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FINAL REPORT 2022

Winetech Number : P04000022

1. PROGRAMME & PROJECT LEADER INFORMATION

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2. PROJECT INFORMATION

Project title	Use of winery wastewater as a resource for irrigation of vineyards in different environments
Short title	Winery wastewater irrigation of vineyards

Fruit kind(s)	Wine grapes		
Start date (mm/yyyy)	2016-04	**End date** (mm/yyyy)	2022-03

Key words	Climate, grapevines, potassium, sodium, soil, wastewater

	CFPA	RAISIN SA	HORTGRO	SATI	WINETECH	ARC	OTHER
TOTALS All years	R 0	R 0	R 0	R 0	R 1933331	R 5534702	R 4000000

Total cost of entire project	R 11468033

3. EXECUTIVE SUMMARY

Objectives and Rationale

Since climatic conditions and soil type range considerably in the Western Cape, it was possible to assess the fitness for use of winery wastewater for irrigation of different soil types in regions with varying rainfall on soil and vineyard performance.Wine grapes are an important crop in regions such as the Western Cape and the Lower Orange River in the Northern Cape. However, wineries produce large volumes of poor quality wastewater, particularly during the harvest period. On the other hand, the Western Cape has experienced a drought. In August 2017, the level in the Theewaterskloof Dam was 25.1%. Therefore, the City of Cape Town had to introduce water restrictions and at once stage, residents were subjected to Level 5 water restrictions. This meant that residents were allocated 87 L of water per person per day. More recently, as of 19 August 2019 the level of water in the Theewaterskloof Dam was 81.7%, and water restrictions are at Level 1. As of 5 October 2020, the dams in the Western Cape were filled to capacity. Taking the afore-mentioned into consideration, it is clear that the Western Cape has experienced severe drought recently, which means that water resources for urban and agricultural uses are extremely limited. The drought also severely restricted the irrigation sector, and will change the way things are done in the future. Wine grape producers will therefore have to use water resources judiciously to produce grapes. In addition to this, it is important that the sustainable use of alternative water sources for vineyard irrigation be investigated.

The use of augmented winery wastewater was investigated in a previous WRC and Winetech funded project. However, this project only addressed the suitability of using winery wastewater for grapevines in a sandy soil under one set of climatic conditions. Results of a pot experiment showed that soil type and winter rainfall have a pronounced effect on salt accumulation where winery wastewater is used for irrigation. Therefore, a field study was necessary to investigate the use of winery wastewater for vineyard irrigation to determine the sustainability of such a practice in other environments. Since climatic conditions range considerably in the Western Cape, it would be possible to investigate the effect of climatic factors such as magnitude of rainfall on the possibility of using winery wastewater for vineyard irrigation. Therefore, three different regions were to be selected where grapevines would be irrigated with winery wastewater. In addition to climatic differences, there are also different soil types. Since it is well known that soil type can influence nutrient element adsorption and accumulation, it would also be possible to investigate different soil types within the same climatic zone.

Experience from a previous study showed that it would be impractical to augment winery wastewater to a pre-determined level before each irrigation, i.e. specifically at the commercial level because it would be difficult to monitor the winery wastewater quality continuously in order to adjust the volumes of raw and wastewater to obtain a required level of augmentation. Therefore, a more practical approach would be applied in this project to use the in-field fractional use (augmentation) of winery wastewater with raw water. According to this approach, grapevines would be irrigated as follows. For each irrigation, a certain percentage of the irrigation requirement would be applied as undiluted winery wastewater. Raw water would then be applied for the other part of the irrigation requirement. All vineyards in the project would be irrigated with micro sprinkler irrigation to ensure that the full soil surface is wetted as well as reduce the risk of clogging of the irrigation pipes. It should be noted that experimental grapevines would be irrigated so that optimum wine

quality would be obtained. Therefore, stem water potential thresholds for optimum wine quality for the specific cultivars would be used to set up the refill points. In this regard, grapevines would therefore be under-irrigated rather than over-irrigated because better wine quality is obtained when grapevines receive less water.

Considering the foregoing, winery wastewater could be an important resource for irrigation of vineyards. Previous studies have used artificial “winery wastewater”, mostly on a laboratory scale or the winery wastewater has been diluted before being used to irrigate vineyards. Until now, the impact of in-field fractional use (augmentation) of winery wastewater with raw water for vineyard irrigation has, however, not yet been studied and this study is the first where vineyards would be irrigated with undiluted wastewater from a commercial winery followed by an equivalent amount of raw water at the field level. Thus, to know the impact of in-field fractional use (augmentation) of winery wastewater with raw water for vineyard irrigation on the chemical composition, in particular potassium (K) and sodium (Na), of the soil as well as grapevine performance and wine quality is indispensable. Furthermore, the study would generate information and guidelines on using winery wastewater as a resource for vineyard irrigation in different environments. The users and beneficiaries of the information are wine makers, farmers, technical advisors, government department officials and legislators. A research project to investigate the use of winery wastewater as a resource for irrigation of vineyards in different environment was initiated and funded by the Water Research Commission of South Africa. The project was co-funded by Winetech and the Agricultural Research Council. Three different regions in the Western Cape were selected where grapevines would be irrigated with the in-field fractional use (augmentation) of winery wastewater with raw water for vineyard irrigation for four seasons (2017/18, 2018/19, 2019/20 & 2020/21). Given that soil type can influence nutrient element adsorption and accumulation, two different soil types were selected within the same climatic zone.

Methods

Vineyards were selected in the three selected production areas, namely the Coastal, Breede River and Olifants River regions. The specific locations were selected due to their vast difference in climate and more specifically their difference in mean annual rainfall. The Coastal region represents a more temperate climate that also has higher rainfall. Vineyards were also selected in climatic regions that had lower rainfall and warmer climatic conditions, namely the Breede River and Lower Olifants River regions. In addition to climatic differences, there are also different soil types. Since it is well known that soil type can influence nutrient element adsorption and accumulation, it would also be possible to investigate different soil types within the same climatic zone. The specific soils were selected to represent soils commonly found within each production region. The two experiment plots within each region were selected to be located as close to each other as possible to minimise spatial variability. The two experiment plots were on the same farm for all of the production regions, with the exception of the Lower Olifants River region where they were on separate farms.

Both experiment plots at Backberg formed part of a newly planted commercial *Vitis vinifera* L. *cv.* Cabernet Sauvignon/US8-7 vineyard which was established in September 2017. Both experiment plots at Madeba were part of a commercial *V. vinifera* L. *cv.* Shiraz/SO4 vineyard which was established in 2001. In the Lower Olifants River region, a *V. vinifera* L. *cv.* Shiraz/Ramsey vineyard established in 2012, was selected near the Lutzville winery to represent the deep, sandy soil which is typically found in the Lower Olifants River region. At

Spruitdrift, the experiment plot was a *V. vinifera* L. *cv.* Cabernet Sauvignon/99R vineyard established in 2001 in a shallow, sandy loam soil overlying Dorbank. Each of the six experiment plots compromised of two rows of ten grapevines each. A buffer row of grapevines was located on the one side of each of the experiment rows and two buffer grapevines at each end that also received the in-field fractional use (augmentation) of winery wastewater with raw water for vineyard irrigation.

Grapevines were irrigated throughout the growing season (from 2017/18 to 2020/21) with in-field fractional use (augmentation) of winery wastewater with raw water according to their water requirements under the given set of climatic and soil conditions. Grapevines were irrigated with winery wastewater from mid-February when suitable wastewater became available from vintage processes. The application of irrigations was stopped either in mid-April or the beginning of May each year when the winter rainfalls began. Irrigation was applied by means of micro-sprinklers in order to apply larger volumes of water. Soil and grapevine responses were measured.

Key Results

Irrigation with the in-field fractional use (augmentation) of winery wastewater with raw water did not lead to a long-term accumulation of salts in the Backsberg sand and clay soils in the region with higher mean annual rainfall. Given that soil EC_e levels at the Madeba clay loam experiment plot was higher at the end of the trial in September 2021 compared to the baseline values, this suggested an accumulation of salts during the grapevine growing season partly due to irrigation in-field fractional use (augmentation) of winery wastewater as well as less effective leaching in the heavier soil. The accumulation of soil K was substantially higher in the Backsberg clay experiment plot compared to the sand one. Similarly, the accumulation of K was substantially higher in the Madeba clay loam compared to the sandy loam. The greater accumulation of K in the soil in the Lower Orange River region was a result of higher amounts of K applied *via* the irrigation water in conjunction with lower winter rainfall. These K increases could have a negative impact on wine colour stability should it be taken up by the grapevine in sufficient quantities. Results from the Spruitdrift experiment plot showed that calcium (Ca), magnesium (Mg), K and Na had accumulated to such an extent that the wastewater irrigation had to be terminated after two seasons.

Each of the vineyards had an experiment plot that was irrigated with winery wastewater and this was compared to the rest of the surrounding block which acted as the control at the end of the project in September 2021. Soil $pH_{(KCl)}$ was higher for the experiment plots irrigated with wastewater compared to their respective controls but was still within the norm of 5.0 to 7.5 recommended for optimal grapevine growth. The electrical conductivity of the saturated soil extract (EC_e) of the Backsberg sand experiment plot was similar to that of the control whereas for the Backsberg clay experiment plot, soil EC_e of the experiment plot was slightly higher compared to its respective control. Consequently, rainfall must have leached some of the salts applied *via* irrigation with augmented wastewater salts from the soil in this particular region. However, this does not rule the possibility that winter rainfall could have leached salts beyond the measured depth. Soil EC_e of the Madeba clay loam experiment plot was higher compared to its respective control which indicated an accumulation of salts during the grapevine growing. Furthermore, in heavier soils, less effective leaching is more likely to result in salt accumulation. Soil Ca and Mg was higher for the Backsberg clay and Madeba clay loam experiment plots compared to their respective controls. Soil K was substantially higher for all of the experiment plots compared to their respective controls regardless of mean annual rainfall. In contrast, soil Na of all the experiment plots irrigated with wastewater was similar or lower compared to their respective controls. This indicated that there was sufficient leaching of Na at all the experiment plots, regardless of soil texture. However, where more Na is applied *via* the irrigation water, Na could accumulate to levels where it could impact negatively on soil physical conditions or grapevine growth and yield.

Despite substantial amounts of K applied *via* the in-field fractional use (augmentation), grapevines did not contain excessive K levels in their leaves. On the heavier textured soil at Madeba, there was an accumulation of Na in the leaves. Furthermore, this particular experiment plot had higher leaf blade Na than the control. This suggested that under the prevailing conditions of this particular climate/soil combination that the amounts of elements applied *via* the in-field fractional use (augmentation) of winery wastewater with raw water as well as less effective leaching caused the Na to accumulate in the grapevine. Leaf blade Na levels at the Spruitdrift experiment plot was substantially higher compared to the other experiment plots. The Madeba clay loam experiment plot had substantially higher permanent wood Na levels compared to the control. Given the accumulation of Na in the leaves and permanent wood parts, this is a likely explanation for the poor performance of the Madeba clay loam experiment plot.

At the end of the trial, cane mass of the Lutzville deep sand and Madeba sandy loam experiment plots was comparable to baseline values measured at the beginning of the trial whereas the cane mass at the Madeba clay loam and Spruitdrift experiment plots were lower than the baseline values. This suggested that the in-field fractional use (augmentation) of winery wastewater with raw water had adverse effects on the vegetative growth of these grapevines and was likely related to the accumulation of Na in grapevine parts. Under the prevailing conditions at the Spruitdrift experiment plot, *i.e.* lower mean annual rainfall and shallow sand, the yield was so low at that not enough grapes could be harvested to make experimental wine after the second year of the in-field fractional use (augmentation) of winery wastewater with raw water for vineyard irrigation. The extremely low yield measured at the Spruitdrift experiment plot was most likely due to the very low rainfall in the region due to drought as well as the excessive amount of elements applied *via* the irrigation water which were not leached. Higher berry mass and bunch mass of some of the experiment plots reflected in higher yields for some of the experiment plot compared to the controls. Results indicated that the grapevines at the Spruitdrift experiment plot had recovered to a certain extent after only receiving raw water for the last two years of the study. This indicated that the grapevines could recover from the detrimental effects that they had incurred from the in-field fractional use (augmentation) of winery wastewater with raw water for the first two seasons of the study. The yield of the Madeba clay loam experiment plot was still substantially lower compared to the control and was likely due to the accumulation of salts in the heavier soil as well as the lower mean annual rainfall.

Irrigation of grapevines using the in-field fractional use (augmentation) of winery wastewater with raw water for vineyard irrigation did not have detrimental effects on juice characteristics with regards to ripeness parameters and ion content under the prevailing conditions. Sodic soil conditions caused high concentrations of Na in grape juice with concomitantly reduced Ca concentrations at the Spruitdrift experiment plot. Wine sensorial quality was not affected by the in-field fractional use (augmentation) of winery wastewater with raw water. Under the prevailing conditions, wines produced where grapevines were irrigated using in-field fractional use (augmentation) of winery wastewater with raw water for vineyard irrigation did not always conform to statutory requirements with regard to their Na content. This was specifically notable in regions with lower rainfall.

Key Conclusion of Discussion

Results indicated that winery wastewater can be a beneficial source of irrigation water, particularly where grapevines are normally grown under dryland conditions, as well as during times of drought. Young grapevines were established successfully with the in-field fractional use (augmentation) of winery wastewater with raw water in the Coastal Region. The in-field fractional use (augmentation) of winery wastewater with raw water can be used for vineyard irrigation under certain prevailing conditions. In the Coastal Region, the in-field fractional use (augmentation) of winery wastewater can be applied on sand and clay soils. A ratio of winery wastewater to raw water of 1:1 or lower should be used. In the Breede River Region, the in-field fractional use (augmentation) of winery wastewater can be applied on sandy loam but should not be applied on clay loams over the long term in this particular region. In the Lower Olifants River Region, the in-field fractional use (augmentation) of winery wastewater for vineyard soils should not be applied on shallow sandy soils over the long term but can be used on deep sandy soils.

Take Home message for Industry

The in-field fractional use (augmentation) of winery wastewater with raw water can be used for vineyard irrigation under certain prevailing conditions. In the Coastal Region, *i.e.* a region of higher mean annual rainfall of *c.* 469.1 mm, the in-field fractional use (augmentation) of winery wastewater can be applied on sand and clay soils using undiluted winery wastewater with chemical oxygen demand (COD) and electrical conductivity (EC) levels of 2 600 mg/L and 1.20 dS/m or lower, respectively. A ratio of winery wastewater to raw water of 1:1 or lower should be used. In the Breede River Region, *i.e.* a region of lower mean annual rainfall of *c.* 152.9 mm, the in-field fractional use (augmentation) of winery wastewater can be applied on sandy loam soils using undiluted winery wastewater with COD and EC levels of 3 400 mg/L and 1.30 dS/m or lower, respectively. A ratio of winery wastewater to raw water of 1:1 or lower should be used. However, the in-field fractional use (augmentation) of winery wastewater for vineyard soils should not be applied on clay loams over the long term in this particular region. In the Lower Olifants River Region, *i.e.* a region of lower mean annual rainfall of *c.* 93.6 mm, the in-field fractional use (augmentation) of winery wastewater for vineyard soils should not be applied on shallow sandy soils over the long term but can be used on deep sandy soils using undiluted winery wastewater with COD and EC levels of 5 500 mg/L and 3.00 dS/m, respectively. A ratio of winery wastewater to raw water of 1:1 or lower should be used. The sodium adsorption ratio (SAR) of the wastewater must be less than 5. Given that winery wastewater has high K contents, the K contents of the winery wastewater as well as the potassium adsorption ratio (PAR) should be considered as a water quality parameter when using winery wastewater for vineyard irrigation.

The raw water irrigation should follow the application of the undiluted winery wastewater immediately to avoid unpleasant odours in the vineyard while irrigations are applied. The internal drainage in the root zone must be unrestricted. Only micro-sprinklers should be used, since drippers have narrow flow paths and/or small orifices and are more susceptible to clogging. Irrigation must be applied with micro-sprinklers in such a way that the bunches are not wetted. At least 50% plant available water depletion should be allowed between irrigations to allow sufficient aeration for oxidation of organic material applied *via* the irrigation water. The irrigation frequency and volumes (schedule) should enhance, rather than negate, wine quality characteristics. A summer interception crop of Pearl millet should be cultivated on the sandy soils in the Coastal Region to intercept substantial amounts of K applied *via* the in-field fractional use (augmentation) of winery wastewater with raw water if growing conditions are favourable. However, the contribution of the slash and removal costs production costs of vineyards which are already high is a further aspect that would need consideration.

4. PROBLEM IDENTIFICATION AND MOTIVATION

Problem Identification

The use of diluted winery wastewater has been investigated in a previous WRC and Winetech funded project (Myburgh & Howell, 2014). However, this project only addressed the suitability of using winery wastewater for grapevines in a sandy soil under one set of climatic conditions. Results of a pot experiment showed that soil type and winter rainfall have a pronounced effect on salt accumulation where winery wastewater is used for irrigation (Mulidzi, 2016). Therefore, a field study was necessary to investigate the use of winery wastewater for vineyard irrigation to determine the sustainability of such a practice in other environments. The primary objective of the project was to assess the fitness for use of winery wastewater for irrigation of different soil types with varying rainfall quantities and leaching levels on vineyard performance in terms of yield and quality under field conditions.

Motivation

Re-using diluted winery wastewater was investigated in a previous WRC and Winetech funded project (Myburgh & Howell, 2014). However, only the suitability of using winery wastewater for irrigating grapevines in a sandy soil under one set of climatic conditions was addressed. A pot study showed that soil type and winter rainfall have a pronounced effect on salt accumulation where winery wastewater is used for irrigation (Mulidzi, 2016). If winery wastewater could be used in a sustainable way for vineyard irrigation, it could reduce energy used for wastewater treatment. Plant nutrients in the wastewater could reduce the necessity to apply fertiliser. Using winery wastewater could also have a positive impact on grape production where water shortages occur. Therefore, a field study was necessary to investigate the use of winery wastewater for vineyard irrigation to determine the sustainability of such a practice in other environments. Since climatic conditions range considerably in Western Cape, it would be possible to investigate the effect of climatic factors such as magnitude of rainfall on using winery wastewater for vineyard irrigation. In addition to climatic differences, there are also different soil types thus it would be possible to investigate different soil types within the same climatic zone.

5. ACCUMULATED PROGRESS TABLE

Objectives	**Milestones (Significant event or stage in a project)**	**Date Achieved**
O1. To determine the feasibility of in-field fractional use (augmentation) of winery wastewater with raw water with specific reference to the pH, EC, SAR/PAR and COD.	M1.1 Review relevant literature on existing guidelines and standards for management and authorisation on using winery wastewater for irrigation. M1.2 Select two experiment plots in each of three different climatic zones. M1.3 Approach wineries and producers for permission to work at their wineries and vineyards. M1.4 Install infrastructure to apply wastewater irrigation. M1.5 Apply in-field fractional use (augmentation) of winery wastewater with raw water for four years. M1.6 Analyse irrigation water applied for four years. M1.7 Determine irrigation volumes applied for four years. M1.8 Calculate amounts of elements applied for four years.	2022-03-31
O2. To measure the change in mainly Na and K status of soils with different clay content, with low/high rainfall and low/high leaching levels with application of winery wastewater.	M2.1 Determine baseline soil chemical status. M2.2 Determine soil chemical status at bud break and after harvest.	2022-03-31
O3. To develop appropriate management guidelines for using winery wastewater as a resource for irrigation of vineyards.	M3.1 Determine effects of in-field fractional use (augmentation) of winery wastewater with raw water on soil properties and grapevine responses. M3.2 Present results and recommendations in a final report.	2022-03-31
O4. To refine regulations for general authorisation of winery wastewater for irrigation of vineyards.	M4.1 Depending on the outcomes of the project, applicable information will be used to assist with refinement of regulations regarding irrigation with winery wastewater.	2022-03-31

6. WORKPLAN (MATERIALS AND METHODS)

W1-In order to obtain variation in climatic conditions, experiment plots were selected in commercial vineyards in three different climatic regions of the Western Cape. The Coastal region (e.g. Stellenbosch) represents a more temperate climate which has higher rainfall. Vineyards were also selected in climatic regions that have lower rainfall and warmer climatic conditions, namely the Breede River (e.g. Robertson) and Olifants River (e.g. Vredendal) regions. In each of the three climatic regions, two experiment plots were selected that are on different soils. Therefore, in total, there are six plots. Experiment plots comprise two rows of 10 experiment grapevines each, with two buffer grapevines at each end and two buffer rows on each side. In all plots, grapevines are managed according to the grower's normal viticultural practices, except that no summer or winter cover crops are grown. (M1.2, M1.3, M1.4, M1.5)

W2-At each winery, undiluted winery wastewater is pumped into 15 m3 storage tanks using pumps. This ensures that there is an adequate supply of wastewater. The water is filtered when it is pumped from the tank to the experiment plot. Following the wastewater application, raw water is pumped directly to the experiment plot using the same pump and supply line from the winery. Irrigation is applied by means of mini-sprinklers. The volume of water delivered to each plot is measured by means of water metres. Initially, the first 50% of the irrigation requirement consists of undiluted winery wastewater and the other half of raw water, i.e. a 1:1 ratio. As soon as soil physical problems occur, e.g. runoff or ponding due to poor infiltration, the ratio of raw water to winery wastewater will be increased to 2:1. If the problem continues, the ratio will again be increased to 3:1. When soil analyses indicate that the wastewater irrigation is having negative effects on the soil chemical status and/or increased SAR, the ratio of raw water to winery wastewater will be increased in the same way. If the soil problem(s) persist, the soil will be considered as unsuitable for irrigation with in-field diluted winery wastewater. The irrigations will then be terminated for that specific climate/soil combination. (M1.4, M1.5, M1.6, M1.7)

W3-Sample of the undiluted winery wastewater is collected every time an irrigation is applied. The sampling is repeated when the raw water part of the irrigation is applied. Samples are analysed by a commercial laboratory. The amount of elements applied via irrigation will be calculated using these analyses and the volumes of water applied. (M1.6, M1.7, M1.8).

W4-Before the start of the first irrigation season, soil samples will be taken over 30 cm increments to a depth of 90 cm. Samples are analysed by a commercial laboratory. (M2.1,M2.2, M3.1)

W5-Before the first irrigation season, cane mass was determined at pruning in July to obtain a baseline indication of growth vigour. Following this, cane mass is measured each year during winter. Grapevine nutrient status will be quantified at the hand of leaf blade analyses. Samples will be analysed by a commercial laboratory. Grapes are harvested when the recommended optimum sugar content in the juice for the specific cultivar is reached. Yield and its components will be determined in all plots. Juice samples will be collected at harvest. Juice ripeness parameters and element contents will be determined. At each experiment plot, grapes will be harvested for wine making. Wine quality will be judged by a trained panel of wine tasters. (M3.1).

7. RESULTS AND DISCUSSIONS

HERE IS THE LINK TO THE WATER RESEARCH COMMISSION FULL REPORT.

https://drive.google.com/file/d/1RxgT3CsIVo2ZDg4royOy6A666E4phggH/view?usp=sharing

EXECUTIVE SUMMARY (As published in the Water Research Commission Full Report)

Background

Wine grapes are an important crop in regions such as the Western Cape and the Lower Orange River in the Northern Cape. However, wineries produce large volumes of poor quality wastewater, particularly during the harvest period. On the other hand, the Western Cape has experienced a drought. In August 2017, the level in the Theewaterskloof Dam was 25.1%. Therefore, the City of Cape Town had to introduce water restrictions and at once stage, residents were subjected to Level 5 water restrictions. This meant that residents were allocated 87 L of water per person per day. More recently, as of 19 August 2019 the level of water in the Theewaterskloof Dam was 81.7%, and water restrictions are at Level 1. As of 5 October 2020, the dams in the Western Cape were filled to capacity. Taking the afore-mentioned into consideration, it is clear that the Western Cape has experienced severe drought recently, which means that water resources for urban and agricultural uses are extremely limited. The drought also severely restricted the irrigation sector, and will change the way things are done in the future. Wine grape producers will therefore have to use water resources judiciously to produce grapes. In addition to this, it is important that the sustainable use of alternative water sources for vineyard irrigation be investigated.

The use of augmented winery wastewater was investigated in a previous WRC and Winetech funded project. However, this project only addressed the suitability of using winery wastewater for grapevines in a sandy soil under one set of climatic conditions. Results of a pot experiment showed that soil type and winter rainfall have a pronounced effect on salt accumulation where winery wastewater is used for irrigation. Therefore, a field study was necessary to investigate the use of winery wastewater for vineyard irrigation to determine the sustainability of such a practice in other environments. Since climatic conditions range considerably in the Western Cape, it would be possible to investigate the effect of climatic factors such as magnitude of rainfall on the possibility of using winery wastewater for vineyard irrigation. Therefore, three different regions were to be selected where grapevines would be irrigated with winery wastewater. In addition to climatic differences, there are also different soil types. Since it is well known that soil type can influence nutrient element adsorption and accumulation, it would also be possible to investigate different soil types within the same climatic zone.

Experience from a previous study showed that it would be impractical to augment winery wastewater to a predetermined level before each irrigation, *i.e.* specifically at the commercial level because it would be difficult to monitor the winery wastewater quality continuously in order to adjust the volumes of raw and wastewater to obtain a required level of augmentation. Therefore, a more practical approach would be applied in this project to use the in-field fractional use (augmentation) of winery wastewater with raw water. According to this approach, grapevines would be irrigated as follows. For each irrigation, a certain percentage of the irrigation requirement would be applied as undiluted winery wastewater. Raw water would then be applied for the other part of the irrigation requirement. All vineyards in the project would be irrigated with micro sprinkler irrigation to ensure that the full soil surface is wetted as well as reduce the risk of clogging of the irrigation pipe. It should be noted that experimental grapevines would be irrigated so that optimum wine quality would be obtained. Therefore, stem water potential thresholds for optimum wine quality for the specific cultivars would be used to set up the refill points. In this regard, grapevines would therefore be under-irrigated rather than over-irrigated because better wine quality is obtained when grapevines receive less water. Grapevines would also grow without a cover crop. Given that the cultivation of a cover crop would have masked effects of the wastewater irrigation as well as increase the cost of analyses, full surface chemical control would be applied to the plots.

Considering the wines produced using the in-field fractional use (augmentation) of winery wastewater with raw water, no health risk was expected to the consumer. Previous research has shown that the negative microbes which could possibly be associated with wastewater are destroyed during the wine making process. In addition to this, the winery wastewater does not get mixed with sewage water so the risk of contamination is extremely low. In addition to this, winery wastewater also generally undergoes some form of treatment.

Considering the foregoing, winery wastewater could be an important resource for irrigation of vineyards. Previous studies have used artificial "winery wastewater", mostly on a laboratory scale or the winery wastewater has been diluted before being used to irrigate vineyards. Until now, the impact of in-field fractional use (augmentation) of winery wastewater with raw water for vineyard irrigation has, however, not yet been studied and this study is the first where vineyards would be irrigated with undiluted wastewater from a commercial winery followed by an equivalent amount of raw water at the field level. Thus, to know the impact of in-field fractional use (augmentation) of winery wastewater with raw water for vineyard irrigation on the chemical composition, in particular potassium (K) and sodium (Na), of the soil as well as grapevine performance and wine quality is indispensable. Furthermore, the study would generate information and guidelines on using winery wastewater as a resource for vineyard irrigation in different environments. The users and beneficiaries of the information are wine makers, farmers, technical advisors, government department officials and legislators. A research project to investigate the use of winery wastewater as a resource for irrigation of vineyards in different environments was initiated and funded by the Water Research Commission of South Africa. The project was co-funded by Winetech and the Agricultural Research Council. Three different regions in the Western Cape were selected where grapevines would be irrigated with the in-field fractional use (augmentation) of winery wastewater with raw water for vineyard irrigation for four seasons (2017/18, 2018/19, 2019/20 & 2020/21). Given that soil type can influence nutrient element adsorption and accumulation, two different soil types were selected within the same climatic zone.

Project objectives

The primary objective of the project was to assess the fitness for use of winery wastewater for irrigation of different soil types with varying rainfall quantities and leaching levels on vineyard performance in terms of yield and quality under field conditions as well as measuring the change in mainly Na and K status of soils. Furthermore, an objective was to develop appropriate management guidelines for using augmented winery wastewater as a resource for vineyard irrigation and to refine regulations for authorization of augmented winery wastewater for irrigation of vineyards.

Experiment layout

Vineyards were selected in the three selected production areas, namely the Coastal, Breede River and Olifants River regions. The specific locations were selected due to their vast difference in climate and more specifically their difference in mean annual rainfall. The Coastal region represents a more temperate climate that also has higher rainfall. Vineyards were also selected in climatic regions that had lower rainfall and warmer climatic conditions, namely the Breede River and Lower Olifants River regions. In addition to climatic differences, there are also different soil types. Since it is well known that soil type can influence nutrient element adsorption and accumulation, it would also be possible to investigate different soil types within the same climatic zone. After visiting a number of wineries in the Coastal region, Backsberg winery was selected as the most suitable farm to carry out the field trial. Since the grapevines at Backsberg would only be planted in the winter of 2017, Dr Myburgh asked the Reference Group of the project at their meeting in November 2016 if the project team could test the irrigation with winery wastewater on newly planted grapevines. At this meeting, Mr. Van Schoor indicated that it was extremely important to test the use of winery wastewater for irrigation on newly planted grapevines. The Reference Group agreed that the young vineyard could be used as the site for the Coastal Region. It would be possible to measure yield and juice quality in three years' time. However, vegetative growth responses could be monitored from the first year. A meeting was held in Robertson with experienced viticulturalists, *i.e.* Messrs Stipp and Lategan, to identify potential suitable sites in the Breede River region. All parties agreed that the Madeba farm was the most suitable option. After discussions with representatives at Madeba, a vineyard was identified with sufficient variation in soil texture. In the Olifants River region, at a meeting held with wine industry representatives at Spruitdrift winery, a suitable site was identified near the winery. The shallow, sandy soil on Dorbank is representative of many vineyard soils in the region. Since the soil type was uniform at the Spruitdrift winery, a meeting was held at the Lutzville winery to select a vineyard on deep, sandy soil that is also typical of the region. A suitable site was selected adjacent to the Lutzville winery. The specific soils were selected to represent soils commonly found within each production region. The two experiment plots within each region were selected to be located as close to each other as possible to minimise spatial variability. The two experiment plots were on the same farm for all of the production regions, with the exception of the Lower Olifants River region where they were on separate farms. Both experiment plots at Backberg formed part of a newly planted commercial *Vitis vinifera* L. *cv*. Cabernet Sauvignon/US8-7 vineyard which was established in September 2017. Both experiment plots at Madeba were part of a commercial *V. vinifera* L. *cv*. Shiraz/SO4 vineyard which was established in 2001. In the Lower Olifants River region, a *V. vinifera* L. *cv*. Shiraz/Ramsey vineyard established in 2012, was selected near the Lutzville winery to represent the deep, sandy soil which is typically found in the Lower Olifants River region. At Spruitdrift, the experiment plot was a *V. vinifera* L. *cv*. Cabernet Sauvignon/99R vineyard established in 2001 in a shallow, sandy loam soil overlying Dorbank. Each of the six experiment plots compromised of two rows of ten grapevines each. A buffer row of grapevines was located on the one side of each of the experiment rows and two buffer grapevines at each end that also received the in-field fractional use (augmentation) of winery wastewater with raw water for vineyard irrigation.

After selection of the vineyards which were to be irrigated with the in-field fractional use (augmentation) of winery wastewater with raw water, Mr. W. Smit, and the project team visited the selected sites in Stellenbosch, Robertson, Lutzville and Vredendal to design the irrigation infrastructure. Following the system designs by Mr. Smit, ARC Infruitec-Nietvoorbij selected contractors responsible for the installation of the irrigation infrastructure in the three different regions.

This study would be the first where the in-field fractional use (augmentation) of winery wastewater with raw water was to be used for vineyard irrigation at the field scale Grapevines were irrigated with winery wastewater from mid-February when suitable wastewater became available from vintage processes. The application of irrigation was stopped either in mid-April or the beginning of May each year, when the winter rainfalls began. Irrigation was applied by means of micro-sprinklers in order to apply larger volumes of water.

Soil chemical status

Baseline soil samples were collected at the six experiment plots between July and August 2017 before irrigation applications commenced. Samples were taken again during May 2018 after the majority of irrigations were applied. In order to establish if applied salts were leached from the experiment soils during the winter rainfall period, soil samples were collected again in October 2018. Thereafter, samples were taken in the same way for the 2018/19, 2019/20 and 2020/21 seasons. Samples were collected at three positions in each experiment plot along the grapevine row. Samples for each depth were pooled together to create a composite sample. Samples were collected over 30 cm increments to a depth of at least 60 cm in all experiment plots and up to 300 cm at the Lutzville deep sand plot using a modified soil auger. Under the prevailing conditions, the element concentrations in the different soils responded to the in-field fractional use (augmentation) of winery wastewater with raw water for vineyard irrigation. Results indicated that irrigation with the in-field fractional use (augmentation) of winery wastewater with raw water did not lead to a long-term accumulation of salts in the Backsberg sand and clay soils in the region with higher mean annual rainfall. Given that soil EC_e levels at the Madeba clay loam experiment plot was higher at the end of the trial in September 2021 compared to the baseline values, this suggested an accumulation of salts during the grapevine growing season partly due to irrigation in-field fractional use (augmentation) of winery wastewater as well as less effective leaching in the heavier soil. The accumulation of soil K was substantially higher in the Backsberg clay experiment plot compared to the sand one. Similarly, the accumulation of K was substantially higher in the Madeba clay loam compared to the sandy loam. In heavier soils, less effective leaching is more likely to result in salt accumulation. Results indicated that the accumulation of the K over the duration of the study was related to the mean annual rainfall. The greater accumulation of K in the soil in the Lower Orange River region was a result of higher amounts of K applied *via* the irrigation water in conjunction with lower winter rainfall. These K increases could have a negative impact on wine colour stability should it be taken up by the grapevine in sufficient quantities. Results from the Spruitdrift experiment plot showed that calcium (Ca), magnesium (Mg), K and Na had accumulated to such an extent that the wastewater irrigation had to be terminated after two seasons.

Each of the vineyards had an experiment plot that was irrigated with winery wastewater and this was compared to the rest of the surrounding block which acted as the control at the end of the project in September 2021. Soil $pH_{(KCl)}$ was higher for the experiment plots irrigated with wastewater compared to their respective controls but was still within the norm of 5.0 to 7.5 recommended for optimal grapevine growth. The electrical conductivity of the saturated soil extract (EC_e) of the Backsberg sand experiment plot was similar to that of the control whereas for the Backsberg clay experiment plot, soil EC_e of the experiment plot was slightly higher compared to its respective control. Consequently, rainfall must have leached some of the salts applied *via* irrigation with augmented wastewater salts from the soil in this particular region. However, this does not rule out the possibility that winter rainfall could have leached salts beyond the measured depth. Soil EC_e of the Madeba clay loam experiment plot was higher compared to its respective control which indicated an accumulation of salts during the grapevine growing. Furthermore, in heavier soils, less effective leaching is more likely to result in salt accumulation. Soil Ca and Mg were higher for the Backsberg clay and Madeba clay loam experiment plots compared to their respective controls. Soil K was substantially higher for all of the experiment plots compared to their respective controls regardless of mean annual rainfall. In contrast, soil Na of all the experiment plots irrigated with wastewater was similar or lower compared to their respective controls. This indicated that there was sufficient leaching of Na at all the experiment plots, regardless of soil texture. However, where more Na is applied *via* the irrigation water, Na could accumulate to levels where it could impact negatively on soil physical conditions or grapevine growth and yield.

Grapevine responses

Vegetative growth and yield: Despite substantial amounts of K applied *via* the in-field fractional use (augmentation), grapevines did not contain excessive K levels in their leaves. On the heavier textured soil at Madeba, there was an accumulation of Na in the leaves. Furthermore, this particular experiment plot had higher leaf blade Na than the control. This suggested that under the prevailing conditions of this particular climate/soil combination that the amounts of elements applied *via* the in-field fractional use (augmentation) of winery wastewater with raw water as well as less effective leaching caused the Na to accumulate in the grapevine. Leaf blade Na levels at the Spruitdrift experiment plot were substantially higher compared to the other experiment plots. The Madeba clay loam experiment plot had substantially higher permanent wood Na levels compared to the control. Given the accumulation of Na in the leaves and permanent wood part of this particular reason, this is a likely explanation for the poor performance of the Madeba clay loam experiment plot. The cultivation of a summer cover crop may intercept substantial amounts of K applied *via* the in-field fractional use (augmentation) of winery wastewater with raw water if growing conditions are favourable for the particular crop. However, the contribution of the slash and removal costs of production costs of vineyards which are already high is a further aspect that would need consideration.

At the end of the trial, cane mass of the Lutzville deep sand and Madeba sandy loam experiment plots was comparable to baseline values measured at the beginning of the trial whereas the cane mass at the Madeba clay loam and Spruitdrift experiment plots were lower than the baseline values. This suggested that the in-field fractional use (augmentation) of winery wastewater with raw water had adverse effects on the vegetative growth of these grapevines and was likely related to the accumulation of Na in grapevine parts. Under the prevailing conditions at the Spruitdrift experiment plot, *i.e.* lower mean annual rainfall and shallow sand, the yield was so low at that not enough grapes could be harvested to make experimental wine after the second year of the in-field fractional use (augmentation) of winery wastewater with raw water for vineyard irrigation. The extremely low yield measured at the Spruitdrift experiment plot was most likely due to the very low rainfall in the region due to drought as well as the excessive amount of elements applied *via* the irrigation water which were not leached. Higher berry mass and bunch mass of some of the experiment plots reflected higher yields for some of the experiment plot compared to the controls. Results indicated that the grapevines at the Spruitdrift experiment plot had recovered to a certain extent after only receiving raw water for the last two years of the study. This indicated that the grapevines could recover from the detrimental effects that they had incurred from the in-field fractional use (augmentation) of winery wastewater with raw water for the first two seasons of the study. The yield of the Madeba clay loam experiment plot was still substantially lower compared to the control and was likely due to the accumulation of salts in the heavier soil as well as the lower mean annual rainfall.

Juice and wine characteristics: Results showed that irrigation of grapevines using the in-field fractional use (augmentation) of winery wastewater with raw water for vineyard irrigation did not have detrimental effects on juice characteristics with regards to ripeness parameters and ion content under the prevailing conditions. Sodic soil conditions caused high concentrations of Na in grape juice with concomitantly reduced Ca concentrations at the Spruitdrift experiment plot. Wine sensorial quality was not affected by the in-field fractional use (augmentation) of winery wastewater with raw water. Under the prevailing conditions, wines produced where grapevines were irrigated using in-field fractional use (augmentation) of winery wastewater with raw water for vineyard irrigation did not always conform to statutory requirements with regard to their Na content. This was specifically notable in regions with lower rainfall.

Recommendations

Based on the project results, the following criteria should be considered for possible amendments to the General Authorisation for wineries when using the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of vineyards:

(i) In the Coastal Region, *i.e.* a region of higher mean annual rainfall of *c.* 469.1 mm, the in-field fractional use (augmentation) of winery wastewater can be applied on sand and clay soils using undiluted winery wastewater with chemical oxygen demand (COD) and electrical conductivity (EC) levels of 2 600 mg/L and 1.20 dS/m or lower, respectively. A ratio of winery wastewater to raw water of 1:1 or lower should be used.
(ii) In the Breede River Region, *i.e.* a region of lower mean annual rainfall of *c.* 152.9 mm, the in-field fractional use (augmentation) of winery wastewater can be applied on sandy loam soils using undiluted winery wastewater with COD and EC levels of 3 400 mg/L and 1.30 dS/m or lower, respectively. A ratio of winery wastewater to raw water of 1:1 or lower should be used.
(iii) In the Breede River Region, *i.e.* a region of lower mean annual rainfall of *c.* 152.9 mm, the in-field fractional use (augmentation) of winery wastewater for vineyard soils should not be applied on clay loams over the long term.
(iv) In the Lower Olifants River Region, *i.e.* a region of lower mean annual rainfall of *c.* 93.6 mm, the in-field fractional use (augmentation) of winery wastewater for vineyard soils should not be applied on shallow sandy soils over the long term.
(v) In the Lower Olifants River Region, *i.e.* a region of lower mean annual rainfall of *c.* 93.6 mm, the in-field fractional use (augmentation) of winery wastewater for vineyard soils can be used on deep sandy soils using undiluted winery wastewater with COD and EC levels of 5 500 mg/L and 3.00 dS/m, respectively. A ratio of winery wastewater to raw water of 1:1 or lower should be used
(vi) The sodium adsorption ratio (SAR) must be less than 5.
(vii) Given that winery wastewater has high K contents, the K contents of the winery wastewater as well as the potassium adsorption ratio (PAR) should be considered as a water quality parameter when using winery wastewater for vineyard irrigation.

(viii) The raw water irrigation should follow the application of the undiluted winery wastewater immediately to avoid unpleasant odours in the vineyard while irrigations are applied.
(ix) The internal drainage in the root zone must be unrestricted.
(x) Only micro-sprinklers should be used, since drippers have narrow flow paths and/or small orifices, and are more susceptible to clogging.
(xi) The irrigation must be applied with micro-sprinklers in such a way that the bunches are not wetted.
(xii) At least 50% plant available water depletion should be allowed between irrigations to allow sufficient aeration for oxidation of organic material applied *via* the irrigation water.
(xiii) The irrigation frequency and volumes (schedule) should enhance, rather than negate, wine quality characteristics.
(xiv) A summer interception crop of Pearl millet should be cultivated on the sandy soils in the Coastal Region.

Proposed future research work
Further research should be done to determine acceptable PAR norms to avoid excessive K application and accumulation in soils, and subsequently in grapevines. The use of other types of wastewater in the region with higher mean annual rainfall, *i.e.* the Coastal Region, should be investigated further. Irrigating vineyards with treated municipal wastewater could be a useful way to recycle poor quality water. The aim of such research should be to determine the effect of irrigation with treated municipal wastewater at different frequencies on soil, grapevine yield and wine quality responses in a field trial to establish if using such waters would be sustainable in the long term. The only variable management practice will be irrigation frequencies.

8. CONCLUSIONS AND RECOMMENDATIONS

RECOMMENDATIONS
Results indicated that winery wastewater can be a beneficial source of alternative irrigation water, particularly in areas where grapevines are normally grown under dryland conditions, as well as during times of drought. Young grapevines were established successfully with the in-field fractional use (augmentation) of winery wastewater with raw water in the Coastal Region. It should be noted that winery wastewater can vary in its availability. Large co-operative wineries may produce wastewater throughout the entire season, whereas smaller private wineries may only produce significant amounts of wastewater during harvest. This is important to consider when planning an irrigation strategy. Furthermore, the quality of wastewater can vary greatly over a short period of time. The composition of winery wastewater will vary according to the specific winemaking or cleaning practices being implemented. In addition, the influx of grapes to wineries during the harvest period increases the COD of the wastewater which has implications for its reuse.

It is therefore recommended to monitor plant and soil water status on a regular basis, and by doing so, avoid over-irrigation. Implementing low frequency irrigation scheduling with a sufficient leaching fraction will allow adequate time between irrigation applications for soils to aerate and organic material to decompose. This will also have the advantage of leaching excess salts beyond the root zone and thereby prevent potential problems associated with salinity and infiltration. If infiltration is negatively affected, the application of a surface mulch may help to restore structural stability at the soil surface. Routine analysis of irrigation water, soils and grapevine leaves are also recommended when irrigating with winery wastewater to ensure that chemical parameters conform to recommended thresholds and norms. This can help to prevent irreversible damage to irrigation equipment, soils and grapevines. Furthermore, grapevines should be monitored for deficiency and toxicity symptoms of trace elements which could accumulate in soils and grapevines under wastewater irrigation. Results of the present study have shown that winery wastewater can supply nutrients to grapevines in a plant-available form. However, due to the variable nature of wastewater, some nutrients may not be supplied in sufficient amounts, whereas others may be supplied in excess. It is therefore recommended to use an integrated fertiliser management program by adjusting fertiliser applications according to the amounts of nutrients present in the wastewater.

Based on the project results, the following criteria should be considered for possible amendments to the General Authorisation for wineries when using the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of vineyards:

(i) In the Coastal Region, *i.e.* a region of higher mean annual rainfall of *c.* 469.1 mm, the in-field fractional use (augmentation) of winery wastewater can be applied on sand and clay soils using undiluted winery wastewater with COD and EC levels of 2 600 mg/L and 1.20 dS/m or lower, respectively. A ratio of winery wastewater to raw water of 1:1 or lower should be used.

(ii) In the Breede River Region, *i.e.* a region of lower mean annual rainfall of *c.* 152.9 mm, the in-field fractional use (augmentation) of winery wastewater can be applied on sandy loam soils using undiluted winery wastewater with COD and EC levels of 3 400 mg/L and 1.30 dS/m or lower, respectively. A ratio of winery wastewater to raw water of 1:1 or lower should be used.

(iii) In the Breede River Region, *i.e.* a region of lower mean annual rainfall of *c.* 152.9 mm, the in-field fractional use (augmentation) of winery wastewater for vineyard soils should not be applied on clay loams over the long term.

(iv) In the Lower Olifants River Region, *i.e.* a region of lower mean annual rainfall of *c.* 93.6 mm, the in-field fractional use (augmentation) of winery wastewater for vineyard soils should not be applied on shallow sandy soils over the long term.

(v) In the Lower Olifants River Region, *i.e.* a region of lower mean annual rainfall of *c.* 93.6 mm, the in-field fractional use (augmentation) of winery wastewater for vineyard soils can be used on deep sandy soils using undiluted winery wastewater with COD and EC levels of 5 500 mg/L and 3.00 dS/m, respectively. A ratio of winery wastewater to raw water of 1:1 or lower should be used

(vi) The SAR must be less than 5.

(vii) Given that winery wastewater has high K contents, the K contents of the winery wastewater as well as the PAR should be considered as a water quality parameter when using winery wastewater for vineyard irrigation.

(viii) The raw water irrigation should follow the application of the undiluted winery wastewater immediately to avoid unpleasant odours in the vineyard while irrigations are applied.

(ix) The internal drainage in the root zone must be unrestricted.

(x) Only micro-sprinklers should be used, since drippers have narrow flow paths and/or small orifices, and are more susceptible to clogging.

(xi) The irrigation must be applied with micro-sprinklers in such a way that the bunches are not wetted.

(xii) At least 50% plant available water depletion should be allowed between irrigations to allow sufficient aeration for oxidation of organic material applied *via* the irrigation water.

(xiii) The irrigation frequency and volumes (schedule) should enhance, rather than negate, wine quality characteristics.

(xiv) A summer interception crop of Pearl millet should be cultivated on the sandy soils in the Coastal Region.

PROPOSED FUTURE RESEARCH WORK

The following are more general recommendations and suggestions that need to be considered if the in-field fractional use (augmentation) of winery wastewater with raw water is used.

(i) Further research should be done to determine acceptable PAR norms to avoid excessive K application and accumulation in soils, and subsequently in grapevines.

(ii) The use of other types of wastewater in the region with higher mean annual rainfall, *i.e.* the Coastal Region, should be investigated further. Irrigating vineyards with treated municipal wastewater could be a useful way to recycle poor quality water. The aim of such research should be to determine the effect of irrigation with treated municipal wastewater at different frequencies on soil, grapevine yield and wine quality responses in a field trial to establish if using such waters would be sustainable in the long term. The only variable management practice will be irrigation frequencies.

9. PLANNED OUTPUTS

a) TECHNOLOGY DEVELOPMENT, PRODUCTS AND PATENTS

b) SUGGESTIONS FOR TECHNOLOGY TRANSFER

The information generated by the Project will be disseminated to the different stakeholders via information sessions, i.e. producers' meetings and Winetech meetings, as well as scientific oral and poster presentations. At the Winetech Soil and Water Committee meeting in September 2021, Mrs. Andrag and Dr Howell agreed to have a meeting to discuss such information dissemination at Winetech producer days once the Final Report has been finalised. At the Winetech Soil and Water Committee meeting in September 2021, Mrs. Andrag and Dr. Howell agreed to have a meeting to discuss a series of popular articles for the Winelands journal once the Final Report has been finalised. Dr Howell has already been asked by Dr Hlophe-Ginindza of WRC to present the project at Circular Economy opportunities in the South African Water Sector WISA Biennial Conference: 28-30 September 2022. Dr Howell has also been invited to speak by Dr S. Lampbrechts at the Soil borne disease Conference in October 2022.

c) HUMAN RESOURCES DEVELOPMENT / TRAINING (STUDENTS)

Student Name and Surname	Student Nationality	Degree (eg Hons, MSc)	Level of studies in final year of project	Total Bursary Cost for Industry for entire project
Masters				
Karla Hoogendijk	South Africa			R 150000
Takalani Sikau	South Africa			R 0
Luvuyo Mabongo	South Africa			R 0

d) LIKELY PUBLICATIONS (POPULAR, PRESS RELEASES, SCIENTIFIC)

A review article was accepted for publication in the South African Journal for Enology and

Viticulture (SAJEV). The review is: Howell, C.L. and Myburgh, P.A., 2018. Management of winery wastewater by re-using it for crop irrigation - A review. S. Afr. J. Enol. Vitic. 39, 116-131.

Hoogendijk, K., 2019. Soil and grapevine responses to irrigation with treated municipal and winery wastewaters. Thesis, Stellenbosch University, Private Bag X1, 7602 Matieland (Stellenbosch), South Africa.

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The following articles are planned:
• Irrigation of agricultural crops with municipal wastewater - A review.
• An assessment of treated municipal wastewater used for irrigation of grapevines with respect to water quality and nutrient load.
• Long-term effects of irrigation with treated municipal wastewater on soil responses in commercial vineyards in the Coastal Region of South Africa.
• Effect of irrigation with treated municipal wastewater on Vitis vinifera L. cvs. Cabernet Sauvignon and Sauvignon blanc in commercial vineyards in the Coastal Region of South Africa - Vegetative growth and yield.
• An assessment of winery wastewater used for the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of grapevines with respect to water quality and nutrient load.
• Effect of the in-field fractional use (augmentation) of winery wastewater with raw water for vineyard irrigation on soil responses.
• Effect of the in-field fractional use (augmentation) of winery wastewater with raw water for vineyard irrigation on grapevine and wine responses.
• An assessment of the below and above ground chemical status of grapevines in the lower Olifants River region in response to in-field fractional use (augmentation) of winery wastewater with raw water

e) PRESENTATIONS/PAPERS THAT COULD BE DELIVERED

10. PROJECT OUTCOME AND IMPACT

New Knowledge	Benefits Supply Chain	Direct Grower Application	Direct Packhouse/Winery/ Cellar Application	Other
X				

Other is:

This study was the first where in-field fractional use (augmentation) of winery wastewater with raw water was used for vineyard irrigation. Results indicated that winery wastewater can be a beneficial source of irrigation water, particularly where grapevines are normally grown under dryland conditions, as well as during times of drought.

The Value of the project to industry

This study was the first where in-field fractional use (augmentation) of winery wastewater with raw water was used for vineyard irrigation. Results indicated that winery wastewater can be a beneficial source of irrigation water.

11. PERSONS PARTICIPATING IN THE PROJECT:

INITIALS AND SURNAME	HIGHEST QUALIFICATION	RACE (M,W)	GENDER (M,F)	INSTITUTE DEPARTM	POSITION	TOTAL COST TO PROJECT
RESEARCH PERSONNEL						R 3738622
Thandile Mdlambuzi	PhD. Agric.	B	M	ARC, Soil and Water Science	Co	R 369416
Gert Malan	M.Sc.Agric.	W	M	ARC, Soil and Water Science	Co	R 592426
Carolyn Howell	PhD Agric	W	F	ARC, Soil and Water Science	PL	R 1454284
Philip Myburgh	PhD Agric	W	M	ARC, Soil and Water Science	Co	R 1083672
Reckson Mulidzi	PhD. Agric.	B	M	ARC, Soil and Water Science	Co	R 238824
SUPPORT PERSONNEL						R 555976
Francos Baron	Matric	B	M	ARC, Soil and Water	RA	R 356684
Trevor Harris	Matric	B	M	ARC, Soil and Water Science	RA	R 157441
Karen Freitag	Matric	W	F	ARC, Soil and Water	TA	R 41851

POSITION: Co = Co-worker (other researcher at your institution)
Coll = Collaborator (participating researcher that does not receive funding for this project from industry)
PF = Post-doctoral fellow
PL = Project leader
RA = Research assistant
TA = Technical assistant/ technician

12. TOTAL COST OF PROJECT

TOTAL ANNUAL COSTS (ALL YEARS)	CFPA	RAISIN SA	HORTGRO	SATI	WINETECH	ARC	WRC	TOTAL
2017	R 0	R 0	R 0	R 0	R 333333	R 1582314	R 500000	R 2415647
2018	R 0	R 0	R 0	R 0	R 333333	R 753106	R 550000	R 1636439
2019	R 0	R 0	R 0	R 0	R 333333	R 841992	R 600000	R 1775325
2020	R 0	R 0	R 0	R 0	R 333333	R 723346	R 680000	R 1736679
2021	R 0	R 0	R 0	R 0	R 266666	R 879796	R 720000	R 1866462
2022	R 0	R 0	R 0	R 0	R 333333	R 754148	R 950000	R 2037481
TOTAL	R 0	R 0	R 0	R 0	R 1933331	R 5534702	R 4000000	R 11468033