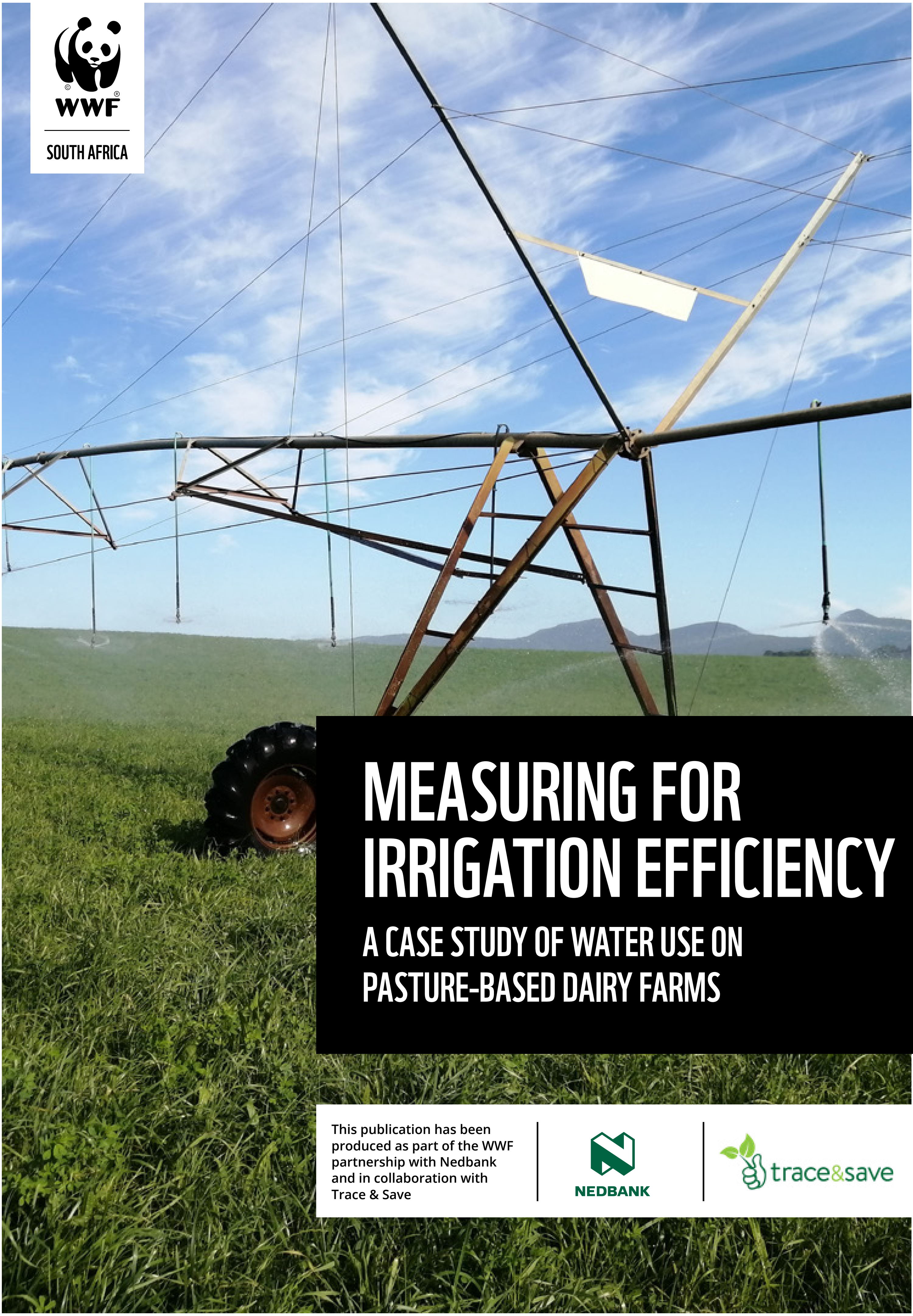
WWF

SOUTH AFRICA



MEASURING FOR IRRIGATION EFFICIENCY

A CASE STUDY OF WATER USE ON PASTURE-BASED DAIRY FARMS

This publication has been produced as part of the WWF partnership with Nedbank and in collaboration with Trace & Save

NEDBANK

trace&save

Authors: Lorraine Phadu, Stephen Avidon, Portia Phohlo and Craig Galloway (Trace & Save)

WWF editorial: Sue Viljoen

Text editor: Marlene Rose

Design and layout: Karen Lilje and Marlene Rose

Cover photo: © Trace & Save

Published in 2022 by WWF – World Wide Fund for Nature (formerly World Wildlife Fund), Cape Town, South Africa. Any reproduction in full or in part must mention the title and credit the above-mentioned publisher as the copyright owner.

Citation: Phadu, L., Avidon, S., Phohlo, P. and C. Galloway. 2022. *Measuring for irrigation efficiency: A case study of water use on pasture-based dairy farms.* WWF South Africa, Cape Town, South Africa.

If you would like to share copies of this report or its annexures, please do so in this printed or electronic PDF format.

Report available online at: https://www.wwf.org.za/report/case_study_water_meters_and_irrigation

For more information, contact sviljoen@wwf.org.za

WWF is one of the world's largest and most experienced independent conservation organisations with over 6 million supporters and a global network active in more than 100 countries. WWF's mission is to stop the degradation of the planet's natural environment and to build a future in which humans live in harmony with nature, by conserving the world's biological diversity, ensuring that the use of renewable natural resources is sustainable and promoting the reduction of pollution and wasteful consumption.

WWF South Africa is a national office in the global WWF network. Started in South Africa in 1968, we are a local NGO with a vision of building a sustainable and equitable future in which humans and nature thrive. We work to champion the Earth's capacity to provide a source of inspiration, sustainable food, fresh water and clean energy for all. For Nature. For You.

wwf.org.za

This case study has been a collaborative project between WWF South Africa and Trace & Save.
traceandsave.com

A special thanks to Woodlands Dairy for their contributions towards this case study.
woodlandsdairy.co.za

Water meter rebates were made possible by funding support from Mondi.
mondigroup.com


© Scott Ramsay

CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS AND ACRONYMS

AC	Active carbon
AM	Active mould
CU	Christiansen's uniformity coefficient
DM	Dry matter
LEPA systems	Low energy precision irrigation
LESA	Low elevation sprinkler systems
PWUE	Pasture water-use efficiency
SWAN	Soil, water, atmosphere, nutrients
TC	Total carbon
TWHC	Total water-holding capacity

GLOSSARY

Average irrigation efficiency: A performance criterion that expresses the overall efficiency of irrigation. Measured as the average (%) system, calibration and scheduling efficiency.

Calibration efficiency: A performance criterion that expresses how accurately an irrigation system delivers the amount of water set to be delivered. Measured as the percentage (%) of water intended by the farmer (i.e. what the pivot is set to apply) or what is recorded passing through the pivot.

Catch can: A water droplet gauge placed in pastures. It is used to collect and measure water droplets that reach the pasture after leaving the irrigation system.

Dry matter (DM): The part of the grass that remains when water is removed from freshly cut grass (tonnes).

Dryland: An area of the farm that is not irrigated and relies on rainfall for pasture growth, i.e. rain-fed.

Evapotranspiration: The combined processes of water movement from the soil into the atmosphere. It includes both evaporation from the soil and transpiration from the leaves (mm).

Irrigation: Applying a controlled amount of water to the soil to assist in the production of pastures.

On-farm product water-use efficiency: The amount of irrigation water used on-farm to produce a litre of milk (ℓ water / ℓ milk).

Pasture water-use efficiency: The amount of water (rain and irrigation) used to produce a tonne of pasture (ℓ water / tonne of pasture DM).

Required irrigation amount: Quantity of water (mm) that is needed by the soil to reach field capacity and thereby supply the needs of the plant.

Scheduling efficiency: A performance criterion that expresses how knowledgeable farmers are in planning for irrigation. Measured as a percentage (%) of the amount of water required by the pasture with the farmer's intended irrigation amounts.

Soil moisture: The water content in the soil (%).

SWAN system: The Soil, Water, Atmosphere, Nutrients (SWAN) system comprises measures of soil health, water management, greenhouse gas emissions and nutrient management.

System efficiency: A performance criterion that expresses how well a pivot performs when it is operated to deliver a specific amount of water. Measured as the percentage (%) of water that reached the pasture compared to what was measured going through the pivot.

Total carbon: The total amount of organic and inorganic carbon in the soil (%).

Water-holding capacity: An indicator of a soil's ability to retain water (%).

Water meters: Devices installed on an irrigation system that records water movement in litres.

KEY MESSAGES

Improving the efficiency of irrigation water use on farms can reduce input costs, improve the sustained delivery of available water to pastures and enhance the provision of water-related ecosystem services.

- In this case study, water use and irrigation efficiencies were analysed in 15 centre pivot irrigation systems, on six mixed (irrigated and dryland) pasture-based dairy farms in the Southern Cape (in the Tsitsikamma and Outeniqua areas), South Africa.

- The study uses scientifically researched data on dairy farms to explore pasture and product water use and various irrigation efficiencies on the farm. It advocates for the efficient use of irrigation water on dairy farms and the use of water meters to this ends.

- The results of the case study demonstrate:
    - There are instances of excess water use and wastage.
    - Cost-effective actions are required to improve water-use efficiency.
    - There are economic opportunities for improving irrigation water-use efficiency.

- A considerable proportion of the total farm pasture and product water use is from irrigation water. Irrigation water efficiency, which is influenced by both the irrigation system and human management elements, is therefore fundamental to agricultural sustainability.

- Actions required to reach efficient irrigation systems involve improving soil health, considering the biophysical parameters that influence irrigation practices, ensuring that irrigation systems are well maintained, and ensuring that irrigation schedules are as precise as possible.

- Improving soil health by building up soil carbon will facilitate improvements to the soil structure and biological activity. These improvements will allow soil to hold water for longer periods, ultimately using water most efficiently to grow pastures.

- Routine check-ups of irrigation systems, ensuring good maintenance regimes and taking into consideration system factors, such as wind, droplet size and sprinkler head distance from the ground, can help to reduce water wastage and improve pasture production.

- Precise scheduling of irrigation is fundamental in optimising pasture water-use efficiency. By using the available technology and scientific understanding, farmers can irrigate in a more efficient manner.

- Implementing simple, practical and cost-effective measures can improve the efficiency of irrigation to provide considerable financial gains, reduce water wastage and enhance water-related agro-ecosystem services.

© Trace & Save

INTRODUCTION

Agriculture accounts for a large amount of the world's freshwater use and is often identified as a sector that has a severe impact on freshwater systems. However, agriculture that is carefully integrated into local ecosystems, monitored and considers all components (social, economic and environmental) of sustainability can play a critical role in facilitating the delivery of important ecosystem services that sustain life and deliver benefits both to people and nature.

Soil health is one of the components in agriculture that plays a critical role in improving ecosystem services linked to water-use efficiency. Healthy soils rich in carbon have a higher water-holding capacity than soils low in carbon. These soils also contain micro-organisms such as fungi that improve the structure of the soil by creating a porous soil structure. This allows for water infiltration and water storage for extended periods. The increased storage capacity of water in soil can assist farmers in reducing irrigation frequency, enabling the agricultural system to utilise available water more effectively. Therefore, soil health is an important component of efficient irrigation.

In South Africa, pasture-based dairy farming offers tangible economic, social and environmental benefits, justifying its contribution to agricultural sustainability. However, the dairy industry requires a relatively large amount of water, whereas most of the land area in South Africa is water scarce. The challenging environment for pasture-based dairy farms is exacerbated by the predicted increase in aridity and frequency of drought, driving the industry to be proactive in finding solutions that promote water security.

As organisations in South Africa committed to promoting sustainable water use and an uptake in water stewardship practices, WWF South Africa and Trace & Save conducted a study to generate a case for cost-effective, environmentally friendly and socially acceptable solutions that promote efficient water use on farms. Water-use efficiency and irrigation efficiency on pasture-based dairy farms were analysed and the following questions posed:

1. **What are the on-farm pasture and product water-use efficiencies?**
2. **How efficient are irrigation methods in delivering water to pasture for dairy production?**
3. **What are the drivers of inefficient irrigation systems?**
4. **Is there a considerable relationship between soil health and pasture water-use efficiency?**
5. **What are the opportunity costs of improved irrigation system efficiency?**

LOCATION AND NATURE OF THE STUDY AREA

The study was conducted in the Tsitsikamma and Outeniqua regions of the Southern Cape, South Africa (Figure 1). The climate zone is warm, temperate and humid with warm summers. All farms in this study are located within the Tsitsikamma and Outeniqua Water Source Areas (Figure 1), which experience an intermediate and varied amount of rainfall per year (average = 740 mm; min = 374 mm; max = 1 220 mm), averaging 80 rain days spread throughout the year. Both regions are classified as strategic water source areas, delivering a disproportionately large amount of good-quality surface water per unit area. Orographic precipitation is a prominent source of water in the region, delivering water to farms through an abundance of perennial mountain streams.

The variation in rainfall and the availability of water are both temporal and spatial. Spatially, the area approximates the winter-summer rainfall transition, gradually experiencing less winter rainfall further eastward. Also, only farms located near the mountains have access to water from perennial streams. The transitional nature of the area lends itself to temporal influences of a changing climate, where it is predicted that the area of hot, semi-arid, steppe-type climate will increase toward the west, while remaining warm, temperate and humid toward the east. Also, the historical variation in normal weather patterns (e.g. El Niño) are represented by significant deviations in the degree of dryness (meteorological drought) relative to normal climate patterns (e.g. 1981 record low of 174 mm rainfall/year).

The soils in the area are derived from Table Mountain Sandstone and are generally sandy with a sand fraction that constitutes more than 90% of the soil texture. These soils naturally have a low pH (3,3–4,5), are leached and have low organic material (< 2%). As a result, they naturally have a low capacity to hold water and plant nutrients. In some areas, soils have strong texture contrasts, are often rocky towards the mountains and have a shallow soil depth. Old, forested areas tend to have a solid podzolic stratum, with greater carbon content and biological composition, improving the soil's water-holding capacity.

Six farms, with 15 centre pivot irrigation systems, volunteered to participate in the study (some farms had more than one pivot in the study). The participating farms are all mixed-irrigation and dryland farms, using irrigation water when rainfall is low. The irrigation water is mostly collected by means of dams and weirs. Water in the irrigation systems is delivered using submersible pumps, powered by electricity transmitted from coal-generated power plants, provided by Eskom (South Africa's public power utility). The standard rate for electricity on the participating farms during the study period was R0,995/kW, generating an estimated 0,95 kg of CO_2 emissions per kW.

The variability in water availability has resulted in some farms being well equipped for efficient irrigation and other farms, usually relying on rainfall, having to irrigate varying amounts of water irregularly. Consequently, some irrigation systems are well maintained, at capacity and are using mechanisms that minimise power usage (e.g. ring feeds and variable speed drives). Others are poorly designed, using more power than required, and/or are old and poorly maintained.

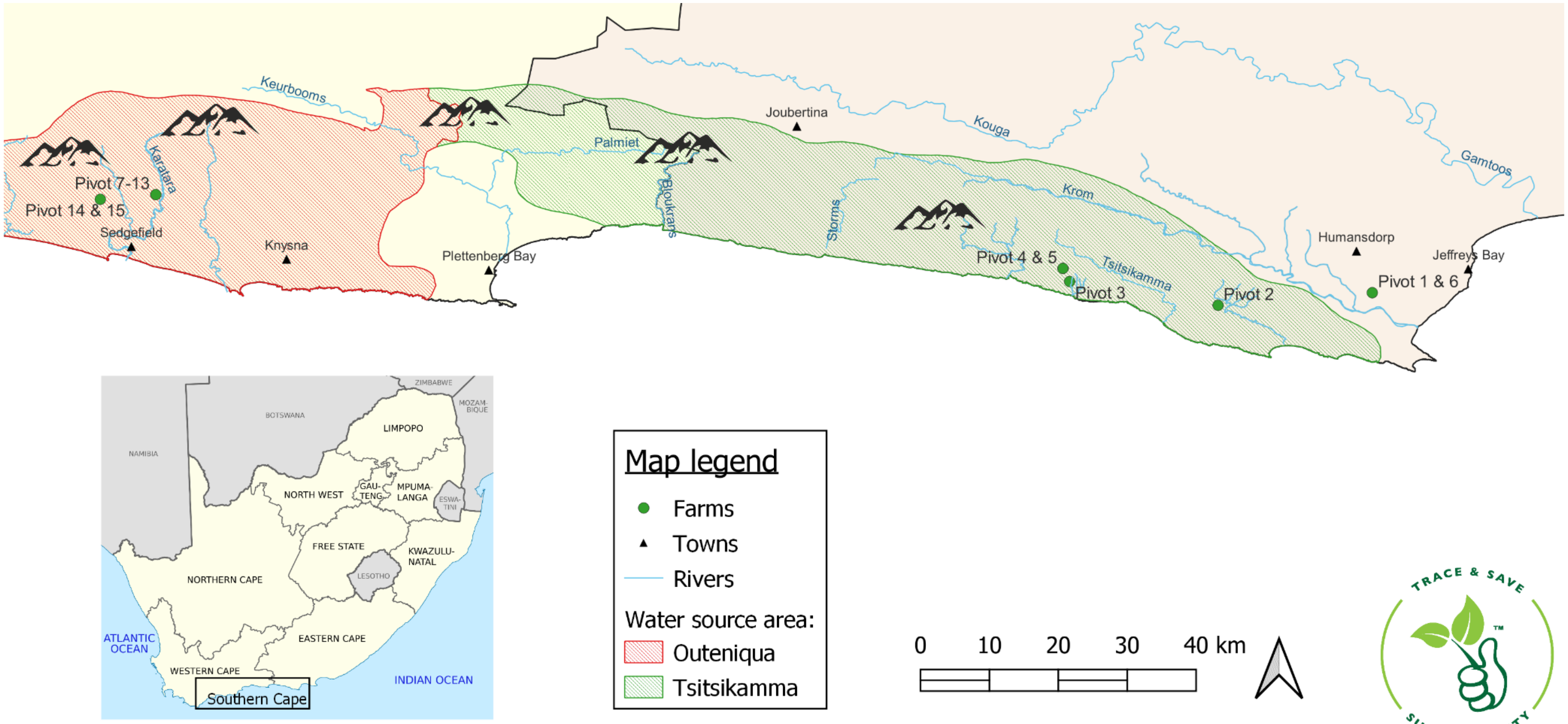


Figure 1: Location of farms included in the case study.

METHODOLOGY

To measure the water use and efficiencies of the irrigation systems on the participating farms, data was collected over 10 months, between March 2021 and December 2021. Water meters with data loggers were connected to irrigation systems to determine the quantity of water (litres) entering the pivot. The amount (litres) of milk produced over the study period was summed from daily recordings. The growth rates of pastures were measured weekly (using a rising plate meter) and used to determine the amount (tonnes) of dry matter produced per month.

Each participating farmer was offered a 50% rebate on the cost of the water meter as an incentive to be part of the project. The type and brand were chosen by the farmer. The total costs of the water meters ranged between approximately R8 000 and R10 000 each. The cost of the water meter installation, the data logger and any adjustments needed on the pipework was covered by the farmer. It was discovered through this project that the installation and adjustment costs (on average R25 000 to R40 000) were unexpectedly far higher than the costs of the water meters themselves. On top of this, each farm bought their own weather station, which cost R8 598 each.

The efficiency of irrigation was measured over a single irrigation event. The quantity of water delivered from the pivot to the pasture was measured using catch cans, placed on the ground, 20 m apart, from the centre outward until the end of the pivot (minimum of 10 cans per pivot). During these assessments, observations of any leakages, droplet size and the distance of the sprinkler head from the ground were recorded. Farmers were also asked to provide their intended irrigation amounts, and a theoretical or ideal amount of water required by the pastures was calculated (based on irrigation scheduling principles for a specific pasture to reach field capacity). These values were used to calculate the following:

- **System efficiency**, which is the proportion of water delivered to the pasture compared to what passed through the water meter.
- **Scheduling efficiency**, which is the proportion of water intended for irrigation (as determined by the farmer) compared to what was required by the pasture to reach field capacity (calculated).
- **Calibration efficiency**, which is the proportion of water passing through the pivot compared to the amount intended for irrigation (as determined by the farmer).

Farmers use different methods for scheduling irrigation. Generally, they use their knowledge, experience and available equipment (e.g. soil moisture probes) to guide them. In this study, three out of six farms use soil moisture probes. These farmers rely on soil moisture content to know when and how much to irrigate. Some farmers do not know how to interpret the soil moisture probe readings and rely on the company that installed the probe to guide them. Other farmers irrigate according to water availability (dam levels and frequency of rainfall), regardless of the soil moisture levels. Some of these farms have very low amounts of water available and schedule irrigation so that their water lasts the entire season. There are also farmers who irrigate according to their gut feeling and experience, anticipating certain pasture growth rates for a season. Lastly, there are farmers who irrigate conservatively, using as little water as possible to ensure the likelihood of water being available throughout periods of low rainfall.

Weather stations were set up on each farm to collect environmental variables known to influence irrigation efficiency, including temperature (°C) and wind speed (m/s). Simultaneously, the weather stations collected information on variables that enable one to determine water requirements for irrigation scheduling. These variables include daily evapotranspiration (mm), humidity (%), vapour pressure (bar) and solar radiation (MJ/m^2/day).

SOIL SAMPLE POINTS IN THE STUDY AREA

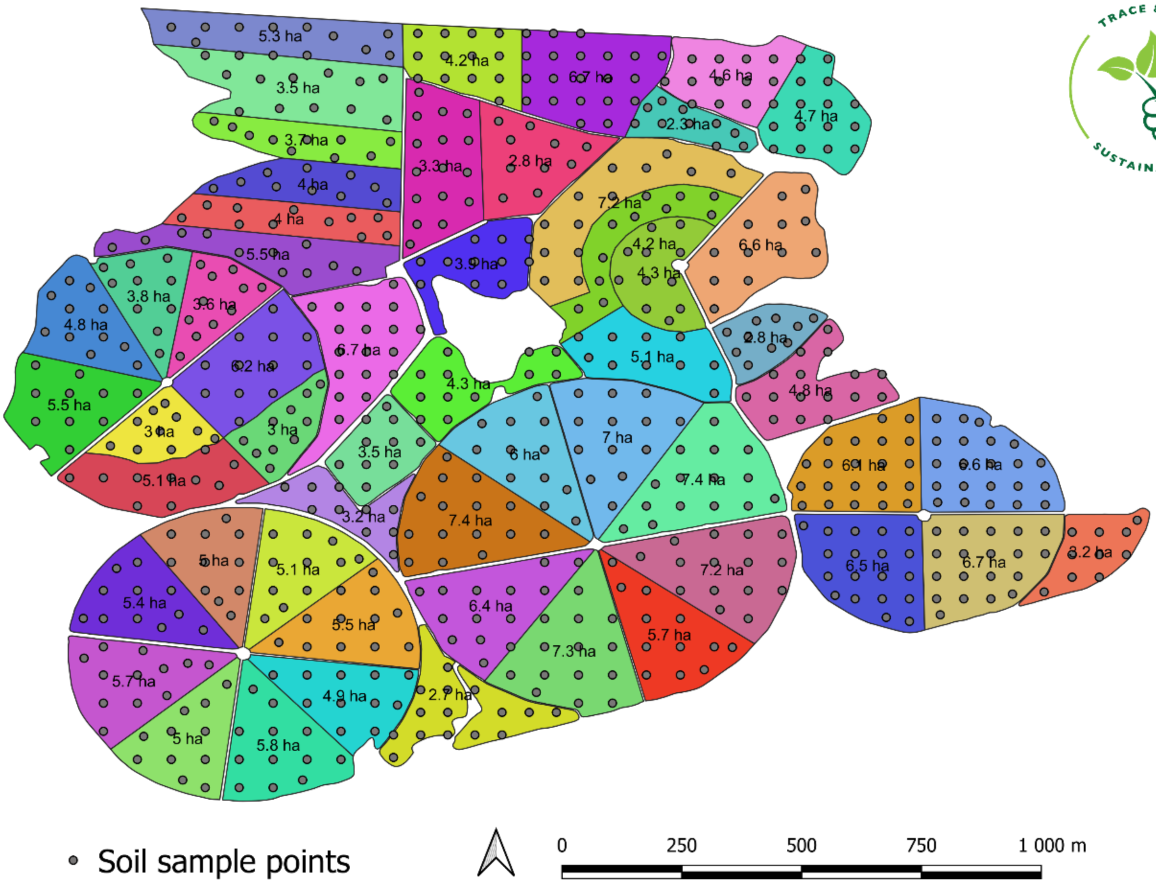


Figure 2: Example of Trace & Save's soil-sampling process. Each colour represents a composite sample, and each point represents where a soil sample was taken. One sample was taken every 0,4 ha, which translates to the sampling points being 60 m apart.

Soil samples were taken on each farm (Figure 2), 15 cm deep, on a 0,4 ha grid, resulting in 2,5 samples per hectare. These samples were grouped into a composite sample for every 5 ha (on average, composite samples represent camps of between 2 and 10 ha). On average, 12,5 soil samples were mixed to form a composite sample representing a 5 ha portion of the farm. Soil health indicators were measured and calculated from these soil samples. The measured soil health indicators included the following:

- **Soil fertility indicators** such as phosphorus levels, cations and micronutrients
- **Biological indicators** such as total carbon, fungi and active carbons
- **Structural measures** such as soil texture, total water-holding capacity, field capacity, permanent wilting point and gravimetric soil moisture.

These indicators were then used to categorise the soil health status as "unhealthy", of "moderate health" or "good health".

WATER USE AND IRRIGATION EFFICIENCY

To understand the amount of water required to grow feed for pasture-based dairy farming, product water-use efficiency measures only irrigation water, whereas pasture water-use efficiency considers both rainfall and irrigation water.

PASTURE AND PRODUCT WATER-USE EFFICIENCY

The results from this study indicate that there was substantial variability between pivots regarding the amount of water used for irrigation (Table 1). This was expected, considering the differences in rainfall experienced between farms and the multitude of factors that play a role in irrigation requirements (e.g. soil properties, pasture diversity, water availability, irrigation equipment and localised weather conditions).

According to an article titled "How much water does it take to produce a litre of milk?" published by Trace & Save, which reports on water-use efficiency data collected between 2012 and 2017,[1] mixed irrigation and dryland farms in the Tsitsikamma region used an average of 160 litres of water on-farm (including water for animal drinking and dairy washing) to produce a litre of milk. In this study, pivots were recorded using between 23 and 253 litres of water (average = 135 ℓ) for irrigation to produce a litre of milk, very much in line with the previous research. These results reiterate the large proportion of water used for irrigation to produce milk. The results of this study emphasise the amount of water (average = 13.8 mm, which equals 138 000 litres) required to grow a tonne of dry matter (Table 1).

© Trace & Save

© Irritech

---

[1] http://traceandsave.com/how-much-water-does-it-take-to-produce-a-litre-of-milk

TABLE 1: WATER USE, WATER-USE EFFICIENCY (WUE) AND IRRIGATION EFFICIENCY RESULTS RECORDED ON DAIRY FARMS IN THE SOUTHERN CAPE, SOUTH AFRICA (MARCH–DECEMBER 2021)

(EFFICIENCY VALUES > 100% REFER TO WHEN FARMERS APPLIED MORE THAN WHAT WAS INTENDED OR REQUIRED ON THE DAY)

Pivot	Average rainfall (mm/month)	Average irrigation (mm/month)	Irrigation water efficiency (mm/tonne)	Pasture WUE (mm$_{water}$/tonne$_{DM}$)	Product WUE (L$_{water}$/L$_{milk}$)	System efficiency (%)	Scheduling efficiency (%)	Calibration efficiency (%)	Average irrigation efficiency (%)
1	78,6	16,0	9,64	62,1	52,4	73,2	166,7	82,0	107,28
2	42,9	16,3	20,12	55,2	142,8	67,7	90,9	81,3	79,95
3	77,7	6,3	4,99	58,0	23,4	80,5	62,5	49,7	64,23
4	42,9	5,7	4,06	35,9	56,4	67,6	136,4	69,1	91,00
5	42,9	18,7	15,23	48,4	213,5	72,5	71,4	69,0	70,96
6	78,6	6,6	6,12	81,7	35,8	30,8	45,5	130,0	68,74
7	76,4	18,9	14,23	59,7	135,8	96,3	72,2	61,3	76,62
8	76,4	13,4	8,50	54,9	81,8	85,7	88,4	85,9	86,65
9	76,4	23,4	19,31	70,5	183,5	60,4	43,0	126,2	76,53
10	76,4	22,0	15,61	61,4	150,7	93,8	62,9	69,6	75,40
11	76,4	22,6	18,86	67,7	182,6	60,8	28,9	83,9	57,83
12	76,4	17,8	20,39	91,2	203,6	60,8	28,9	83,9	67,45
13	76,4	16,2	19,17	84,1	191,3	61,6	41,2	99,6	71,02
14	68,6	22,2	19,11	69,3	253,2	85,1	71,4	54,9	70,43
15	68,6	18,9	12,13	51,6	114,4	87,1	72,5	100,4	86,70
Average	**69,1 (691 000 ℓ)**	**16,3 (163 000 ℓ)**	**13,8 (138 000 ℓ)**	**63,5 (635 000 ℓ)**	**134,8**	**72,2**	**72,2**	**83,1**	**76,72**
Min	**42,9 (429 000 ℓ)**	**5,7 (57 000 ℓ)**	**4,1 (41 000 ℓ)**	**35,9 (359 000 ℓ)**	**23,4**	**30,8**	**28,9**	**49,7**	**57,83**
Max	**78,6 (786 000 ℓ)**	**23,4 (234 000 ℓ)**	**20,4 (204 000 ℓ)**	**91,2 (912 000 ℓ)**	**253,2**	**96,3**	**166,7**	**130,0**	**107,28**

Irrigation efficiency

On average (72,2%, see Table 1 and Figure 3), **system efficiency** was below an excellent standard (96%, as set by the most efficient irrigation system in this study) and could contribute to inefficient product and pasture water-use efficiency.

System efficiency and **scheduling efficiency** were similar, on average, but there is a much bigger range in scheduling efficiency (min = 28,9%; max = 166,7%). In some instances, both system and scheduling efficiency were as high as 95%, showing excellent irrigation efficiency. However, some pivots had very low system and scheduling efficiency scores (±30%). In other cases, scheduling efficiency was greater than 100%, meaning that farmers ended up applying more than was necessary during that irrigation event.

Calibration efficiency ranged between 49,7% and 130,0%. The average of 83,1% is the highest of the efficiency measures, but the data shows how wide a range there is in what happens on the farms. Where there are low scores, it is because the amount actually flowing through the pivot is considerably lower than what the farmers intended to irrigate. On the two farms with calibration efficiencies of over 100%, this happened when the pivot delivered much more water than what the farmers had intended. Both cases result in inefficiencies in the system and indicate the inaccuracy of irrigation systems and practices.

MINIMUM, AVERAGE AND MAXIMUM SYSTEM, SCHEDULING AND CALIBRATION EFFICIENCIES

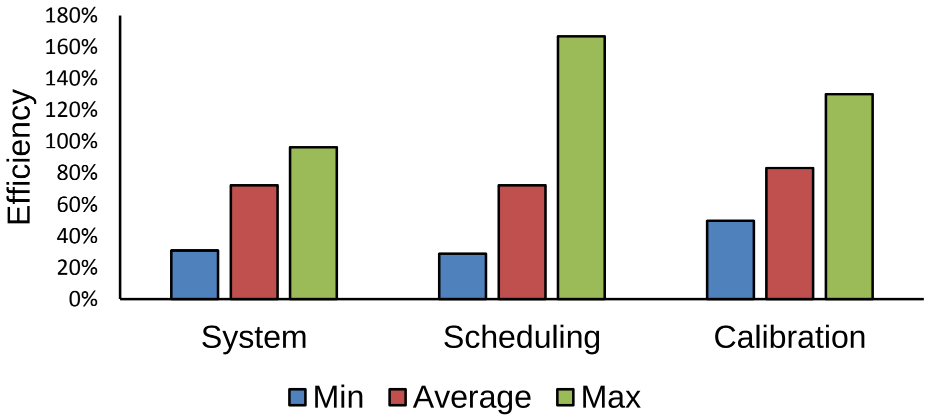


Figure 3: Graph showing the minimum (Min), average and maximum (Max) system, scheduling and calibration efficiencies across the 15 pivots included in the case study. For system efficiency, the maximum possible efficiency is 100%, but on scheduling and calibration efficiencies, values above 100% imply that over-irrigation has taken place.

The variation in these efficiencies highlights the potential for greater efficiency in the use of irrigation water. On average, farms with greater overall irrigation efficiency (average of all efficiency measures) tend to use less water to produce a tonne of dry matter and a litre of milk. This relationship is clearly illustrated in Figure 4. Both pasture water-use efficiency and product water-use efficiency are lower on the farms that have higher irrigation efficiency. Although there are too few observations to test this statistically, it is an important observation to note.

RELATIONSHIP BETWEEN AVERAGE IRRIGATION EFFICIENCY, PASTURE AND PRODUCT WATER-USE EFFICIENCY

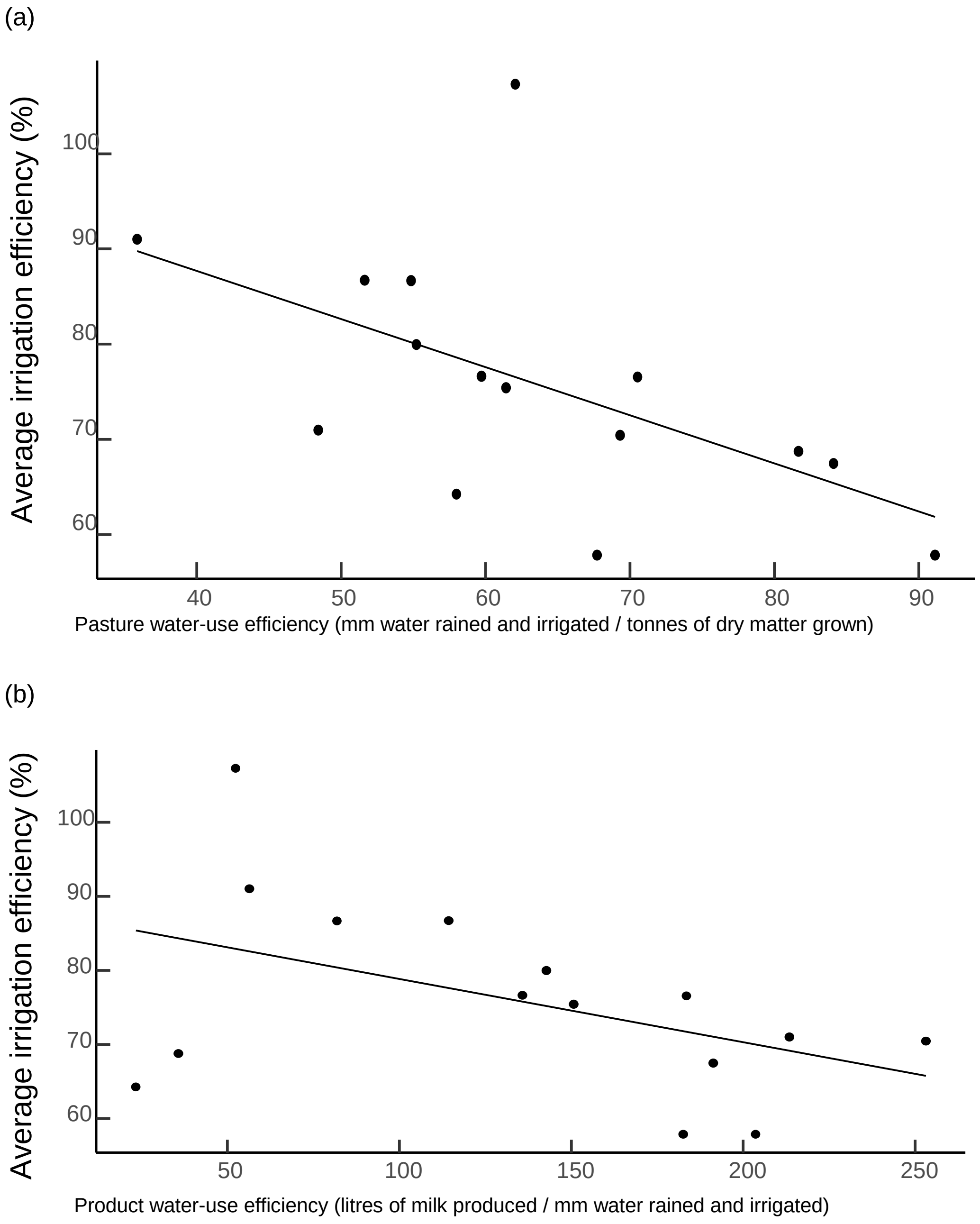


Figure 4: Scatter plot showing the relationship between average irrigation efficiency and (a) pasture water-use efficiency and (b) product water-use efficiency of farms analysed in this case study.

DRIVERS OF SYSTEM EFFICIENCY

Although only 15 pivots were included in the case study, which are too few to do any form of robust statistics, it was observed that certain factors have a greater effect than others on system efficiency. The three most influential factors are, in order of impact:

1. **Wind speed:** The higher the wind speed, the more water is wasted.
2. **Distance from the ground:** The higher the sprinkler head from the ground, the more water is lost.
3. **Droplet size:** The bigger the droplets, the less water is lost.

The differences in these variables in and of themselves are not necessarily notable, but when combined, they have a large impact. To understand the combined influence of these variables on irrigation system efficiency, pivots were grouped according to their relative performance in delivering water to the pasture. This resulted in two distinct groups, eight which performed relatively well (> 70% system efficiency) and seven which performed less well (< 70% system efficiency). Table 2 shows the variable averages of the top eight and bottom seven pivots (according to their relative system efficiency) used to determine the “ideal” and “not ideal” systems represented in Figure 5.

TABLE 2: VARIABLE AVERAGES OF THE TOP EIGHT AND BOTTOM SEVEN PIVOTS USED TO DETERMINE “IDEAL” AND “NOT IDEAL” SYSTEMS

System efficiency	Average wind speed (m/s)	Average distance from the ground (m)	Droplet size (1 = small; 2 = medium; 3 = large)
Top 8 pivots (> 70%)	1,63	1,37	1,88
Bottom 7 pivots (< 70%)	2,63	1,45	1,71

The averages of the variables described above and in Table 2 were then used to define systems that are “ideal”, in that they had a large or medium droplet size, the sprinkler head was equal to or lower than 1,5 m from the ground and the wind speed was lower than 2 m/s on the day that the system efficiency was tested. Figure 5 shows the difference in system efficiency between these six “ideal pivots” (average = 79%) versus the nine “not ideal” pivots (average = 68%). The system efficiencies are considerably higher in “ideal” pivots, illustrating the heightened effect that the combination of irrigation system variables have on irrigation system efficiency.

> *“I recommend that other farms also use water meters to help pinpoint problem pivots and optimise water use.”*
>
> – Dairy farmer 5 from the study area

> *“You can’t manage what you don’t measure.”*
>
> – Dairy farmer 1 from the study area

AVERAGE IRRIGATION EFFICIENCY FOR "IDEAL" AND "NOT IDEAL" PIVOTS

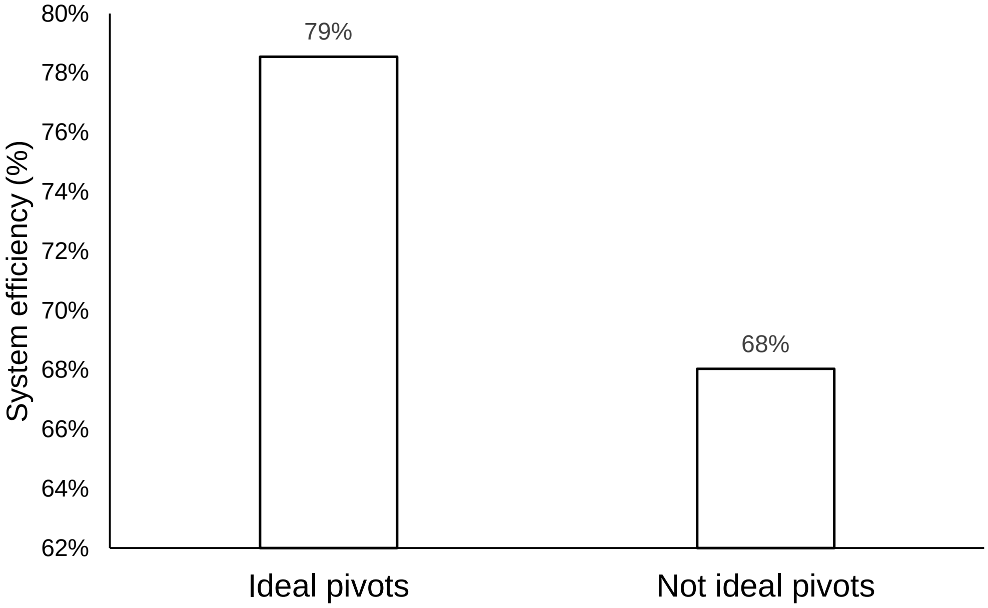


Figure 5: The average efficiency between six "ideal" pivots (where there was a large or medium droplet size, the sprinkler head was 1,5 m from the ground or lower and the wind speed was less than 2 m/s on the day that the system efficiency was tested), and the average system efficiency of the other nine "not ideal" pivots (where droplet size was small, the sprinkler head was more than 1,5 m from the ground and the wind speed was more than 2 m/s).

ECONOMIC IMPLICATIONS OF IRRIGATION EFFICIENCY

Cost of irrigation

The cost of irrigation (pumping) was calculated from the energy (kWh) used by each pivot according to the pump size responsible for powering that pivot, and the total amount of hours pumped (hours of water flowing through the pivot recorded by the water meter) during the study period (March–December 2021). The total energy used by each pivot was divided by the amount of water measured during the study period (recorded by the water meter) to provide the amount of energy used (kW) per unit (mm) of water used for irrigation. This value was then multiplied by the standard electricity tariff (R0,995/kW) to determine the cost of pumping a unit of water per pivot. Similarly, a standard value of 0,95 kg CO2e/kWh (the greenhouse gas emissions from Eskom electricity) was multiplied by the kW of power used per pivot area (ha) to determine the amount of CO_2 emitted per hectare in this study. The cost of pumping water was divided by the proportion of water irrigated to produce a tonne of dry matter to determine the cost of pumping required by each pivot to produce a tonne of dry matter.

This study shows that mixed-irrigation and dryland farms are spending large amounts of money and carbon dioxide emissions to pump water for irrigation (Table 3). The variation seen in these results can be attributed to the variation in water requirements on each farm. It is then hugely important from a financial point of view that each fraction of water is accounted for. At the time of this study (March–December 2021), the cost of buying in roughage was approximately R2 940 per tonne. **The results here highlight the financial opportunity of using available water to capitalise on growing feed on the farm rather than buying it in**.

TABLE 3: SHOWING THE AVERAGE, MINIMUM AND MAXIMUM COST, IN RAND (R) AND CARBON DIOXIDE (CO_2), OF PUMPING WATER ON DAIRY FARMS IN THE SOUTHERN CAPE, SOUTH AFRICA (MARCH–DECEMBER 2021)

	Average	Minimum	Maximum
R/mm	R3,08	R1,07	R9,70
R/tonne pasture	R54,73	R12,50	R118,59
Co_2 (kg)/ha	507,29	88,52	1 748,00

Potential water wastage and opportunity costs

System efficiencies measured during one irrigation event were used to estimate the amount of water wasted over the period of measured water use (March–December 2021). This wastage happens between the water flowing through the water meter and what actually reaches the ground. The main sources of wastage are leaks and evaporation.

This study found that substantial financial opportunities could be extrapolated from the irrigation system efficiency results. These results can be seen in Table 4 and are illustrated in the infographic (Figure 6). An average amount of 507 414 ℓ/ha or 50,7 mm water is potentially wasted every year due to irrigation system inefficiencies. The most efficient systems waste considerably less water per year (84 210 ℓ/ha or 8,4 mm/ha), while less efficient systems waste as much as 1113 079 ℓ/ha or 111,3 mm/ha. This means that on average, if every farm fixed all inefficiencies in their irrigation systems, as per the most efficient system (96,3%) in this case study, then there is the potential to save 423 204,68 litres/ha/year per farm.

The pasture equivalents of wasted water describe how much dry matter could have been grown or not bought in, had the water flowing through the water meter actually reached the pasture as applied irrigation. Approximately 1,6 tonnes of dry matter could be grown from the 50,7 mm of water wasted every year (average). These potential tonnes of dry matter amount to R4 598/ha, which is R1 149 500/year on a 250 ha farm. The value of the extra pasture grown on the farm has greater value when considering the additional input required (financial, logistical and environmental) to buy in roughage grown elsewhere.

The extra time associated with pumping this amount of water (average = 17 hours/ha/year) amounts to 15 769,30 kg Co_2/ha and approximately R483,95/ha/year in Eskom electricity bills. This additional cost of pumping water to achieve the intended irrigation amount will have a significant influence on profit margins. According to the values extrapolated from this study, for example, the cost of an inefficient pivot covering an area of 30 ha will be approximately R57 419,10/year for pumping water that did not reach the pasture. This is considerably more than the most efficient pivot in this study, for which the cost would be R14 515,50/year for pumping water that did not reach the pasture.

> *"Water meters and weather stations are helpful tools that assist in monitoring water usage, evaporation rates and other weather variables."*
>
> – Dairy farmer 6 from the study area

TABLE 4: FINANCIAL, ENERGY AND CARBON OPPORTUNITY COSTS EXTRAPOLATED FROM WASTED WATER DUE TO IRRIGATION SYSTEM INEFFICIENCIES ON DAIRY FARMS IN THE SOUTHERN CAPE, SOUTH AFRICA (MARCH-DECEMBER 2021)

	Average	Minimum	Maximum
Amount of water wasted (ℓ/ha/year)	507 414,85	84 210,17	1 113 079,46
Amount of water wasted (mm/ha/year)	50,74	8,42	111,31
Extra time pumped (hours)	17,38	1,72	51,30
Dry mater produced (tonne/year)	1,56	0,26	3,43
Extra Co_2 emitted (kg/year)	476,65	33,72	1 885,11
Cost of extra pumping	R483,95	R34,23	R1 913,97
Value of dry matter from wasted water	R4 597,92	R763,07	R10 086,13

© Irritech

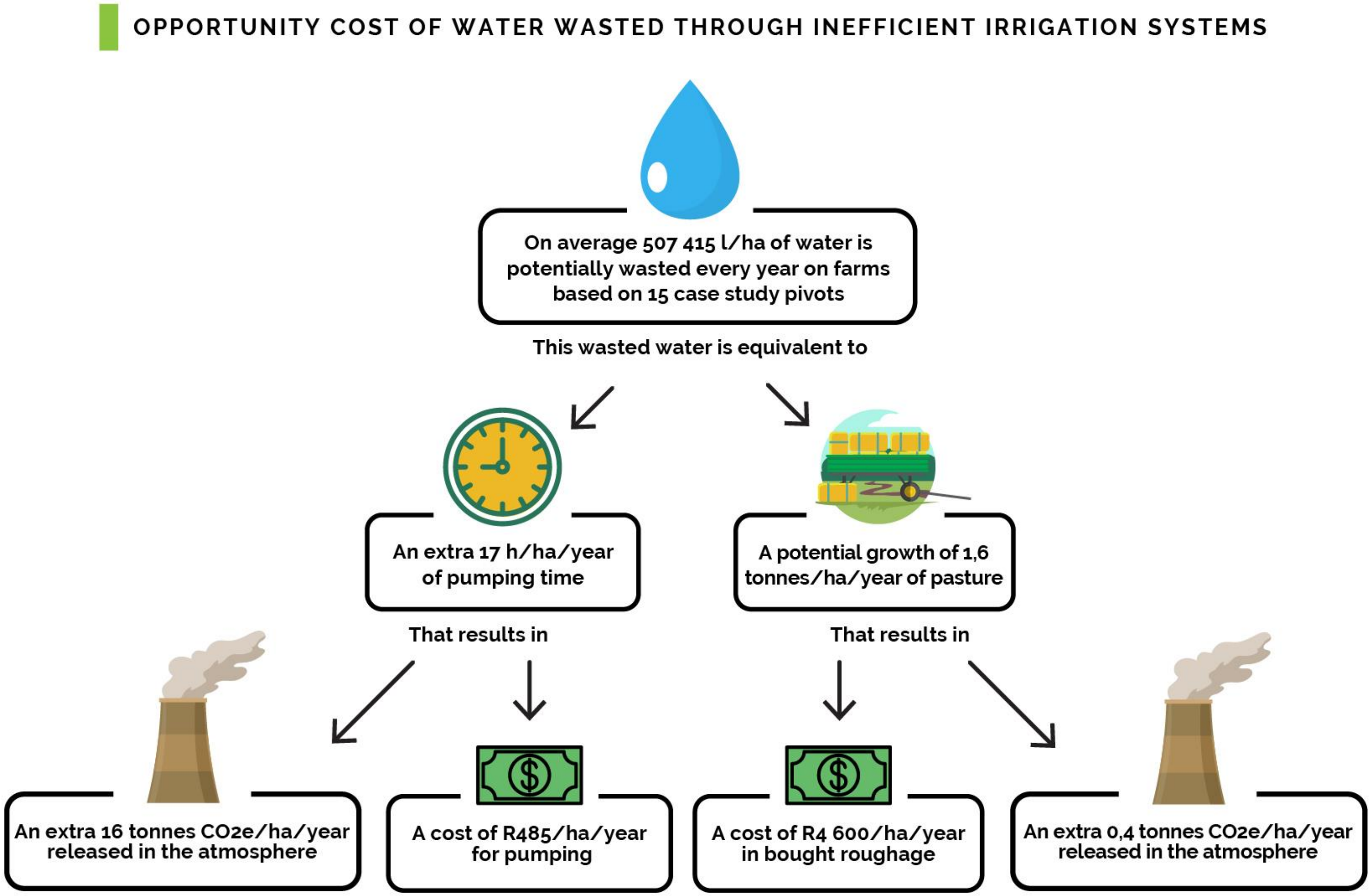


Figure 6: Flow diagram describing the potential opportunity costs extrapolated from the average amount of water wasted due to inefficient application of irrigation in this study. System efficiencies measured during one irrigation event were used to estimate the amount of water wasted over the period of measured water use.

MOVING TOWARDS EFFICIENT WATER USE

This case study identified key areas that need to be addressed in order to improve water-use efficiency on farms. These include improving soil health, effective irrigation scheduling, maintenance and upkeep of irrigation equipment, and designing irrigation system to reduce the negative impacts from environmental factors.

SOIL HEALTH FOR IMPROVED WATER-USE EFFICIENCY

Soil health describes the integrity of a soil ecosystem. It defines the state of the soil in terms of its ability to sustain biological productivity, maintain the quality and quantity of water, and cycle nutrients. Soil health is one of the components that make up Trace & Save's SWAN (Soil, Water, Atmosphere, Nutrients) system, which is used to measure the overall sustainability of the farming system. Soil health is categorised using soil indicators such as total carbon, soil fungi, active carbon and total water-holding capacity (TWHC). These indicators describe the soils' ability to facilitate water movement and storage. Carbon serves as an energy source for billions of micro-organisms inhabiting the soil (including fungi) and improves soil structure, making it crumbly and porous so that it can hold large amounts of water for longer periods. Fungi rely on water to maintain activity and can also store water. The potential of the soil to store water is measured as the TWHC. The water stored in the soil is released when required by plants; thus, pasture water-use efficiency is closely associated with soil health.

RELATIONSHIP BETWEEN SOIL HEALTH AND PASTURE WATER-USE EFFICIENCY

As expected, in the study, soil health played an important role in how efficiently pastures could utilise water. Figure 7 illustrates the relationship between soil health and pasture water-use efficiency. Pastures that were deemed "healthy" (i.e. within the parameters of soil variable measurements known to elevate soil quality) were using approximately 53,08 mm (average) of water to produce a tonne of dry matter. These "healthy" soils used less water to grow pasture (i.e. were more efficient) than soil categorised as of "moderate health" or "unhealthy", reinforcing the importance of soil health in improving the water-use efficiency of pastures.

RELATIONSHIP BETWEEN INDICATORS OF SOIL HEALTH AND PASTURE WATER-USE EFFICIENCY

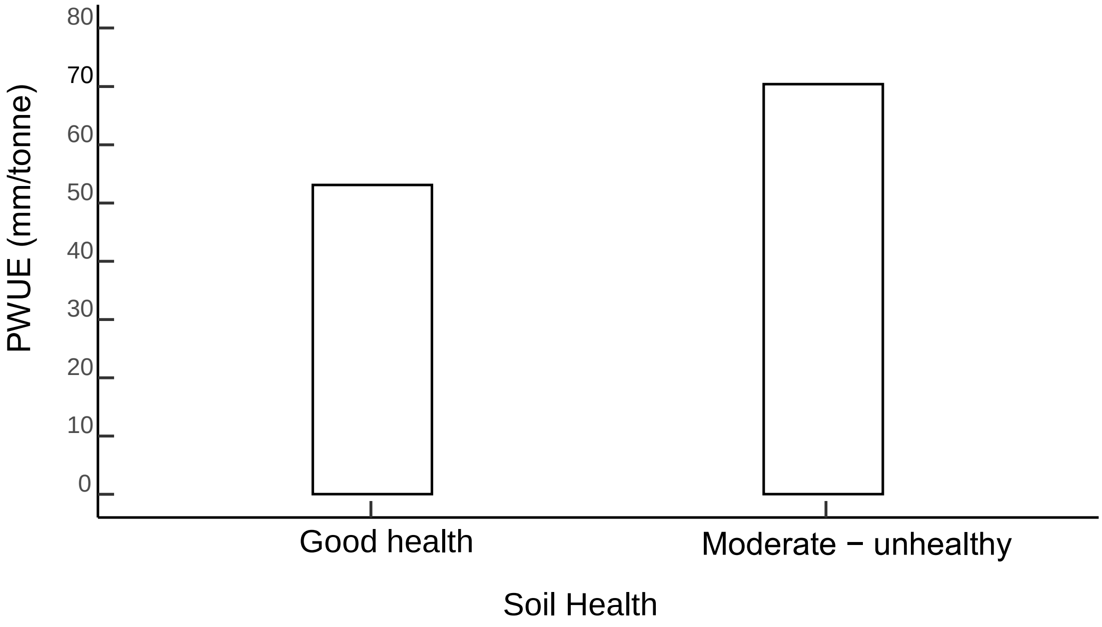


Figure 7: The relationship between soil health, as defined by Trace & Save's SWAN system, which is used to measure the overall sustainability of the farming system and pasture water-use efficiency, i.e. the amount of water used to grow a tonne of pasture, measured on farms in this study.

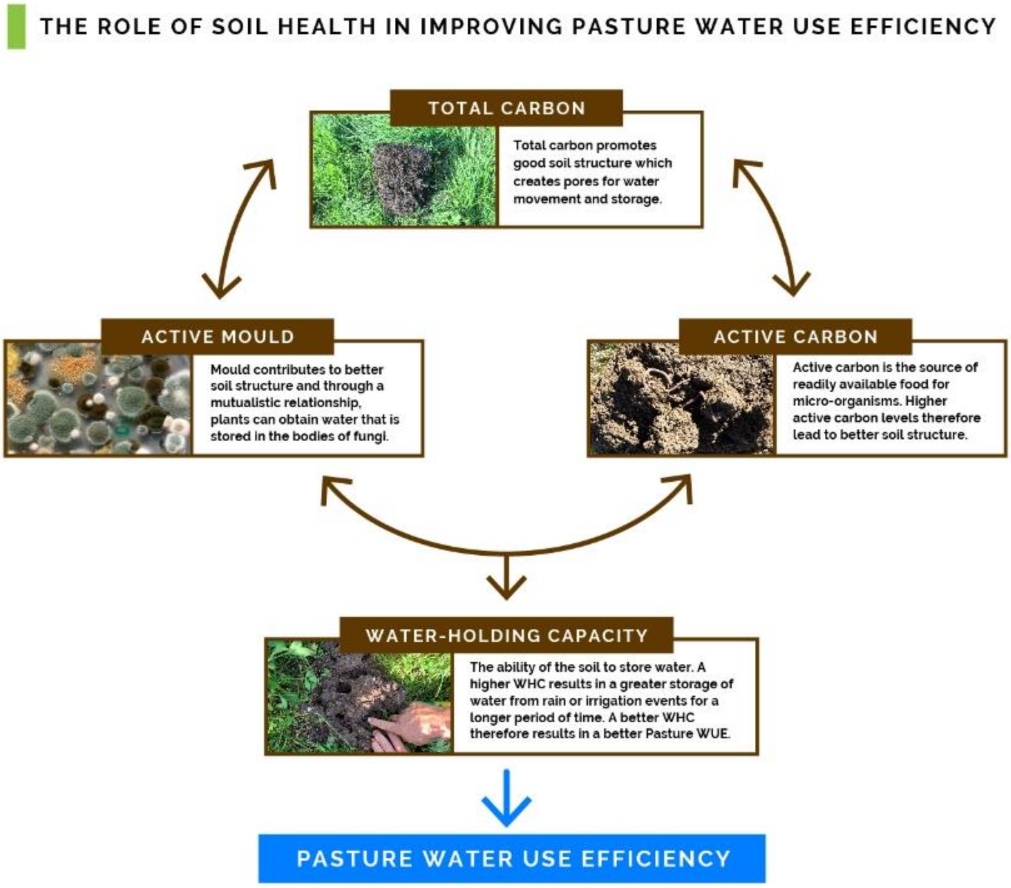
The variables related to soil-water storage and movement that were used by Trace & Save were correlated and reported in Table 5. Although the limited number of data points in this study makes it problematic to interpret the correlation coefficient values with statistical confidence, the relationships found between these variables (described in Figure 8) reflect the patterns identified in the literature.

In this study, **soil fungi** (active mould) were more abundant in soil when carbon measurements (both total and active) were higher, all of which were associated with better pasture water-use efficiency. This is because fungi can absorb and store water and release it in times of need by plants. It is also important to note that fungi are made up of carbon and therefore would contribute to the soil organic carbon pool (dead or in their live state). A directly proportional relationship between fungi and soil carbon can therefore be expected.

TABLE 5: DESCRIPTIVE STATISTICS AND CORRELATION MATRIX OF SOIL VARIABLES KNOWN TO INFLUENCE THE STORAGE AND MOVEMENT OF WATER IN SOIL, SOUTHERN CAPE, SOUTH AFRICA (MARCH-DECEMBER 2021)

(COMPOSITE SAMPLES WERE TAKEN FROM IRRIGATED AREAS INCLUDED IN THIS STUDY)

	Descriptive statistics			Spearman correlation coefficient				
	Average	Min	Max	TWHC	TC	AM	AC	PWUE
Total water-holding capacity (TWHC) (%)	45,12	43,71	46,65	1,00	N.A.	0,39	0,13	0,22
Total carbon (TC) (%)	3,24	2,28	3,89	N.A.	1,00	0,26	0,28	0,01
Active mould (AM) (CFU/g)	15 745,00	0,00	48 000,00	0,39	0,05	1,00	0,39	-0,1
Active carbon (AC) (mg/kg)	810,35	383,26	1123,44	0,12	0,28	0,39	1,00	-0,04
Pasture water-use efficiency (PWUE) (mm/tonne/ha/ month)	63,45	35,87	91,15	0,21	0,01	-0,10	-0,04	1,00



Total carbon promotes good soil structure which creates pores for water movement and storage.

Mould contributes to better soil structure and through a mutualistic relationship, plants can obtain water that is stored in the bodies of fungi.

Active carbon is the source of readily available food for micro-organisms. Higher active carbon levels therefore lead to better soil structure.

The ability of the soil to store water. A higher WHC results in a greater storage of water from rain or irrigation events for a longer period of time. A better WHC therefore results in a better Pasture WUE.

Figure 8: Pictograph explaining the relationship of soil health indicators (known to influence the movement and storage of water) with one another and with pasture water-use efficiency.

Active carbon defines the amount of readily available carbon to be used by micro-organisms such as bacteria and fungi. The active carbon mostly comes from root exudates that release carbon to attract micro-organisms, which trade nutrients in exchange for carbon. The advantage of attracting micro-organism near the root surface is not only for nutrient exchange but also for protection against pests and pathogens. Most importantly, this process allows for easy absorption of water from the soil to the micro-organism and then to the plant root to which the micro-organism is attached. Thus, the amount of carbon in the soil also provides a buffer that improves not only water-holding capacity but also water-use efficiency.

Water-holding capacity describes the amount of water the soil can store. A higher water-holding capacity is helpful in irrigation management because it indicates greater potential for that soil to hold water. This means that farmers can irrigate less frequently and make the most of rainfall occurrences. The increased storage time of rainwater in the soil is most beneficial when considering the decline in rainfall frequency experienced and forecast for the study region. Table 5 shows a positive relationship between water-holding capacity and pasture water-use efficiency. This was to be expected, as there is much more water in the soil for plants to use. The unintended consequence of improving water-holding capacity is that not all the water is converted to pasture, possibly due to other soil restrictions. Irrigation management needs to account for this fact and incorporate it into irrigation scheduling. Other possible restrictions to plant water usage that are hindering optimal use of the available water also need to be investigated.

SCHEDULING PRECISION FOR IMPROVED WATER USE

This study has underlined the challenges that farmers face when trying to achieve optimum efficiency in scheduling irrigation. Farmers who obtain accurate weather and environmental data, and have a good understanding of their systems, can successfully work towards refining scheduling precision to optimise the efficiency of pasture water use. Combining science and management for effective monitoring of irrigation efforts can assist in cutting down the costs of over-irrigation while maintaining ideal pasture growth. Effectively, farmers should consider applying higher quantities of water per irrigation event, but irrigating less often, given the fact that the soil has the capacity to hold the water. This would result in less overall water used for irrigation, and rather relying on healthy soil and efficient irrigation systems to make the most of the available water.

Table 6 shows some of the data from pivots in the case study, reported in the Trace & Save scheduling system. This scheduling system has been developed to assist farmers in assessing irrigation efficiency and plan for (schedule) more effective irrigation in future. It compares what the irrigation requirement of the farm was versus what was applied through irrigation on a weekly basis. For these pivots, farmers used weather data, soil health results and environmental data related to the area of the farms and plant variables to determine temporally and crop-specific scheduling for weekly water use. The irrigation schedule assists farmers in providing the amount of water required by individual pastures to reach field capacity. It also helps farmers to determine the critical point (soil moisture level between field capacity and permanent wilting point), which, if soil moisture levels go below, will compromise water accessibility to pastures.

The **critical point** helps farmers to know how much water to put down to reach the soil to field capacity. It is ideal to allow the soil to dry out to the critical point and then irrigate the amount required to reach field capacity in a single irrigation event if the pivot's capacity can accommodate it. The schedule also identifies the settings and time required by each pivot to irrigate the required amount of water, and provides feedback on the estimated costs of irrigation.

Refining the irrigation scheduling system is a process and in the example provided in Table 6, an increase of about 10% scheduling efficiency was observed from the scheduling system (the difference between the scheduling efficiency from the case study and the scheduling efficiency for the weekly report on that farm).

CONSIDERING BIOPHYSICAL PARAMETERS AND SYSTEM MAINTENANCE FOR EFFICIENT IRRIGATION

This study has suggested (in the “Drivers of system efficiency” section on page 18) that system efficiency can be enhanced by structural improvements (reducing leakage, removing blockages, and increasing water droplet size and sprinkler head height from the ground), with considerable opportunity for reducing water loss. Considering the influence of environmental variables (e.g. wind speed and temperature), and being mindful of the methods and timing of irrigation can reduce water wastage. Table 7 shows the improvements in system efficiency after infrastructure on two of the pivots (5 and 6) in this study was upgraded. The new pivots with changes to water droplet size and sprinkler heads distance from the ground, notwithstanding other variables, show improved irrigation system efficiency, reducing the amount of water wasted through the irrigation system.

© WWF South Africa

TABLE 6: POST-IRRIGATION SCHEDULING REPORT PROVIDED TO FARMERS, DESCRIBING OPERATIONAL PARAMETERS OF SOME OF THE PIVOTS INCLUDED IN THIS STUDY, MONITORED WEEKLY ON DAIRY FARMS IN THE SOUTHERN CAPE, SOUTH AFRICA (2022)

			Cost of post-irrigation		**Weekly report: 18–25 January 2022**					
	Irrigation (mm)		**Pumping time (hours)**		**Power usage (kW)**		**Estimated $C0_2$ emissions (kg)**		**Estimate cost of pumping (R/mm/ha)**	
Pivot No.	**Required**	**Applied**	**Required**	**Applied**	**Estimated**	**Applied**	**Required**	**Applied**	**Required**	**Applied**
12	45,75	33,95	162,25	149,00	6084,38	5 587,50	5 962,69	5 475,75	R5,94	R5,46
13	34,00	20,29	120,00	166,00	4500,00	6 225,00	4 410,00	6 100,50	R5,25	R7,27
14	38,92	23,12	162,25	152,00	12 168,75	11 400,00	11 925,38	11 172,00	R9,70	R9,08
11	27,27	38,54	100,00	15,00	3750,00	562,50	3 675,00	551,25	R3,12	R0,47
8	35,16	33,95	162,25	142,00	3 001,63	2627,00	2 941,59	2 574,46	R4,00	R3,50
9	18,45	34,35	81,17	221,00	1 501,58	4 088,50	1 471,55	4 006,73	R3,84	R10,45
15	26,10	15,97	100,00	99,00	1 500,00	1 485,00	1 470,00	1 455,30	R4,06	R4,02

Farm summary for the week		
	Required	**Applied**
Power (KW)	38 506,33	36 813,00
Total cost (R)	R38 487,08	R36 794,59
Carbon emission (kg)	37 736,21	36 076,74
Average cost per mm water/ha	R5,52	R6,14
Scheduling efficiency (absolute average)	67,70	
Average scheduling efficiency from the case study	56,17 (= 10% improvement)	

TABLE 7: RESULTS FROM IRRIGATION EFFICIENCY TEST AFTER NEW IRRIGATION SYSTEMS WERE FITTED ON TWO PIVOTS USED ON PASTURE-BASED DAIRY FARMS IN THE SOUTHERN CAPE, SOUTH AFRICA (MARCH-DECEMBER 2021)

Pivot	Irrigation system efficiency (%)	Sprinkler distance from the ground (m)	Tem-perature (°C)	Droplet size	Wind speed (m/s)
5 old	67,60	2,00	30,00	small	2,60
5 new	81,00	0,40	26,50	small	6,10
6 old	72,50	1,65	30,00	small	2,68
6 new	90,00	0,5–1,65	25,00	small	1,80

© Irritech

> *"Water meters definitely assisted in managing water on the farm."*
>
> – Dairy farmer 2 from the study area

INSIGHTS GAINED AND LESSONS LEARNT

The study demonstrated that improving irrigation efficiency can have substantial economic benefits and that this should incentivise dairy farmers to become as efficient as possible when using irrigation systems.

It was found that overall, irrigation efficiency was generally not good in the study area and varied between farms, showing considerable room for improvement. Farmers can use the insights gained from this case study to identify where they can improve water-use efficiency on their farms. The study motivated some farmers to make significant improvements to their irrigation systems after seeing their efficiency results.

By looking after the freshwater ecosystems in their vicinity, dairy farmers can increase the resilience of pastures while strengthening the ability of these ecosystems to deliver vital ecosystem services.

OBSTACLES TO THE UPTAKE OF IRRIGATION BEST PRACTICE

Although there are clear opportunities for improved water-use efficiency through more efficient irrigation, there are numerous regulatory and other obstacles to the widespread uptake of these best-management practices. These include:

- Major financial costs for the implementation and upkeep of infrastructure, both to improve irrigation system efficiency and monitor water use.
- A lack of support from irrigation equipment service providers (e.g. maintenance and follow-up consultations).
- Much time and effort that is needed to change and/or adopt new methods.
- A lack of information to motivate the need for change or upgrades. Most farmers were not aware that their systems were not as efficient as they had been told, or farmers often stick to traditional methods of irrigation scheduling and are satisfied with their results.
- Varying opinions from farmers, researchers and sales companies have caused a despondency to changing the norm.
- Current water allocation regulations do not account for costs incurred by farmers if less water is used for irrigation. Consequently, there is little incentive for farmers to use less water than what is allocated to them.

> *"I need better support from the people selling the equipment for it to be valuable."*
>
> – Dairy farmer 1 from the study area

IMPROVEMENTS TO WATER-USE EFFICIENCY ARISING FROM THIS STUDY

Over the duration of this case study, many of the participating farms already began to address issues and implement better practices. The following improvements have been made:

- One farm has installed 12 water meters and serviced all their pivots.
- Another farm fixed one of their pumps and replaced the other. They also installed water meters on all their pivots as well as low-energy precision irrigation (LEPA) systems to improve energy-use efficiency.
- Two of the farms installed two additional LEPA systems and fixed the leaks on problem pivots.
- One of the farms replaced three of their old systems with new low-elevation sprinkler (LESA) systems and fixed all leaks.
- One farm not included in this study has since volunteered to join the project and has funded everything themselves, including water meters and a weather station.

> *"It's important to use water meters to know how much water you're really using, not what you think you're using."*
>
> – Dairy farmer 2 from the study area

AGRI-ECOLOGICAL IMPLICATIONS OF SAVING WATER FROM EFFICIENT IRRIGATION

This study has shown that there is substantial opportunity to reduce the amount of water wasted from inefficient irrigation. The implication this has for the local ecological system depends on what is done with the water that is saved. Unfortunately, water allocation regulations provide little direct incentive for farmers to not use the saved water and to preserve it in their local freshwater systems. Instead, most farmers prefer to use their full allocation (due to the "use it or lose it" principle). Many would also rather choose to use the extra available water to increase their area of production.

However, it is worth considering the benefits that storing this extra water within the local freshwater system has for the environment, which in turn supports ecosystem services related to farming activities (agro-ecosystem services).

The additional storage and sustained release of water into streams also provides sustenance for wetlands, which is fundamental to both surface and underground water quality filtration for downstream users. Saving excess water can also assist with drought resilience, i.e. there will be more water available for a farm during unexpected dry periods. It can thus be argued that the more water that is stored in the natural environment, the better the natural environment will be at delivering vital agro-ecological services to the farmer. Therefore, it is not a matter of "water not used for irrigation is water wasted by flowing into the sea". Rather, water not used for irrigation is water used to maintain a healthy and productive ecosystem.

HOW DO DAIRY FARMS BENEFIT FROM LOCAL FRESHWATER SYSTEMS?

Dairy farms rely on freshwater ecosystems to purify water for drinking and irrigation, cycle excess nutrients from effluent and agricultural chemicals, sequester carbon from agricultural emissions and protect pastures from flooding and erosion. All freshwater ecosystems are valuable in this process, whether lentic (still), lotic (flowing) or wetland, both natural and artificial.

The integrity of these ecosystems and their ability to perform the desired services are influenced by a variety of factors, including disturbances related to low water levels and frequency of drying out. Abstracting water from streams (including weirs), for example, reduces the system's ability to maintain hydrological connectivity (areas linked by surface and subsurface water flow). This connectivity is fundamental to sustaining biological communities responsible for stabilising the surrounding habitat, reducing erosional surface area and retaining organic matter.

All these functions improve the absorption of water into the surrounding soil, which in turn maintains soil biology and porosity for better pasture water-use efficiency.

© Irritech

Lasting positive outcomes for people and nature in the places where we work and from priority environmental challenges we focus on.

FOR NATURE. FOR YOU. wwf.org.za

1st Floor, Bridge House, Boundary Terraces, Mariendahl Lane, Newlands, Cape Town.
PO Box 23273, Claremont 7735 T: +27 21 657 6600 E: info@wwf.org.za wwf.org.za