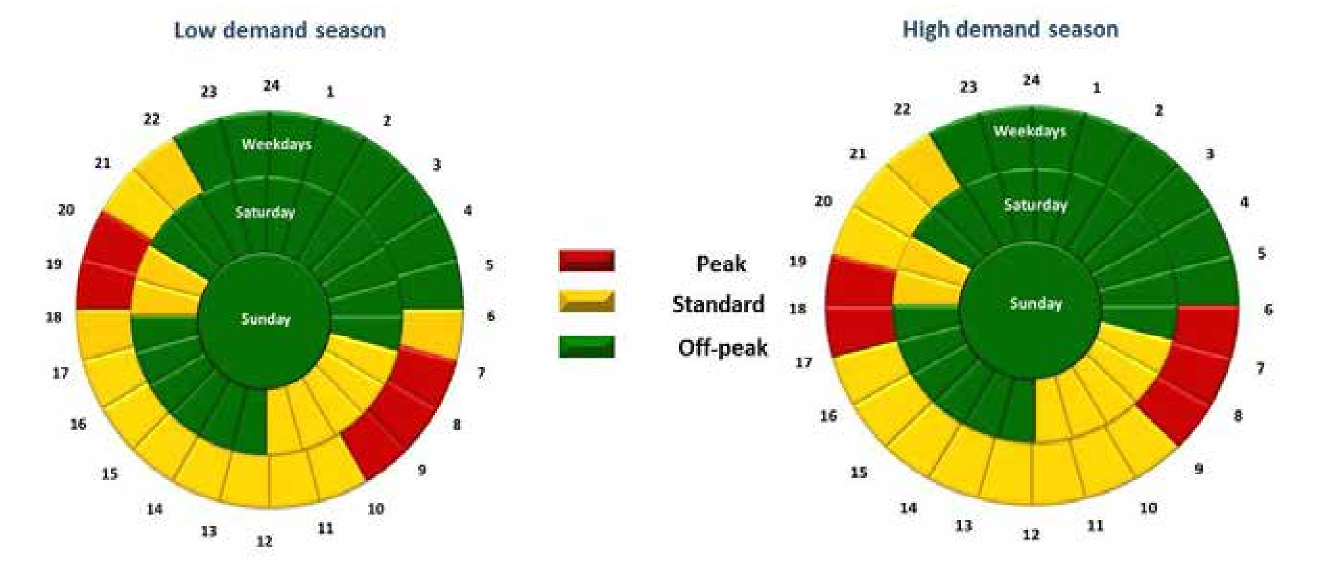


Figure 5: Daily distribution of Eskom peak, standard and off-peak times during high (June to August) and low (September to May) demand periods

cost for Ruraflex, if farmers are able to avoid peak times. Figure 5 shows the peak, standard and off-peak times during the week for Ruraflex during 2016/ 2017 (when the study was conducted), with high demand being from June to August.

The use of Ruraflex has significant management implications because the off-peak times occur during weekends and at night. Although only five hours per week day fall within the peak time, the tariff during peak times is extremely high and can easily lead to Ruraflex being more expensive than Landrate, should peak times not be avoided.

Table 5: Costs of alternative scenarios in each of the three case studies

		Case study 1		Case study 2		Case study 3	
	Unit	Current	Scenario	Current	Scenario	Current	Scenario
System capacity	kW/ha	1.10	1.58	3.19	2.72	1.80	1.80
Eskom tariff		Ruraflex	Ruraflex	Ruraflex	Ruraflex	Landrate	Ruraflex
Total number of pumping hours	Hours/ season	1 651	1 040	1 226	1 226	1 395	1 395
Actual yield	ton/ha	50	50	60	60	55	55
Irrigation applied (mm)	mm	520	520	530	530	537	537
Variable electricity costs:							
Per hectare	R/ha	1 274	1 102	2 659	2 227	2 670	1 690
Per mm water pumped	R/mm	2.45	2.12	5.02	4.20	4.98	3.15
Average calculated electricity tariff :							
Variable electricity cost component	R/kWh	0.70	0.67	0.68	0.67	1.06	0.67
Variable and fixed electricity cost	R/kWh	1.14	1.16	1.23	1.46	1.66	1.16
Energy use efficiency	kWh/ton	726	655	482	410	594	594

Effects of different scenarios on electricity costs

In each case study an alternative scenario was tested to establish if electricity cost could be reduced. The results are shown in Table 5.

In Study Case 1 the scenario analysed was where the irrigation system received the correct pressure and flow from the boreholes (see discussion of Case Study 1 in Table 4). The implication is that the number of pumping hours per season is now much less (1 040 versus 1 651) to apply the same quantity of water (520 mm) (see Table 5). The effect is that the variable cost of water applied per hectare decreases from R1 274/ha to R1 102/ha and the energy use efficiency improves from 726 kWh/ton to 655 kWh/ton. This is due to the fact that if the correct size pump is used, the total number of pumping hours for the season will come down.

In Case Study 2 the layout of the main line was analysed by an irrigation system designer and it was found that if the reservoir is moved, the mainline can be shortened and the pivot can be operated by means of gravitation from the reservoir. If the changes are effected the water has to be pumped only once with less friction losses in the main line. The implication of these changes are that the capacity of the system decreases from 3.19 kW/ha to 2.72 kW/ha. The effect of this drop is that the variable cost for water applied per hectare decreases from R2 659/ha to R2 227/ha, and the energy use efficiency improves from 482 kWh/ton to 410 kWh/ton.

In Case Study 3 the effect of the selected Eskom tariff structure was analysed by calculating the energy costs if the producer changes from Landrate to Ruraflex. The implication of this change is that the electricity tariff can be reduced from R1.66/kWh to R1.16/kWh if the producer irrigates when the tariff is at its lowest. The effect of this reduction is that the variable cost of water applied per hectare decreases from R2 670/ha to R1 690/ha, a saving of more than 36%.

In none of the abovementioned cases was the cost to implement the changes taken into account. In some cases the cost to effect the changes could be extensive and it is, therefore, important to conduct a detailed assessment of implementation costs before any changes are implemented.

Recommendations

Most systems offer opportunities for optimisation that will lead to a reduction in electricity costs. The following general recommendations will assist producers in making decisions that could save energy:

- Eskom tariff structure: Ruraflex is a subsidised tariff structure for agricultural water users. Electricity can be purchased at lower rates, compared to Landrate. However, it is essential that the irrigation system is correctly managed to ensure irrigation does not take place during the tariff structure's peak times, as that will negate any advantage. The use of Ruraflex therefore requires proper irrigation scheduling.
- Efficient irrigation systems: Producers should evaluate the nozzle package on the pivot at least every two years by conducting a uniformity test with rain gauges. Adjustments to the pivot or nozzle package without consulting an irrigation system designer is also not recommended as it would impact on the total system – from the pump station to where the irrigated water is applied to the soil.
- Planning and designing of water supply systems: It is recommended that an expert irrigation system designer (such as designers approved by the South African Irrigation Institute, SABI) be approached to plan the main lines and pump stations on a farm. That will ensure that the most economical pipelines, pumps and motors are installed. Visit www.sabi.co.za for more information on SABI approved designers and system evaluators.
- The use of variable speed drives (VSDs) was not addressed in this article, but this important new technology can, with proper advice from an expert, assist in reducing the power needs of a system substantially.
- The use of suitable scheduling tools to determine the water content of the soil during the growing season will ensure that the correct quantity of water is applied and thereby prevent over-irrigation and energy wastage. Ⓒ

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- Roger Stones, Senior Energy Advisor of Eskom, Tzaneen.

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Optimisation of energy usage for potato production in the Sandveld

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Energy cost remain one of the most expensive inputs required for potato production under irrigation, and following a survey conducted during 2015/2016 in Limpopo, Potatoes South Africa launched a similar project in the Sandveld during 2016/2017.

The aim of the project was to conduct an economic evaluation of alternative strategies to decrease electricity costs, improve water productivity and increase profitability. The project was undertaken during a summer planting (September) of potatoes in the Sandveld.

The project consisted of the following activities:

- Energy audits were conducted by Eskom at 11 participants to obtain an overview of typical energy usage on farms in the Sandveld.
- Irrigation system evaluations were conducted on five pivots to determine the efficiency and application uniformity of the irrigation systems.
- The irrigation hours and amounts of the same five pivots were monitored during the season to determine the actual water usage.
- The measured information was used to calculate the energy and water use efficiencies of the systems.

Energy audits

The total annual energy usage for 2016 of the 11 participants in the Sandveld was determined by an Eskom advisor. The distribution of energy usage by the different components found on a farm, as an average for the 11 participants, is indicated in Figure 1. About 68% of the

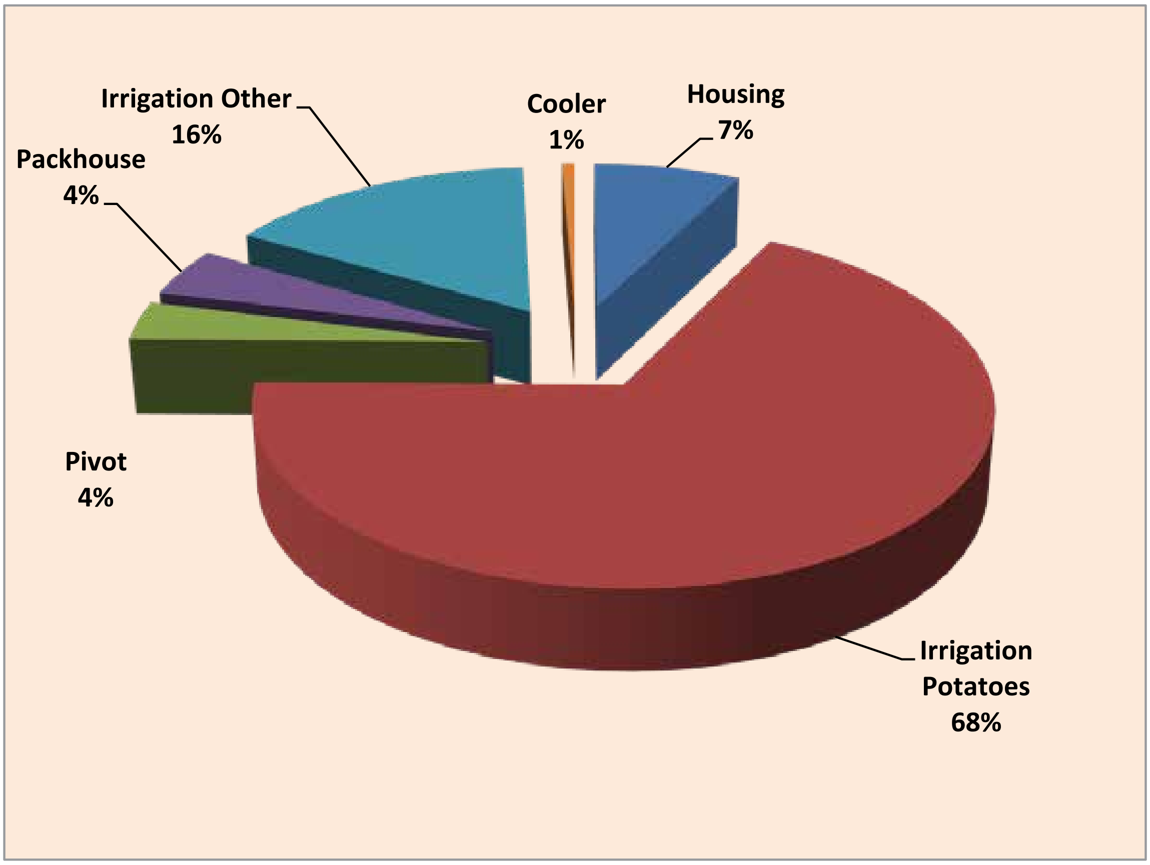


Figure 1: Average usage of electricity (kWh per year) per co-worker

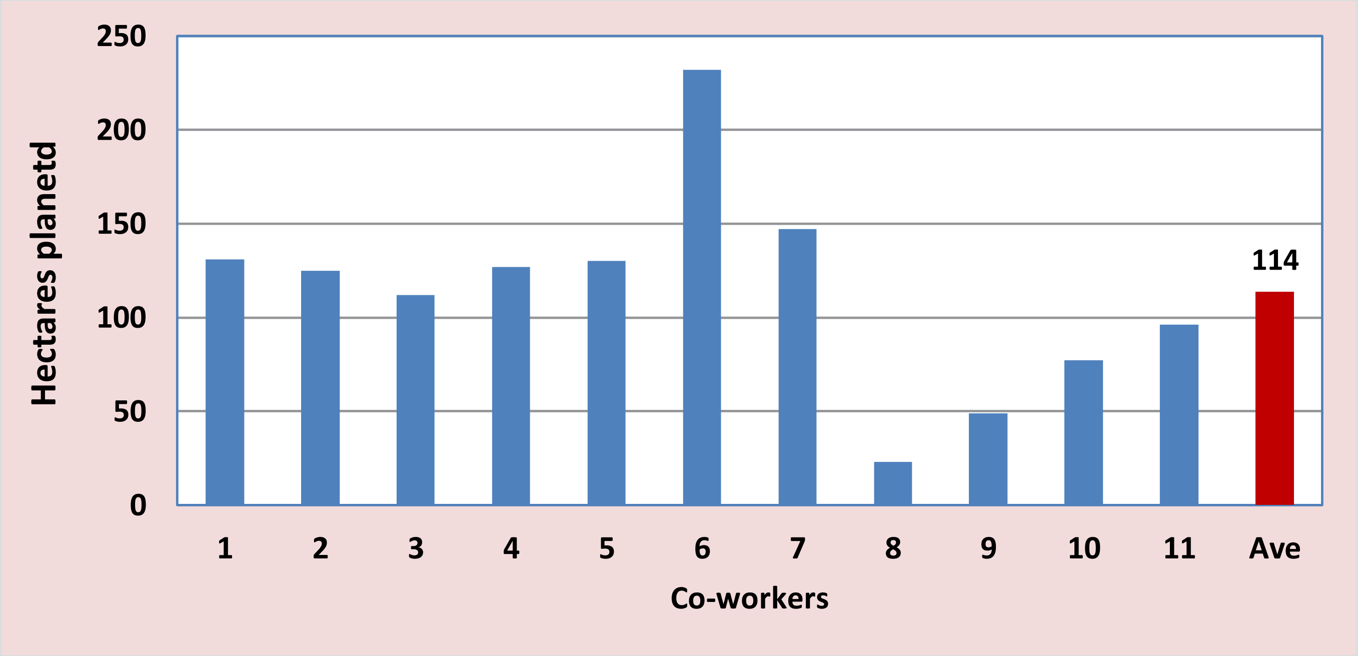


Figure 2: Hectares of potatoes irrigated by each co-worker

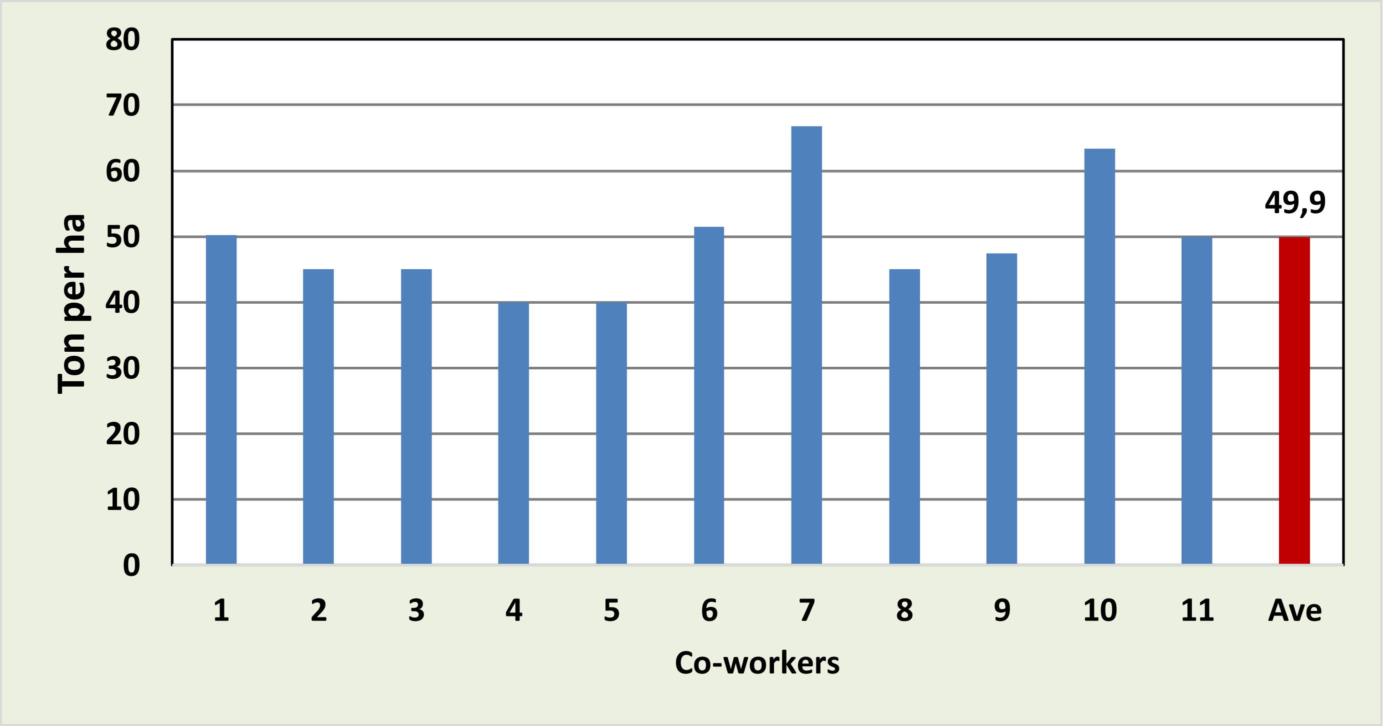


Figure 3: Yield (ton per ha) realised by co-workers

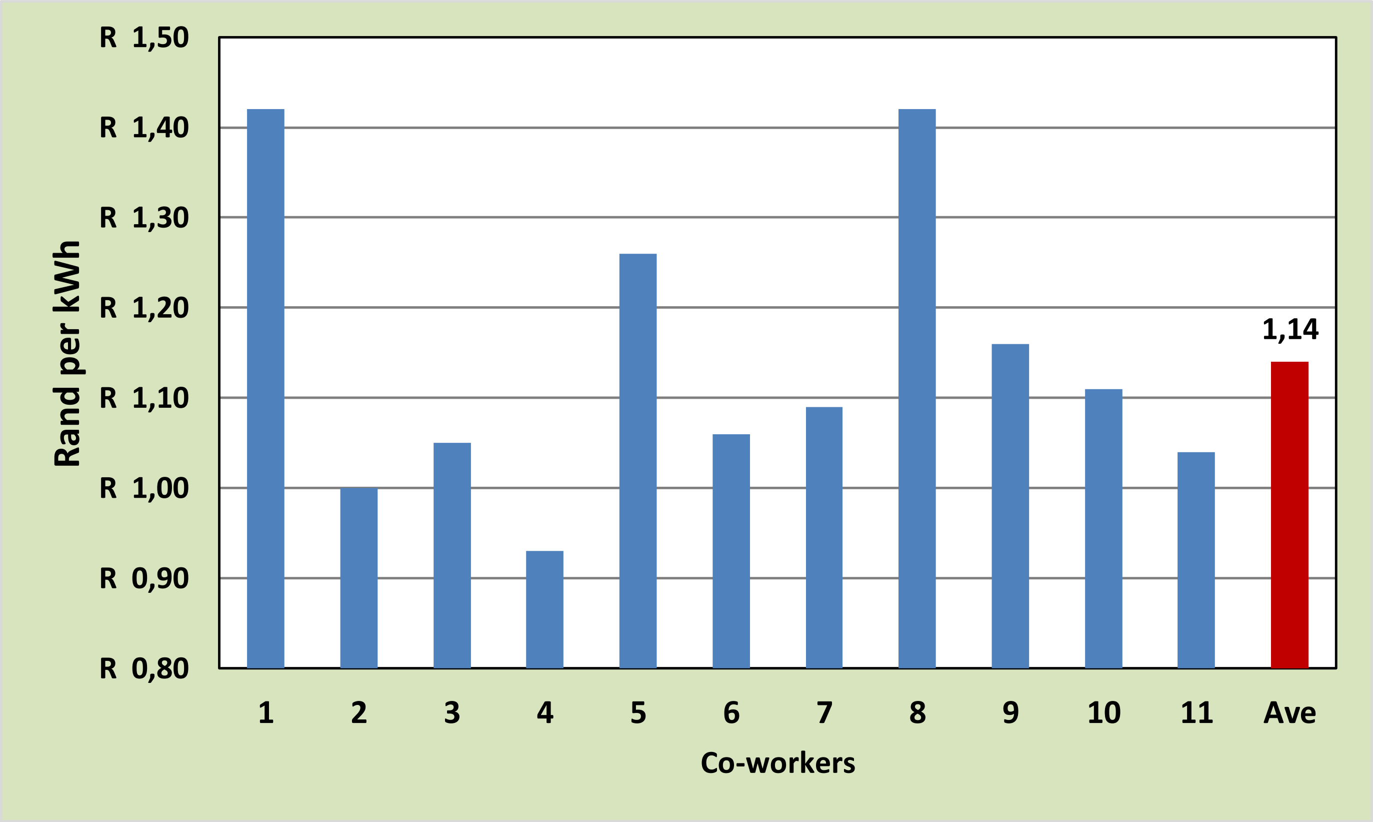


Figure 4: Average electricity tariffs (Rand per kWh) as calculated for co-workers

annual electricity usage on a Sandveld farm is utilised for the irrigation of potatoes. Pivots and packhouses utilise only 4% each of the total electricity usage (kWh). The areas planted with potatoes and that were irrigated varied between 23 ha and 232 ha per participant, with an average of 114 ha (Figure 2), whilst the yields of the 11 participants ranged from 40 to 67 ton/ha, with an average of 49.9 ton/ha (Figure 3).

The average calculated energy tariff for the 11 participants

Figure 5: Calculated electricity costs per hectare of irrigated potatoes

Figure 6: Using a portable flow meter to determine the water flow rate of a centre pivot irrigation system

was R1.14/kWh (Figure 4), whereas the average electricity cost for the cultivation of potatoes in the Sandveld was calculated as R7 272/ha (Figure 5).

The significant variations observed in the tariffs and costs can be ascribed to the different conditions on the 11 farms. There were different combinations of Landrate and Ruraflex power points, as well as different transformer sizes and usage profiles, which influenced the total cost on each farm. Eskom advisors revisited participants at the end of the study to discuss their data and make recommendations to improve energy use efficiency.

Irrigation system evaluations

The next phase of the project entailed an investigation of the performance of five centre pivot systems by measuring their efficiency and uniformity of water application.

The evaluation of a centre pivot firstly entails measurement of the water flow rate at the pivot centre, using a portable flow meter (Figure 6). The distribution uniformity of the water applied is measured by packing out a series of rain gauges across the length of the pivot (Figure 7), in accordance with the guidelines of the Institute of Agricultural Engineering of the Agricultural Research Council (ARC-IAE). The running speed of the pivot and maximum application rate under the overhang were also measured. During the evaluation, general observations were also made regarding the condition of the system (e.g. any leakages observed and the depth of the wheel tracks), and the prevailing weather conditions (temperature, humidity, wind speed and direction) were measured.

The results of the five evaluations are shown in Table 1. The uniformities of the systems, as indicated by the Heerman

Figure 7: Rain gauges are used to evaluate the distribution uniformity of a centre pivot irrigation system

Figure 8: Mounting of an electromagnetic sensor to monitor pivot run time

& Hein uniformity coefficient (CUHH) and the distribution uniformity of the lowest quadrant (DUlq) were generally good (all were better than the norm, except for SV 5), especially if the conditions at the time of the tests are taken into account. Uniformity refers to the consistency of water application over the length of the pivot, in other words whether all the plants received the same amount of water during an irrigation event. In three of the case studies (SV 2, SV 3 and SV 5) the wind speed was very high (17-18 km/h), and at SV 3 the temperature was also extremely high (39 °C) during system evaluation, which probably affected system performance negatively.

The application efficiency (AE) is the ratio between the volume of water measured in the rain gauges and water volume delivered by the pivot, i.e. the percentage of the water from the sprayers that reaches the soil surface. The AE of all five systems were higher than the minimum requirement of 80%, except for SV 3 with 78%, where high wind speed and temperatures occurred during the test. This caused the humidity to drop, which consequently led to higher evaporation losses. For SV 3 the AE of 78% means that 22% of the water emitted from the sprayers was lost between the sprayer and the soil surface, compared to a water loss of only 3% for SV 4.

The total pump pressure indicated in Table 1 is the sum of all the operating pressures on the water that is transported to the pivot, e.g. if the water is firstly pumped from a borehole into a dam and then from the dam to the pivot, the total pump pressure is the sum of the pressure of the borehole pump and the dam pump, including any approximate friction losses and topographic height differences (e.g. 10 m pump pressure is equivalent to about 100 kPa or 1 bar of water pressure).

Monitoring of water usage

Previous studies in the Sandveld have shown that there were significant differences between producers in the total amounts of water applied to potato crops. This project also aimed to accurately measure irrigation amounts to be able to accurately quantify actual electricity usage and costs.

The monitoring was conducted by measuring the run time of the electrical motor on the last tower of each pivot, using a sensor that registers the electromagnetic field of the motor when it switches on (Figure 8). The information obtained was then analysed to determine exactly when and at what speed setting each pivot ran during the season.

The planting dates for the five case studies varied between 30 August and 11 October 2016, and the actual and calculated irrigation requirements are indicated in Table 2. The measured irrigation data included the water applied for cooling of the crop at the end of the season. The average actual irrigation applied (705 mm) was only about 7% higher than the calculated net irrigation requirement of 661 mm. The irrigation requirement represents the volume of water that must infiltrate the soil in order to ensure that the crop does not experience any water stress. It is a theoretical value that is calculated using a model and depends on the prevailing weather conditions and growth stage of the crop. Since irrigation systems are not 100% efficient, more water has to be applied to make provision for losses. The actual gross irrigation volume is therefore always higher than the net requirement. The calculated irrigation requirement and actual irrigation as a function of the different planting dates are indicated in Figure 9. Participant SV 4 differed the most from the calculated irrigation requirements, with a 30% higher

Table 1: Summary of the system evaluation results for five case studies in the Sandveld

	Case study number				
Parameter	SV 1	SV 2	SV 3	SV 4	SV 5
Pump set-up	Borehole and Dam	Borehole and Booster pump	Borehole	Dam and/or Borehole	Borehole and Dam
Rate of flow at pivot, m^3/h	71,3	57	46,5	61	88
Pivot area, ha	11,2	11,0	11,9	12,6	25,0
Gradient, %	3,4	3,5	0,5	0	1,7
Total pump pressure, m	171	76	57	90	151
Power, kW	55	15	10.8	31.2	55.8
VSD in use (Variable speed drive)	No	Yes	No	No	No (yes with soft starter)
Eskom tariff plan	Landrate	Landrate	Ruraflex	Ruraflex	Landrate
Sprayer package, mm/day	14	13,5	8,4	12	8
Sprayers	Fixed sprayer	Fixed sprayer	Wobbler ("i-Wob")	Wobbler ("i-Wob")	Fixed sprayer
Speed setting, %	50	55	39	50	80
Speed measured, %	50	57	40	49	70
Uniformity:					
CU_{HH} (>85%), %	89	89	87	86	83
DU_{lq} (>75%), %	86	83	76	76	84
Application efficiency:					
AE (>80%), %	83	90	78	97	94
Wind during test, km/h	12	18	17	11	18
Temperature, ˚C	32	21	39	24	27
Humidity, %	43	70	27	71	51

application than the calculated requirement. In practice it is permissible that actual irrigation amounts exceed the calculated net requirements by 15-20% to make provision for system losses and unfavourable weather conditions (e.g. wind and low humidity). In addition, it is clear that earlier planting dates result in significantly lower water requirements due to lower atmospheric evaporative demand during cooler months. That will also be reflected in electricity savings. The data shows that at SV 3 and SV 5 only 84% and 83% of the irrigation requirements were applied, respectively. In the case of SV 3, problems were experienced with the seed potatoes planted, which negatively affected plant growth, development and yield. It also resulted in much lower water requirements for SV 3. At SV 5 the maximum system design of 8 mm/day was insufficient to meet the crop water requirements, which probably resulted in lower total water usage and final yield.

Figure 10 and Table 2 indicate the actual yield attained by each producer versus the calculated yield potential. The yield potential is calculated using a crop model and indicates the theoretical maximum yield that can be attained for a specific environment, climate and cultivar. Producers who can effectively utilise the available environment and inputs should attain at least 65% of the environmental potential. The yields achieved in three of the case studies were 65% or higher than the potential yield, whereas SV 3 and SV 5 attained lower yields because of the reasons mentioned earlier.

Table 2: Summary of monitoring results for five case studies in the Sandveld

	Case study number					
Parameter	**SV 1**	**SV 2**	**SV 3**	**SV 4**	**SV 5**	**Average**
Planting date (2016)	11 Oct	26 Sept	30 Aug	27 Sept	10 Sept	
Actual irrigation (mm): A	864	737	505	901	516	705
Calculated irrigation requirement (mm): B	723	673	598	693	619	661
% of requirement (A/B x 100)	120	110	84	130	83	105
Actual yield (t/ha): C	68	75	35	73	58	59
Calculated yield potential (t/ha): D	104	104	108	106	105	106
% of potential (C/D X 100)	65	72	32	69	55	57
Actual WUE (kg/ha/mm)	79	102	69	81	112	91
Potential WUE (kg/ha/mm)	144	155	181	153	170	161

Table 3: Summary of pivot management for five case studies in the Sandveld

	Case study number				
Parameter	**SV 1**	**SV 2**	**SV 3**	**SV 4**	**SV 5**
Eskom tariff plan	Landrate	Landrate	Ruraflex	Ruraflex	Landrate
Total pumping hours	1 357	1 357	1 291	1 414	1 475
Hour distribution according to Eskom time groupings, % (Peak: Standard: Off-peak)	14:35:51	16:28:56	14:34:52	14:33:53	15:35:50
Hour distribution per month:					
Sep (2016)	0	66	36	172	33
Oct	80	137	186	77	349
Nov	414	437	571	503	492
Dec	624	563	474	551	538
Jan (2017)	105	74	24	111	63
Feb	55	81	0	0	0
Mar	81	0	0	0	0

Figure 11 and Table 2 indicate the water use efficiency (WUE) for the five case studies as a function of the planting date. WUE gives an indication as to how efficiently water is converted into potatoes (i.e. how many kg potatoes were produced using 1 mm of water). SV 5 had the best WUE, whilst SV 2 had the highest yield and also a good WUE. WUE figures better than 80 kg/ha/mm (8 x 10 kg bags/mm irrigated) are regarded as acceptable, whereas values of 100 kg/ha/mm and higher can easily be attained with good management and under favourable climatic conditions. Too much water applied at the wrong time does not contribute to yield, but instead increases electricity cost and contributes to diseases, while it often also results in lower tuber quality. Scheduling and water measurement

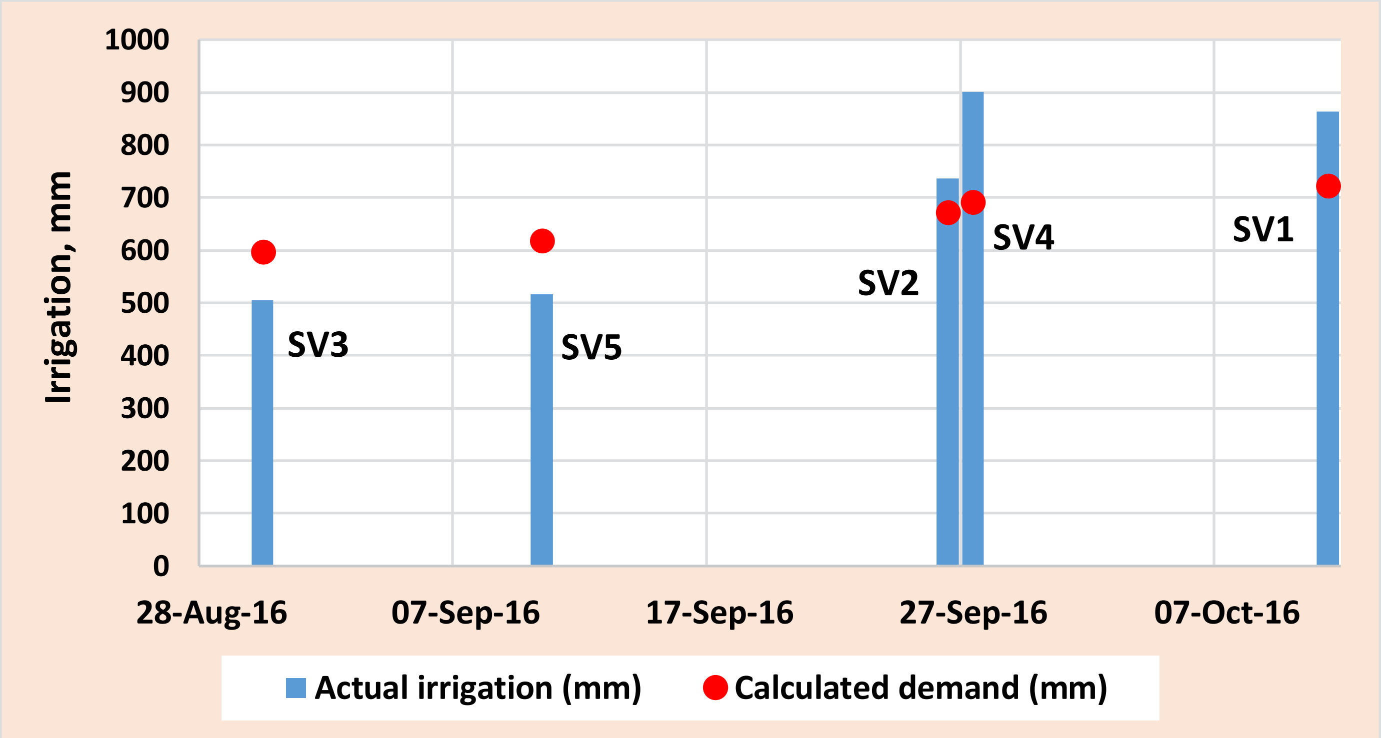


Figure 9: Calculated demand and actual irrigation for different planting dates

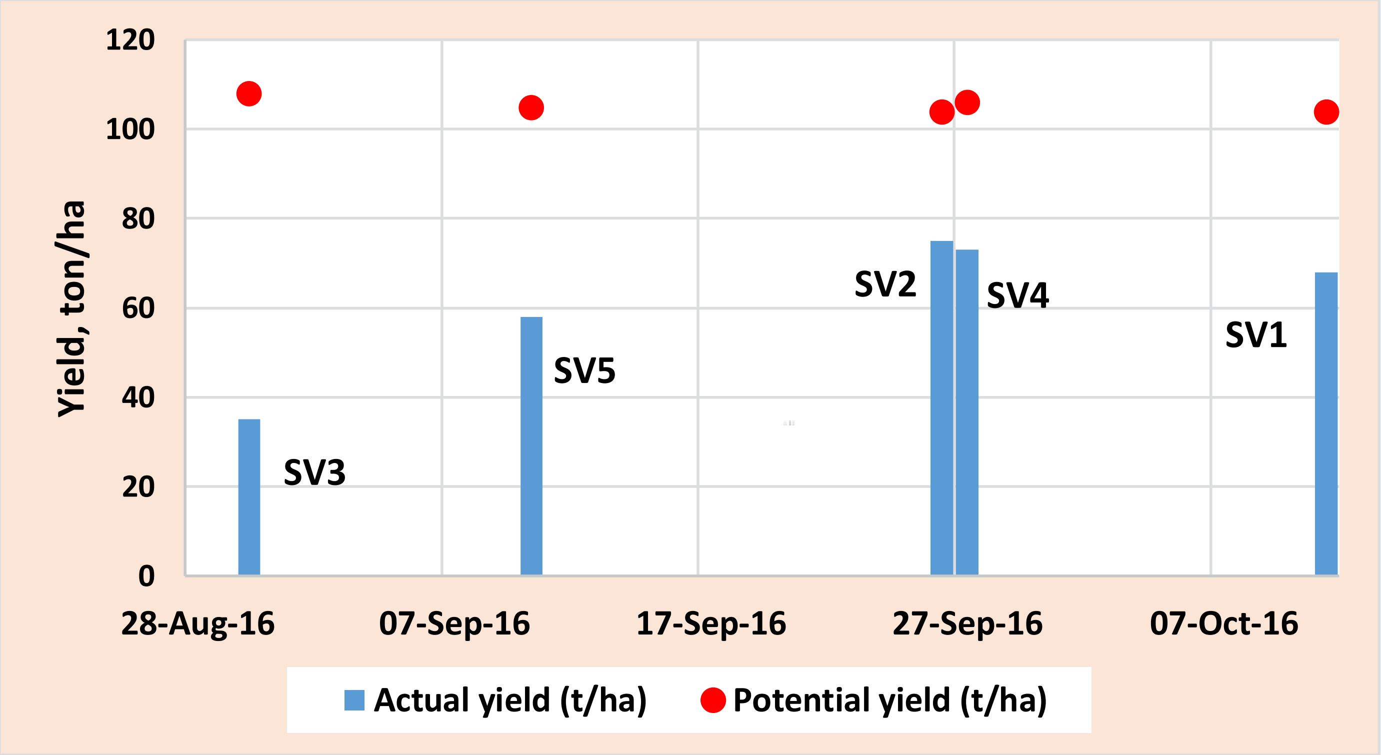


Figure 10: Potential and actual yields for different planting dates

tools can be used to apply water more accurately (see the sections on scheduling tools earlier in this series) and thereby save water and increase WUE. From Figure 9 and Figure 10 it is clear that yield potential decreases and water requirements increase, the later in summer the planting date. Water usage efficiency consequently also drops more when the planting date is postponed (Figure 11).

Monitoring of pivot energy usage

The data from the electromagnetic sensors was analysed to obtain the total pumping hours of each pivot, as indicated in

Table 4: Results of electricity cost calculations

		Case study number					
		SV 1		**SV 2**			
				No VSD		VSD	
Parameter		Landrate	Ruraflex	Landrate	Ruraflex	Landrate	Ruraflex
		Currrent	Alternat.	Alternat.	Alternat.	Currrent	Alternat.
Landrate option		3		1		1	
Fixed electricity cost, R		13 323	9 049	7 557	5 268	7 557	4 813
	Per hectare, R/ha	1 190	808	687	479	687	438
Variable electricity cost:							
	R/ha	7 922	5 531	2 479	1 716	2 200	1 523
	R/mm	9,16	6,40	3,36	2,33	2,98	2,07
	R/kWh	1,19	0,83	1,19	0,82	1,19	0,82
Total electricity cost:							
	R/ha	9 112	6 339	3 166	2 195	2 887	1 961
	R/mm	10,54	7,33	4,29	2,98	3,92	2,66
	R/kWh	1,37	0,95	1,52	1,05	1,56	1,06
	R/ton	134	93	42	29	38	26
	kW/ha	4,9	4,9	1,5	1,5	1,4	1,4
	Total kWh	74 630	74 630	22 938	22 938	20 359	20 359
	kWh/ha	6 663	6 663	2 085	2 085	1 851	1 851
	kWh/ton	98	98	28	28	25	25
Energy use efficiency:							
	kg/ha/kWh	0,91		3,27		3,68	
Saving with Ruraflex, R/annum		31 057				10 192	
Conversion cost, R		13 675				10 597	
Saving with VSD, R/annum				3 066			
Conversion cost, R				±16 500			

Table 3. The average pumping hours were 1 379 hours for the season.

The data could also be analysed to determine the running time profiles of the pivots according to peak, standard and off-peak groupings for Ruraflex usage (Figure 12). Although only SV 3 and SV 4 are subject to Ruraflex tariffs, the information was later used to conduct optimisation calculations for all five systems.

Table 3 indicates how the pumping hours were spread over the different months during which irrigation took place. This information could be converted to mm irrigation applied per month, as indicated graphically in Figure 13. The monthly water usage quantities follow a typical pattern of the crop's growth curve. Water requirements are low early in the season, peak by the middle of the season and then later drop again as the crop matures. From Figure 13 it is also clear that monthly water usage increases the later in summer planting takes place.

Electricity cost calculations

The information obtained through monitoring was

Case study number						
SV 3		**SV 4**		**SV 5**		**Ave.**
						(current)
Landrate	Ruraflex	Landrate	Ruraflex	Landrate	Ruraflex	
Alternat.	Currrent	Alternat.	Currrent	Currrent	Alternat.	
1		2		2		
5 285	3 209	8 934	6 396	11 241	7 698	
444	270	709	508	450	308	582
1 393	969	4 163	2 885	3 914	2 751	3 608
2,76	1,92	4,62	3,20	7,53	5,29	5,40
1,19	0,83	1,19	0,82	1,19	0,84	1,06
1 837	1 238	4 872	3 392	4 364	3 059	4 190
3,64	2,45	5,41	3,77	8,40	5,88	6,24
1,57	1,06	1,39	0,97	1,33	0,93	1,26
52	35	67	46	75	53	67
0,9	0,9	2,5	2,5	2,2	2,2	2,3
13 944	13 944	44 119	44 119	82 312	82 312	
1 172	1 172	3 501	3 501	3 292	3 292	3 283
33	33	48	48	57	57	53
2,51		1,65		0,70		1,66
7 128		18 643		32 638		
Already on Ruraflex		Already on Ruraflex		10 597		

furthermore used to calculate the electricity cost for the production systems in the five case studies by making use of the costing procedures that were developed during the earlier project undertaken in the Limpopo production region. The results are indicated in Table 4. For each of the case studies a survey was conducted on the costs for both Landrate and Ruraflex, since the choice of tariff plan offers the biggest opportunity for electricity cost savings. At case studies SV 3 and SV 4, Ruraflex is already being used. At case study SV 2 consideration was also given to the cost saving that could be brought about by making use of a VSD. The averages indicated in the last column are the weighted averages calculated for the inputs in respect of the current situations as indicated by each case study. The average fixed cost of electricity was R582/ha. It is evident that where Ruraflex is used, the fixed electricity cost of systems is in all cases cheaper than where Landrate is used.

The variable cost to supply water to the pivots varied between R1.92/mm and R9.16/mm, with an average of R5.40/mm. These huge differences can be ascribed to the topographic differences between systems – at SV 1 and SV 5 there are huge height differences that must be overcome between the water sources to the irrigation systems, whereas in the case of SV 3 the water is directly supplied from the borehole to the pivot. The producer at SV 1 can reduce the variable cost of R9.16 per mm to R6.40 by converting from Landrate to Ruraflex.

If the average total electricity cost is reviewed (fixed cost plus variable cost), it is R6.42/mm or R1.26 per kiloWatt-hour (kWh), which compares reasonably favourably with the R1.14/kWh determined through the energy audits. The slightly higher calculated values can be ascribed to the fact that the total fixed cost was allocated to the production of potatoes. Note that the total cost of the Ruraflex options was cheaper throughout than the Landrate options for all the different case studies. The conversion cost (Landrate to Ruraflex) is taken into account later.

The electricity cost per ton of potatoes, which varied between R29/ton and R134/ton, with an average of R67/ton, is an interesting index to investigate. Once again, the lowest cost was incurred at a system that is currently operating on Ruraflex (SV 3), and the highest cost at a system on Landrate (SV 1).

The electricity usage was on average 3 283 kWh/ha

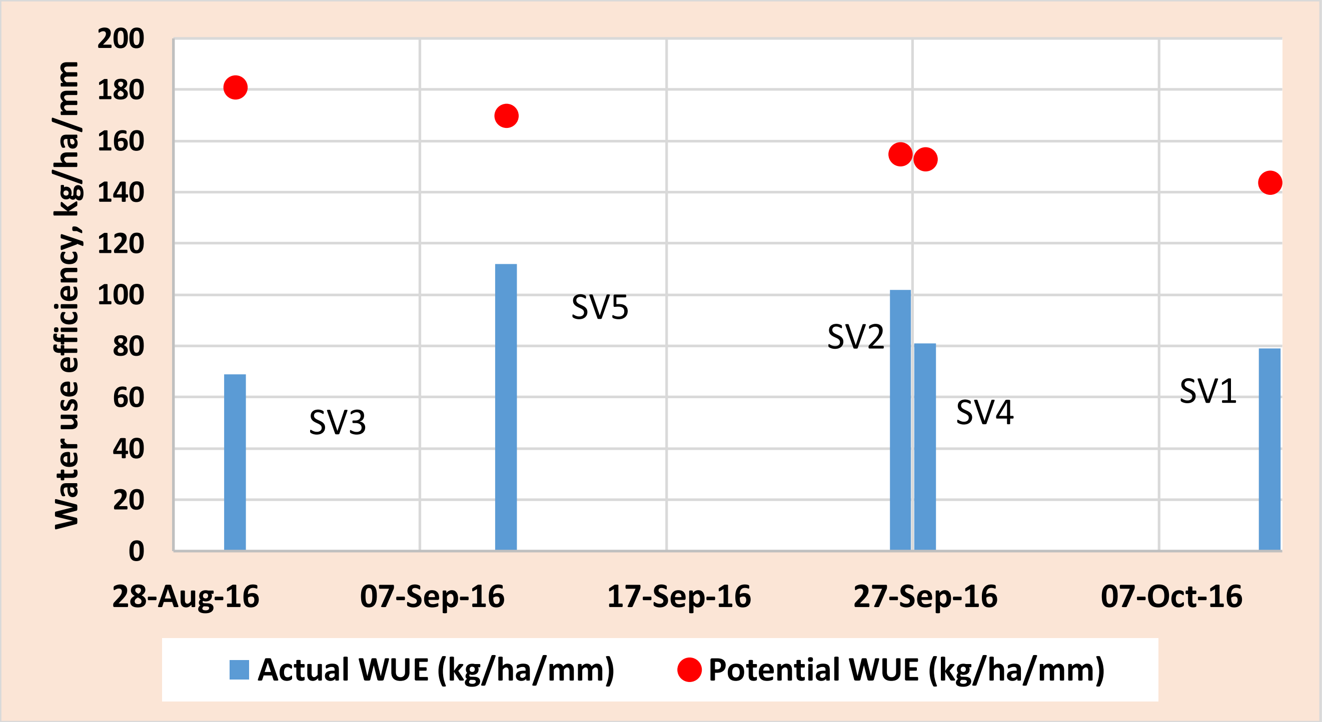
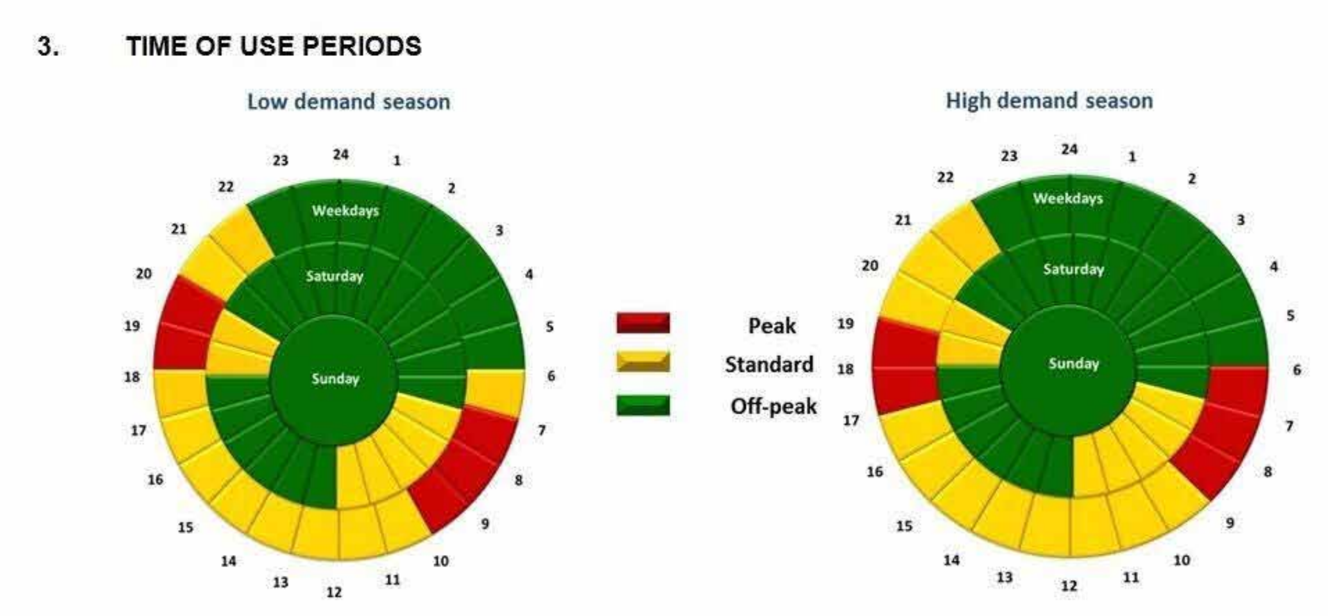


Figure 11: Actual and potential water use efficiencies for different planting dates



September to May

June to August

Figure 12: Eskom's peak, standard and off-peak time groupings

or 53 kWh/ton, compared to the 2 277 kWh/ha or 42 kWh/ton measured in Limpopo. However, a winter planting was monitored in Limpopo, and the average irrigation application was only about 520 mm, compared to the 705 mm applied in the Sandveld. In addition, there were larger topographic differences to overcome with pump pressure at two of the Sandveld case studies, which increased the average kWh usage.

The energy use efficiency (EUE) for the five case studies varied between 0.7 and 3.68 kg/ha/kWh, with an average of 1.66 kg/ha/kWh, which is slightly higher than the EUE measured in Limpopo (1.63 kg/ha/kWh).

Table 4 also indicates the savings that can be attained at SV 1, SV 2 and SV 5 by converting from Landrate to Ruraflex. According to the calculations, the investment

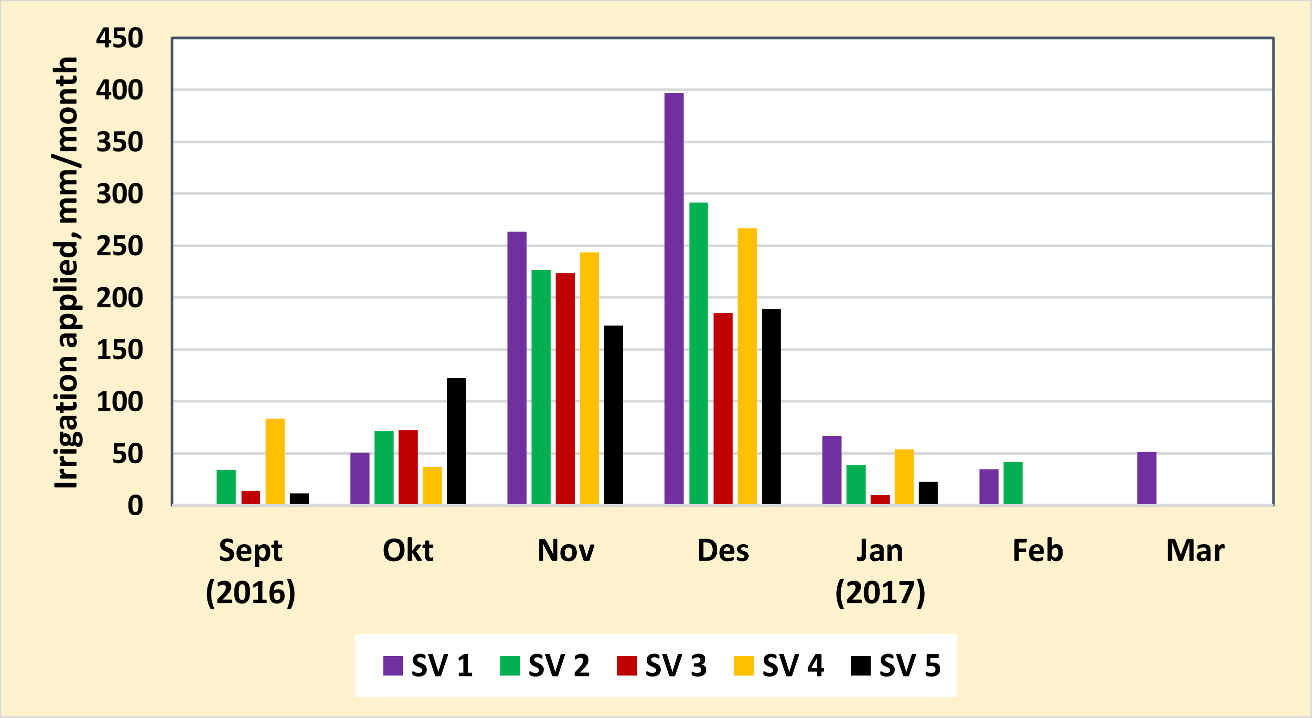


Figure 13: Irrigation application amounts (mm) per month for each case study

required by all three participants to implement the conversion could be recovered within a year. It is also evident that the saving of R3 066/ha attained by the use of a VSD at SV 2 is relatively small compared to the savings that are possible by converting the power points from Landrate to Ruraflex.

Conclusions and recommendations

- The performance of irrigation systems at the five case studies in the Sandveld was generally good, with the measured uniformities and application efficiencies at five pivots above the minimum required values, notwithstanding high temperatures and wind speeds that prevailed during the time when the evaluations were conducted.
- Yields obtained were good in general and water use efficiencies varied from reasonable to good. For the three case studies where WUE was lower than 100 kg/ha/mm, there is an opportunity to save energy and water by adapting irrigation amounts to actual crop requirements.
- Irrigation amounts were in general high as a result of the very high evaporative demand during the monitored summer season. With a few exceptions, there was a reasonably good agreement between the calculated irrigation requirements and the actual amounts irrigated.
- Yield potential dropped, water requirements increased and the water use efficiencies decreased the later in summer plantings took place. Consequently, the energy cost per mm water irrigated also increased as the planting date was delayed.
- Although the electricity usage per ton and hectare was higher than for the Limpopo study, the average energy use efficiency was slightly higher in the Sandveld at 1.66 kg/ha/kWh.
- The biggest opportunities for savings in electricity cost are in the selection of the Eskom tariff plan (conversion from Landrate to Ruraflex) and the choice of planting date (earlier planting dates result in lower water requirements). The use of VSD technology can also bring about savings, but the application value thereof will depend on the topography of the environment.
- The study should be repeated to include an autumn (March – April) planting to evaluate the seasonal effect on irrigation requirements and energy costs. ©

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