USE OF WINERY WASTEWATER AS A RESOURCE FOR IRRIGATION OF VINEYARDS IN DIFFERENT ENVIRONMENTS

Report to the

WATER RESEARCH COMMISSION and WINETECH

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EXECUTIVE SUMMARY

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 were 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 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 of the soil, in particular potassium (K) and sodium (Na), 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 a 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.

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 Backsberg 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 installed the infrastructure.

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 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 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 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.

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 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 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 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 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.

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.

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Prof. S Mpandeli	Water Research Commission (Chairman)
Dr SN Hlophe-Ginindza	Water Research Commission
Dr L Nhamo	Water Research Commission
Ms A Andrag	Winetech
Ms M Cornelissen	Namaqua Wines
Mr J . de Jager	Vinpro
Ms M Lintnaar-Strauss	Department of Water and Sanitation
Mr E Mametja	Department of Agriculture, Land Reform and Rural Development (DALRRD: DWUID)
Ms N Mjadu	Department of Agriculture, Land Reform and Rural Development (DALRRD: DWUID)
Ms E Rossouw	Breede-Gouritz Catchment Area (BGCMA)
Mr J Rossouw	Distell
Ms T Nell	Secretary, ARC Infruitec-Nietvoorbij

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LIST OF ABBREVIATIONS

°B	: degree Balling
°C	: degree Celsius
%	: percent
Ψ_S	: stem water potential
ARC	: Agricultural Research Council
B	: boron
Ca	: calcium
CEC	: cation exchange capacity
Cl	: chloride
cm	: centimetre
$cmol^{(+)}/kg$	: centimole charge per kilogram
COD	: chemical oxygen demand
Cu	: copper
dS/m	: decisiemens per m
EC	: electrical conductivity
EC_e	: electrical conductivity of the saturated soil extract
EPP	: exchangeable potassium percentage
ESP	: exchangeable sodium percentage
EPP´	: extractable potassium percentage
ESP´	: extractable sodium percentage
Fe	: iron
HCO_3^-	: bicarbonate
IR	: constant head water infiltration rate
K	: potassium
kg/ha	: kilogram per hectare
K_{ns}	: near-saturation hydraulic conductivity
L	: litre
LTM	: long term mean
m	: metre
m/s	: metre per second
Mg	: magnesium
mg	: milligram
mg/kg	: milligram per kilogram
mg/L	: milligram per litre
mm	: millimetres

mm/day	: millimetres per day
mm/h	: millimetres per hour
Mn	: manganese
MPa	: mega Pascal
Na	: sodium
NH_4-N	: ammonium nitrogen
NO_3-N	: nitrate nitrogen
P	: phosphorus
PAR	: potassium adsorption ratio
RH_x	: daily maximum relative humidity
RH_n	: daily minimum relative humidity
S	: sulphur
SAR	: sodium adsorption ratio
SO_4	: sulphate
SWC	: soil water content
T_n	: daily minimum temperature
T_x	: daily maximum temperature
TOC	: total organic carbon
Total-N	: total nitrogen
TSS	: total soluble solids
TTA	: total titratable acidity
U_2	: wind speed
Zn	: zinc

CHAPTER 1: MANAGEMENT OF WINERY WASTEWATER BY RE-USING IT FOR CROP IRRIGATION

1.1. 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.

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Experience from a previous study (Myburgh & Howell, 2014b) 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 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 (Lategan & Howell, 2016). 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 inhibited 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.

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1.2. 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.

1.3. KNOWLEDGE REVIEW

1.3.1. INTRODUCTION

In South Africa, grapes are an important crop in regions such as the Western Cape Province and the Lower Orange River region in the Northern Cape Province. The wine industry makes a significant contribution to the economy in these regions. In 2020 there were 2 693 primary wine grape growers (South African Wine Industry Statistics, 2020). Furthermore, the wine industry provides a large number of employment opportunities, particularly in the rural areas. In 2020, the vineyards planted for wine production in South Africa amounted to 92 005 hectares, of which *c.* 91% is considered as producing, *i.e.* four years and older (South African Wine Industry Statistics, 2020). The number of wineries which crush grapes almost doubled from 1991 to 2002 but has declined since 2013 (Table 1.1). The industry produced around one billion litres of grape related products annually from 2013 to 2020 with the exception of 2018 and 2019 (Table 1.2).

Table 1.1. Growth trends in the South African wine industry (South African Wine Industry Statistics, 2015 & 2020).

Role player	Number							
	1991	2002	2013	2016	2017	2018	2019	2020
Wine cellars which crush grapes	212	427	564	493	472	468	460	457
Co-operatives	70	66	50	48	48	47	45	45
Wine producing wholesalers	6	11	21	27	26	27	28	27

Table 1.2. Wine production trends in the South African wine industry (South African Wine Industry Statistics, 2020).

Product	Production (million litres)							
	2013	2014	2015	2016	2017	2018	2019	2020
Wine	915.5	958.8	968.4	898.4	918.7	824.3	836.7	898.0
Rebate	42.0	53.6	41.8	37.8	47.9	36.5	39.0	39.2
Juice	58.7	35.1	30.9	35.9	38.2	15.4	3.1	3.5
Distilling wine	140.7	133.6	112.9	116.9	115.5	89.5	94.7	101.2
Total	1156.9	1181.1	1154.0	1089.0	1012.8	965.7	973.6	1042.0

Using raw water is an integral part of wine production processes. However, these processes generate wastewater of low quality that cannot be disposed of in water sources. Winery wastewater can cause salinization and eutrophication of water resources, *i.e.* natural streams, rivers, dams, groundwater and wetlands (Van Schoor, 2005 and references therein; Laurenson *et al.*, 2012). Furthermore, wastewaters can cause soil sodicity, salinity, contamination with a wide range of chemicals, waterlogging and anaerobiosis, as well as loss of soil structure and increased susceptibility to erosion. Where solid wastes are present, offensive odours may be generated and seepage may result in the contamination of soil and water resources that can inhibit vegetative performance (Van Schoor, 2005 and references therein).

1.3.2. VOLUME OF WATER INVOLVED IN THE WINEMAKING INDUSTRY

1.3.2.1. Water used for winemaking

Information on the actual amounts of water used by wineries is limited and appears to be inconsistent. A survey carried out in South Africa, which included wineries that crush up to 22 000 tonnes of grapes annually, showed that the volume of raw water increased significantly with the amount of grapes crushed (Sheridan *et al.*, 2005). Although the variability among wineries was high, the slope of the relationship indicated that approximately 2 m^3 of water was required to crush one tonne of grapes. The Lutzville Vineyards' winery uses a measured average of 100 000 m^3 water to produce between 30 million and 40 million litres of wine annually (Kriel, 2008). Since this particular winery crushes approximately 47 500 tonnes per year (G. Theron, personal communication), about 2.1 m^3 of raw water is required to process one tonne of grapes. Although the amount of grapes crushed is substantially higher, the amount of water used by Lutzville Vineyards' winery agrees with the results of the survey carried out by Sheridan *et al*. (2005). According to Mosse *et al.* (2011), wineries in Australia generally require 3 m^3 to 5 m^3 water to crush a tonne of grapes. The average annual grape production in South Africa was 1.33 million tonnes from 2010 until 2012 (SAWIS, 2013). If it is assumed that winemaking in South Africa requires approximately 2 m^3 of water to process one tonne of grapes, it can be roughly estimated that the wine industry is currently using 2.66 million litres of raw water annually. It was reported that 30-40% of the water used by wineries is used during the harvest period (Conradie, 2015).

1.3.2.2. Volume of wastewater generated during winemaking

Reports on the actual volumes of wastewater that are generated by wineries are also extremely limited. It is estimated that medium to large wineries generate more than 15 000 m^3 of wastewater annually, whereas small wineries generate less than 15 000 m^3 annually (Van Schoor, 2005 and references therein). Australian wineries generate about 5 m^3 of wastewater per tonne of grapes crushed (Chapman *et al.*, 1995). Crushing *c.* 50 000 tonnes of grapes annually generates about 175 000 m^3 of wastewater at the Berri estates' winery in the Riverland region of South Australia (Anonymous, 2010). Hence, their wastewater generation amount to *c.* 3.5 m^3 per tonne of grapes. Usually most of the raw water entering wineries ends up as wastewater. It is estimated that 50%, *i.e.* 50 000 m^3, of the raw water used by the Lutzville Vineyards' winery ends up as wastewater (Kriel, 2008). The other half of the water is presumably lost to evaporation under the warm windy atmospheric conditions. This means that this particular winery generates about 1.1 m^3 of wastewater per tonne of grapes crushed. In comparison, substantially lower volumes, *i.e.* 0.359 m^3 and 0.357 m^3 wastewater per tonne of grapes crushed was generated for off-skin white winemaking, and rosé and thermo-vinification of red wines, respectively, in French cellars (Bories & Sire, 2010). An even lower value of 0.262 m^3 of wastewater generated per tonne of grapes crushed, was reported for on-skin vinification of red wines (Bories & Sire, 2010).

1.3.3. ORIGIN OF WINERY WASTEWATER AND ASSOCIATED POLLUTANTS

1.3.3.1. Sources of pollutants

Wineries vary in size, operational procedures and management practices. They undertake similar, yet highly site-specific processes. The variations result in the production of different qualities and quantities of wastewater (Van Schoor, 2005). Winemaking methods can have an impact on the quality of the wastewater generated (Bories & Sire, 2010). In off-skin winemaking, wastewaters are produced which contain mainly sugars. On the other hand, in cellars where classical red wine making methods are followed, wastewaters are generated which have high ethanol levels. The typical wine production process can be divided into various stages (Table 1.3). Medium to large wineries with year-round operations generate *c.* 50% of their wastewater during the vintage period, whereas small wineries may generate up to 80% of their wastewater during harvest (Van Schoor, 2005). The major form of wastewater from wineries is water used for cleaning processes (Van Schoor, 2005). Primary winemaking processes related to winery wastewater generation and their associated contribution to wastewater quantity and quality, as well as possible effects on legal wastewater quality parameters are summarized in Table 1.4. The primary water quality parameters in South Africa are chemical oxygen demand (COD), electrical conductivity (EC), sodium adsorption ratio (SAR) and pH.

Table 1.3. Typical stages of winery activities and their role in wastewater generation (after Van Schoor, 2005 and references therein).

Stage	Activities	Duration (weeks)
1. Pre-harvest	Bottling takes place and tanks are washed out with sodium or potassium hydroxide. Other equipment is also washed to prepare for the harvest period.	1 to 4
2. Early harvest	Wastewater generation increases drastically during this period and reaches 40% of the maximum weekly rate measured at peak. White wine production dominates harvest activities.	2 to 3
3. Peak harvest	Wastewater generation and harvest activities reach their peak.	3 to 14
4. Late harvest	Wastewater generation decreases to 40% of the maximum (peak) weekly flow and red wine production dominates harvest activities. Distillation of ethanol may take place.	2 to 6
5. Post-harvest	Pre-fermentation activities come to an end and maximum usage of hydroxide occurs.	6 to 12
6. None harvest	Wastewater volume is at its minimum (less than 30% of the peak weekly flow). Wastewater quality depends on daily activities.	10 to 20

Table 1.4. Major processes related to winery wastewater generation and their associated contribution to wastewater quantity and quality as well as possible effects on legal wastewater quality parameters (after Van Schoor, 2005).

Winery operation	Contribution to total wastewater quantity	Contribution to wastewater quality	Effect on legal wastewater quality parameters
Cleaning water			
Alkali washing (removal of K-bitartrate) and neutralization	Up to 33%	Increase in Na, K, COD and pH Decrease in pH	Increase in EC, SAR, COD Variation in pH
Rinse water (tanks, floors, transfer lines, bottles, barrels, *etc.*)	Up to 43%	Increase in Na, P, Cl, COD	Increase in EC, SAR, COD Variation in pH
Process water			
Filtration with filter aid	Up to 15%	Various contaminants	Increase COD and EC
Acidification and stabilization of wine	Up to 3%	H_2SO_4 or NaCl	Increase COD and EC Decrease in pH
Cooling tower waste	Up to 6%	Various salts	Increase COD and EC
Other sources			
Laboratory practices	Up to 5-10%	Various salts, variation in pH, *etc.*	Increase COD and EC

1.3.3.2. Quality of wastewater generated in wineries

In contrast to the volumes of wastewater produced, there are many reports on the quality thereof, particularly in terms of COD or biological oxygen demand (BOD) (Chapman *et al*., 1995; Ryder, 1995; Deans, 2003; Jeison *et al.*, 2003; Sheridan *et al*., 2005; Baker & Hinze, 2007; Kriel, 2008; Matthews, 2008; Arienzo *et al*., 2009; Mulidzi *et al*., 2009a; Conradie *et al.*, 2014; Howell *et al.*, 2014a; Buelow *et al.*, 2015b). The BOD is estimated as 66% of the COD (Van Schoor, 2005). Winery wastewater also contain high levels of K and Na (Laurenson *et al.*, 2012; Conradie *et al.*, 2014). Although various parameters may be used to evaluate winery wastewater, COD, pH, SAR, EC, chloride (Cl), K and Na are considered to be the most important. A survey was carried out in 2000 to evaluate the winery wastewater generated by the South African industry in terms of these variables (Mulidzi *et al*., 2009a). Results of this survey showed that there is considerable variation in wastewater quality parameters among wineries, but there is also a strong seasonal variation at most wineries. A similar seasonal trend was reported for winery wastewater in Australia (Arienzo *et al*., 2009). These trends were confirmed where effluents of two wineries were monitored frequently (Sheridan *et al.*, 2011). Considering the legal requirements for irrigation water quality in South Africa (Table 1.5), results of the survey confirmed that the majority of South African wineries are not able to irrigate crops beneficially as part of the General Authorisation with wastewater unless the water is first subjected to an effective form of pre-treatment, or unless there is relaxation of the General Authorisations.

Table 1.5. General Authorisations for legislated limits for chemical oxygen demand (COD), faecal coliforms, pH, electrical conductivity (EC) and sodium adsorption ratio (SAR) for irrigation using wastewater in South Africa (Department of Water Affairs, 2013).

Parameter	Maximum irrigation volume allowed (m^3/day)		
	< 50	**< 500**	**< 2 000**
COD (mg/L)	5 000	400	75
Faecal coliforms (per 100 mL)	1 000 000	100 000	1 000
pH	6-9	6-9	5.5-9.5
EC (mS/m)	200	200	70-150
SAR	<5	<5	Other criteria apply

Different winemaking processes also affect the composition of winery wastewater. In the case of off-skin winemaking, sugars are the main component of the organic load in the effluent water, whereas classical winemaking methods generate wastewater containing high levels of ethers and ethanol (Bories & Sire, 2010). However, it is also possible that spikes of extremely low water quality can be caused by process interruptions. Power failure, fire, flood, storms, over- or under-loading of wastewater treatment systems, temporary unavailability of wastewater holding dam capacity and the absence of trained operators may cause process interruptions (Campos *et al*., 2000; Van Schoor, 2005; Baker & Hinze, 2007).

1.3.4. MANAGEMENT OF WINERY WASTEWATER

1.3.4.1. Wastewater treatment

Wastewater is usually collected in one or more sumps at the wineries. The first step in the treatment of winery wastewater is usually to remove the solids such as grape seeds, skins and stems by passing the water through a screen filter. This is a simple, but effective step and helps to prevent other treatment machinery from getting clogged with solids (Mosse *et al.*, 2011). The wastewater is normally acidic and the pH can be less than 3. Therefore lime is added to the water in order to increase the pH to the legal or crop requirement (Van Schoor, 2005). The water is then pumped to sedimentation or maturation ponds to allow settling of the remaining solids. Depending on the quality of the wastewater at this stage, the water can be used to irrigate selected crops, such as Kikuyu grass, in specific soils. A further step could be to circulate and aerate the wastewater in dams using an aeration pump system. If these steps are managed correctly, the treatment of the wastewater can be fairly successful, particularly in reducing the COD levels (Tables 1.6 & 1.7 & Fig. 1.1).

Table 1.6. Mean winery wastewater quality during the crushing season and in aerated storage ponds in California's North Coast region (after Ryder 1995).

Parameter	Crushing season	Reclaimed water
COD[1] (mg/L)	3 780	15
pH	4.1	7.7
Nitrogen (mg/L)	20	5
Phosphorus (mg/L)	10	2
Dissolved solids (mg/L)	800	500

[1] Adjusted from biological oxygen demand (BOD) where BOD = 66% of COD.

Table 1.7. Variation of chemical oxygen demand (COD) and total suspended solids (TSS) in raw and treated winery effluent (after Baker & Hinze, 2007).

Sampling date	COD[1] (mg/L)		TSS (mg/L)	
	Wastewater	Final effluent	Wastewater	Final effluent
18 November 2005	9 091	16	1 700	92
19 December 2005	2 727	28	265	66
13 February 2006	3 788	8	280	16
23 March 2006	6 621	788	940	1 080
28 April 2006	644	72	319	683
08 June 2006	5 788	64	245	460
18 January 2007	4 848	14	400	53
28 March 2007	6 712	379	1 040	617

[1] Adjusted from biological oxygen demand (BOD) where BOD = 66% of COD.

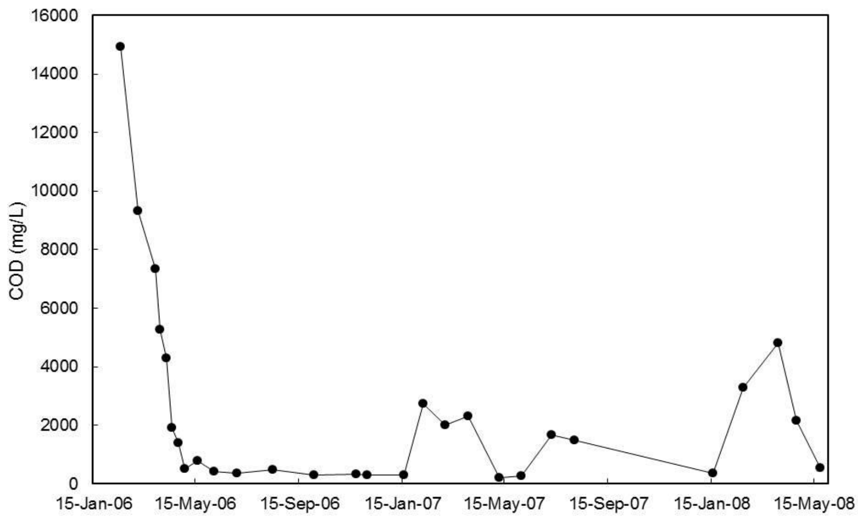

Figure 1.1. Seasonal variation in level of chemical oxygen demand (COD) in treated winery wastewater following aeration of the water which commenced in January 2006 (data supplied by the courtesy of the Botha winery).

Up-flow anaerobic sludge blanket (UASB) technology can also be used to treat winery wastewater (Matthews, 2008). This technology relies on anaerobic digestion, a biological process in which organic matter is converted to methane and carbon dioxide in the absence of air. The process involves a synergistic relationship between four different groups of bacteria, namely hydrolytic, fermentative-acidogenic, acetogenic and methanogenic. The bacteria cluster into granules which settle out to form a dense bed of sludge that is retained in the system. This is a distinct advantage over aerobic systems which produce masses of surplus sludge that must be disposed of. The methane is produced as a waste gas, which can be recovered as an energy source (Mosse *et al.*, 2011). However, disadvantages are that nutrient removal is not feasible in anaerobic systems and trained staff are needed to operate UASB systems. Anaerobic digestion is often limited by the presence of refractory and toxic compounds in the wastewater, but ozone helps counter this effect. Pre-ozonation enhances the biodegradability of organic matter by converting these compounds into simpler molecules. Post-ozonation may be used as a “polishing” step. In addition, installation costs are relatively high (Mosse *et al.*, 2011).

Worldwide, most UASB plants have operational volumes of 100 000 litres to 10 million litres (Matthews, 2008). Only a few operate on less than 50 000 litres. A winery near Franschhoek operates a relatively small, fully automatic UASB system which can treat 25 000 L per day. This particular wastewater treatment plant reduces the COD to *c.* 250 mg/L throughout the year. It was also shown that UASB technology can be used for the successful treatment of wastewater generated in the production of Chilean pisco, an aged drink distilled from grapes (Jeison *et al*., 2003). Expanded granular sludge bed (EGSB) technology was also tested in this study, but it was more difficult to operate and required higher capital investment, as well as operational costs compared to the UASB technology.

1.3.4.2. Disposal or utilization of winery wastewater

1.3.4.2.1. Return to natural resources

In terms of the General Authorisations published in Government Notice No. 665 (Department of Water Affairs, 2013) in terms of section 39 of the National Water Act (1998), untreated wastewater from wine cellars would rarely, if ever, qualify for discharge into natural water resources (Van Schoor, 2005). Given the quality of the treated water, most wastewaters would still not be suitable for discharge into natural water resources. Consequently, this practice is not really considered as a disposal option.

1.3.4.2.2. Disposal ponds

Some wineries pump the treated wastewater into ponds or storage dams. If the water is not re-used for irrigation, it evaporates or seeps into deeper soil layers when the ponds or dams are unlined (Mulidzi *et al.*, 2009b). Multi-stage facultative aerobic ponds have been used successfully for some 30 years for treatment and storage of winery wastewater in California (Ryder, 1995). These ponds are lined to prevent seepage of water into underground water streams and are aerated sufficiently to prevent objectionable odour generation.

1.3.4.2.3. Irrigation with winery wastewater

In South Africa more than 93% of wine cellars dispose of their effluent by means of land application (Van Schoor, 2005). The majority of cellars currently dispose effluent by irrigation as the primary disposal option. Land application systems are ideally suited for the treatment of organic C contained in winery effluents because the water in the soil system transports the organic contaminants to the aerobic microbial populations. However, it is important that waterlogging should be avoided. Consequently, it is essential to allow sufficient time between irrigations for the soil to become aerobic (Chapman *et al.*, 1995).

1.3.4.2.3.1. Crops irrigated with winery wastewater

In most cases, the wastewater is used for the irrigation of small, permanent pasture grazing paddocks close to the wineries. The pastures mainly consist of Kikuyu grass, but Fescue grass can also be irrigated with winery wastewater (Arienzo *et al*., 2009). There are also cases in Australia where treelots, *e.g. Eucalyptus camaldulensis*, are irrigated with winery wastewater (Chapman *et al.*, 1995; Deans, 2003; Anonymous, 2010). Research results have also shown that lemon nursery trees could successfully be irrigated with wastewater generated by a pisco distillery after the water had been treated using UASB technology (Jeison *et al*., 2003). The pisco distillery wastewater was also disposed of in a Eucalyptus tree lot on a commercial scale.

Winery wastewater stored in lined and aerated ponds is used for vineyard irrigation during the rain-free spring and summer in California (Ryder, 1995). At a winery in the Clare Valley in Australia, treated wastewater of which the COD contents are presented in Table 7, is recycled into the raw irrigation water to be used for irrigation of grapevines (Baker & Hinze, 2007). In this particular case, the treated wastewater constituted only 10% of the annual irrigated volume. The actual wastewater applied was less than 10 mm. Although some vineyards have been irrigated using winery wastewater for long periods, the effect thereof on the soils and grapevines have not been reported. Although there is extensive literature available regarding the irrigation of grapevines with saline water (Walker *et al*., 1997; Stevens *et al*., 1999; Ben-Asher *et al*., 2006; Stevens *et al.*, 2011), there is little information on using winery wastewater diluted to a pre-determined COD level on grapevine growth, yield and juice responses. Irrigation of grapevines using winery wastewater diluted up to 3 000 mg/L COD did not affect grapevine water status, vegetative growth, production or evapotranspiration, irrespective of the level of dilution (Howell *et al.*, 2014b). Results showed that irrigation of grapevines using diluted winery wastewater did not have detrimental effects on juice characteristics with regard to ripeness parameters and ion content. Wine sensorial characteristics were not affected by irrigation using diluted winery wastewater (Howell *et al.*, 2014c). The grapevines did not respond to COD level *per se*. This indicated that sufficient aeration occurred between irrigations which allowed organic C breakdown. Although salinity and sodicity levels in the diluted winery wastewater were below the thresholds where growth and yield reductions are expected for grapevines, it should be monitored frequently. The low salinity and sodicity levels in the diluted winery wastewater could be a further explanation why the grapevines did not respond negatively to the wastewater irrigation. Where treated wastewater was used for vineyard irrigation at two different sites, grapevine leaf content contained higher Na and magnesium (Mg), and lower K and calcium (Ca) than where "control" water was used for irrigation (Hirzil *et al.*, 2017). Unfortunately, no growth or yield data was reported.

Where "simulated" winery wastewater was used for vineyard irrigation, there were no substantial differences in ripeness parameters, yield and vegetative growth after one year (Mosse *et al.*, 2013). Although high K concentrations in artificial wastewater promoted the accumulation of harvest petiole K, petiole Ca was reduced substantially. When artificial wastewater contained organic matter together with high K levels, petiole Ca was not reduced to the same extent. The use of Na based artificial wastewater increased petiole Na levels substantially.

In a glass house study, where winery wastewater was applied either undiluted, or diluted in different ratios to potted Shiraz grapevines, petiole K contents were below recommended levels irrespective of dilution level (Kumar *et al.*, 2014). In addition to the different levels of winery wastewater dilution, there were also treatments where solutions of differing K and Na nutrient loads were used to irrigate the potted grapevines. Increasing K concentrations increased petiole K (Kumar *et al.*, 2014). On a field-scale, in two paired field trials where grapevines were irrigated with either main water or winery wastewater, there was no difference in sensorial evaluation of the wines (Kumar *et al.*, 2014). Furthermore, where grapevines were irrigated with winery wastewater, wine Na levels were still below 100 mg/L, whereas wine K ranged from 1 220 mg/L to 1 400 mg/L, and was within industry norms for red wines in Australia (Kumar *et al.*, 2014).

A range of leaf analyses has been carried out from representative areas in the Eucalyptus plantation where the Berri Estate's winery dispose their wastewater (Anonymous, 2010). The relatively low nutrient levels in the winery wastewater reflected in declining, but still acceptable, levels of nitrogen (N), phosphorus (P) and K in the leaves. However, it was concluded that some nutrient addition might be necessary during the lifespan of the trees. During the first weeks after planting, leaves of Eucalyptus saplings that were irrigated with wastewater treated in a UASB reactor showed symptoms of Na^+ toxicity (Jeison *et al*., 2003). The lemon trees used in the experiments showed similar symptoms. The problem was caused by the NaOH required for pH control in the UASB reactor. Approximately 2 g/L NaOH had been applied during the first weeks after reactor start up. However, after a few weeks the biogas production provided a significant level of alkalinity by CO_2 dissolution. Consequently, NaOH application was reduced to less than 20% of its original level. The Eucalyptus saplings recovered without any permanent damage. Unfortunately, the Na concentrations in the treated wastewater were not reported. There are also no other reports on the effects of irrigation with winery wastewater on the performance of most of the different species mentioned above.

Recently, research has shown that potted fodder beet grown during summer in sandy soil collected from the field trial at Rawsonville, absorbed 38% of the Na applied *via* Na-enriched irrigation water (Myburgh & Howell, 2014a). The concentration of Na applied was equal to that of the Na concentration in the irrigation water of the 3 000 mg/L COD treatment in the field trial. Furthermore, the fodder beet reduced exchangeable soil K (K_{ex}) by 50%, indicating that it could also absorb K applied *via* winery wastewater.

Where *Pennisetum glaucum* L. cv. Babala (pearl millet) was cultivated as an interception crop to intercept salts applied *via* diluted winery wastewater for vineyard irrigation, the use of winery wastewater improved the DMP of the specific crop (Fourie *et al.*, 2015). It was also clear that the pearl millet intercepted substantial amounts of K applied *via* the diluted winery wastewater. In contrast, the pearl millet did not absorb substantial amounts of Na applied *via* the diluted winery wastewater. In winter, a cover crop of oats was also cultivated. It was reported that the oats cover crop also absorbed substantial amounts of K applied *via* the diluted winery wastewater.

1.3.4.2.3.2. Irrigation systems used to dispose winery wastewater

High volume sprinklers are commonly used for applying irrigation to grazing paddocks. Full surface flood irrigation was used to dispose winery wasterwater onto Fescue grass (Arienzo *et al.*, 2009) and a Eucalyptus plantation (Anonymous, 2010). It must be noted that in the latter case, diatomaceaous earth solids entered the pipeline used to transport the winery wastewater to the plantation during the grape harvesting period. This required annual flushing and/or pigging to avoid blockages. Unfortunately, most other reports on the disposal of winery wastewater by means of irrigation did not mention the systems used to irrigate the different species. Since vineyards in Australia are almost invariably drip irrigated, it can be assumed that the winery in the Clare Valley in Australia disposed of the treated wastewater by means of a drip irrigation system (Baker & Hinze, 2007). Aboveground as well as subsurface drip irrigation was used in a field experiment in Israel to irrigate grapevines with water from sewerage waste stabilization ponds (Campos *et al*., 2000). The rationale for using drip irrigation, and particularly subsurface drip, was to minimise the risk of disease contamination by preventing direct contact between the wastewater and the edible part of the crop.

1.3.4.2.3.3. Effects of winery wastewater on soil conditions

Soil chemical status: Irrigation with wastewater containing high levels of K, such as winery wastewater, could be beneficial to overall soil fertility, although long-term application could have negative effects on soil chemical properties (Smiles & Smith, 2004; Kumar *et al.*, 2009; Laurenson *et al*., 2011; Mosse *et al.*, 2011). Land application of wastewater can increase the levels of soluble and exchangeable forms of potassium (K & K_{ex}) more rapidly than with conventional inorganic fertilizers (Arienzo *et al.*, 2009). Furthermore, most of the K in wastewater is immediately available. The effects of high K concentrations on soil properties have not been extensively researched and are still unclear (Kumar *et al.*, 2009; Mosse *et al.*, 2011; Laurenson *et al*., 2012). In addition, the fate of K in soils and on grapevines irrigated with winery wastewater has received limited attention (Laurenson *et al.*, 2012). A further advantage of using winery wastewater as a source of K over the use of conventional fertiliser is that it could be an efficient recycling practice in areas where the soil has low K. It is highly likely that high soil K could lead to an increase in K uptake by grapevines. This could have negative consequences on grapevine responses, such as musts with high pH, malate concentrations and poor colour (Jackson & Lombard, 1993; Mpelasoka *et al.*, 2003; Kodur, 2011). However, the effect of soil K on K concentrations in must is often negligible unless excessive amounts are applied (Jackson & Lombard, 1993). In addition to Na and K ions, winery wastewater typically contains Ca and Mg ions (Mosse *et al.*, 2011). Neither of the latter mentioned ions are harmful to soil structure and can ameliorate the impacts of Na *via* their role in reducing the SAR. A further matter of potential concern is Na and Mg accumulation in surface soils and subsequent loss of Ca (Laurenson, 2010).

A survey was carried out in South Africa to assess the soil chemical status where winery wastewater had been disposed over prolonged periods (Mulidzi *et al*., 2009b). Control soil samples were collected close to the area of land where the wastewater was disposed. Unfortunately, there was no history about the volumes of water or the quality of the wastewater that had been applied to the disposal sites. However, by comparing the disposal site to the control samples it was shown that the winery wastewater almost invariably induced negative effects, irrespective of soil type (Mulidzi *et al*., 2009b). Furthermore, it was concluded that (i) in general, effluent disposal is poorly planned and managed, and disposal sites rarely seem to have been properly selected, because their soil properties are inappropriate for effluent disposal. In particular, deep sandy soils are unsuitable for disposal by ponding, mainly because of their high infiltration rates (IR), high permeability and low water storage capacity and (ii) many disposal sites are too limited in area to permit the large volumes of effluent to be absorbed without surface runoff. This problem invariably persists despite the presence of Kikuyu swards and sandy subsoil (Mulidzi *et al*., 2009b). Irrigation using undiluted winery wastewater increased soil K to a depth of 90 cm (Mulidzi *et al.*, 2009b). A literature search revealed that the effect of irrigation with winery wastewater on soil P is not well-documented. With respect to P, Mulidzi *et al.* (2009b) reported that land application of undiluted winery wastewater increased soil P, but that the P in the different soil horizons fluctuated throughout the season.

More recently, Mulidzi (2016) investigated the effect of the application of undiluted winery wastewater by wineries on the soil chemical dynamics in two different soils that were irrigated with treated undiluted winery wastewater for three years. Over-irrigation with the winery wastewater in combination with winter rainfall caused large amounts of cations, particularly K and Na, to leach beyond a soil depth of 90 cm. The leached elements will most likely end up in natural water resources over time. It was reported that irrigation with undiluted winery wastewater did not have a pronounced effect on soil $pH_{(KCl)}$. This was probably due to the decomposition of organic matter and the fact that the applied salts as well as dissolved organic or mineral acids leached beyond 90 cm depth.

In a pot study where four soils, varying in parent material and clay content, were irrigated with either winery wastewater diluted to 3 000 mg/L COD or municipal water for four ‘simulated’ seasons, the rate of K increase in the shale-derived soil which contained 20% clay was higher than in the soils containing 13% or less (Mulidzi *et al.*, 2015). This indicated that heavier soils will increase the risk of high soil K levels. Excessive soil K could lead to excessive uptake by the grapevine, increasing juice and wine pH, with negative effects on wine colour and microbial stability (Mpelasoka *et al.*, 2003; Kodur, 2011). It was also reported that the risk of Na accumulation increased linearly with clay content (Mulidzi *et al.*, 2015). Irrigation with diluted winery wastewater increased soil $pH_{(KCl)}$ due to the addition of organic/bicarbonate salts to the soil. The $pH_{(KCl)}$ in the shale and granite derived soils was increased to such an extent that it was increased into the optimum range for P availability. Although $pH_{(KCl)}$ in the aeolic sand was initially above the optimum range, relatively high Na levels also caused available P to increase as the $pH_{(KCl)}$ increased (Mulidzi *et al.*, 2016). However, there was a reduction in available P in the case of the alluvial sand as the soil $pH_{(KCl)}$ increased beyond the optimum range (Mulidzi *et al.*, 2016). This indicates that irrigation with diluted winery wastewater may only enhance P absorption if the pH shift is towards the optimum (Mulidzi *et al.*, 2016). It should be noted that results reported were for a worst case scenario, *i.e.* in the absence of rainfall or crops (Mulidzi *et al.*, 2015).

There was no change in soil pH where winery wastewater was used for irrigation of soil with clay content of 50% to 60% (Quale *et al.*, 2010). In contrast, soil $pH_{(H2O)}$ of a silty clay loam soil that received solid and liquid winery waste for 30 years tended to increase compared to soil where no waste was applied (Mosse *et al*., 2012). In two case studies where pastures and a vineyard were irrigated with winery wastewater, soil pH also increased (Kumar *et al.*, 2014). However, comparing the results with a historical data set of soil chemical properties, it seemed that irrigation with winery wastewater actually caused a decrease in soil pH. In a laboratory study where mains water, municipal wastewater or winery wastewater was used for irrigation of a sand, loamy sand and sandy loam, an increase in soil $pH_{(1:5)}$ occurred (Laurenson, 2010). However, it should be borne in mind that the winery wastewater pH in that particular study was 8.5. There has also been conflicting reports of either an increase or decrease in soil pH (Laurenson *et al.*, 2012 and references in). It was suggested that these soil pH changes can be related to the characteristics of the wastewater. If wastewaters contain high concentrations of bicarbonate, application to soils will increase pH, whereas acidic wastewaters could reduce soil pH. In a laboratory study, soil $EC_{(1:5)}$ was not affected by irrigation with either mains water, municipal wastewater or winery wastewater, regardless of soil type (Laurenson, 2010). Similarly, in another laboratory study, soil EC of a loam and loamy sandy soil did not respond to winery wastewater irrigation (Kumar *et al.*, 2006). However, soil EC was higher where woodlots were irrigated with winery wastewater compared to a control (Kumar *et al.*, 2009).

In pastures irrigated with undiluted winery wastewater for over 100 years, total organic carbon (TOC), N, K, Na, Mg and Ca levels increased relative to the control (Kumar *et al.*, 2006). Although soil K, Na, Mg and Ca of pastures irrigated with undiluted winery wastewater for 15 to 20 years increased, these increases were not as substantial as where pastures had been irrigated for 100 years (Kumar *et al.*, 2006). Irrigation using winery wastewater containing high levels of organic C increased total soil organic C content (Kumar *et al.*, 2009). In addition, soil K, as well as salinity and sodicity levels were higher in wastewater treated plots compared to control plots, particularly woodlot and pasture sites at certain wineries. Soil K and Na levels were also higher in vineyard soils irrigated with winery wastewater compared to a control vineyard which was irrigated with river water (Kumar *et al.*, 2006). They also reported that higher organic C content of winery wastewater resulted in an increased total organic C content in soils irrigated using such wastewater. According to Kumar *et al.* (2014), both soil K and SAR increased throughout the soil profile where winery wastewater was used for irrigation. In a laboratory study, irrigation with winery wastewater increased soil Na and K in a loamy sand, a loam and a clayey soil (Kumar *et al.*, 2006). It should be noted that these soils were collected from areas where winery wastewater is currently being used for irrigation of woodlots, pastures or vineyards.

Where winery wastewater was applied to a silty clay loam soil for 30 years, soil K, Na, Ca, Mg and B were substantially higher compared to soil where no winery wastewater was applied (Mosse *et al*., 2012). Furthermore, soil that had been irrigated with winery wastewater for 30 years showed a decrease in soil pH with depth. The increased concentrations of the cations were attributed to higher levels encountered in the wastewater.

It was reported that K in the surface layer increased where winery wastewater was used for irrigation of soil with clay content of 50% to 60% (Quale *et al.,* 2010). However, there were no changes in sub-soil K due to slow mobility of K^+ in the soils. There were no changes in soil Ca but soil Mg tended to decrease.

Although there is extensive literature available regarding the effect of irrigation with wastewaters of various origins on soil chemical properties, there is little information regarding the re-use of winery wastewater diluted to pre-determined levels of COD, for any crop. It should be noted that most of the studies investigating the effects of winery wastewater on soil properties were where responses were compared to a control where no winery wastewater was applied or were conducted in pots in laboratories, often with artificial “winery wastewater”. In a field trial where a sandy alluvial soil was irrigated with winery wastewater diluted up to 3 000 mg/L COD, there were no clear trends in soil $pH_{(KCl)}$, electrical conductivity of the saturated soil extract (EC_e) or acidity, but EC_e was substantially higher after the seasonal wastewater irrigations compared to at bud break (Howell & Myburgh, 2014b). This was probably due to the higher salt content in the diluted wastewaters. Soil K (Bray II) after wastewater application consistently increased with a decrease in the dilution of the wastewater and after four years, only the lowest level of dilution, *i.e.* 3 000 mg/L COD, maintained baseline K levels. The increase in soil Bray II-K was linearly related to the additional amounts of K applied *via* the diluted winery wastewater. Soil K increases could have a negative impact on wine colour stability should it be taken up by the grapevine in sufficient quantities, particularly if soil K accumulates to such an extent that it is excessively absorbed by grapevines. Soil Ca and Mg did not show any consistent responses to the different levels of wastewater augmentation because there were no substantial differences in amounts of these elements applied *via* the irrigation water. Soil Na also increased linearly as the level of wastewater dilution decreased, particularly in the top-soil. Changes in cation ratios due to the accumulation of K and Na with no consequent increase in Ca and Mg could be detrimental in terms of soil physical properties.

In this particular study, it was reported that there were no consistent trends with regard to soil organic C that could be related to the level of dilution of the winery wastewater. This indicated that the organic C content in the diluted wastewater was still too low to have had a positive effect on soil fertility. It is also possible that organic material in the diluted wastewater, which could have led to an accumulation of organic soil C, decomposed when the soil was aerated between irrigations. It should be noted that the results represent a specific in-field situation, *i.e.* in the presence of rainfall and crops. Although irrigation with winery wastewater had almost no other effects under the prevailing conditions, it was reported that element accumulation, particularly with respect to K and Na, might be more prominent in heavier soils or in regions with low winter rainfall. In addition, natural water resources could be polluted with leached elements such as K and Na during winter.

In the only field study of its kind investigating the irrigation of an established vineyard using artificial winery wastewater, grapevines were either irrigated with lake water or artificial wastewater containing high K, high K plus wine, low K, and Na (Mosse *et al.*, 2013). All treatments caused an increase in soil K and Na. The accumulation of K was restricted to the 0-20 cm soil layer, with the exception of the treatment where wine was added to the irrigation water. The addition of wine enhanced K transport into the subsoil. Elevated Na levels were found in the 0-20 cm and 20-40 cm soil layers. Therefore, the presence of wine, *i.e.* organic material, facilitated the transport of the K within the profile.

Soil physical status: Unfortunately, no references on the effect(s) of irrigation using winery wastewater on in-field soil physical properties could be found in the literature. Although the effect of irrigation using winery wastewater on soil chemical properties is well documented, its effect on soil physical properties is largely unknown, particularly when used for vineyard irrigation (Buelow *et al.*, 2015a). This could be due to the fact that changes in soil physical properties are difficult to quantify because they tend to occur only over the long term, and that soil physical properties are greatly variable (Hawke & Summers, 2006). Furthermore, most of the studies were conducted in laboratories using artificial solutions.

Soil chemical properties can be altered by wastewater irrigation (Vogeler, 2009; Lado & Ben-Hur, 2010) and this could influence soil structure (Sparling *et al*., 2006) and hydraulic properties (Mathan, 1994; Sort & Alcaniz, 1999; Tarchitzky *et al*., 1999; Al-Haddabi *et al*., 2004; Coppola *et al.*, 2004; Viviani & Iovino, 2004; Hawke & Summers, 2006; Gonçalves *et al.*, 2007; Arienzo *et al*., 2009; Vogeler, 2009). Dissolved and suspended solids, both organic and inorganic, may induce soil clogging through physical, chemical, and biological processes (Viviani & Iovino, 2004). Degradation of soil hydraulic properties due to physical clogging of the surface layer of soil is one of the expected risks involved in wastewater reuse for irrigation (Viviani & Iovino, 2004). The effects of wastewater irrigation are closely related to both wastewater and soil properties. An accumulation of monovalent cations, such as K and Na which are generally associated with winery wastewater, can have negative effects on soil structure (Laurenson *et al.*, 2012).

Soil column studies showed that the reductions of saturated hydraulic conductivity were only restricted to the 0-2 cm depth layer, and the lower part of the column was not affected by wastewater application (Viviani & Iovino, 2004).

Irrigation using olive mill wastewater increased soil hydrophobicity and reduced drainable porosity because of increasing organic matter content (Mahmoud *et al.*, 2010). Furthermore, soil hydraulic conductivity was reduced compared to a control site. After 15 years of application of such wastewater, the highest IR was observed because of the presence of large and deep shrinkage cracks. According to Barbera *et al.* (2013), irrigation using olive mill wastewater can have a temporary positive effect on soil. However, in clay soils, salt accumulation could lead to disintegration of the soil structure. Subsequently the hydraulic conductivity would decrease. Regarding the use of wastewater generated by oil production, research showed that the use of such water created a sodicity problem, which had negative effects on soil physical properties such as IR, saturated hydraulic conductivity and pore size distribution (Al-Haddabi *et al.*, 2004).

After four years of irrigation using secondary-treated municipal wastewater, saturated and near saturated hydraulic conductivity of a soil decreased from 567 mm/h and 40 mm/h to 56 mm/h and 3 mm/h, respectively (Sparling *et al.*, 2006). In a study on a sewage farm to investigate the effects of long-term irrigation using sewage effluent on soil physical properties, bulk density was significantly lower compared to soil which was irrigated with well-water. Furthermore, the longer the irrigation with sewage water took place, the lower the bulk density became (Mathan, 1994). Subsequently, hydraulic conductivity increased. In a study to evaluate the long-term effect of wastewater application on soil physical properties, it was also found that this practice increased organic matter content and reduced bulk density. In addition to this, long-term wastewater irrigation resulted in a higher aggregate stability and saturated hydraulic conductivity (Vogeler, 2009). In a column study, leaching a loamy and a clay soil with treated sewage effluent reduced saturated hydraulic conductivity (Lado & Ben-Hur, 2009 and references therein) due to plugging of pores with suspended solids. However, the saturated hydraulic conductivity of a sandy soil was not affected because of its large pore size. In a non-calcareous, sandy soil, higher sodicity enhanced seal formation, reduced infiltration, and increased runoff. However, there were no effects of the effluent on runoff of a calcareous soil under similar conditions. According to Tarchouna *et al*. (2010), irrigation using wastewater from a sludge treatment plant reduced both saturated and unsaturated hydraulic conductivity of a very sandy soil, but it was still high enough to allow water percolation.

The negative effects of high Na levels in irrigation water on the hydraulic properties of soils are well known. According to Levy and Van der Watt (1990), increasing the amount of K resulted in a decrease in hydraulic conductivity and IR of soils. There is a broad spectrum of possible effects of K on infiltration, ranging from being similar to Na, to being similar to Ca (Arienzo *et al.*, 2009). Furthermore, it was concluded that, relative to exchangeable Ca and Na, K had an intermediate effect on the soil hydraulic properties. Since winery wastewater can contain high Na and/or K concentrations, the effect of SAR and potassium adsorption ratios (PAR) on the soil hydraulic conductivity at a wastewater disposal site was investigated in a laboratory study (Arienzo *et al*., 2009). The results showed that the soil hydraulic conductivity was considerably reduced when the SAR or the PAR exceeded 20. These negative effects occurred even when the electrolyte concentrations in the soil were relatively high, *i.e.* > 40 meq/L. It was also shown that the negative effect of Na was more pronounced compared to K at the same electrolyte concentration.

Results of a laboratory study investigating the effect of SAR and PAR on soil hydraulic conductivity showed that it was considerably reduced when the SAR or the PAR exceeded 20 (Arienzo *et al*., 2009; Arienzo *et al*., 2012). In another study, Laurenson *et al*. (2012) used a combination of solutions with known SAR and PAR to investigate the binding of Na and K, and concluded that exchangeable sodium percentage (ESP) corresponding to a given SAR was increasingly lowered at higher K concentrations. Subsequently, if SAR in wastewater remains similar during vintage, reductions in ESP may occur because of increasing K and exchangeable potassium percentage (EPP). In this regard, changes in soil structure will therefore be less pronounced compared to where wastewater with comparable monovalent concentrations of only Na were to be used for irrigation. Therefore, in the case of winery wastewater, replacing Na-based cleaners with K-based cleaners can contribute towards decreasing clay dispersion risks. Due to the high K content in winery wastewater, substitution of K-based cleaning agents with Na-based ones has been proposed (Arienzo *et al*., 2009). Using Na-based cleaning agents might reduce the K, but in the long run increased Na levels in soil will probably cause more structural damage compared to K. In addition, Na could reach toxic levels in soils. On the other hand, K accumulation in the soil could be reduced through uptake and removal by crops grown on winery wastewater disposal sites. Furthermore, it should be kept in mind that the cost of potassium hydroxide is substantially higher than NaOH (Mosse *et al.*, 2011).

Where diluted winery wastewater was used to irrigate different soils in a field vineyard set up, near-saturation hydraulic conductivity (K_{ns}) of shale-derived soil, as well as alluvial and aeolian sands decreased with a decrease in dilution level of winery wastewater after three years (Howell & Myburgh, 2014b). It should be noted that the soils received no river water irrigation which could have influenced the effect of the wastewater on K_{ns}. In spite of this, the results indicated that severe reductions in K_{ns} will occur in the long run if diluted winery wastewater is used for irrigation on these soils. Furthermore, the reduction in K_{ns} might be more pronounced if undiluted winery wastewater is used for irrigation of crops. Using three soils of contrasting mineralogy packed in soil columns, it was found that soil mineralogy and Na and K concentrations in solutions were key factors influencing the soil hydraulic conductivity (Buelow *et al.*, 2015a).

1.3.5. AVAILABLE MANAGEMENT GUIDELINES AS WELL AS EXISTING STANDARDS FOR AUTHORISATION ON USE OF AUGMENTED WINERY WASTEWATER FOR IRRIGATION OF VINEYARDS

1.3.5.1. Australia

According to Day *et al.* (2011), the main focus in Australia is to (i) know your wastes; (ii) assess your treatment options; (iii) know your environment and end-use options; (iv) develop a holistic business case and (v) establish a duty of care on people. In South Australia, the principal legislation that addresses pollution is the Environment Protection Act where Section 25 imposes a general environmental duty on anyone who undertakes an activity that pollutes, or has the potential to pollute, to take all reasonable and practicable measures to prevent or minimise environmental harm. The management of winery waste is legislated under the South Australian Environment Protection Authority (EPA) Guidelines for Wineries and Distilleries (South Australian EPA, 2004). Facilities within the Mt Lofty Ranges Water protection Area (Day *et al.*, 2011) that process more than 50 tonnes of grapes or grape products per year must have an EPA license and all licensed wineries and distilleries must develop and implement an environmental monitoring program and submit the data collected to EPA annually. According to this legislation, where winery wastewater is irrigated at rates greater than 100 mm per annum, routine soil testing is required to prove that the use of winery wastewater for irrigation did not negatively affect soil properties, in particular its' hydraulic properties. In the EPA Guidelines for Wineries and Distilleries, emphasis is placed on producing and managing winery wastewater of a given quality that is fit for the intended purpose rather than general classifications.

As the quantity and types of wastes produced by wineries vary due to waste management practices and the activities undertaken, wineries must review and amend their monitoring programs regularly to allow for changes in production methods and scale. The environmental monitoring program submitted to EPA must include (i) a schematic diagram to show the inputs and outputs in the winery; (ii) clear and concise descriptions of the processes being undertaken at the winery and (iii) details of annual processing inputs and outputs.

Wineries must develop procedures to sample and monitor water coming into the winery (influent water), wastewater, soil, ground water and other receiving environments (South Australian EPA, 2004). Analyses of all water samples must be undertaken by specific accredited laboratories. The monitoring programme must be approved by the EPA before it is implemented. In addition, data obtained from the monitoring requirements must be forwarded to the EPA, where it will be used to establish industry bench marks and inform the public. As part of the quality management system, the EPA also requires that the monitoring activity and resulting data are verified by an independent qualified professional. According to the guidelines, the influent water of the winery must be analysed annually for pH, EC, Ca, Mg, Na and the SAR calculated. Optional analyses of the influent water include BOD, N, K and Cl.

Wastewater flow volumes must be measured at a single location after wastewater has been collected and treated, and before it is disposed or re-used with properly calibrated flow meters. The flow measurements must also be synchronised with wastewater quality measurements to determine hydraulic and chemical loads. A record of winery wastewater volume must be provided annually to the EPA. According to the guidelines, sampling of the winery wastewater must reflect wastewater quality during the various production periods and must be performed at a suitable location before it is disposed of to land or re-used for irrigation. The number of samples required per production period depends on the wastewater produced per year. Winery wastewater must be analysed annually for BOD, pH, EC, N, P, Ca, Mg, K, Na and Cl and the water SAR calculated. Optional analyses of the winery wastewater include COD, TOC, sulphate (SO_4), carbonate (CO_3) and bi-carbonate (HCO_3).

In South Australia, the EPA requires that the rate of wastewater application to land must be regulated according to four different criteria, namely (i) the dominant soil type in irrigated sites; (ii) the concentration of organic C, nutrients and salts in the wastewater; (iii) organic C, nutrient and salt balance analysis to determine the potential effects on crop growth and long-term salt loadings, and (iv) the sensitivity of the area.

Wineries that irrigate with wastewater at a rate of 100 mm per year must include annual soil chemistry monitoring in their programs. To minimise percolation to groundwater, wastewater must be applied at a rate equal to that at which it is removed by crops. Daily water requirements can be estimated from a water balance. Soil water monitoring before and after wastewater application is an important tool, and records should be kept and made available to the EPA for inspection when required. It is also recommended that wineries seek the assistance of irrigation specialists to determine the system that best suits the needs of the site. According to the guidelines, soil monitoring must only be undertaken by qualified professionals and monitoring locations must be properly marked to enable samples to be collected at locations adjacent to previous sampling points for comparison. Two samples of each dominant soil type must be taken in September or October at 0-20, 20-60 and below 60 cm and should be analysed for pH, N, P, K, TOC and water soluble EC_e, Ca, Mg, Na and the SAR calculated. A reference site is also required.

In addition to the soil samples, wineries that irrigate at 100 mm per year must monitor groundwater in the irrigation site if there is a groundwater aquafer less than 15 m below the surface. As in the case of the soil samples, sampling must only be undertaken by qualified professionals. The groundwater samples must be analysed for pH, EC, nitrate N, ammonia N and TOC.

In terms of vegetation health, it is recommended that the health of plants irrigated with winery wastewater be monitored visually. It is also recommended that wineries have a complaint register for complaints. It should be noted that most complaints relate to odour and noise.

1.3.5.2. New Zealand

According to Laurenson and Houlsbrooke (2012), it is important to prevent harmful effects of applying winery wastes to land on aquatic environments and soil and plant health. The major concern regarding winery wastes is nutrients, high BOD and salts. However, concentrations of heavy metals and other contaminants are low and pose limited environmental risk. In New Zealand, the Resources Management Act aims to promote the sustainable management of natural and physical resources and provide the basis upon which regional policy statements, policies and district plans are prepared. Although the Act does not clearly address the management of waste, it does require that adverse effects associated with their disposal are avoided, mitigated or remedied. Therefore, wineries have to dispose of their wastewater in a sustainable manner that does not contaminate drinking water sources or result in off-site pollution.

It is recommended that a record of the amount of wastewater produced be kept (Laurenson & Houlsbrooke, 2012) and wastewater be sampled during vintage to determine the appropriate loading rates to land. It is recommended that the upper limit of cation ratio of structural stability (CROSS) in winery wastewater should be 20 when EC of the winery wastewater is 1.5 dS/m. It should be noted that CROSS is a new ratio proposed by Kumar *et al.* (2014) and is similar to SAR but incorporates the differential effects of Na and K in dispersing soil clays, and Ca and Mg in flocculating soil clays.

Before winery wastewater is applied to land, the soil depth, IR and maximum water deficit should be determined to identify irrigation management units. The quantity of wastewater applied to a specific area on a certain date should be recorded. In New Zealand, the code of practice for winery waste management recommends a BOD loading no greater than 120 kg BOD/ha/day. High BOD in winery wastewater can reduce soil oxygen, particularly when the soil is saturated with large amounts of wastewater. However, the ability of soils to assimilate wastewater is rapid and anaerobic conditions are not persistent, particularly if winery wastewater is applied at rates suitable to the nutrient demand and when there is a suitable soil water deficit.

Soil samples should be collected every one to two years to identify imbalances in soil fertility and/or build-up of salts and a nutrient budget should be drawn up for areas that are irrigated with winery wastewater (Laurenson & Houlsbrooke, 2012). For a land treatment system to be sustainable, it must be efficient in retaining waste constituents in both the soil and plants. The longer the wastewater remains in the root zone, the greater the time for the soil to physically filter out constituents thereby diminishing potential contaminants and nutrients. In order to prevent the loss of nutrients in run off and drainage, the volume of winery wastewater applied by land application should be less than the total volume of water required by the soil. Therefore, a basic knowledge of the soil to which winery wastewater is being applied is required. Where sites contain more than one soil type, the hydraulic loadings should be adjusted for each soil. Where this is not possible, it is recommended that wastewater applications should be made for the most limiting soil. In New Zealand it is recommended that the Agresearch Soil Risk Framework for effluent adopts irrigation management units based on drainage classes.

Guidelines from all over the world state that no contamination of ground or surface water should occur during winery wastewater irrigation (Laurenson & Houlsbrooke, 2012). This requires consideration of both the depth and rate of application for each irrigation management units. The application rate of winery wastewater has a strong influence on nutrient treatment efficiency when applied to soils that have a high degree of preferential flow, drainage limitations or that are located on sloping land. Different soils have different IR and abilities to absorb and drain water. Winery wastewater application rates should be matched to the soils' ability to absorb it. It should also be kept in mind that lower application rates increase the likelihood of retaining the applied nutrients in the root zone, decrease the likelihood of preferential flow and allow a greater volume of applied wastewater to move through the smaller soil pores.

Ideally wineries in New Zealand that also irrigate more than 100 mm of winery wastewater per year should monitor ground water if it is less than 15 m below the surface and surface water bodies if they are less than 50 m from the wastewater application site (Laurenson & Houlsbrooke, 2012). Soil processes responsible for the attenuation and amelioration of waste constituents occur mostly within the active root zone. Hydraulic loading depths that allow for a longer contact time between soil and waste constituents in the root zone will maximise nutrient assimilation.

In New Zealand, the permissible loading of N is restricted to 150 to 200 kg N per ha (Laurenson & Houlsbrooke, 2012). In some soils, cracking, root and worm channels and large macro pores may promote preferential flow that minimises the interaction between the soil and the winery wastewater, thereby limiting plant uptake. If the application of winery wastewater exceeds the water holding capacity of the soil or if the soil is wet, a large volume of the applied winery wastewater will flow preferentially through the macro pores. By increasing the application frequency, the applied depth and nutrient loading rate in a single event can be reduced, thereby extending the retention time of winery wastewater in the root zone and improving plant nutrient use efficiency by better matching demand. According to the authors, further knowledge of site-specific conditions, including assessment of soil characteristics, mineralisation rates, climate and agronomic need of the crop, is still required. Furthermore, it is critical to know how much nutrient is directly available to the crop and how much will be removed by the crop. In the case of winery wastewater, the supply of large quantities of K *via* winery wastewater could affect the nutrient balances and the mineral composition on the crop.

During winery wastewater irrigation, odour can be a problem and in this regard, the frequency, intensity, duration and offensiveness of the odour are key factors. Generally, odours can be avoided by preventing anaerobic conditions in the winery wastewater during storage and during irrigation, maintaining adequate separation distances to neighbouring properties and irrigating downwind at night.

1.3.5.3. California

Wastewater quality standards were proposed for irrigation of vineyards using treated winery wastewater stored in aerated ponds in California (Ryder, 1995). The maximum COD, faecal coliforms, pH, EC and SAR standards, given in Table 1.8 are more or less comparable to the legislated limits for irrigation with wastewater in South Africa, *i.e.* if less than 2 000 m^3 is irrigated per day (Table 1.5).

1.3.5.4. South Africa

According to Van Schoor (2005), where winery wastewater is used for irrigation of land, the intended water use must be registered with Department of Water and Sanitation before irrigation can commence. Where granted, the guidelines stipulated in the General Authorisation (Table 1.5) must be adhered to. In terms of South African guidelines, it should be noted that irrigation may only take place above the 100 year flood line. In addition, irrigation with wastewater may only take place 100 m or more from the edge of a water resource. No contamination of ground or surface water may take place. It is also necessary that wineries measure the quantity of wastewater irrigated on a weekly basis. In addition to this, wineries must measure the quality of the wastewater every month. It is recommended that over-irrigation, waterlogging and damage to the soil be prevented at all times. It should be noted that the purpose of wastewater irrigation should not only be the disposal of winery wastewater, but that there should be a beneficial use of water to irrigate crops (Van Schoor, 2005). In terms of South African guidelines for wineries, weekly water balances should be drawn up with the assistance of a soil scientist, and the accuracy of these calculations should be checked by continuous monitoring of soil water. When selecting crops for irrigation with winery wastewater, soil characteristics and climatic conditions as well as wastewater quality and quantity should be considered (Van Schoor, 2005). It is important to collect soil samples from wastewater irrigated soils at three depth intervals at a minimum of five locations per hectare every three months. In addition, samples must be collected from a control area where no irrigation has taken place. All the soil samples must be analysed for pH, EC, N, P, Ca, Mg, K, Na, iron (Fe), manganese (Mn), copper (Cu), zinc (Zn), boron (B), Cl, sulphur (S), and ESP. If any indications of soil degradation are identified, the area should be rehabilitated and another area or disposal method must be identified.

Table 1.8. Proposed reclaimed effluent water quality standards for vineyard re-use (after Ryder, 1995).

Parameter	Optimum value	Maximum values
pH	6.5-8.4	6.0-9.0
EC (dS/m)	< 0.75	< 1.50
TDS (mg/L)	< 500	< 1 000
Alkalinity (mg/L $CaCO_3$)	< 150	< 250
Hardness (mg/L $CaCO_3$)	< 250	< 400
Ca (mg/L)	< 60	< 100
Mg (mg/L)	< 25	< 50
Na (mg/L)	< 65	< 100
K (mg/L)	< 5	< 10
Fe (mg/L)	< 5	< 5
Mn (mg/L)	< 0.2	< 0.5
Cu (mg/L)	< 0.01	< 0.05
Zn (mg/L)	< 2	< 5
Bicarbonate (mg/L)	< 200	< 300
Carbonate (mg/L)	< 5	< 10
Chloride (mg/L)	< 70	< 120
Sulfate (mg/L)	< 150	< 250
N (mg/L)	< 5	< 10
P (mg/L)	< 5	< 10
B (mg/L)	< 0.5	< 1
SAR	< 6	< 9
COD(1) (mg/L)	< 60	< 100
Coliforms (MPN(2)/100 ml)	< 23	< 230

(1) Adjusted from biological oxygen demand (BOD) where BOD = 66% of COD.
(2) Most probable number.

1.3.6. CONCLUSIONS

Wineries generate large volumes of poor quality wastewater, particularly during harvest. The use of winery wastewater for vineyard irrigation could have many potential benefits for the wine industry. Since water is becoming increasingly scarce, the use of winery wastewater as an alternative source of irrigation water for vineyards could reduce the pressure on water resources. However, there is no available information to guide legislators regarding what specific quality of winery wastewater could be permitted to be applied for vineyard irrigation under a specific set of conditions to minimize the effects on soil and grapevine responses. Most of the information generated with regard to wastewater has been collected in laboratory studies with either municipal wastewater or simulated wastewater. Consequently, there is therefore a need for further studies in actual vineyards where winery wastewater is applied to vineyards over a longer term. In terms of South African guidelines for wineries, they need to register their intended wastewater use with the Department of Water and Sanitation. The quantity of wastewater irrigated on a weekly basis must be measured. In addition to this, winery wastewater quality needs to be measured monthly. Weekly water balances should be drawn up with the input of a soil scientist. In the selection of a crop with which to irrigate with winery wastewater, soil characteristics and climatic conditions as well as wastewater quality and quantity should be taken into account. In South Africa, soil chemical responses to application of winery wastewater must be quantified every three months. Most importantly, South African guidelines state that if there are any indications of soil degradation, the area should be rehabilitated and another area for wastewater irrigation must be identified.

CHAPTER 2: WATER QUALITY, IRRIGATION VOLUMES AND AMOUNT OF ELEMENTS APPLIED *VIA* IN-FIELD FRACTIONAL USE (AUGMENTATION) OF WINERY WASTEWATER WITH RAW WATER

2.1. INTRODUCTION

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 low quality wastewater, particularly during the harvest period. Reports on the actual volumes of wastewater that are generated by wineries are extremely limited. However, it is estimated that medium to large wineries generate more than 15 000 m^3 of wastewater annually, whereas small wineries generate less than 15 000 m^3 annually (Van Schoor, 2005 and references therein). Australian wineries generate about 5 m^3 of wastewater per tonne of grapes crushed (Chapman *et al.*, 1995). Crushing approximately 50 000 tonnes of grapes annually generate about 175 000 m^3 of wastewater at the Berri estates' winery in the Riverland region of South Australia (Anonymous, 2010). Hence, their wastewater generation amount to *ca.* 3.5 m^3 per tonne of grapes. It can be estimated that the Lutzville Vineyards' winery generates about 1.1 m^3 of wastewater per tonne of grapes crushed. However, this relatively low value is misleading, since 50% of the wastewater is presumably lost to evaporation (Kriel, 2008).

International requirements, as well as national legislation, are putting pressure on wine producers regarding the responsible management of this winery wastewater, which may have large-scale detrimental impact on the environment. In the Western Cape wine industry, most vineyards need irrigation and the ideal situation would be to implement a sustainable use of winery wastewater for wine grape irrigation by adding winery wastewater to existing irrigation water resources (augmentation). Re-using winery wastewater for vineyard irrigation was investigated in a previous project (Myburgh & Howell, 2014b) on one soil type. Thus, to investigate the impact of irrigating with winery wastewater on different soils in different climatic regions, which differ substantially in their mean annual rainfall, on the chemical composition of the soil, grapevine performance, and wine quality, is indispensable. In particular, information pertaining to the water quality used in the in-field fractional use (augmentation) of winery wastewater with raw water is necessary in order to determine what the quality of the water is that could be used sustainably in the different climatic regions given the substantial differences in their mean annual rainfall. In addition to this, the amount of extra elements applied *via* the in-field fractional use (augmentation) of winery wastewater with raw water for vineyard irrigation is important to quantify to determine the additional nutrient load added to the vineyard.

2.2. MATERIALS AND METHODS

2.2.1. Selected experiment plots

Experiment plots were selected in the three selected production areas, namely the Coastal, Breede River and Olifants River regions (Fig. 2.1 & Table 2.1). 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.

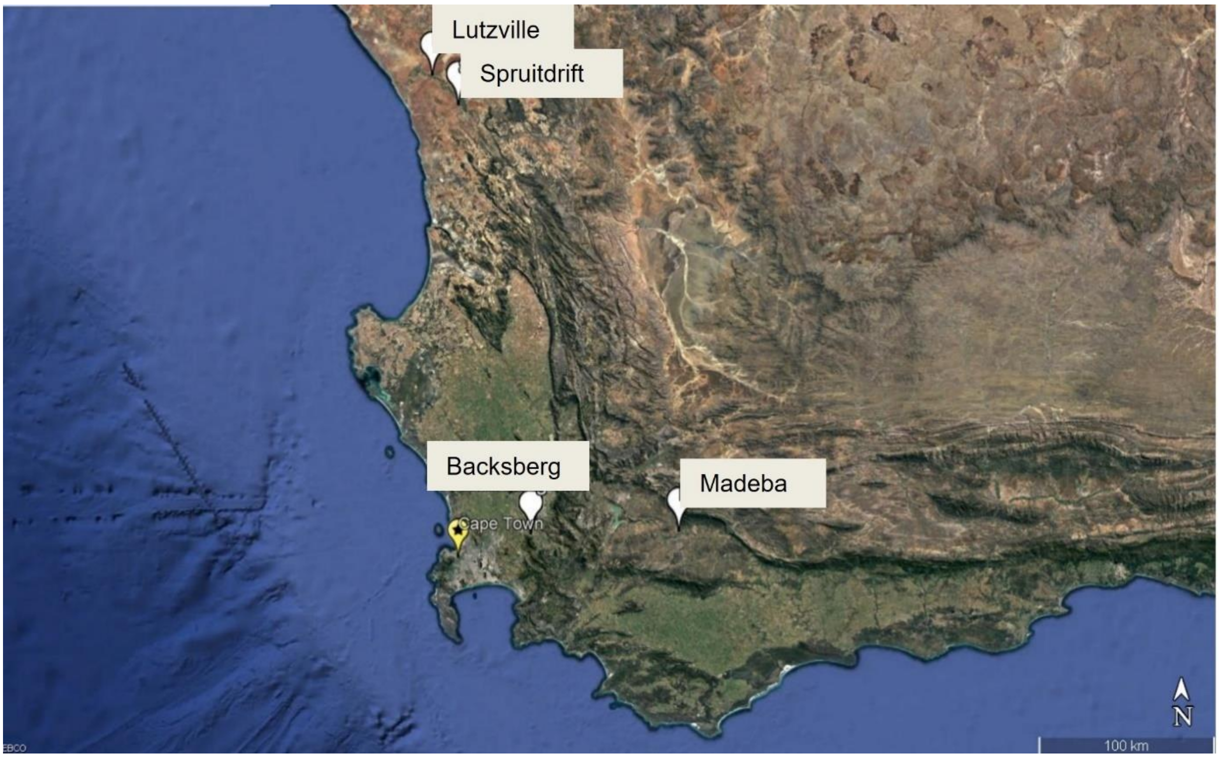

Figure 2.1. Map of selected experiment plots for determining the effect of in-field fractional use (augmentation) of winery wastewater with raw water for vineyard irrigation on soil properties and grapevine responses in different climatic regions.

Table 2.1. Experiment plots selected for determining the effect of in-field fractional use (augmentation) of winery wastewater with raw water for vineyard irrigation on soil properties and grapevine responses in different climatic regions according to the Winkler index (Le Roux, 1974).

Wine region	Climatic index	Locality	Plot	Soil texture	Cultivar
Coastal	III	Paarl	Backsberg farm	Sand	Cabernet Sauvignon
			Backsberg farm	Loam	Cabernet Sauvignon
Breede River	V	Robertson	Madeba farm	Sandy loam	Shiraz
			Madeba farm	Clay loam	Shiraz
Olifants River	V	Vredendal	Lutzville Winery	Sand	Shiraz
			Spruitdrift Winery	Sand	Cabernet Sauvignon

The total rainfall, total number of rainfall days and rainfall per day from May to September for Stellenbosch, Robertson and Lutzville given in Table 2.2 was reported previously by Mulidzi (2016).

Table 2.2. Rainfall, total number of rainfall days and rainfall per day for Stellenbosch, Robertson and Lutzville (after Mulidzi, 2016).

Locality	Rainfall (mm)	Rainfall days	Rainfall per day (mm/day)
Stellenbosch	469.1	50.4	9.3
Robertson	152.9	33.8	4.5
Lutzville	93.6	24.9	3.7

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 the experiment plots were on separate farms.

2.2.2. Atmospheric conditions

Weather data, including maximum (T_x) and minimum (T_n) temperatures, rainfall, relative humidity (RH) and average wind speed, were measured by means of automatic weather stations situated near each of the experiment plots. The data was provided by the ARC-Institute for Soil, Climate and Water in Pretoria. The maximum (T_x) and minimum (T_n) temperatures, relative humidity (RH) and average wind speed ($U_{2)}$ for all the sites for the 2017/18, 2018/19, 2019/20 and 2020/21 seasons is given in Appendix C, D and E.

2.2.3. Vineyard characteristics

Both experiment plots at Backsberg formed part of a newly planted commercial *Vitis vinifera* L. *cv*. Cabernet Sauvignon/US8-7 vineyard which was established in September 2017 (Table 2.3). Both experiment plots at Madeba were part of a commercial *V. vinifera* L. *cv*. Shiraz/SO4 vineyard which was established in 2001 (Table 2.3). In the Lower Olifants River region, a *V. vinifera* L. *cv*. Shiraz/Ramsey vineyard established in 2012 (Table 2.3), 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 (Table 2.3). Each of the six experiment plots compromised of two rows of ten grapevines each, *i.e.* 20 experiment grapevines per plot. 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. Based on general plant spacing in South African vineyards, each experiment plot cover approximately 80 m^2. The experiment plots were marked in July and August 2017. The experiment plots were managed according to the grower's normal viticultural practices in terms of canopy management. No fertilisers were applied with the exception of 20 kg/ha LAN in the winter of 2018 at Backsberg. No winter or summer cover crops were sown at the experiment plots. Since growers may use different cover crops, the latter reduced variability between experiment plots. Furthermore, cover crops would have doubled the number of soil and plant analyses, which would have increase project costs substantially. It should be noted that the role of cover crops in winery wastewater irrigation is already being investigated by ARC Infruitec-Nietvoorbij (Project P04000027-Evaluation of selected grass and broadleaf crops suitable for fodder as interception crops where winery wastewater is re-used for irrigation). Weeds were removed routinely by means of chemical and mechanical control.

Table 2.3. Vineyard characteristics, including scion cultivar, rootstock, plant spacing, planting date and trellis system of the experiment plots in the Coastal, Breede River and Lower Olifants River regions where grapevines were irrigated using the in-field fractional use (augmentation) of winery wastewater with raw water.

Plot no.	Scion cultivar	Root-stock	Spacing (m × m)	Planting date	Trellis system
Backsberg sand	Cabernet Sauvignon	US8-7	3.0 × 0.6	2017	modified Lyre
Backsberg clay	Cabernet Sauvignon	US8-7	3.0 × 0.6	2017	modified Lyre
Madeba sandy loam	Shiraz	SO4	2.5 × 1.5	2001	5-strand lengthened Perold
Madeba clay loam	Shiraz	SO4	2.5 × 1.5	2001	5-strand lengthened Perold
Lutzville deep sand	Shiraz	Ramsey	2.0 × 2.0	2012	5-strand lengthened Perold
Spruitdrift shallow sand	Cabernet Sauvignon	99R	1.5 × 2.6	2001	4-strand lengthened Perold

In terms of soil texture, clay content in the 0-30 cm soil layer ranged from 5% to 27% (Fig. 2.2), and in the 30-60 cm soil layer ranged from 5% to 29%. In the 60-90 cm soil layer, clay content ranged from 3% to 25%. The silt content in the 0-30 cm soil layer ranged from 5% to 27% (Fig. 2.3). The silt content in the 30-60 cm soil layer ranged from 0% to 14% (Fig. 2.x). In the 60-90 cm soil layer, silt content ranged from 4% to 12%. The sand content in the 0-30 cm soil layer ranged from 59% to 95% (Fig. 2.4), and in the 30-60 cm soil layer ranged from 57% to 91%. In the 60-90 cm soil layer, the sand content ranged from 63% to 91%. The sandy soil at Backsberg was classified as a loamy sand, whereas the clay soil was classified as a sandy loam to sandy clay loam. At the Madeba farm, the lighter textured experiment plot was characterised as a loamy sand to sandy loam. The heavier textured soil was classified as a sandy clay loam. The soil at the Lutzville vineyard was classified as a sand. At the Spruitdrift vineyard, the soil was classified as sand to loamy sand.

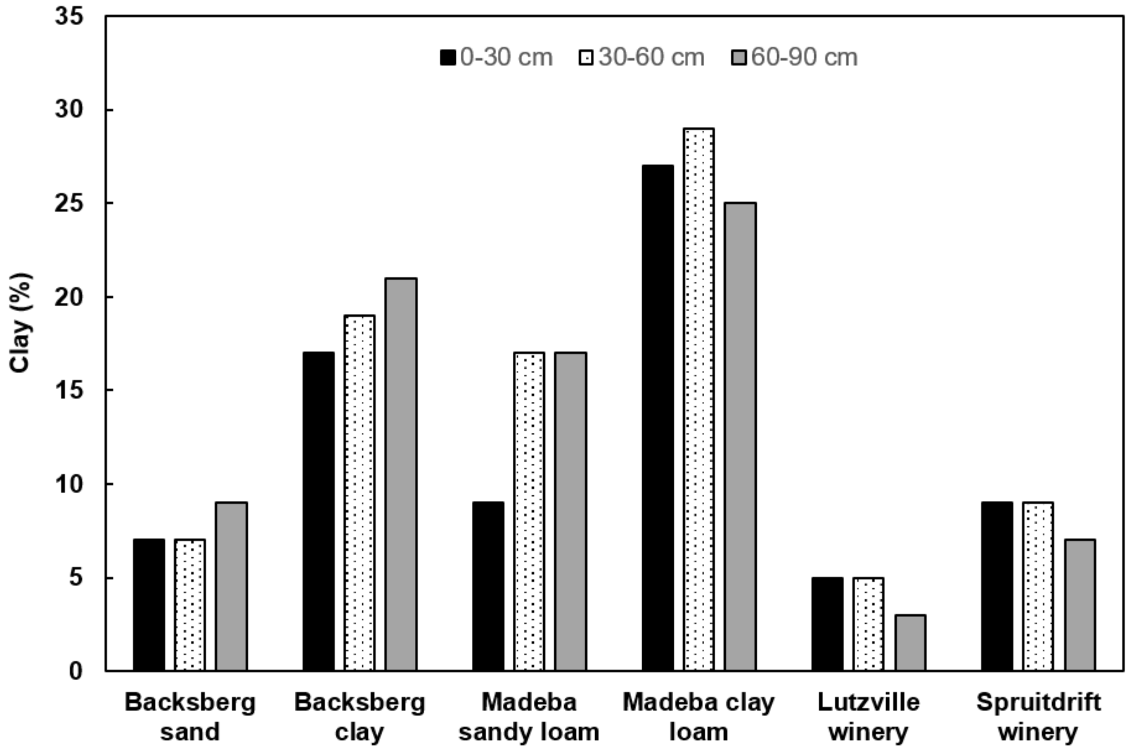

Figure 2.2. The clay content in the 0-30 cm, 30-60 cm and 60-90 cm soil layers at the different experiment plots.

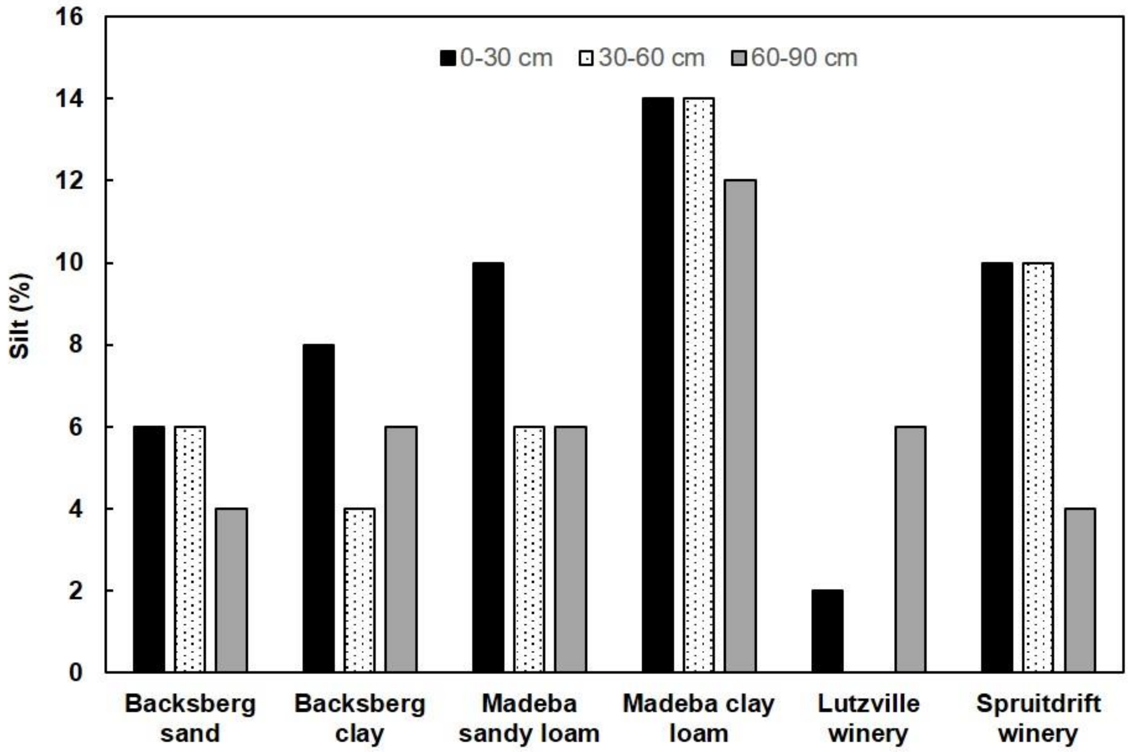

Figure 2.3. The silt content in the 0-30 cm, 30-60 cm and 60-90 cm soil layers at the different experiment plots.

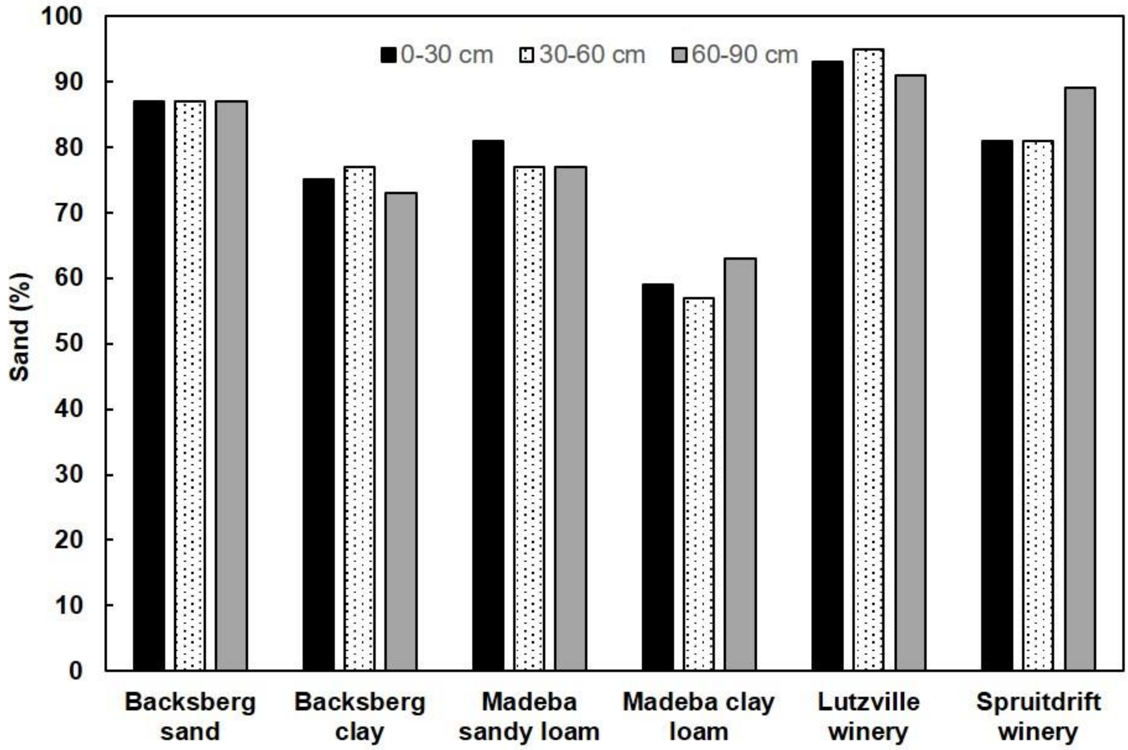

Figure 2.4. The sand content in the 0-30 cm, 30-60 cm and 60-90 cm soil layers at the different experiment plots.

Results of the textural analyses of the selected soils showed that there was a substantial difference in their textural properties. In this regard, it was expected that they would respond differently to the in-field fractional use (augmentation) of winery wastewater with raw water for vineyard irrigation.

2.2.4. Procedure for the in-field fractional use (augmentation) of winery wastewater with raw water

A more practical approach to irrigating vineyards with winery wastewater was applied in this project and that was to use the in-field fractional use (augmentation) of winery wastewater with raw water for the irrigation of the experiment vineyards (Fig. 2.5). According to this approach, grapevines were irrigated as follows. For each irrigation, a certain percentage of the irrigation requirement was applied as undiluted winery wastewater. Raw water was applied for the other part of the irrigation requirement. All vineyards in the project were irrigated with micro sprinkler irrigation. This was to ensure that the full soil surface was wetted as well as reduce the risk of clogging of the irrigation pipe.

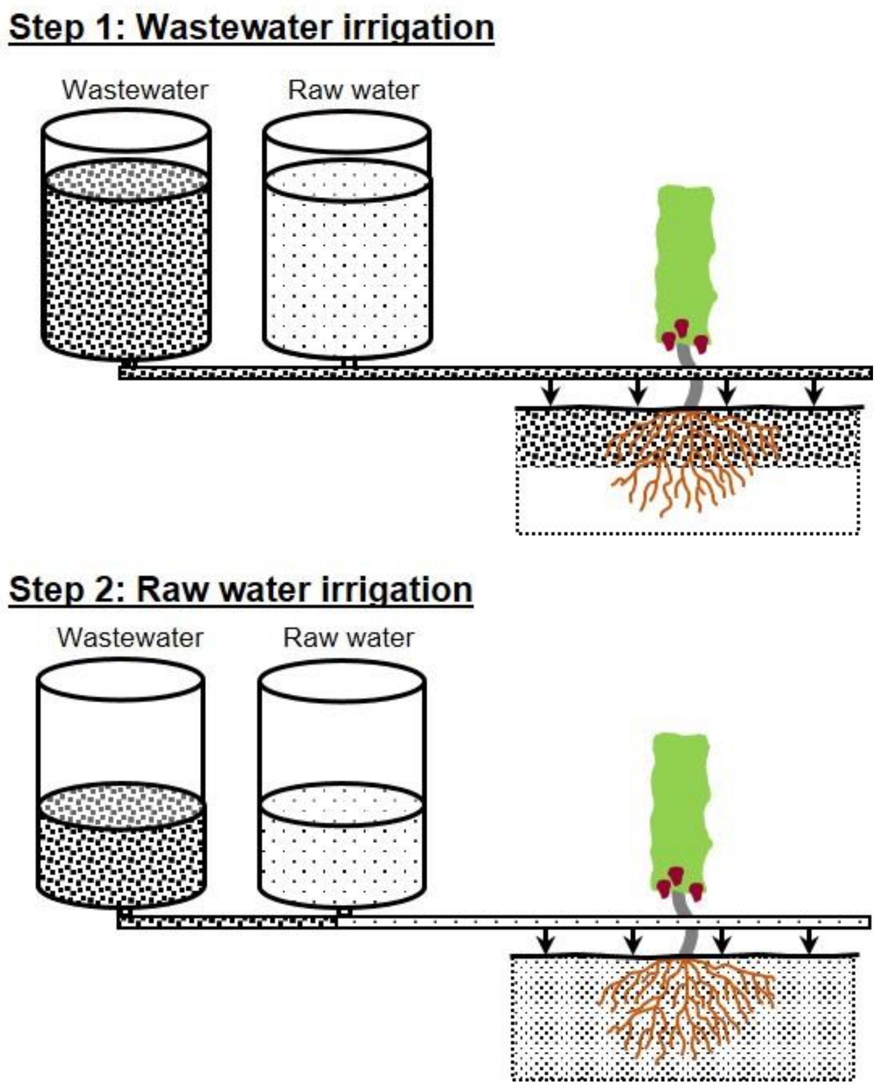

Figure 2.5 Schematic illustration of in-field fractional use (augmentation) of winery wastewater with raw water when grapevines in experiment plots were irrigated with wastewater followed by raw water.

It should be noted that experimental grapevines were irrigated so that optimum wine quality is obtained. After irrigation, soil water content was measured by means of a neutron probe. At the same time, stem water potential of grapevines was measured (Fig. 2.6). Therefore, stem water potential (Ψ_S) thresholds for optimum wine quality for the specific cultivars were used to set up the refill points (Figs. 2.7, 2.8 & 2.9). In this regard, grapevines were therefore be under-irrigated rather than over-irrigated because better wine quality would be obtained when grapevines received less water (Lategan & Howell, 2016).

Figure 2.6. Determining the irrigation refill line by means of stem water potential measurements. Encircled are the leaves enclosed with aluminium bags.

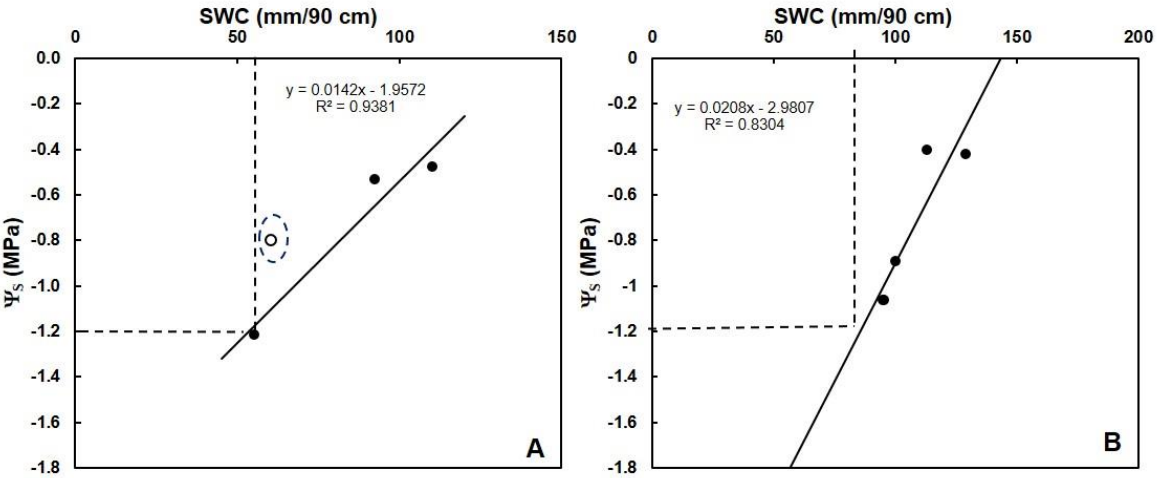

Figure 2.7. Correlation between Ψ_S and soil water content (SWC) to a depth of 90 cm for (A) the sand and (B) clay experiment plots of Cabernet Sauvignon grapevines on Backsberg farm.

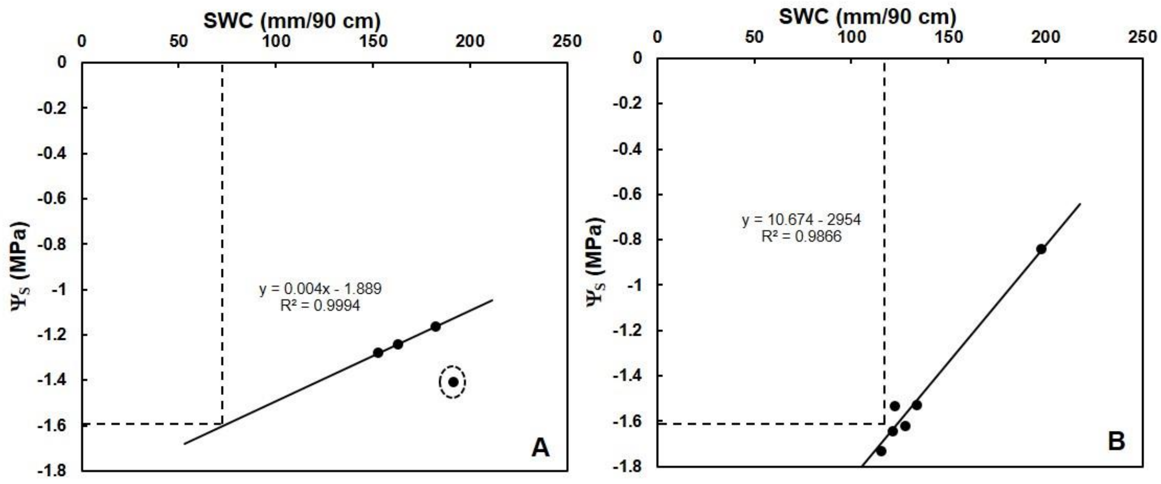

Figure 2.8. Correlation between Ψ_S and SWC to a depth of 90 cm for the (A) sandy loam and (B) clay loam experiment plots of Shiraz grapevines on Madeba farm.

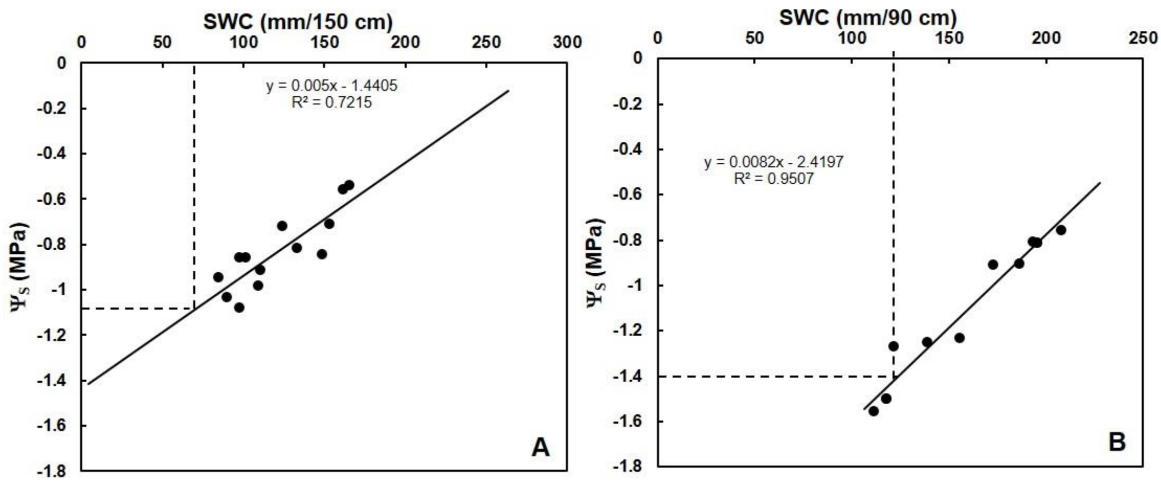

Figure 2.9. Correlation between Ψ_S and soil water content to a depth of (A) 150 cm for Shiraz grapevines near Lutzville and (B) 90 cm for Cabernet Sauvignon grapevines near Spruitdrift wineries.

After selection of the vineyards which were to be irrigated with the in-field fractional use (augmentation) of winery wastewater with raw water, an irrigation system expert from Netafim, Mr. W. Smit, and the project team visited them 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 (Figs. 2.10, 2.11, 2.12 & 2.13) in the three different regions.

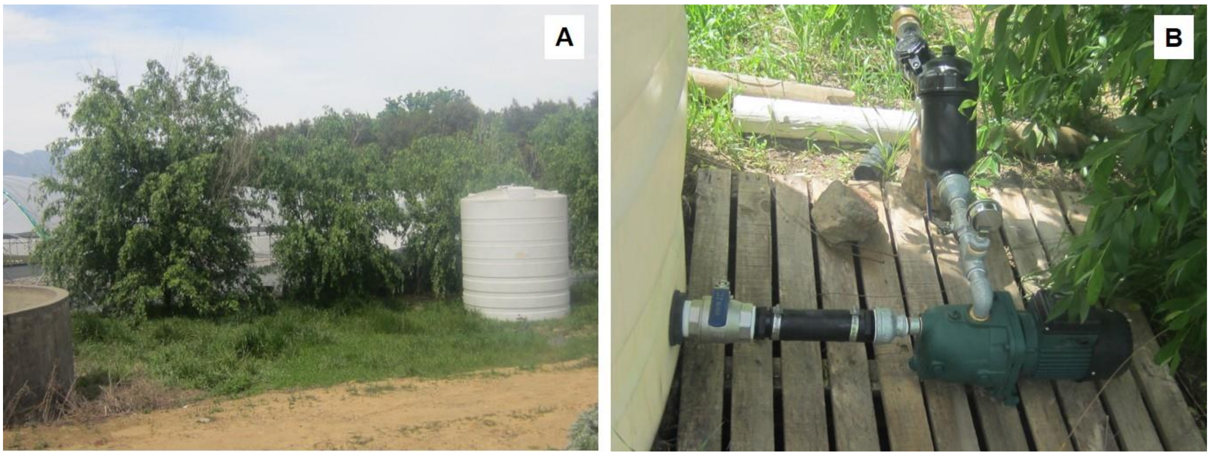

Figure 2.10. The irrigation system at Backsberg farm. Wastewater was stored in the (A) white collection tank. Wastewater was (B) pumped from the collection tank to the vineyard.

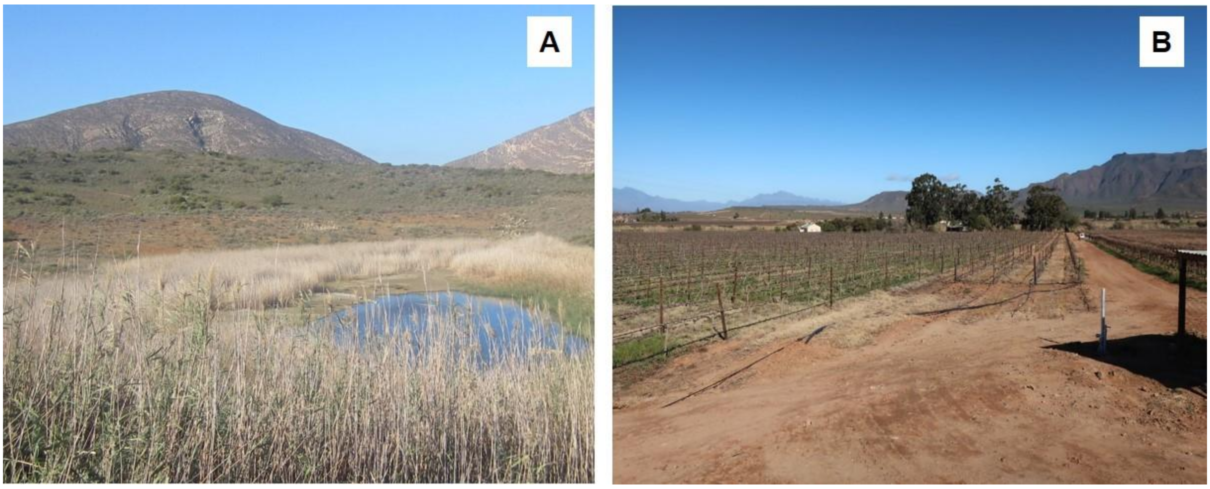

Figure 2.11. The (A) wastewater collection dam at Madeba farm and (B) the sandy loam experiment plot.

Figure 2.12. The (A) collection pit at Lutzville winery where the wastewater was sourced and (B) the pump and filter which was used to apply the wastewater irrigations.

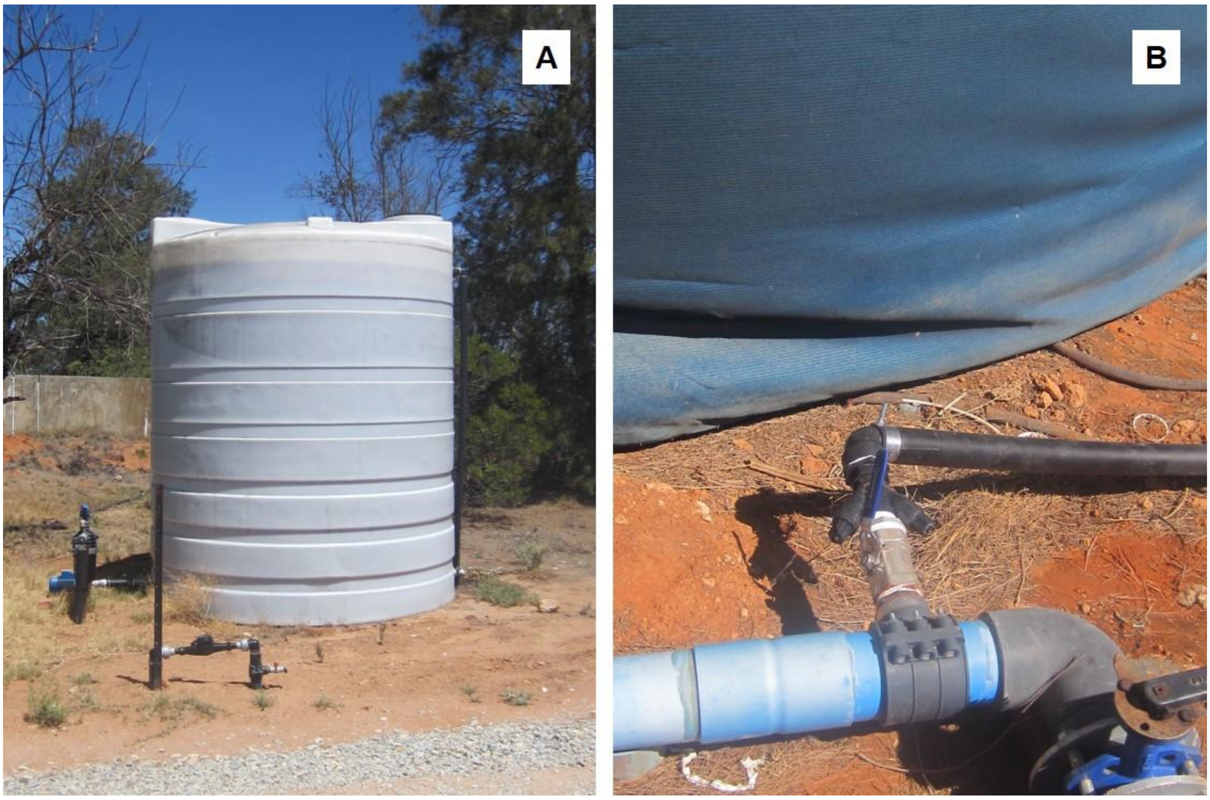

Figure 2.13. The (A) wastewater collection tank at Spruitdrift winery with the filter and water meters visible in the foreground and (B) the connection for the raw water.

2.2.5. Irrigation volumes applied

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. Water meters were used to monitor the irrigation volumes of winery wastewater and raw water applied to each experiment plot.

2.2.6. Water quality

Approximately one hour after a wastewater irrigation started, a 2 L water sample was collected at the collection point for each experiment plot. A sample was also taken for the raw water. The COD in the samples was measured using a portable spectrophotometer (Aqualitic COD-reactor®, Dortmund) with the appropriate test kits (COD, CSB, 0-15 000 mg/L) as described previously (Myburgh & Howell, 2014b). The samples were also analysed by a commercial laboratory (Bemlab, Strand & Labserve, Stellenbosch) for pH, EC, NH_4-N, NO_3-N, P, Ca, Mg, K, Na, C, HCO_3, SO_4, B, Fe, Mn, Cu, Zn and fluoride (F) according to methods described by Clesceri *et al.* (1998).

The potassium adsorption ratio (PAR) was calculated as follows:

$PAR = K \div [(Ca + Mg) \div 2]^{0.5}$ (Eq. 2.1)

where K is the potassium concentration (mg/L) divided by the molecular mass, *i.e.* 39 g/mol, Ca is the calcium concentration (mg/L) divided by the equivalent molecular mass, *i.e.* 20 g/mol and Mg is the magnesium concentration (mg/L) divided by the equivalent molecular mass, *i.e.* 12.15 g/mol.

Similarly, the SAR was calculated as follows:

$SAR = Na \div [(Ca + Mg) \div 2]^{0.5}$ (Eq. 2.2)

where Na is the sodium concentration (mg/L) divided by the molecular mass, *i.e.* 23 g/mol. The NH_4-N and NO_3-N concentrations were summed to obtain the total nitrogen (Total-N). Assessment of the microbial status of the winery wastewater as well the raw water was beyond the scope of the study.

2.2.7. Amount of elements applied

The amount of wastewater applied was converted from mm to L per ha as follows:

$V = I \times 10^4$ (Eq. 2.3)

where I is the amount of irrigation applied (mm) and 10^4 is the factor used to convert depth of water (mm) to volume (L) per hectare (1 mm = 10 m^3 per ha = 10^4 L per ha).

For each irrigation, the element concentrations in the undiluted winery wastewater were used to calculate the amounts of elements added to the soil per irrigation per hectare as follows:

$m = V \times C_e$ (Eq. 2.4)

where m is amount of element (mg/ha), V is the volume of water applied per hectare (L/ha) and C_e is the element concentration (mg/L) in the irrigation water.

In addition, the contribution of the elements deposited by the raw water was taken into account. The same procedure was followed for the raw water. The amount of element in milligram per hectare was converted to kilogram per hectare (M) as follows:

$M = m \div 10^6$ (Eq. 2.5)

The amount of elements applied per irrigation were summed to obtain the seasonal applications.

2.3. RESULTS AND DISCUSSION

2.3.1. Rainfall

The LTM for rainfall at the Bien Donne weather station is 69.72 mm, 33.32 mm and 39.58 mm for September, October and November, respectively. The LTM for rainfall at the Bien Donne weather station is 14.88 mm, 18.89 mm and 9.52 mm for December, January and February, respectively. The LTM for rainfall at the weather station at Bien Donne is 17.54 mm, 51.78 mm and 109.58 mm for March, April and May, respectively. The LTM for rainfall at the weather station at the Bien Donne weather station is 136.6 mm, 123.71 mm and 127.59 mm for June, July and August respectively. As expected, the rainfall increased from summer to winter (Table 2.4). In the 2018/19 season, the rainfall increased from summer to winter (Table 2.4). Rainfall in September 2018, December 2018 and March 2019 was higher than the LTM. In the 2019/20 season, rainfall increased from summer to winter (Table 2.4). Rainfall in October 2019, December 2019 and February 2020 was higher than the LTM. As expected, the rainfall in the 2020/21 season increased from summer to winter (Table 2.4). Rainfall in September and November 2020, as well as March, May, June and July 2021 was higher than the LTM.

The LTM for rainfall at the weather station close to Madeba farm is 14.01 mm, 27.75 mm and 26.41 mm for September, October and November, respectively. The LTM for rainfall at the weather station close to Madeba farm is 8.01 mm, 17.91 mm and 13.80 mm for December, January and February, respectively. The LTM for rainfall at the weather station close to Madeba farm is 10.95 mm, 23.92 mm and 23.06 mm for March, April and May, respectively. The LTM for rainfall at the weather station close to Madeba farm is 37.41 mm, 39.41 mm and 36.09 mm for June, July and August, respectively. Taking above-mentioned into consideration in the 2017/18 season, rainfall (Table 2.5) in September, October, December, January, March, April, May, July and August was lower than the LTM. Rainfall in October and November 2018 as well as January, April, May and June 2019 was lower than the LTM. The rainfall in September and October 2019 as well as January 2020 was higher than the LTM. Rainfall in September and November 2020 as well as March to June 2021 was higher than the LTM.

The LTM for rainfall at the weather station close to Lutzville winery is 15.81 mm, 10.26 mm and 13.07 mm for September, October and November, respectively. The LTM for rainfall at the weather station close to Lutzville winery is 14.97 mm, 9.74 mm and 3.51 mm for December, January and February, respectively. The LTM for rainfall at the weather station close to Lutzville winery is 6.74 mm, 15.37 mm and 33.48 mm for March, April and May, respectively. The LTM for rainfall at the weather station close to Lutzville winery is 44.91 mm, 32.51 mm and 34.45 mm for June, July and August, respectively. Taking above-mentioned into consideration, rainfall (Table 2.6) in September, October, November and December 2017 as well as January, February, April, May, June, July and August 2018 was lower than the LTM. The rainfall in the entire 2018/19 season was lower than the LTM. In the 2019/20 season, only the rainfall in October 2019 was lower than the LTM. In the 2020/21 season, rainfall in October 2020 and August 2021 was higher than the LTM.

The LTM for rainfall at the weather station close to Spruitdrift winery is 7.87 mm, 7.98 mm and 10.60 mm for September, October and November, respectively. The LTM for rainfall at the weather station close to Spruitdrift winery is 27.23 mm, 12.31 mm and 7.90 mm for December, January and February, respectively. The LTM for rainfall at the weather station close to Spruitdrift winery is 6.69 mm, 14.63 mm and 30.84 mm for March, April and May, respectively. The LTM for rainfall at the weather station close to Spruitdrift winery is 36.66 mm, 29.01 mm and 19.59 mm for June, July and August, respectively. Taking above-mentioned into consideration, rainfall (Table 2.7) in September, October, November and December 2017 as well as January, February, April, May, June and July 2018 was lower than the LTM. Annual summer rainfall of 89.8 mm, 80.2 mm, 70.8 mm and 33.5 mm was reported by Southey (2017) for the Vredendal region for the 2012/13, 2013/14, 2014/15 and 2015/16 seasons. In the current study, the annual summer rainfall for the 2017/18 season was 18.29 mm. Given the extreme drought experienced in the Western Cape in the 2017/18 season, the summer rainfall is what one would have expected under the prevailing conditions. Annual winter rainfall of 138.2 mm, 233.1 mm, 121.4 mm and 109.3 mm was reported by Southey (2017) for the Vredendal region for the 2012/13, 2013/14, 2014/15 and 2015/16 seasons. In the current study, the annual winter rainfall for the 2017/18 season was 138.94 mm. The winter rainfall was therefore similar to that of the 2012/13 and 2014/15 seasons. In the 2018/19 season, taking above-mentioned into consideration, rainfall (Table 2.7) for the entire season with the exception of September 2018 was lower than the LTM. In the 2019/20 season, rainfall was lower than the LTM. Rainfall for the entire 2020/21 season with the exception of October 2020 and August 2021 was lower than the LTM.

Table 2.4. Rainfall, total number of rainfall days and rainfall per day for Backsberg for the 2017/18, 2018/19, 2019/20 and 2020/21 seasons.

Month	Rainfall (mm)				Rainfall days				Rainfall per day (mm/day)			
	2017/18	2018/19	2019/20	2020/21	2017/18	2018/19	2019/20	2020/21	2017/18	2018/19	2019/20	2020/21
September	25.4	91.8	37.4	80.7	3	18	5	8	8.5	5.1	7.5	10.9
October	28.0	9.2	92.8	12.8	10	4	5	4	2.8	2.3	18.6	3.2
November	36.4	8.8	4.8	63.6	6	2	1	6	6.1	4.4	4.8	10.6
December	22.6	42.8	22.1	8.3	3	7	4	4	7.5	6.1	5.5	2.1
January	9.8	15.2	15.2	9.5	4	2	2	3	2.5	7.6	4.8	3.2
February	5.2	9.0	9.6	1.6	4	4	0	1	1.3	2.3	0.0	1.6
March	10.4	19.7	1.4	39.1	5	8	1	6	2.1	2.5	1.4	6.5
April	46.4	30.3	24.3	14.5	9	7	2	2	5.2	4.3	12.2	7.3
May	65.2	72.5	79.3	144.5	11	12	6	11	5.9	6.0	13.2	13.1
June	146.2	113.2	70.9	158.7	16	10	11	11	9.1	11.3	6.5	14.4
July	53.9	182.0	162.8	120.0	7	15	8	13	7.7	12.1	20.4	9.2
August	79.2	54.3	156.8	148.4	15	8	15	11	5.3	6.8	10.5	13.4

Table 2.5. Rainfall, total number of rainfall days and rainfall per day for Madeba for the 2017/18, 2018/19, 2019/20 and 2020/21 seasons.

Month	Rainfall (mm)				Rainfall days				Rainfall per day (mm/day)			
	2017/18	2018/19	2019/20	2020/21	2017/18	2018/19	2019/20	2020/21	2017/18	2018/19	2019/20	2020/21
September	8.8	42.6	39.6	26.2	5	17	1	4	1.8	2.5	39.6	6.6
October	3.2	4.8	48.6	18.6	5	5	2	5	0.6	1.0	24.3	3.7
November	39.6	8.6	16.4	27.6	5	4	3	4	7.9	2.2	5.5	6.9
December	2.6	15.8	5.6	3.4	2	5	2	3	1.3	3.2	2.8	1.1
January	5.0	0.6	58.2	5.4	6	1	4	2	0.8	0.6	14.6	2.7
February	21.8	16.4	1.8	0.0	2	7	1	0	10.9	2.3	1.8	0.0
March	18.6	40.8	6.2	22.0	11	6	2	4	1.7	6.8	3.1	5.5
April	5.6	6.6	7.2	2.6	8	7	1	2	0.7	0.9	7.2	1.3
May	15.6	11.2	5.2	103.8	8	10	1	7	2.0	1.1	5.2	14.8
June	38.2	23.6	44.5	44.2	17	2	3	7	2.3	11.9	14.8	6.3
July	29.6	26.4	35.0	37.0	16	5	4	8	1.9	5.3	8.8	4.7
August	29.2	1.8	32.0	34.8	16	1	4	8	1.88	1.8	8.0	4.4

Table 2.6. Rainfall, total number of rainfall days and rainfall per day for Lutzville for the 2017/18, 2018/19, 2019/20 and 2020/21 seasons.

Month	Rainfall (mm)				Rainfall days				Rainfall per day (mm/day)			
	2017/18	2018/19	2019/20	2020/21	2017/18	2018/19	2019/20	2020/21	2017/18	2018/19	2019/20	2020/21
September	0.0	23.9	7.6	8.6	0	9	2	5	0.00	2.7	3.8	6.6
October	14.2	2.3	15.5	29.0	3	3	4	1	4.74	0.8	3.9	3.7
November	12.7	0.8	0.0	3.3	4	2	0	3	3.18	0.4	0.0	6.9
December	1.0	3.1	1.8	1.0	1	4	1	1	1.02	0.8	1.8	1.1
January	4.8	1.8	2.3	1.0	2	2	1	1	2.42	0.9	2.3	2.7
February	2.8	0.0	0.0	0.0	3	0	0	0	0.93	0.0	0.0	0.0
March	8.6	1.0	1.5	5.6	2	1	1	4	4.32	1.0	1.5	5.5
April	7.9	3.8	8.1	2.3	7	4	2	1	1.12	1.0	4.1	1.3
May	29.7	30.0	6.4	23.4	9	5	1	4	3.30	6.0	6.4	14.8
June	16.3	16.5	16.3	35.3	10	5	4	8	1.63	3.3	4.1	6.3
July	26.9	31.2	42.9	27.4	4	5	6	7	6.73	5.2	7.2	3.9
August	24.9	6.4	14.7	39.9	10	2	2	7	2.49	3.2	7.4	5.7

Table 2.7. Rainfall, total number of rainfall days and rainfall per day for Vredendal for the 2017/18, 2018/19, 2019/20 and 2020/21 seasons.

Month	Rainfall (mm)				Rainfall days				Rainfall per day (mm/day)			
	2017/18	2018/19	2019/20	2020/21	2017/18	2018/19	2019/20	2020/21	2017/18	2018/19	2019/20	2020/21
September	0.0	22.1	6.1	4.3	0	9	2	4	0.0	2.6	3.1	1.1
October	9.9	3.6	2.0	22.9	3	2	1	2	3.3	1.4	2.0	11.4
November	3.3	1.0	0.0	0.8	3	1	0	1	1.1	0.8	0.0	0.8
December	0.0	1.8	0.8	1.0	0	1	1	1	0.0	1.8	0.8	1.0
January	5.1	0.0	0.0	0.5	1	0	0	1	5.1	0.0	0.0	0.5
February	0.0	0.0	0.0	0.0	0	0	0	0	0.0	0.0	0.0	0.0
March	0.0	0.0	0.0	1.5	0	0	0	2	0.0	0.0	0.0	0.8
April	0.0	0.0	12.7	0.0	0	0	2	0	0.0	0.0	6.4	0.0
May	1.3	20.8	5.8	12.5	3	4	1	4	0.4	5.2	5.8	3.1
June	71.1	9.1	14.2	33.8	5	5	3	8	14.2	1.8	4.7	4.2
July	42.9	22.1	34.8	29.2	6	3	4	5	7.2	7.4	8.7	5.8
August	23.6	1.5	14.5	20.3	12	1	6	6	2.0	1.5	2.4	3.4

As expected, rainfall was higher in the Coastal region in the 2017/18 season than in the other regions (Fig. 2.14). Most of the rainfall occurred during May to August (Fig. 2.14). The experiment plots in the Breede River region also received appreciable amounts of rainfall during the summer months of February and March. The rainfall at the Lutzville and Vredendal experiment plots was low. Given these prevailing conditions, as well as the sandier soils in the Lower Olifants River region with lower water holding capacities, it was expected that the grapevines growing in this region would require more irrigation during the growing season than the other two regions.

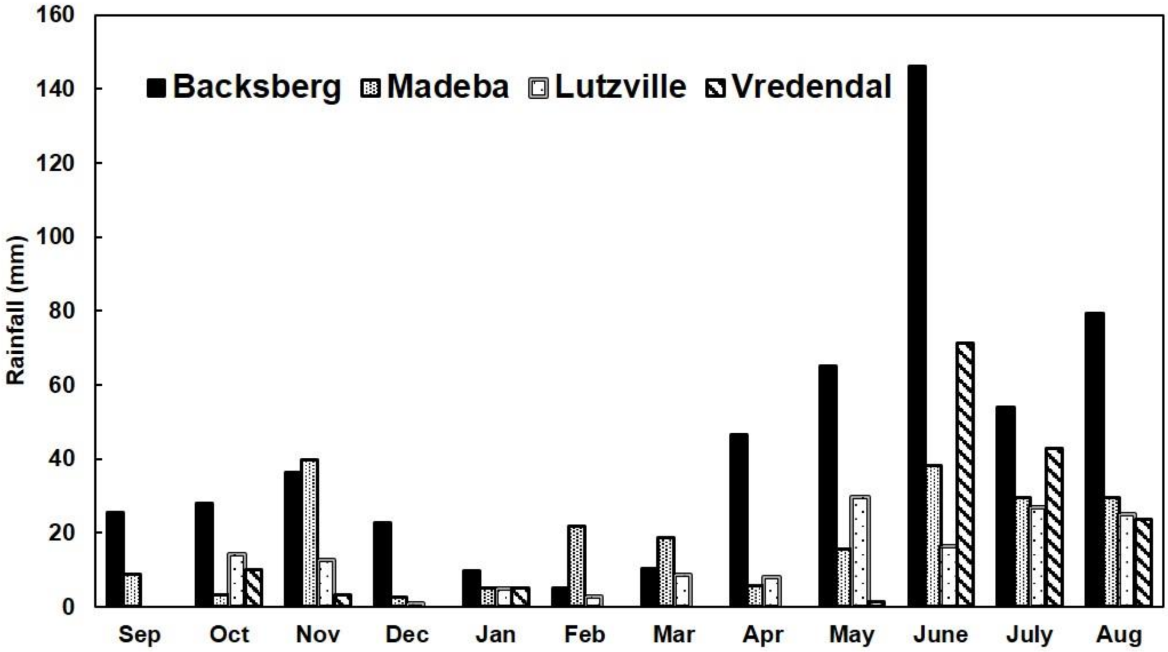

Figure 2.14. Monthly rainfall during the 2017/18 growing season at the experiment plots where grapevines were irrigated *via* the in-field fractional use (augmentation) of winery wastewater with raw water.

The total rainfall during the 2018/19 season was 412.5 mm, 171 mm, 83.1 mm and 59.2 mm for the Coastal region, Breede River region, Lutzville and Vredendal experiment plots, respectively. Most of the rainfall occurred during May to August (Fig. 2.15). The experiment plots in the Breede River region also received appreciable amounts of rainfall during the summer months of February and March. As expected, the experiment plots in the Coastal region received the highest amounts of rainfall throughout the 2018/19 season. The mean monthly rainfall at this site was 37.6 mm, compared to 15.5 mm, 7.6 mm and 5.4 mm at the Breede River, Lutzville and Vredendal experiment plots, respectively. The rainfall at the Lutzville and Vredendal experiment plots was low. As expected, rainfall was higher in the Coastal region than in the other regions (Fig. 2.15).

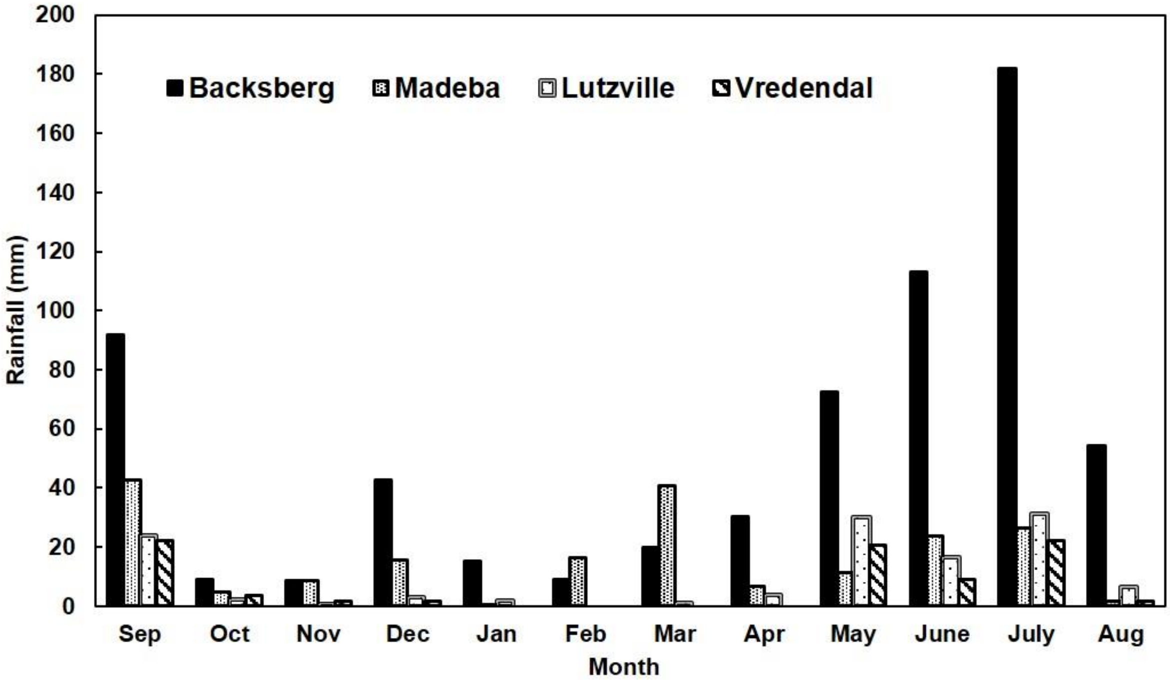

Figure 2.15. Monthly rainfall during the 2018/19 growing season at the experiment plots where grapevines were irrigated *via* the in-field fractional use (augmentation) of winery wastewater with raw water.

The total rainfall from September to May during the 2019/20 season was 271.7 mm, 188.8 mm, 43.2 mm and 27.4 mm for the Coastal region, Breede River region, Lutzville and Vredendal experiment plots, respectively. Most of the rainfall occurred during May to August (Fig. 2.16). The experiment plots in the Breede River region also received appreciable amounts of rainfall during the summer month of January. As expected, the experiment plots in the Coastal region received the highest amounts of rainfall throughout the 2019/20 season. The rainfall at the Lutzville and Vredendal experiment plots was low. As expected, rainfall was higher in the Coastal region than in the other regions (Fig. 2.16).

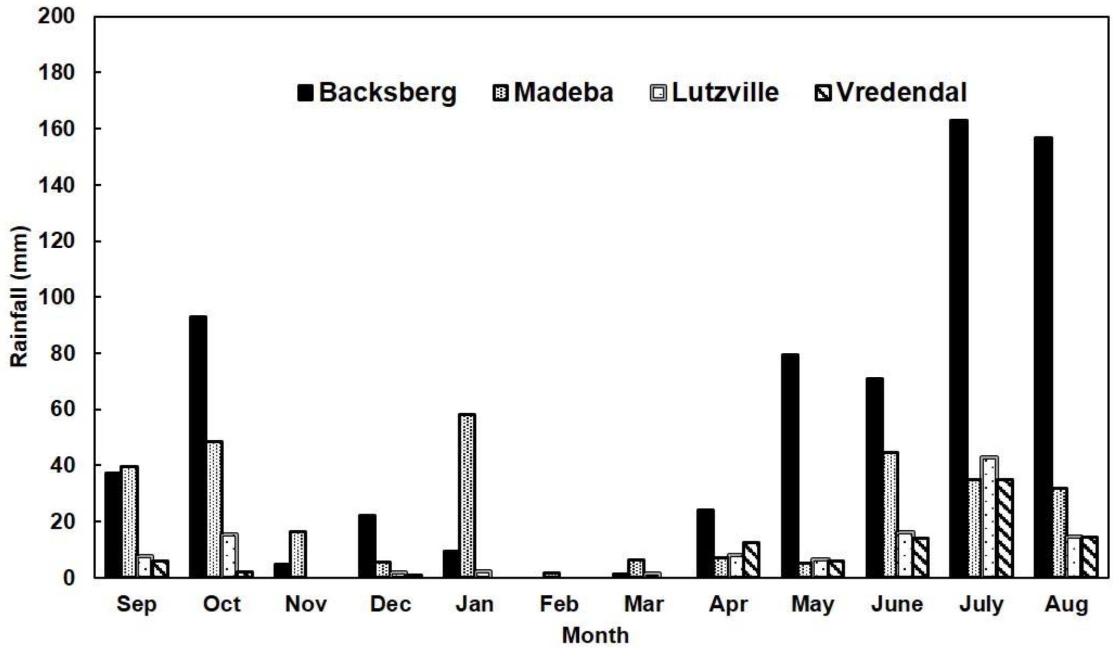

Figure 2.16. Monthly rainfall during the 2019/20 growing season at the experiment plots where grapevines were irrigated *via* the in-field fractional use (augmentation) of winery wastewater with raw water.

The total rainfall from September to June during the 2020/21 season was 533.3 mm, 253.8 mm, 109.5 mm and 77.2 mm for the Coastal region, Breede River region, Lutzville and Vredendal experiment plots, respectively. Most of the rainfall occurred during May to June (Fig. 2.17). The experiment plots in the Breede River region also received appreciable amounts of rainfall during the summer month of January. As expected, the experiment plots in the Coastal region received the highest amounts of rainfall throughout the 2020/21 season. The rainfall at the Lutzville and Vredendal experiment plots was low. As expected, rainfall was higher in the Coastal region than in the other regions (Fig. 2.17).

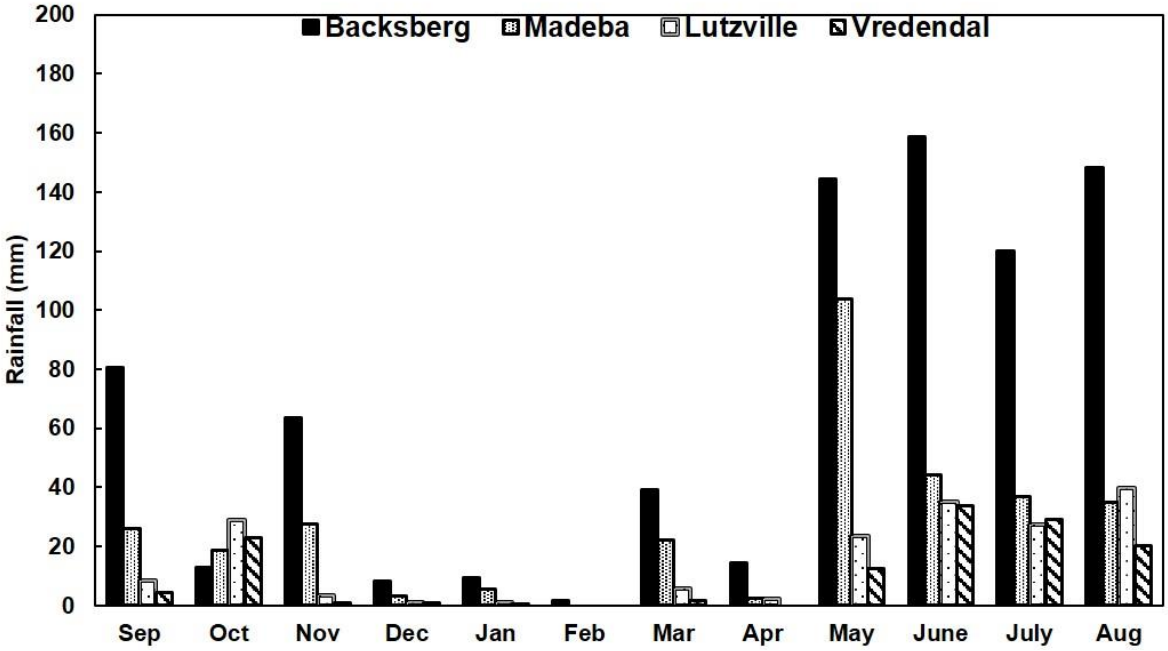

Figure 2.17. Monthly rainfall during the 2020/21 growing season at the experiment plots where grapevines were irrigated *via* the in-field fractional use (augmentation) of winery wastewater with raw water.

2.3.2. Irrigation volumes applied

The average amounts of irrigation water applied in the 2017/18 season is given in Table 2.8.

The total amounts of irrigation water applied in the 2017/18 season is given in Table 2.9.

Table 2.8. Mean amount of winery wastewater (mm) and raw water (mm) applied per irrigation to the different experiment plots where the in-field fractional use (augmentation) of winery wastewater with raw water was used to irrigate grapevines during the 2017/18 season.

Experiment plot	Mean amounts of winery wastewater applied per irrigation (mm)	Mean amounts of raw water applied per irrigation (mm)	Mean total amount of irrigation water applied per irrigation (mm)
Backsberg sand	30.5±6.2	27.9±9.8	58.4±15.9
Backsberg clay	30.5±6.2	27.9±9.8	58.4±15.9
Madeba sandy loam	33.5±8.3	33.1±8.1	66.8±16.5
Madeba clay loam	35.3±5.2	33.5±2.6	68.8±7.8
Lutzville deep sand	37.7±12.8	37.8±12.6	75.5±25.4
Spruitdrift shallow sand	40.2±4.3	39.6±4.1	79.8±8.3

Table 2.9. Total amount of winery wastewater (mm) and raw water (mm) applied per irrigation to the different experiment plots where the in-field fractional use (augmentation) of winery wastewater with raw water was used to irrigate grapevines during the 2017/18 season.

Experiment plot	Total amounts of winery wastewater applied (mm)	Total amounts of raw water applied (mm)	Total amount of irrigation water applied (mm)
Backsberg sand	61.0	55.9	116.9
Backsberg clay	61.0	55.9	116.9
Madeba sandy loam	67.0	66.7	133.7
Madeba clay loam	70.7	66.9	137.6
Lutzville deep sand	188.4	189.2	377.6
Spruitdrift shallow sand	241.0	237.7	478.6

The average amounts of irrigation water applied in the 2018/19 season is given in Table 2.10. The total amounts of irrigation water applied in the 2018/19 season is given in Table 2.11.

Table 2.10. Mean amount of winery wastewater (mm) and raw water (mm) applied per irrigation to the different experiment plots where the in-field fractional use (augmentation) of winery wastewater with raw water was used to irrigate grapevines during the 2018/19 season.

Experiment plot	Mean amounts of winery wastewater applied per irrigation (mm)	Mean amounts of raw water applied per irrigation (mm)	Mean total amount of irrigation water applied per irrigation (mm)
Backsberg sand	33.6±2.4	32.7±2.6	66.3±4.9
Backsberg clay	20.2±3.5	25.0±5.4	45.2±4.3
Madeba sandy loam	28.7±7.2	27.3±7.9	56.0±14.9
Madeba clay loam	28.2±11.8	29.8±10.6	58.0±22.5
Lutzville deep sand	43.4±5.3	42.9±21	84.5±23.6
Spruitdrift shallow sand(1)	25.6±10.2	55.9±17.4	81.5±15.5

(1) Fractional ratio of winery wastewater to raw water changed to 0.25.

Table 2.11. Total amount of winery wastewater (mm) and raw water (mm) applied per irrigation to the different experiment plots where the in-field fractional use (augmentation) of winery wastewater with raw water was used to irrigate grapevines during the 2018/19 season.

Experiment plot	Total amounts of winery wastewater applied (mm)	Total amounts of raw water applied (mm)	Total amount of irrigation water applied (mm)
Backsberg sand	100.7	220.7(1)	321.5(1)
Backsberg clay	60.7	74.9	135.6
Madeba sandy loam	86.1	82.0	168.1
Madeba clay loam	56.5	209.6(2)	266.0(2)
Lutzville deep sand	216.8	171.7	338.2
Spruitdrift shallow sand(3)	230.5	502.9	733.4

(1) Includes 122.7 mm raw water applied before winery wastewater became available.
(2) Includes 150.0 mm raw water applied before winery wastewater became available.
(3) Fractional ratio of winery wastewater to raw water changed to 0.25.

The average amounts of irrigation water applied in the 2019/20 season is given in Table 2.12.

The total amounts of irrigation water applied in the 2019/20 season is given in Table 2.13.

Table 2.12. Mean amount of winery wastewater (mm) and raw water (mm) applied per irrigation to the different experiment plots where the in-field fractional use (augmentation) of winery wastewater with raw water was used to irrigate grapevines during the 2019/20 season.

Experiment plot	Mean amounts of winery wastewater applied per irrigation (mm)	Mean amounts of raw water applied per irrigation (mm)	Mean total amount of irrigation water applied per irrigation (mm)
Backsberg sand	30.3	32.3	62.5
Backsberg clay	30.3	32.3	62.5
Madeba sandy loam	28.0	56.0	84.0
Madeba clay loam	31.7	53.9	85.68
Lutzville deep sand	35.4	44.2	79.6

Table 2.13. Total amount of winery wastewater (mm) and raw water (mm) applied per irrigation to the different experiment plots where the in-field fractional use (augmentation) of winery wastewater with raw water was used to irrigate grapevines during the 2019/20 season.

Experiment plot	Total amounts of winery wastewater applied (mm)	Total amounts of raw water applied (mm)	Total amount of irrigation water applied (mm)
Backsberg sand	90.8	259.3(1)	350.1(1)
Backsberg clay	90.8	259.3(1)	350.1(1)
Madeba sandy loam	55.9	510.9(2)	566.8(2)
Madeba clay loam	63.4	523.7(3)	587.1(3)
Lutzville deep sand	141.5	737.0(4)	878.5(4)

(1) Includes 162.5 mm raw water applied before winery wastewater became available.
(2) Includes 398.9 mm raw water applied before winery wastewater became available.
(3) Includes 415.9 mm raw water applied before winery wastewater became available.
(4) Includes 560.1 mm raw water applied before winery wastewater became available.

The average amounts of irrigation water applied in the 2020/21 season is given in Table 2.14.

The total amounts of irrigation water applied in the 2020/21 season is given in Table 2.15.

Table 2.14. Mean amount of winery wastewater (mm) and raw water (mm) applied per irrigation to the different experiment plots where the in-field fractional use (augmentation) of winery wastewater with raw water was used to irrigate grapevines during the 2020/21 season.

Experiment plot	Mean amounts of winery wastewater applied per irrigation (mm)	Mean amounts of raw water applied per irrigation (mm)	Mean total amount of irrigation water applied per irrigation (mm)
Backsberg sand	28.5	29.2	57.6
Backsberg clay	28.5	29.2	57.6
Madeba sandy loam	16.2	47.8	64.0
Madeba clay loam	17.5	47.6	65.2
Lutzville deep sand	31.6	41.8	73.4

Table 2.15. Total amount of winery wastewater (mm) and raw water (mm) applied per irrigation to the different experiment plots where the in-field fractional use (augmentation) of winery wastewater with raw water was used to irrigate grapevines during the 2020/21 season.

Experiment plot	Total amounts of winery wastewater applied (mm)	Total amounts of raw water applied (mm)	Total amount of irrigation water applied (mm)
Backsberg sand	113.8	413.8$^{(1)}$	527.6$^{(1)}$
Backsberg clay	113.8	347.6$^{(2)}$	461.4$^{(2)}$
Madeba sandy loam	32.4	445.9$^{(3)}$	478.3$^{(3)}$
Madeba clay loam	35.0	465.7$^{(4)}$	500.7$^{(4)}$
Lutzville deep sand	63.2	735.0$^{(5)}$	798.2$^{(5)}$

(1) Includes 297.1 mm raw water applied before winery wastewater became available.
(2) Includes 231.0 mm raw water applied before winery wastewater became available.
(3) Includes 350.3 mm raw water applied before winery wastewater became available.
(4) Includes 370.4 mm raw water applied before winery wastewater became available.
(5) Includes 577.5 mm raw water applied before winery wastewater became available and 73.9 mm applied in April.

2.3.3. Water quality

2017/18 season: During the 2017/18 season, the COD level in the winery wastewater at Backsberg was *c.* 2 000 mg/L (Table 2.16). Up to 50 m^3, 500 m^3 and 2 000 m^3 of wastewater may be irrigated on any given day provided that the COD is lower than 5 000 mg/L, 400 mg/L and 40 mg/L, respectively (Department of Water Affairs, 2013). The pH of the winery wastewater was lower than that of the raw water. The pH levels were also below the recommended pH for irrigation water, which ranges from 6.5 to 8.4 (Department of Water Affairs & Forestry, 1996). According to the General Authorisations of 2013, up to 500 m^3 of wastewater may be irrigated on any given day provided that the pH is between 6 and 9 (Department of Water Affairs, 2013). The electrical conductivity (EC) was higher in the winery wastewater. The EC in the winery wastewater exceeded the critical value of 0.8 dS/m, *i.e.* the salinity threshold for water used in the irrigation of grapevines. With regard to the General Authorisations of 2013 (Department of Water Affairs, 2013), up to 500 m^3 of wastewater may be irrigated on any given day provided that the EC_{iw} is less than 2 dS/m. There were no consistent trends for NH_4-N and NO_3-N in the waters. The P levels were higher in the winery wastewater compared to the raw water (Table 2.16). As expected, K levels were substantially higher in the winery wastewater. Therefore, the PAR of the winery wastewater was substantially higher than the raw water. The Ca, Mg and Na was higher in the winery wastewater compared to the raw water. However, SAR was similar. This suggested that the increase in Ca and Mg counterbalanced the effect of increased Na on the SAR. The SAR was still within acceptable limits for the irrigation of grapevines, *i.e*. < *c.* 6. With regard to the

General Authorisations of 2013, up to 500 m^3 of wastewater may be irrigated on any given day provided that the SAR is less than 5 (Department of Water Affairs, 2013). Boron, Mn, Cu, Zn and Fe were higher in the winery wastewater compared to the raw water (Table 2.17). No trends were evident for Cl, HCO_3 and SO_4 levels in the water.

During the 2017/18 season, the COD level in the winery wastewater at Madeba was *c.* 6 010 mg/L (Table 2.18). The pH of the winery wastewater was lower than that of the raw water. The EC was higher in the winery wastewater. The EC in the winery wastewater exceeded the critical value of 0.8 dS/m for the second irrigation. There was no NH_4-N and NO_3-N in the waters. The P levels were higher in the winery wastewater compared to the raw water (Table 2.18). As expected, K levels were substantially higher in the winery wastewater. Therefore, the PAR of the winery wastewater was substantially higher than the raw water. The Ca, Mg and Na was higher in the winery wastewater compared to the raw water. However, SAR was similar. This suggested that the increase in Ca and Mg counterbalanced the effect of increased Na on the SAR. The SAR was still within acceptable limits for the irrigation of grapevines, *i.e*. < *c.* 6. Boron, Mn, Cu, Zn and Fe were higher in the winery wastewater compared to the raw water (Table 2.19). The Cl, HCO_3 and SO_4 levels in the winery wastewater were higher than the raw water.

During the 2017/18 season, the COD level in the winery wastewater at Lutzville ranged from 1 760 mg/L to 9 130 mg/L (Table 2.20). The pH of the winery wastewater was similar to that of the raw water. The EC was higher in the winery wastewater. The EC in the winery wastewater exceeded the critical value of 0.8 dS/m for all irrigations. The NH_4-N and NO_3-N levels in the winery wastewater was higher than in the raw water. The P levels were consistently higher in the winery wastewater compared to the raw water. As expected, K levels were substantially higher in the winery wastewater. Therefore, the PAR of the winery wastewater was substantially higher than the raw water. The Ca, Mg and Na was higher in the winery wastewater compared to the raw water. However, SAR was similar or even lower in the case of the winery wastewater. This suggested that the increase in Ca and Mg counterbalanced the effect of increased Na on the SAR. The SAR was still within acceptable limits for the irrigation of grapevines, *i.e*. < *c.* 6. Boron, Mn, Zn and Fe were higher in the winery wastewater compared to the raw water (Table 2.21). The Cl, HCO_3 and SO_4 levels in the winery wastewater were higher than the raw water.

During the 2017/18 season, the COD level in the winery wastewater at Spruitdrift ranged from 3 680 mg/L to 12 380 mg/L (Table 2.22). In general, the pH of the winery wastewater was lower than that of the raw water. The EC was higher in the winery wastewater. The EC in the winery wastewater exceeded the critical value of 0.8 dS/m for all irrigations. The NH_4-N levels in the winery wastewater was higher than in the raw water. The P levels were consistently higher in the winery wastewater compared to the raw water. As expected, K levels were substantially higher in the winery wastewater. Therefore, the PAR of the winery wastewater was substantially higher than the raw water. The Ca, Mg and Na was higher in the winery wastewater compared to the raw water. The SAR was generally higher in the case of the winery wastewater. This suggested that the increase in Ca and Mg could not counterbalance the effect of increased Na on the SAR. The SAR was still within acceptable limits for the irrigation of grapevines, *i.e*. < *c.* 6. Boron, Mn, Zn and Fe were higher in the winery wastewater compared to the raw water (Table 2.23). The Cl, HCO_3 and SO_4 levels in the winery wastewater were higher than the raw water.

Taking the water quality measured in the 2017/18 season for the undiluted winery wastewater used for its in-field fractional use (augmentation) with raw water for vineyard irrigation into consideration, the average pH, EC, COD, K, PAR, Na and SAR was 4.95, 1.10 dS/m, 2 010 mg/L, 203 mg/L, 7.43, 28 mg/L and 1.70 for the Backsberg experiment plots, respectively. Average pH, EC, COD, K, PAR, Na and SAR was 5.40, 2.96 dS/m, 6 010 mg/L, 265 mg/L, 5.17, 34 mg/L and 1.15 for the Madeba experiment plots, respectively. Average pH, EC, COD, K, PAR, Na and SAR was 6.58, 3.94 dS/m, 3 685 mg/L, 494 mg/L, 4.27, 82 mg/L and 1.21 for the Lutzville deep sand experiment plot, respectively. Average pH, EC, COD, K, PAR, Na and SAR was 6.25, 58, 3.85 dS/m, 6 812 mg/L, 441 mg/L, 4.47, 250 mg/L and 4.92 for the Spruitdrift shallow sand experiment plot, respectively.

Table 2.16. The pH, EC, COD, NH_4-N, NO_3-N, Total-N, P, Ca, Mg, K, PAR, Na and SAR in water used for the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Cabernet Sauvignon at Backsberg during the 2017/18 season.

Irrigation no.	pH	EC (dS/m)	COD (mg/L)	NH_4-N (mg/L)	NO_3-N (mg/L)	Total-N (mg/L)	P (mg/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	PAR	Na (mg/L)	SAR
						Raw water							
1	6.5	0.18	53	0.00	0.00	0.00	0.00	2.5	3.4	2.0	0.12	15.2	1.48
2	6.8	0.24	34	345.85	0.00	345.85	0.02	2.8	5.0	3.3	0.16	29.5	2.47
						Winery wastewater							
1	4.8	1.14	1 910	0.00	0.00	0.00	6.86	7.8	4.6	202.2	8.42	23.1	1.63
2	5.1	1.06	2 110	345.53	0.46	345.99	11.79	15.5	6.7	203.3	6.44	32.9	1.77

Table 2.17. The B, Mn, Cu, Zn, Fe, Cl, HCO_3, SO_4 and F in water used for the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Cabernet Sauvignon at Backsberg during the 2017/18 season.

Irrigation no.	B (mg/L)	Mn (mg/L)	Cu (mg/L)	Zn (mg/L)	Fe (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	SO_4 (mg/L)	F (mg/L)
					Raw water				
1	0.00	0.06	0.00	0.07	0.9	37	41	7	0.0
2	0.00	0.05	0.00	0.00	0.5	54	46	12	0.3
					Winery wastewater				
1	0.08	0.06	0.04	0.46	2.7	43	0	15	0.0
2	0.10	0.13	0.00	0.19	5.5	51	0	6	0.1

Table 2.18. The pH, EC, COD, NH_4-N, NO_3-N, Total-N, P, Ca, Mg, K, PAR, Na and SAR in water used for the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Shiraz at Madeba during the 2017/18 season.

Irrigation no.	pH	EC (dS/m)	COD (mg/L)	NH_4-N (mg/L)	NO_3-N (mg/L)	Total-N (mg/L)	P (mg/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	PAR	Na (mg/L)	SAR
Raw water													
1	5.6	0.17	4	0.00	0.00	0.00	0.01	2.7	3.5	0.8	0.05	15.1	1.44
2	7.0	0.25	10	0.00	0.00	0.00	0.02	4.5	6.0	1.2	0.05	27.8	2.04
Winery wastewater													
1	4.5	0.66	4 720	0.00	0.00	0.00	1.46	34.5	10.1	82.0	1.87	18.8	0.73
2	6.3	5.25	7 300	0.00	0.00	0.00	5.43	46.4	16.8	447.1	8.47	49.0	1.57

Table 2.19. The B, Mn, Cu, Zn, Fe, Cl, HCO_3, SO_4 and F in water used for the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Shiraz at Madeba during the 2017/18 season.

Irrigation no.	B (mg/L)	Mn (mg/L)	Cu (mg/L)	Zn (mg/L)	Fe (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	SO_4 (mg/L)	F (mg/L)
Raw water									
1	0.00	0.00	0.00	0.00	0.5	43	26	8	0.0
2	0.00	0.00	0.03	0.04	0.4	63	29	12	0.2
Winery wastewater									
1	0.18	0.32	0.03	5.46	1.9	45	0	26	0.0
2	0.57	0.28	0.44	6.63	3.6	86	2361	71	0.1

Table 2.20. The pH, EC, COD, NH_4-N, NO_3-N, Total-N, P, Ca, Mg, K, PAR, Na and SAR in water used for the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Shiraz at Lutzville during the 2017/18 season.

Irrigation no.	pH	EC (dS/m)	COD (mg/L)	NH_4-N (mg/L)	NO_3-N (mg/L)	Total-N (mg/L)	P (mg/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	PAR	Na (mg/L)	SAR
Raw water													
1	7.0	0.28	70	0.39	0.00	0.39	0.03	5.2	5.8	2.0	0.09	32.3	2.33
2	6.9	0.25	0	0.30	0.00	0.30	0.00	6.1	6.2	2.5	0.10	32.0	2.20
3	6.8	0.24	12	0.15	0.00	0.15	0.01	5.5	5.3	2.3	0.10	25.9	1.89
4	6.7	0.23	24	0.00	0.00	0.00	0.02	4.8	4.3	2.0	0.09	19.7	1.59
5	6.9	0.45	16	0.00	0.00	0.00	0.04	10.1	9.9	9.3	0.30	55.0	2.97
Winery wastewater													
1	7.5	3.18	1 780	4.21	0.00	4.21	6.45	280.3	14.5	395.2	3.68	45.8	0.72
2	6.5	3.99	3 250	6.73	0.00	6.73	9.62	332.4	32.0	529.8	4.39	100.6	1.41
3	6.8	4.00	2 505	18.51	0.00	18.51	7.05	292.1	30.5	504.4	4.44	103.3	1.55
4	7.0	4.01	1 760	30.29	0.00	30.29	4.47	251.8	29.0	479.0	4.50	106.0	1.69
5	5.1	4.50	9 130	17.25	0.00	17.25	24.43	395.8	28.5	561.5	4.33	52.1	0.68

Table 2.21. The B, Mn, Cu, Zn, Fe, Cl, HCO_3, SO_4 and F in water used for the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Shiraz at Lutzville during the 2017/18 season.

Irrigation no.	B (mg/L)	Mn (mg/L)	Cu (mg/L)	Zn (mg/L)	Fe (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	SO_4 (mg/L)	F (mg/L)
					Raw water				
1	0.00	0.00	0.00	0.00	0.1	67	28	12	0.2
2	0.00	0.00	0.00	0.00	0.1	60	26	13	0.1
3	0.05	0.00	0.00	0.02	0.1	59	24	12	0.1
4	0.10	0.00	0.00	0.04	0.1	57	22	11	0.1
5	0.00	0.00	0.03	0.00	0.1	122	20	35	0.2
					Winery wastewater				
1	0.57	0.37	0.00	0.04	0.4	57	1848	86	0.8
2	0.87	0.17	0.00	0.06	0.6	254	2247	578	0.1
3	0.81	0.11	0.00	0.03	0.4	195	2311	1147	0.4
4	0.75	0.05	0.00	0.00	0.2	135	2375	1716	0.6
5	0.70	0.30	0.10	0.15	3.7	104	0	188	0.3

Table 2.22. The pH, EC, COD, NH_4-N, NO_3-N, Total-N, P, Ca, Mg, K, PAR, Na and SAR in water used for the in-field fractional use of winery wastewater with raw water for irrigation of Cabernet Sauvignon at Spruitdrift during the 2017/18 season.

Irrigation no.	pH	EC (dS/m)	COD (mg/L)	NH_4-N (mg/L)	NO_3-N (mg/L)	Total-N (mg/L)	P (mg/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	PAR	Na (mg/L)	SAR
Raw water													
1	7.1	0.30	20	0.00	0.00	0.00	0.06	5.5	6.8	3.0	0.12	36.9	2.51
2	7.5	0.28	42	0.00	0.00	0.00	0.00	3.8	6.4	2.0	0.09	32.0	2.35
3	7.1	0.25	0	0.29	0.00	0.29	0.00	5.8	7.1	2.3	0.09	31.8	2.11
4	6.2	0.22	0	0.00	0.00	0.00	0.00	4.1	4.7	1.6	0.08	19.0	1.53
5	6.5	0.22	15	0.00	0.00	0.00	0.02	3.8	4.4	1.6	0.08	17.4	1.45
6	5.6	0.23	40	50.08	0.00	50.08	0.00	4.7	5.6	2.4	0.11	24.5	1.82
Winery wastewater													
1	6.4	5.33	7 220	7.89	0.00	7.89	16.13	75.1	30.7	507.9	7.39	726.1	17.91
2	7.2	3.09	4 660	19.45	0.00	19.45	14.25	218.6	22.1	480.7	4.89	191.0	3.30
3	7.0	3.89	4 290	4.47	0.00	4.47	8.01	256.9	23.1	520.3	4.92	154.6	2.48
4	6.9	3.73	3 680	0.00	0.00	0.00	7.29	207.4	21.6	422.8	4.41	119.5	2.11
5	5.7	4.10	8 640	19.15	0.00	19.15	24.49	503.0	43.8	364.4	2.47	213.5	2.45
6	4.3	2.94	12 380	0.00	0.00	0.00	22.76	366.5	36.5	349.1	2.75	95.2	1.27

Table 2.23. The B, Mn, Cu, Zn, Fe, Cl, HCO_3, SO_4 and F in water used for the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Cabernet Sauvignon at Spruitdrift during the 2017/18 season.

Irrigation no.	B (mg/L)	Mn (mg/L)	Cu (mg/L)	Zn (mg/L)	Fe (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	SO_4 (mg/L)	F (mg/L)
Raw water									
1	0.00	0.00	0.00	0.00	0.0	65	33	13	0.2
2	0.00	0.00	0.00	0.00	0.2	73.8	32	13	0.1
3	0.00	0.03	0.00	0.00	0.2	59	31	14	0.1
4	0.00	0.03	0.04	0.04	0.1	59	28	10	0.0
5	0.00	0.00	0.00	0.00	0.0	60	21	14	0.0
6	0.00	0.04	0.00	0.00	0.1	58	17	13	0.1
Winery wastewater									
1	1.03	0.58	0.00	0.05	2.3	264	1604	77	0.2
2	0.57	0.19	0.00	0.00	1.6	118	1535	50	0.1
3	0.76	0.14	0.00	0.04	1.5	155	2040	52	0.1
4	0.45	0.12	0.00	0.00	0.7	170	1262	995	0.1
5	0.73	0.29	0.00	0.05	1.6	201	1306	2863	0.0
6	0.87	0.40	0.02	0.06	5.5	161	0	734	0.1

2018/19 season: During the 2018/19 season, the COD level in the winery wastewater at Backsberg was generally low (Tables 2.24 & 2.26). The pH of the winery wastewater was lower than that of the raw water. The EC was higher in the winery wastewater. The EC in the winery wastewater exceeded the critical value of 0.8 dS/m, *i.e.* the salinity threshold for water used in the irrigation of grapevines. There were no consistent trends for NH_4-N and NO_3-N in the waters. The P levels were higher in the winery wastewater compared to the raw water (Tables 2.24 & 2.26). As expected, K levels were substantially higher in the winery wastewater. Therefore, the PAR of the winery wastewater was substantially higher than the raw water. The Ca, Mg and Na was higher in the winery wastewater compared to the raw water. However, SAR was similar. This suggested that the increase in Ca and Mg counterbalanced the effect of increased Na on the SAR. The SAR was still within acceptable limits for the irrigation of grapevines, *i.e*. < *c.* 6. Boron, Mn, Zn, Fe, Cl and HCO_3 were higher in the winery wastewater compared to the raw water (Tables 2.25 & 2.27). No trends were evident for SO_4 levels in the water.

During the 2018/19 season, the COD level in the winery wastewater at Madeba was *c.* 8 565 mg/L (Tables 2.28 & 2.30) with the exception of the last irrigation applied to the sandy loam experiment plot. The pH of the winery wastewater was lower than that of the raw water. The EC was higher in the winery wastewater. The EC in the winery wastewater exceeded the critical value of 0.8 dS/m for the second irrigation. There was generally no NH_4-N and NO_3-N in the waters. The P levels were slightly higher in the winery wastewater compared to the raw water (Tables 2.28 & 2.30). As expected, K levels were substantially higher in the winery wastewater. Therefore, the PAR of the winery wastewater was substantially higher than the raw water. The Ca, Mg and Na was higher in the winery wastewater compared to the raw water. However, SAR was similar. This suggested that the increase in Ca and Mg counterbalanced the effect of increased Na on the SAR. The SAR was still within acceptable limits for the irrigation of grapevines, *i.e*. < *c.* 6. Boron, Mn, Cu, Zn and Fe were higher in the winery wastewater compared to the raw water (Tables 2.29 & 2.31). The Cl, HCO_3 and SO_4 levels in the winery wastewater were higher than the raw water.

During the 2018/19 season, the COD level in the winery wastewater at Lutzville ranged from 79 mg/L to 14 400 mg/L (Table 2.32). The pH of the winery wastewater was similar to that of the raw water. The EC was higher in the winery wastewater. The EC in the winery wastewater exceeded the critical value of 0.8 dS/m for all irrigations. The NH_4-N levels in the winery wastewater was higher than in the raw water. The P levels were consistently higher in the winery wastewater compared to the raw water. As expected, K levels were substantially higher in the winery wastewater. Therefore, the PAR of the winery wastewater was substantially higher than the raw water. The Ca, Mg and Na was higher in the winery wastewater compared to the raw water. However, SAR was similar or even lower in the case of the winery wastewater. This suggested that the increase in Ca and Mg counterbalanced the effect of increased Na on the SAR. The SAR was still within acceptable limits for the irrigation of grapevines, *i.e*. < *c.* 6. Boron, Mn, Zn and Fe were higher in the winery wastewater compared to the raw water (Table 2.33). The Cl, HCO_3 and SO_4 levels in the winery wastewater were higher than the raw water.

During the 2018/19 season, the COD level in the winery wastewater at Spruitdrift ranged from 1 353 mg/L to 16 420 mg/L (Table 2.34). In general, the pH of the winery wastewater was lower than that of the raw water. The EC was higher in the winery wastewater. The EC in the winery wastewater exceeded the critical value of 0.8 dS/m for all irrigations. The NH_4-N levels in the winery wastewater was higher than in the raw water. The P levels were consistently higher in the winery wastewater compared to the raw water. As expected, K levels were substantially higher in the winery wastewater. Therefore, the PAR of the winery wastewater was substantially higher than the raw water. The Ca, Mg and Na was higher in the winery wastewater compared to the raw water. The SAR was generally higher in the case of the winery wastewater. This suggested that the increase in Ca and Mg could not counterbalance the effect of increased Na on the SAR. With the exception of two irrigations, the SAR was still within acceptable limits for the irrigation of grapevines, *i.e*. < *c.* 6. Boron, Mn, Zn and Fe were higher in the winery wastewater compared to the raw water (Table 2.35). The Cl, HCO_3 and SO_4 levels in the winery wastewater were higher than the raw water.

Taking the water quality measured in the 2018/19 season for the undiluted winery wastewater used for its in-field fractional use (augmentation) with raw water for vineyard irrigation into consideration, the average pH, EC, COD, K, PAR, Na and SAR was 5.97, 1.11 dS/m, 1 382 mg/L, 277 mg/L, 7.78, 32 mg/L and 1.52 for the Backsberg experiment plots, respectively. Average pH, EC, COD, K, PAR, Na and SAR was 4.87, 0.79 dS/m, 5 734 mg/L, 136 mg/L, 2.73, 30 mg/L and 1.01 for the Madeba experiment plots, respectively. Average pH, EC, COD, K, PAR, Na and SAR was 5.72, 3.21 dS/m, 6 906 mg/L, 557 mg/L, 5.54, 133 mg/L and 2.32 for the Lutzville deep sand experiment plot, respectively. Average pH, EC, COD, K, PAR, Na and SAR was 5.26, 1.75 dS/m, 6 666 mg/L, 246 mg/L, 3.45, 155 mg/L and 3.47 for the Spruitdrift shallow sand experiment plot, respectively.

Table 2.24. The pH, EC, COD, NH_4-N, NO_3-N, Total-N, P, Ca, Mg, K, PAR, Na and SAR in water used for the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Cabernet Sauvignon at the Backsberg sand experiment plot during the 2018/19 season.

Irrigation no.	pH	EC (dS/m)	COD (mg/L)	NH_4-N (mg/L)	NO_3-N (mg/L)	Total-N (mg/L)	P (mg/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	PAR	Na (mg/L)	SAR
Raw water													
1	6.9	0.17	0	0.00	0.00	0.00	0.0	4.4	3.5	1.7	0.09	8.5	0.74
2	6.1	0.20	0	0.00	0.00	0.00	0.0	22.1	3.6	2.8	0.09	14.8	0.77
3	6.7	0.18	0	0.00	0.00	0.00	0.0	5.8	4.3	2.3	0.10	12.5	0.97
4	6.9	0.14	0	0.00	0.00	0.00	0.0	4.9	3.6	3.1	0.15	17.8	1.50
5	6.7	0.22	25	0.00	0.00	0.00	0.0	5.9	5.4	4.3	0.18	23.1	1.67
Winery wastewater													
1[(1)]	-	-	-	-	-	-	-	-	-	-	-	-	-
2[(1)]	-	-	-	-	-	-	-	-	-	-	-	-	-
3	6.3	1.05	996	11.93	0.00	11.93	12.5	24.9	9.8	207.1	5.27	41.9	1.81
4	6.4	0.90	702	6.36	0.00	6.36	12.7	19.3	5.6	224.8	6.86	29.4	1.52
5	5.6	1.15	2 830	14.05	0.63	14.70	16.5	17.1	8.6	230.5	6.73	44.8	2.22

[(1)] No winery wastewater was applied for this irrigation.

Table 2.25. The B, Mn, Cu, Zn, Fe, Cl, HCO_3, SO_4 and F in water used for the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Cabernet Sauvignon at the Backsberg sand experiment plot during the 2018/19 season.

Irrigation no.	B (mg/L)	Mn (mg/L)	Cu (mg/L)	Zn (mg/L)	Fe (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	SO_4 (mg/L)	F (mg/L)
Raw water									
1	0.08	0.00	0.00	0.09	0.26	35	41	7	0.10
2	0.17	0.24	0.00	0.49	1.23	37	43	9	0.00
3	0.00	0.00	0.00	0.10	0.41	14	44	8	0.60
4	0.00	0.02	0.00	0.00	0.22	37	15	6	0.10
5	0.00	0.04	0.00	0.14	0.58	46	56	10	0.10
Winery wastewater									
1[(1)]	-	-	-	-	-	-	-	-	-
2[(1)]	-	-	-	-	-	-	-	-	-
3	0.23	0.13	0.03	0.20	4.04	15	539	16	0.50
4	0.00	0.08	0.00	0.17	4.16	67	325	10	0.20
5	0.42	0.11	0.00	0.12	5.58	54	514	13	0.10

[(1)] No winery wastewater was applied for this irrigation.

Table 2.26. The pH, EC, COD, NH_4-N, NO_3-N, Total-N, P, Ca, Mg, K, PAR, Na and SAR in water used for the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Cabernet Sauvignon at the Backsberg clay experiment plot during the 2018/19 season.

Irrigation no.	pH	EC (dS/m)	COD (mg/L)	NH_4-N (mg/L)	NO_3-N (mg/L)	Total-N (mg/L)	P (mg/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	PAR	Na (mg/L)	SAR
Raw water													
1	7.0	0.20	0	0.00	0.00	0.00	0.1	6.1	6.4	3.4	0.14	7.8	0.53
2	6.9	0.17	24	0.00	0.00	0.00	0.0	6.7	5.1	4.1	0.17	20.2	1.44
3	6.7	0.19	9	0.10	0.14	0.24	0.0	6.9	5.6	5.3	0.22	30.0	2.07
Winery wastewater													
1	5.9	0.97	814	16.16	0.00	16.16	13.7	24.1	11.8	202.4	5.01	15.1	0.63
2	6.3	1.56	589	14.96	0.00	14.96	14.6	21.4	6.5	464.9	13.37	29.6	1.44
3	5.3	1.02	2 360	15.87	0.07	15.94	13.0	20.0	7.7	331.0	9.44	31.0	1.50

Table 2.27. The B, Mn, Cu, Zn, Fe, Cl, HCO_3, SO_4 and F in water used for the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Cabernet Sauvignon at the Backsberg clay experiment plot during the 2018/19 season.

Irrigation no.	B (mg/L)	Mn (mg/L)	Cu (mg/L)	Zn (mg/L)	Fe (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	SO_4 (mg/L)	F (mg/L)
Raw water									
1	0.24	0.04	0.00	0.04	0.54	40	49	17	0.30
2	0.00	0.10	0.00	0.04	0.52	36	38	9	0.20
3	0.00	0.00	0.02	0.09	0.00	39	53	12	0.21
Winery wastewater									
1	0.33	0.13	0.04	1.26	4.86	80	303	39	0.40
2	0.11	0.11	0.00	0.08	4.49	63	638	7	0.40
3	0.13	0.12	0.00	0.15	1.50	41	445	5	0.61

Table 2.28. The pH, EC, COD, NH_4-N, NO_3-N, Total-N, P, Ca, Mg, K, PAR, Na and SAR in water used for the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Shiraz at the Madeba sandy loam experiment plot during the 2018/19 season.

Irrigation no.	pH	EC (dS/m)	COD (mg/L)	NH_4-N (mg/L)	NO_3-N (mg/L)	Total-N (mg/L)	P (mg/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	PAR	Na (mg/L)	SAR
						Raw water							
1	6.3	0.18	0	0.00	0.00	0.00	0.0	6.1	4.3	1.4	0.06	10.9	0.83
2	6.3	0.17	11	0.00	0.00	0.00	0.0	5.4	4.1	1.0	0.05	16.7	1.33
3	7.0	0.21	0	0.00	0.00	0.00	0.0	8.3	6.3	3.7	0.14	31.0	1.99
						Winery wastewater							
1	3.5	0.91	9 087	0.00	0.00	0.00	1.6	45.4	17.4	154.4	2.93	29.3	0.94
2	4.2	1.06	8 042	0.00	0.00	0.00	1.3	39.8	13.4	238.2	4.94	24.2	0.85
3	6.9	0.40	72	0.63	0.00	0.63	0.2	39.0	15.0	16.0	0.33	36.0	1.25

Table 2.29. The B, Mn, Cu, Zn, Fe, Cl, HCO_3, SO_4 and F in water used for the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Shiraz at the Madeba sandy loam experiment plot during the 2018/19 season.

Irrigation no.	B (mg/L)	Mn (mg/L)	Cu (mg/L)	Zn (mg/L)	Fe (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	SO_4 (mg/L)	F (mg/L)
Raw water									
1	0.09	0.00	0.00	0.00	0.54	15	31	10	0.30
2	0.00	0.01	0.00	0.00	0.52	37	25	10	0.00
3	0.00	0.00	0.00	0.00	0.00	47	47	12	0.29
Winery wastewater									
1	0.43	0.53	0.19	3.05	2.66	289	0	37	0.80
2	0.28	0.60	0.00	3.06	3.85	49	0	43	0.30
3	0.00	0.09	0.00	0.00	0.26	59	121	354	0.47

Table 2.30. The pH, EC, COD, NH_4-N, NO_3-N, Total-N, P, Ca, Mg, K, PAR, Na and SAR in water used for the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Shiraz at the Madeba clay loam experiment plot during the 2018/19 season.

Irrigation no.	pH	EC (dS/m)	COD (mg/L)	NH_4-N (mg/L)	NO_3-N (mg/L)	Total-N (mg/L)	P (mg/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	PAR	Na (mg/L)	SAR
Raw water													
1	7.3	0.23	0	0.00	2.06	2.06	0.0	7.0	5.7	2.0	0.08	14.4	0.99
2	6.3	0.18	0	0.00	0.00	0.00	0.0	6.1	4.3	1.4	0.06	10.9	0.83
3	6.3	0.17	11	0.00	0.00	0.00	0.0	5.4	4.1	1.0	0.05	16.7	1.33
Winery wastewater													
1[(1)]	-	-	-	-	-	-	-	-	-	-	-	-	-
2	3.5	0.91	9 087	0.00	0.00	0.00	1.6	45.4	17.4	154.4	2.93	29.3	0.94
3	4.2	0.11	8 042	0.00	0.00	0.00	1.3	39.8	13.4	238.2	4.94	24.2	0.85

[(1)] No winery wastewater was applied for this irrigation.

Table 2.31. The B, Mn, Cu, Zn, Fe, Cl, HCO_3, SO_4 and F in water used for the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Shiraz at the Madeba clay loam experiment plot during the 2018/19 season.

Irrigation no.	B (mg/L)	Mn (mg/L)	Cu (mg/L)	Zn (mg/L)	Fe (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	SO_4 (mg/L)	F (mg/L)
					Raw water				
1	0.10	0.00	0.00	0.00	0.50	52	40	14	0.10
2	0.09	0.00	0.00	0.00	0.54	15	31	10	0.30
3	0.00	0.01	0.00	0.00	0.52	37	25	10	0.00
					Winery wastewater				
1(1)	-	-	-	-	-	-	-	-	-
2	0.43	0.53	0.19	3.05	2.66	289	0	37	0.80
3	0.28	0.60	0.00	3.06	3.85	49	0	43	0.30

(1) No winery wastewater was applied for this irrigation.

Table 2.32. The pH, EC, COD, NH_4-N, NO_3-N, Total-N, P, Ca, Mg, K, PAR, Na and SAR in water used for the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Shiraz at Lutzville during the 2018/19 season.

Irrigation no.	pH	EC (dS/m)	COD (mg/L)	NH_4-N (mg/L)	NO_3-N (mg/L)	Total-N (mg/L)	P (mg/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	PAR	Na (mg/L)	SAR
Raw water													
1	6.1	0.19	0	0.00	0.00	0.00	0.1	4.0	3.6	4.8	0.25	20.4	1.80
2	6.4	0.16	0	0.00	0.00	0.00	0.0	4.7	3.4	1.0	0.05	13.0	1.12
3	5.7	0.13	0	0.00	0.00	0.00	0.1	4.0	2.9	1.3	0.07	13.0	1.22
4	6.4	0.14	0	0.00	0.01	0.006	0.0	4.7	3.6	2.0	0.10	21.0	1.79
Winery wastewater													
1	4.6	3.04	7 630	18.01	0.00	18.01	23.3	226.9	26.7	432.0	4.27	104.5	1.75
2	6.1	4.08	5 001	52.79	0.00	52.79	27.7	219.1	30.7	553.2	5.48	272.6	4.58
3A(1)	7.7	3.31	79	31.54	0.00	31.54	9.2	144.7	35.7	797.9	9.11	231.4	4.48
3B(1)	4.0	2.09	14 400	0.00	0.00	0.00	10.0	173.8	18.2	519.0	5.91	25.3	0.49
4	6.2	3.53	7 420	46.40	0.00	46.40	10.2	676	19.0	483.0	2.95	29	0.30

(1) Winery wastewater was applied in two batches.

Table 2.33. The B, Mn, Cu, Zn, Fe, Cl, HCO_3, SO_4 and F in water used for the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Shiraz at Lutzville during the 2018/19 season.

Irrigation no.	B (mg/L)	Mn (mg/L)	Cu (mg/L)	Zn (mg/L)	Fe (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	SO_4 (mg/L)	F (mg/L)
					Raw water				
1	0.00	0.00	0.00	0.00	0.21	49	17	13	0.00
2	0.32	0.00	0.00	0.00	0.12	40	16	8	0.10
3	0.00	0.03	0.00	0.00	0.25	35	7	6	0.00
4	0.00	0.00	0.00	0.02	0.00	36	53	2	0.23
					Winery wastewater				
1	0.70	0.30	0.05	0.16	4.65	131	0	567	0.00
2	1.16	0.40	0.03	0.09	2.58	209	2140	2875	2.58
3A(1)	0.83	0.56	0.00	0.00	0.41	85	2112	97	0.41
3B(1)	0.83	0.23	0.02	0.14	3.24	36	0	128	3.24
4	0.42	0.19	0.02	0.02	1.60	45	1188	16	0.84

(1) Winery wastewater was applied in two batches.

Table 2.34. The pH, EC, COD, NH_4-N, NO_3-N, Total-N, P, Ca, Mg, K, PAR, Na and SAR in water used for the in-field fractional use of winery wastewater with raw water for irrigation of Cabernet Sauvignon at Spruitdrift during the 2018/19 season.

Irrigation no.	pH	EC (dS/m)	COD (mg/L)	NH_4-N (mg/L)	NO_3-N (mg/L)	Total-N (mg/L)	P (mg/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	PAR	Na (mg/L)	SAR
						Raw water							
1	5.8	0.18	126	0.00	0.00	0.00	0.1	3.7	4.3	5.3	0.26	19.7	1.67
2	6.4	0.14	17	0.00	0.00	0.00	0.2	3.2	2.7	2.4	0.14	12.8	1.28
3	8.9	0.16	0	0.00	0.00	0.00	0.0	4.0	3.5	0.8	0.04	8.8	0.78
4(1)	6.9	0.13	0	0.00	0.00	0.00	0.1	4.0	3.4	1.1	0.06	10.1	0.90
5	6.4	0.14	0	0.00	0.00	0.00	0.1	3.7	3.1	0.8	0.04	11.0	1.03
6	6.8	0.12	0	0.00	0.00	0.00	0.0	4.1	4.5	1.0	0.05	4.1	0.34
7	6.4	0.12	0	0.00	0.00	0.00	0.1	3.7	3.0	1.5	0.08	11.7	1.10
8	6.2	0.15	42	0.00	0.00	0.00	0.1	3.5	3.2	1.7	0.09	7.9	0.74
9	5.9	0.14	139	0.00	0.12	0.12	0.3	6.5	3.9	9.0	0.41	18.0	1.39
						Winery wastewater							
1	5.8	2.77	7 260	18.48	0.00	18.48	13.9	141.7	30.7	315.5	3.70	232.9	4.64
2	4.9	2.49	11 170	4.52	0.00	4.52	13.4	61.8	21.1	345.6	5.73	191.7	5.39
3	4.9	3.12	9 230	2.45	0.00	2.45	29.4	262.5	34.2	484.7	4.41	293.2	4.53
4(1)	5.3	3.14	9 050	32.31	0.00	32.31	25.8	96.9	19.4	357.9	5.13	496.8	12.08
5	5.7	3.31	7 761	43.64	0.00	43.64	24.9	97.0	23.8	402.3	5.61	500.8	11.85
6	7.6	3.17	1 353	40.40	0.00	40.40	25.5	95.7	23.1	353.8	4.98	207.9	4.96
7	4.5	1.61	16 090	9.15	0.00	9.15	23.7	3.4	1.4	31.8	2.17	3.5	0.41
8	4.4	1.77	16 420	5.32	0.00	5.32	28.6	45.2	25.4	397.3	6.95	85.8	2.55
9	4.2	1.82	13 990	1.82	0.00	1.82	31.6	64.0	22.0	585.0	9.53	54.0	1.49

(1) Fractional ratio of winery wastewater to raw water changed to 0.25.

Table 2.35. The B, Mn, Cu, Zn, Fe, Cl, HCO_3, SO_4 and F in water used for the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Cabernet Sauvignon at Spruitdrift during the 2018/19 season.

Irrigation no.	B (mg/L)	Mn (mg/L)	Cu (mg/L)	Zn (mg/L)	Fe (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	SO_4 (mg/L)	F (mg/L)
Raw water									
1	0.00	0.00	0.00	0.00	0.14	45	19	21	0.00
2	0.00	0.04	0.00	0.00	0.00	28	22	8	0.10
3	0.42	0.05	0.00	0.00	0.18	37	8	9	0.00
4[(1)]	0.42	0.04	0.00	0.00	0.38	29	18	27	0.10
5	0.32	0.10	0.00	0.00	0.46	31	19	7	0.00
6	0.00	0.06	0.00	0.00	0.21	11	17	7	0.20
7	0.00	0.15	0.00	0.04	0.39	32	9	5	0.00
8	0.00	0.05	0.00	0.04	0.15	36	23	9	0.00
9	0.00	0.19	0.00	0.07	0.38	31	50	8	0.32
Winery wastewater									
1	0.46	0.25	0.03	0.41	3.03	151	828	2036	0.00
2	0.40	0.31	0.06	0.31	5.68	74	0	800	0.00
3	1.19	0.46	0.07	0.83	11.88	80	0	230	0.00
4[(1)]	0.82	0.31	0.07	0.65	5.42	83	0	330	0.10
5	0.73	0.32	0.03	0.16	5.45	119	1807	1157	0.50
6	0.69	0.34	0.04	0.10	2.38	100	1251	956	0.30
7	0.69	0.23	0.00	0.53	3.69	64	0	10	0.10
8	0.68	0.32	0.00	0.16	4.84	48	0	68	0.00
9	0.80	0.37	0.03	0.17	7.40	40	291	57	0.00

[(1)] Fractional ratio of winery wastewater to raw water changed to 0.25

2019/20 season: During the 2019/20 season, the COD level in the winery wastewater at Backsberg was above 2 610 mg/L (Table 2.36). Up to 50 m^3, 500 m^3 and 2 000 m^3 of wastewater may be irrigated on any given day provided that the COD is lower than 5 000 mg/L, 400 mg/L and 40 mg/L, respectively (Department of Water Affairs, 2013). The pH of the winery wastewater was lower than that of the raw water. The pH levels were also below the recommended pH for irrigation water, which ranges from 6.5 to 8.4 (Department of Water Affairs & Forestry, 1996). According to the General Authorisations of 2013, up to 500 m^3 of wastewater may be irrigated on any given day provided that the pH is between 6 and 9 (Department of Water Affairs, 2013). The EC was higher in the winery wastewater. The EC in the winery wastewater exceeded the critical value of 0.8 dS/m, *i.e.* the salinity threshold for water used in the irrigation of grapevines. With regard to the General Authorisations of 2013 (Department of Water Affairs, 2013), up to 500 m^3 of wastewater may be irrigated on any given day provided that the EC_{iw} is less than 2 dS/m. There were no consistent trends for NH_4-N and NO_3-N. The P levels were higher in the winery wastewater compared to the raw water (Table 2.36). As expected, K levels were substantially higher in the winery wastewater. Therefore, the PAR of the winery wastewater was substantially higher than the raw water. The Ca, Mg and Na was higher in the winery wastewater compared to the raw water. However, SAR was similar. This suggested that the increase in Ca and Mg counterbalanced the effect of increased Na on the SAR. The SAR was still within acceptable limits for the irrigation of grapevines, *i.e.* < *c.* 6. With regard to the General Authorisations of 2013, up to 500 m^3 of wastewater may be irrigated on any given day provided that the SAR is less than 5 (Department of Water Affairs, 2013). Boron, Mn, Zn, Fe, Cl, HCO_3 and SO_4 were higher in the winery wastewater compared to the raw water (Table 2.37).

During the 2019/20 season, the COD level in the winery wastewater at Madeba ranged from 220 mg/L to 3 430 mg/L (Table 2.38). The pH of the winery wastewater was lower than that of the raw water. The EC was higher in the winery wastewater. The EC in the winery wastewater exceeded the critical value of 0.8 dS/m. P levels were slightly higher in the winery wastewater compared to the raw water (Table 2.38). As expected, K levels were substantially higher in the winery wastewater. Therefore, the PAR of the winery wastewater was substantially higher than the raw water. The Ca, Mg and Na was higher in the winery wastewater compared to the raw water. However, SAR was similar. This suggested that the increase in Ca and Mg counterbalanced the effect of increased Na on the SAR. The SAR was still within acceptable limits for the irrigation of grapevines, *i.e.* < *c.* 6. Boron, Mn and Fe were higher in the winery wastewater compared to the raw water (Table 2.39). The HCO_3 levels in the winery wastewater were higher than the raw water.

During the 2019/20 season, the COD level in the winery wastewater at Lutzville ranged from 4 570 mg/L to 6 710 mg/L (Table 2.40). The pH of the winery wastewater was lower compared to that of the raw water. The EC was higher in the winery wastewater. The EC in the winery wastewater exceeded the critical value of 0.8 dS/m for all irrigations. The NH_4-N levels in the winery wastewater was higher than in the raw water. The P levels were consistently higher in the winery wastewater compared to the raw water. As expected, K levels were substantially higher in the winery wastewater. Therefore, the PAR of the winery wastewater was substantially higher than the raw water. The Ca, Mg and Na was higher in the winery wastewater compared to the raw water. However, SAR was similar or even lower in the case of the winery wastewater. This suggested that the increase in Ca and Mg counterbalanced the effect of increased Na on the SAR. The SAR was still within acceptable limits for the irrigation of grapevines, *i.e*. < *c.* 6. Boron, Mn, Cu, Zn and Fe were higher in the winery wastewater compared to the raw water (Table 2.41). The Cl, HCO_3 and SO_4 levels in the winery wastewater were higher than the raw water.

Although the grapevines at the Spruitdrift experiment plot were not irrigated with wastewater during the 2019/20 season, samples were still taken of the raw water during the progression of the season (Tables 2.42 & 2.43).

Taking the water quality measured in the 2019/20 season for the undiluted winery wastewater used for its in-field fractional use (augmentation) with raw water for vineyard irrigation into consideration, the average pH, EC, COD, K, PAR, Na and SAR was 4.73, 1.10 dS/m, 4 173 mg/L, 229 mg/L, 5.92, 31 mg/L and 1.38 for the Backsberg experiment plots, respectively. Average pH, EC, COD, K, PAR, Na and SAR was 5.75, 0.83 dS/m, 1 825 mg/L, 132 mg/L, 2.84, 29 mg/L and 1.07 for the Madeba experiment plots, respectively. Average pH, EC, COD, K, PAR, Na and SAR was 5.85, 1.82 dS/m, 5 913 mg/L, 538 mg/L, 5.02, 29 mg/L and 0.48 for the Lutzville deep sand experiment plot, respectively.

Table 2.36. The pH, EC, COD, NH_4-N, NO_3-N, Total-N, P, Ca, Mg, K, PAR, Na and SAR in water used for the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Cabernet Sauvignon at the Backsberg sand and clay experiment plots during the 2019/20 season.

Irrigation no.	pH	EC (dS/m)	COD (mg/L)	NH_4-N (mg/L)	NO_3-N (mg/L)	Total-N (mg/L)	P (mg/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	PAR	Na (mg/L)	SAR
Raw water													
1	7.3	0.20	20	0.00	0.15	0.15	0.0	7.0	5.2	4.6	0.19	26.0	1.83
2	6.9	0.05	0	1.26	0.00	1.26	0.0	2.7	0.4	0.5	0.05	4.3	0.65
3	7.1	0.21	230	1.22	0.13	1.35	0.0	3.3	2.2	2.3	0.14	11.0	1.16
4	6.9	0.18	150	1.58	0.34	1.92	0.0	6.2	3.8	3.7	0.17	18.0	1.41
5	6.9	0.18	150	1.26	0.00	1.26	0.0	5.8	3.8	4.2	0.20	19.0	1.52
6	6.7	0.15	40	0.21	0.06	0.27	0.0	4.7	3.4	3.4	0.17	17.0	1.47
Winery wastewater													
1(1)	-	-	-	-	-	-	-	-	-	-	-	-	-
2(1)	-	-	-	-	-	-	-	-	-	-	-	-	-
3(1)	-	-	-	-	-	-	-	-	-	-	-	-	-
4	5.5	0.95	2 610	29.41	0.00	29.41	11.47	20.0	8.6	141.0	3.94	31.0	1.47
5	4.3	1.05	4 950	8.16	0.00	8.16	5.83	25.0	8.5	229.0	5.98	33.0	1.46
6	4.4	1.30	4 960	8.77	0.10	8.87	7.93	30.0	8.2	318.0	7.85	29.0	1.21

(1) No winery wastewater was applied for this irrigation.

Table 2.37. The B, Mn, Cu, Zn, Fe, Cl, HCO_3, SO_4 and F in water used for the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Cabernet Sauvignon at the Backsberg sand and clay experiment plots during the 2019/20 season.

Irrigation no.	B (mg/L)	Mn (mg/L)	Cu (mg/L)	Zn (mg/L)	Fe (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	SO_4 (mg/L)	F (mg/L)
Raw water									
1	0.00	0.00	0.00	0.06	0.07	36	15	11	0.28
2	0.00	0.00	0.06	0.10	0.00	10	8	0	0.02
3	0.00	0.00	0.00	0.02	0.06	345	38	2	0.09
4	0.00	0.00	0.00	0.08	0.08	26	31	6	0.40
5	0.00	0.00	0.00	0.05	0.11	26	33	6	0.11
6	0.00	0.00	0.02	0.09	0.12	31	41	10	0.14
Winery wastewater									
1(1)	-	-	-	-	-	-	-	-	-
2(1)	-	-	-	-	-	-	-	-	-
3(1)	-	-	-	-	-	-	-	-	-
4	0.15	0.14	0.00	0.03	5.90	49	364	90	0.33
5	0.13	0.12	0.00	0.20	7.30	56	281	213	0.00
6	0.18	0.13	0.00	0.05	6.90	57	295	201	0.13

(1) No winery wastewater was applied for this irrigation.

Table 2.38. The pH, EC, COD, NH_4-N, NO_3-N, Total-N, P, Ca, Mg, K, PAR, Na and SAR in water used for the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Shiraz at the Madeba sandy loam and clay loam experiment plots during the 2019/20 season.

Irrigation no.	pH	EC (dS/m)	COD (mg/L)	NH_4-N (mg/L)	NO_3-N (mg/L)	Total-N (mg/L)	P (mg/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	PAR	Na (mg/L)	SAR
Raw water													
1	7.3	0.52	0	0.10	0.44	0.54	0.0	17.0	14.0	7.0	0.18	63.0	2.76
2	7.4	0.52	0	0.00	0.22	0.22	0.0	19.0	14.0	8.8	0.22	62.0	2.65
3	7.0	0.22	0	1.27	0.00	1.27	0.0	7.1	5.2	2.3	0.09	24.0	1.68
4	7.1	0.24	0	1.27	0.00	1.27	0.0	8.4	5.8	4.5	0.17	25.0	1.63
5	7.1	0.26	0	1.22	0.00	1.22	0.0	8.5	5.9	4.0	0.15	26.0	1.69
6	6.7	0.25	0	0.32	0.09	0.41	0.0	7.9	6.0	3.8	0.15	28.0	1.84
7	7.5	0.30	0	0.87	0.10	0.97	0.0	8.9	7.3	2.0	0.07	36.0	2.17
Winery wastewater													
1[(1)]	-	-	-	-	-	-	-	-	-	-	-	-	-
2[(1)]	-	-	-	-	-	-	-	-	-	-	-	-	-
3[(1)]	-	-	-	-	-	-	-	-	-	-	-	-	-
4[(1)]	-	-	-	-	-	-	-	-	-	-	-	-	-
5[(1)]	-	-	-	-	-	-	-	-	-	-	-	-	-
6	5.0	1.21	3 430	17.49	0.21	17.70	4.7	38.0	12.0	216.0	4.63	31.0	1.13
7	6.5	0.44	220	0.70	2.49	3.19	0.3	35.0	12.0	47.0	1.04	27.0	1.00

[(1)] No winery wastewater was applied for this irrigation.

Table 2.39. The B, Mn, Cu, Zn, Fe, Cl, HCO_3, SO_4 and F in water used for the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Shiraz at the Madeba sandy loam and clay loam experiment plots during the 2019/20 season.

Irrigation no.	B (mg/L)	Mn (mg/L)	Cu (mg/L)	Zn (mg/L)	Fe (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	SO_4 (mg/L)	F (mg/L)
Raw water									
1	0.00	0.00	0.00	0.02	0.00	111	33	36	0.36
2	0.00	0.00	0.00	0.01	0.14	109	42	33	0.41
3	0.00	0.00	0.00	0.05	0.07	43	26	9	0.00
4	0.00	0.00	0.00	0.02	0.06	42	36	8	0.15
5	0.00	0.00	0.00	0.04	0.00	46	32	8	0.04
6	0.00	0.00	0.00	0.02	0.12	47	44	11	0.13
7	0.00	0.00	0.00	0.02	0.00	58.6	54	16	0.05
Winery wastewater									
1[(1)]	-	-	-	-	-	-	-	-	-
2[(1)]	-	-	-	-	-	-	-	-	-
3[(1)]	-	-	-	-	-	-	-	-	-
4[(1)]	-	-	-	-	-	-	-	-	-
5[(1)]	-	-	-	-	-	-	-	-	-
6	0.12	0.54	0.00	0.05	5.60	52	522	10	0.66
7	0.00	0.27	0.00	0.20	1.20	43.3	177	222	0.67

[(1)] No winery wastewater was applied for this irrigation.

Table 2.40. The pH, EC, COD, NH_4-N, NO_3-N, Total-N, P, Ca, Mg, K, PAR, Na and SAR in water used for the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Shiraz at Lutzville during the 2019/20 season.

Irrigation no.	pH	EC (dS/m)	COD (mg/L)	NH_4-N (mg/L)	NO_3-N (mg/L)	Total-N (mg/L)	P (mg/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	PAR	Na (mg/L)	SAR
							Raw water						
1	7.2	0.16	0	0.00	5.04	5.04	0.0	5.0	3.5	1.0	0.05	20.0	1.69
2	6.9	0.16	0	0.00	0.18	0.18	0.0	4.6	3.5	0.9	0.05	20.0	1.72
3	7.1	0.15	0	0.00	0.15	0.15	0.0	4.5	3.3	0.9	0.04	19.0	1.67
4	7.1	0.13	0	0.00	0.26	0.26	0.0	4.3	3.2	0.8	0.04	15.0	1.34
5	6.7	0.18	0	1.32	0.00	1.32	0.0	5.8	3.8	1.7	0.08	18.0	1.44
6	6.8	0.16	0	1.25	0.00	1.25	0.2	5.1	3.3	4.1	0.21	16.0	1.37
7	6.9	0.15	0	1.33	0.00	1.33	0.0	4.0	2.9	1.3	0.07	16.0	1.50
8	6.9	0.13	0	1.31	0.00	1.31	0.0	3.9	3.0	1.4	0.08	13.0	1.21
9	6.1	0.15	120	0.06	0.08	0.14	0.0	3.6	3.1	2.3	0.13	16.0	1.50
10	7.2	0.21	0	0.69	0.26	0.95	0.0	6.5	5.1	2.0	0.08	28.0	2.00
							Winery wastewater						
1[(1)]	-	-	-	-	-	-	-	-	-	-	-	-	-
2[(1)]	-	-	-	-	-	-	-	-	-	-	-	-	-
3[(1)]	-	-	-	-	-	-	-	-	-	-	-	-	-
4[(1)]	-	-	-	-	-	-	-	-	-	-	-	-	-
5[(1)]	-	-	-	-	-	-	-	-	-	-	-	-	-
6[(1)]	-	-	-	-	-	-	-	-	-	-	-	-	-
7	4.3	1.65	6 710	1.38	0.00	1.38	5.6	102.0	11.0	400.0	5.93	28.0	0.70
8	5.2	2.37	6 130	6.74	0.00	6.74	7.3	268.0	11.0	269.0	2.58	21.0	0.34
9	6.2	2.59	4 570	17.07	0.00	17.07	10.0	180.0	10.0	516.0	5.98	25.0	0.49
10	7.7	0.65	6 240	32.13	0.00	32.13	6.9	726.0	34.0	965.0	5.60	40.0	0.39

[(1)] No winery wastewater was applied for this irrigation.

Table 2.41. The B, Mn, Cu, Zn, Fe, Cl, HCO_3, SO_4 and F in water used for the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Shiraz at Lutzville during the 2019/20 season.

Irrigation no.	B (mg/L)	Mn (mg/L)	Cu (mg/L)	Zn (mg/L)	Fe (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	SO_4 (mg/L)	F (mg/L)
					Raw water				
1	0.00	0.01	0.00	0.00	0.06	36	7	8	1.07
2	0.00	0.00	0.00	0.00	0.00	36	8	8	0.27
3	0.00	0.02	0.00	0.00	0.00	35	9	7	0.41
4	0.00	0.00	0.00	0.00	0.06	27	9	7	0.34
5	0.00	0.02	0.00	0.03	0.05	34	18	4	0.03
6	0.00	0.02	0.00	0.02	0.25	29	19	3	0.08
7	0.00	0.01	0.00	0.03	0.08	34	14	2	0.00
8	0.00	0.00	0.00	0.01	0.05	29	8	3	0.00
9	0.00	0.02	0.00	0.02	0.21	34	27	5	0.00
10	0.00	0.00	0.00	0.00	0.09	48	21	13	0.00
					Winery wastewater				
1[(1)]	-	-	-	-	-	-	-	-	-
2[(1)]	-	-	-	-	-	-	-	-	-
3[(1)]	-	-	-	-	-	-	-	-	-
4[(1)]	-	-	-	-	-	-	-	-	-
5[(1)]	-	-	-	-	-	-	-	-	-
6[(1)]	-	-	-	-	-	-	-	-	-
7	0.35	0.10	0.18	0.30	2.20	47	652	33	0.38
8	0.24	0.14	0.10	0.06	2.30	84	986	10	0.69
9	0.25	0.11	0.00	0.02	1.70	46	1031	7	0.44
10	0.42	0.18	0.03	0.00	0.35	89	1352	818	0.35

[(1)] No winery wastewater was applied for this irrigation.

Table 2.42. The pH, EC, COD, NH_4-N, NO_3-N, Total-N, P, Ca, Mg, K, PAR, Na and SAR in raw water used for irrigation of Cabernet Sauvignon at Spruitdrift during the 2019/20 season.

Date	pH	EC (dS/m)	NH_4-N (mg/L)	NO_3-N (mg/L)	Total-N (mg/L)	P (mg/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	PAR	Na (mg/L)	SAR
16/10/19	7.06	0.13	0.00	0.40	0.40	0.0	4.9	2.8	0.9	0.05	16.0	1.44
24/02/20	6.49	0.24	6.96	8.00	14.96	1.9	3.9	3.0	8.9	0.49	13.0	1.21
18/03/20	4.84	0.16	0.21	0.08	0.29	0.0	3.0	3.1	2.5	0.14	14.0	1.36
04/06/20	7.10	0.35	1.13	0.16	1.29	0.0	9.8	8.0	5.2	0.18	44.0	2.55

Table 2.43. The B, Mn, Cu, Zn, Fe, Cl, HCO_3, SO_4 and F in raw water used for irrigation of Cabernet Sauvignon at Spruitdrift during the 2019/20 season.

Date	B (mg/L)	Mn (mg/L)	Cu (mg/L)	Zn (mg/L)	Fe (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	SO_4 (mg/L)	F (mg/L)
Raw water									
16/10/19	0.00	0.00	0.00	0.00	0.00	29	8	7	0.10
24/02/20	0.00	0.00	0.00	0.01	0.05	36	43	3	0.24
18/03/20	0.00	0.00	0.00	0.01	0.07	38	18	5	0.27
04/06/20	0.00	0.00	0.00	0.03	0.22	84	51	26	0.00

2020/21 season: During the 2020/21 season, the COD level in the winery wastewater at Backsberg was above 3 500 mg/L with the exception of the first irrigation (Tables 2.44 & 2.46). Up to 50 m^3, 500 m^3 and 2 000 m^3 of wastewater may be irrigated on any given day provided that the COD is lower than 5 000 mg/L, 400 mg/L and 40 mg/L, respectively (Department of Water Affairs, 2013). The pH of the winery wastewater was lower than that of the raw water. The pH levels were also below the recommended pH for irrigation water, which ranges from 6.5 to 8.4 (Department of Water Affairs & Forestry, 1996). According to the General Authorisations of 2013, up to 500 m^3 of wastewater may be irrigated on any given day provided that the pH is between 6 and 9 (Department of Water Affairs, 2013). The EC was higher in the winery wastewater. The EC in the winery wastewater exceeded the critical value of 0.8 dS/m, *i.e.* the salinity threshold for water used in the irrigation of grapevines. With regard to the General Authorisations of 2013 (Department of Water Affairs, 2013), up to 500 m^3 of wastewater may be irrigated on any given day provided that the EC_{iw} is less than 2 dS/m. There were no consistent trends for NH_4-N and NO_3-N. The P levels were higher in the winery wastewater compared to the raw water (Tables 2.44 & 2.46). As expected, K levels were substantially higher in the winery wastewater. Therefore, the PAR of the winery wastewater was substantially higher than the raw water. The Ca, Mg and Na was higher in the winery wastewater compared to the raw water. However, SAR was similar. This suggested that the increase in Ca and Mg counterbalanced the effect of increased Na on the SAR. The SAR was still within acceptable limits for the irrigation of grapevines, *i.e*. < *c.* 6. Boron, Mn, Fe, Cl, HCO_3 and SO_4 were higher in the winery wastewater compared to the raw water (Tables 2.45 & 2.47).

During the 2020/21 season, the COD level in the winery wastewater at Madeba was very low and did not exceed 140 mg/L (Table 2.48). The pH of the winery wastewater was similar to that of the raw water. The EC was higher in the winery wastewater. The EC in the winery wastewater exceeded the critical value of 0.8 dS/m for the first irrigation. The P levels were slightly higher in the winery wastewater compared to the raw water (Table 2.48). As expected, K levels were higher in the winery wastewater. Therefore, the PAR of the winery wastewater was higher than the raw water. The Ca and Mg was higher in the winery wastewater compared to the raw water. However, SAR was similar. This suggested that the increase in Ca and Mg counterbalanced the effect of increased Na on the SAR. The SAR was still within acceptable limits for the irrigation of grapevines, *i.e*. < *a.* 6. Manganese and Fe were higher in the winery wastewater compared to the raw water (Table 2.49). The HCO_3 levels in the winery wastewater were higher than the raw water.

During the 2020/21 season, the COD level in the winery wastewater at Lutzville ranged from 4 310 mg/L to 7 050 mg/L (Table 2.50). The pH of the winery wastewater was similar to that of the raw water. The EC was higher in the winery wastewater. The EC in the winery wastewater exceeded the critical value of 0.8 dS/m for all irrigations. The NH_4-N levels in the winery wastewater was higher than in the raw water. The P levels were consistently higher in the winery wastewater compared to the raw water. As expected, K levels were substantially higher in the winery wastewater. Therefore, the PAR of the winery wastewater was substantially higher than the raw water. The Ca, Mg and Na was higher in the winery wastewater compared to the raw water. However, SAR was similar or even lower in the case of the winery wastewater. This suggested that the increase in Ca and Mg counterbalanced the effect of increased Na on the SAR. The SAR was still within acceptable limits for the irrigation of grapevines, *i.e*. < *c.* 6. Boron, and Mn were higher in the winery wastewater compared to the raw water (Table 2.51). The Cl, HCO_3 and SO_4 levels in the winery wastewater were substantially higher than the raw water.

Although the grapevines at the Spruitdrift experiment plot were not irrigated with wastewater during the 2020/21 season, samples were still taken of the raw water during the progression of the season (Tables 2.52 & 2.53).

Taking the water quality measured in the 2020/21 season for the undiluted winery wastewater used for its in-field fractional use (augmentation) with raw water for vineyard irrigation into consideration, the average pH, EC, COD, K, PAR, Na and SAR was 5.78, 1.62 dS/m, 2 848 mg/L, 416 mg/L, 9.64, 40 mg/L and 1.64 for the Backsberg experiment plots, respectively. Average pH, EC, COD, K, PAR, Na and SAR was 7.60, 0.75 dS/m, 95 mg/L, 128 mg/L, 2.86, 25 mg/L and 0.99 for the Madeba experiment plots, respectively. Average pH, EC, COD, K, PAR, Na and SAR was 6.80, 3.33 dS/m, 5 680 mg/L, 640 mg/L, 6.05, 65 mg/L and 1.05 for the Lutzville deep sand experiment plot, respectively.

Taking the water quality measured in all seasons for the undiluted winery wastewater used for its in-field fractional use (augmentation) with raw water for vineyard irrigation into consideration, the average pH, EC, COD, K, PAR, Na and SAR was 5.36, 1.23 dS/m, 2 603 mg/L, 281 mg/L, 7.69, 33 mg/L and 1.56 for the Backsberg experiment plots, respectively. Average pH, EC, COD, K, PAR, Na and SAR was 5.90, 1.33 dS/m, 3 416 mg/L, 165 mg/L, 3.40, 29 mg/L and 1.05 for the Madeba experiment plots, respectively. Average pH, EC, COD, K, PAR, Na and SAR was 6.24, 3.07 dS/m, 5 546 mg/L, 557 mg/L, 5.22, 77 mg/L and 1.26 for the Lutzville deep sand experiment plot, respectively. Average pH, EC, COD, K, PAR, Na and

SAR was 5.75, 2.80 dS/m, 6 739 mg/L, 343 mg/L, 3.96, 202 mg/L and 4.20 for the Spruitdrift shallow sand experiment plot, respectively.

Table 2.44. The pH, EC, COD, NH_4-N, NO_3-N, Total-N, P, Ca, Mg, K, PAR, Na and SAR in water used for the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Cabernet Sauvignon at the Backsberg sand experiment plot during the 2020/21 season.

Irrigation no.	pH	EC (dS/m)	COD (mg/L)	NH_4-N (mg/L)	NO_3-N (mg/L)	Total-N (mg/L)	P (mg/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	PAR	Na (mg/L)	SAR
						Raw water							
1	7.5	0.27	0	0.00	1.28	1.28	0.20	10.0	6.9	1.8	0.06	34.0	2.04
2	7.7	0.23	0	0.00	0.16	0.16	0.00	12.0	5.7	2.5	0.09	32.0	1.91
3	7.8	0.23	0	0.00	0.00	0.00	0.20	6.7	4.9	0.0	0.00	30.0	2.16
4	7.7	0.18	0	0.00	0.00	0.00	0.00	14.0	4.8	0.0	0.00	25.0	1.48
5	7.5	0.11	140	0.00	0.00	0.00	0.00	17.0	2.6	0.0	0.00	13.0	0.78
6	7.4	0.12	0	0.00	0.00	0.00	0.06	3.5	2.6	3.5	0.12	13.0	1.29
7	7.0	0.11	0	0.00	0.00	0.00	0.05	3.1	2.2	3.1	0.12	11.0	1.18
8	6.9	0.11	0	1.16	0.00	1.16	0.05	3.0	2.1	3.0	0.14	11.0	1.20
						Winery wastewater							
1[(1)]	-	-	-	-	-	-	-	-	-	-	-	-	-
2[(1)]	-	-	-	-	-	-	-	-	-	-	-	-	-
3[(1)]	-	-	-	-	-	-	-	-	-	-	-	-	-
4[(1)]	-	-	-	-	-	-	-	-	-	-	-	-	-
5	8.7	1.43	140	47.26	0.00	47.26	18.50	26.0	9.6	355.0	8.95	38.0	1.62
6	4.9	1.96	3 860	24.34	0.00	24.34	19.56	66.0	8.8	550.0	9.97	34.0	1.04
7	4.8	1.80	3 550	22.23	0.00	22.23	18.17	27.0	8.0	483.0	12.42	34.0	1.48
8	4.7	1.30	3 840	21.94	0.00	21.94	14.78	26.0	7.7	275.0	7.20	54.0	2.40

[(1)] No winery wastewater was applied for this irrigation.

Table 2.45. The B, Mn, Cu, Zn, Fe, Cl, HCO_3, SO_4 and F in water used for the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Cabernet Sauvignon at the Backsberg sand experiment plot during the 2020/21 season.

Irrigation no.	B (mg/L)	Mn (mg/L)	Cu (mg/L)	Zn (mg/L)	Fe (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	SO_4 (mg/L)	F (mg/L)
Raw water									
1	0.00	0.00	0.03	2.30	0.00	40.8	55.0	17.7	0.19
2	0.00	5.70	0.00	0.03	0.18	33.5	51.0	13.5	0.00
3	0.00	0.00	0.00	0.00	0.42	30.7	48.0	9.0	0.19
4	0.00	0.05	0.00	0.00	0.28	25.9	39.0	6.9	0.00
5	0.00	0.03	0.00	0.02	0.22	17.3	25.0	4.8	0.00
6	0.00	0.01	0.03	0.10	0.06	18.9	14.0	5.1	0.00
7	0.00	0.02	0.10	0.24	0.09	15.1	10.0	4.5	0.00
8	0.00	0.01	0.00	0.04	0.06	15.4	9.0	3.9	0.00
Winery wastewater									
1[(1)]	-	-	-	-	-	-	-	-	-
2[(1)]	-	-	-	-	-	-	-	-	-
3[(1)]	-	-	-	-	-	-	-	-	-
4[(1)]	-	-	-	-	-	-	-	-	-
5	0.00	0.08	0.00	0.00	1.30	35.9	696.0	6.59	0.30
6	0.18	0.13	0.00	0.10	3.20	39.8	711.0	83.9	0.47
7	0.18	0.13	0.00	0.03	5.70	40.7	651.0	22.8	0.37
8	0.13	0.12	0.04	0.15	3.40	40.9	467.0	14.4	0.49

[(1)] No winery wastewater was applied for this irrigation.

Table 2.46. The pH, EC, COD, NH_4-N, NO_3-N, Total-N, P, Ca, Mg, K, PAR, Na and SAR in water used for the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Cabernet Sauvignon at the Backsberg clay experiment plot during the 2020/21 season.

Irrigation no.	pH	EC (dS/m)	COD (mg/L)	NH_4-N (mg/L)	NO_3-N (mg/L)	Total-N (mg/L)	P (mg/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	PAR	Na (mg/L)	SAR
						Raw water							
1	7.7	0.23	0	0.00	0.16	0.16	0.00	12.0	5.7	2.5	0.09	32.0	1.91
2	7.8	0.23	0	0.00	0.00	0.00	0.20	6.7	4.9	0.0	0.00	30.0	2.16
3	7.7	0.18	0	0.00	0.00	0.00	0.00	14.0	4.8	0.0	0.00	25.0	1.48
4	7.5	0.11	0	0.00	0.00	0.00	0.00	17.0	2.6	0.0	0.00	13.0	0.78
5	7.4	0.12	140	0.00	0.00	0.00	0.06	3.5	2.6	3.5	0.12	13.0	1.29
6	7.0	0.11	0	0.00	0.00	0.00	0.05	3.1	2.2	3.1	0.12	11.0	1.18
7	6.9	0.11	0	1.16	0.00	1.16	0.05	3.0	2.1	3.0	0.14	11.0	1.20
						Winery wastewater							
1[(1)]	-	-	-	-	-	-	-	-	-	-	-	-	-
2[(1)]	-	-	-	-	-	-	-	-	-	-	-	-	-
3[(1)]	-	-	-	-	-	-	-	-	-	-	-	-	-
4	8.7	1.43	140	47.26	0.00	47.26	18.50	26.0	9.6	355.0	8.95	38.0	1.62
5	4.9	1.96	3 860	24.34	0.00	24.34	19.56	66.0	8.8	550.0	9.97	34.0	1.04
6	4.8	1.80	3 550	22.23	0.00	22.23	18.17	27.0	8.0	483.0	12.42	34.0	1.48
7	4.7	1.30	3 840	21.94	0.00	21.94	14.78	26.0	7.7	275.0	7.20	54.0	2.40

[(1)] No winery wastewater was applied for this irrigation.

Table 2.47. The B, Mn, Cu, Zn, Fe, Cl, HCO_3, SO_4 and F in water used for the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Cabernet Sauvignon at the Backsberg clay experiment plot during the 2020/21 season.

Irrigation no.	B (mg/L)	Mn (mg/L)	Cu (mg/L)	Zn (mg/L)	Fe (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	SO_4 (mg/L)	F (mg/L)
Raw water									
1	0.00	5.70	0.00	0.03	0.18	33.5	51.0	13.5	0.00
2	0.00	0.00	0.00	0.00	0.42	30.7	48.0	9.0	0.19
3	0.00	0.05	0.00	0.00	0.28	25.9	39.0	6.9	0.00
4	0.00	0.03	0.00	0.02	0.22	17.3	25.0	4.8	0.00
5	0.00	0.01	0.03	0.10	0.06	18.9	14.0	5.1	0.00
6	0.00	0.02	0.10	0.24	0.09	15.1	10.0	4.5	0.00
7	0.00	0.01	0.00	0.04	0.06	15.4	9.0	3.9	0.00
Winery wastewater									
1[(1)]	-	-	-	-	-	-	-	-	-
2[(1)]	-	-	-	-	-	-	-	-	-
3[(1)]	-	-	-	-	-	-	-	-	-
4	0.00	0.08	0.00	0.00	1.30	35.9	696.0	6.59	0.30
5	0.18	0.13	0.00	0.10	3.20	39.8	711.0	83.9	0.47
6	0.18	0.13	0.00	0.03	5.70	40.7	651.0	22.8	0.37
7	0.13	0.12	0.04	0.15	3.40	40.9	467.0	14.4	0.49

[(1)] No winery wastewater was applied for this irrigation.

Table 2.48. The pH, EC, COD, NH_4-N, NO_3-N, Total-N, P, Ca, Mg, K, PAR, Na and SAR in water used for the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Shiraz at the Madeba sandy loam and clay loam experiment plots during the 2020/21 season.

Irrigation no.	pH	EC (dS/m)	COD (mg/L)	NH_4-N (mg/L)	NO_3-N (mg/L)	Total-N (mg/L)	P (mg/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	PAR	Na (mg/L)	SAR
Raw water													
1	7.9	0.35	0	0.00	0.00	0.00	0.00	12.0	9.3	3.1	0.10	44.0	2.33
2	7.9	0.31	0	0.00	0.00	0.00	0.00	11.0	8.5	0.0	0.00	40.0	2.22
3	7.7	0.24	0	0.00	0.00	0.00	0.00	7.9	6.2	0.0	0.00	30.0	1.95
4	7.5	0.18	0	0.00	0.00	0.00	0.00	5.5	4.5	0.0	0.00	24.0	1.85
5	7.0	0.25	0	0.93	0.24	1.17	0.04	8.4	6.5	5.2	0.19	29.0	1.84
6	7.4	0.25	0	0.00	0.00	0.00	0.01	7.5	6.3	3.4	0.13	29.0	1.90
Winery wastewater													
1[(1)]	-	-	-	-	-	-	-	-	-	-	-	-	-
2[(1)]	-	-	-	-	-	-	-	-	-	-	-	-	-
3[(1)]	-	-	-	-	-	-	-	-	-	-	-	-	-
4[(1)]	-	-	-	-	-	-	-	-	-	-	-	-	-
5	7.6	1.14	0	22.69	0.00	22.69	5.53	31.0	14.0	230.0	5.10	27.0	1.02
6	7.6	0.36	190	0.00	0.00	0.00	0.01	27.0	10.0	25.0	0.62	23.0	0.96

[(1)] No winery wastewater was applied for this irrigation.

Table 2.49. The B, Mn, Cu, Zn, Fe, Cl, HCO_3, SO_4 and F in water used for the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Shiraz at the Madeba sandy loam and clay loam experiment plots during the 2020/21 season.

Irrigation no.	B (mg/L)	Mn (mg/L)	Cu (mg/L)	Zn (mg/L)	Fe (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	SO_4 (mg/L)	F (mg/L)
Raw water									
1	0.00	0.00	0.00	0.02	0.00	61.0	53.0	21.0	0.00
2	0.00	0.00	0.00	0.01	0.00	54.0	52.0	18.0	0.00
3	0.00	0.00	0.00	0.01	0.00	39.0	39.0	14.0	0.00
4	0.00	0.00	0.00	0.01	0.00	34.0	32.0	10.0	0.11
5	0.00	0.00	0.04	0.06	0.17	42.0	30.0	13.0	0.00
6	0.00	0.00	0.02	0.04	0.00	42.0	24.0	13.0	0.00
Winery wastewater									
1[(1)]	-	-	-	-	-	-	-	-	-
2[(1)]	-	-	-	-	-	-	-	-	-
3[(1)]	-	-	-	-	-	-	-	-	-
4[(1)]	-	-	-	-	-	-	-	-	-
5	0.15	0.22	0.02	0.03	0.23	34.0	495.0	11.0	0.41
6	0.00	0.17	0.02	0.03	0.19	26.6	126.0	10.8	0.34

[(1)] No winery wastewater was applied for this irrigation.

Table 2.50. The pH, EC, COD, NH_4-N, NO_3-N, Total-N, P, Ca, Mg, K, PAR, Na and SAR in water used for the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Shiraz at Lutzville during the 2020/21 season.

Irrigation no.	pH	EC (dS/m)	COD (mg/L)	NH_4-N (mg/L)	NO_3-N (mg/L)	Total-N (mg/L)	P (mg/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	PAR	Na (mg/L)	SAR
							Raw water						
1	7.2	0.14	0	0.00	0.00	0.00	0.00	4.2	2.8	0.0	0.00	17.0	1.59
2	7.2	0.14	0	0.00	0.00	0.00	0.00	3.8	3.0	0.0	0.00	17.0	1.59
3	7.2	0.18	0	0.00	0.00	0.00	0.00	5.2	4.0	0.0	0.00	23.0	1.86
4	7.4	0.19	0	0.00	0.00	0.00	0.00	5.7	4.2	0.0	0.00	23.0	1.79
5	7.3	0.15	0	0.00	0.00	0.00	0.00	10.0	3.7	0.0	0.00	19.0	1.31
6	7.3	0.15	0	0.00	0.00	0.00	0.00	4.8	3.4	0.0	0.00	17.0	1.46
7	7.3	0.15	0	0.00	0.00	0.00	0.00	5.2	3.4	0.0	0.00	17.0	1.43
8	7.2	0.16	0	0.00	0.00	0.00	0.00	4.4	3.8	2.7	0.14	19.0	1.61
9	7.0	0.19	0	0.00	0.00	0.00	0.00	5.0	4.3	3.3	0.16	22.0	1.76
10	7.1	0.20	0	0.60	0.00	0.60	0.02	6.7	5.1	3.4	0.14	25.0	1.78
							Winery wastewater						
1(1)	-	-	-	-	-	-	-	-	-	-	-	-	-
2(1)	-	-	-	-	-	-	-	-	-	-	-	-	-
3(1)	-	-	-	-	-	-	-	-	-	-	-	-	-
4(1)	-	-	-	-	-	-	-	-	-	-	-	-	-
5(1)	-	-	-	-	-	-	-	-	-	-	-	-	-
6(1)	-	-	-	-	-	-	-	-	-	-	-	-	-
7(1)	-	-	-	-	-	-	-	-	-	-	-	-	-
8	6.1	2.97	7 050	14.95	0.00	14.95	0.71	163.0	17.0	730.0	8.58	76.0	1.52
9(1)	-	-	-	-	-	-	-	-	-	-	-	-	-
10	7.5	3.69	4 310	13.12	0.00	13.12	4.37	618.0	17.0	549.0	3.51	53.0	0.57

(1) No winery wastewater was applied for this irrigation.

Table 2.51. The B, Mn, Cu, Zn, Fe, Cl, HCO_3, SO_4 and F in water used for the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Shiraz at Lutzville during the 2020/21 season.

Irrigation no.	B (mg/L)	Mn (mg/L)	Cu (mg/L)	Zn (mg/L)	Fe (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	SO_4 (mg/L)	F (mg/L)
Raw water									
1	0.00	0.00	0.00	0.00	0.08	0.0	17.0	7.8	0.00
2	0.00	0.00	0.00	0.00	0.09	31.6	18.0	7.8	0.00
3	0.00	0.00	0.00	0.00	0.00	38.0	21.0	10.8	0.00
4	0.00	0.02	0.00	0.02	0.00	35.0	25.0	10.2	0.00
5	0.00	0.03	0.00	0.00	0.00	32.6	12.0	7.5	0.00
6	0.00	0.02	0.00	0.00	0.00	25.0	25.0	7.5	0.00
7	0.00	0.00	0.00	0.02	0.00	32.0	19.0	7.2	0.00
8	0.00	0.01	0.00	0.02	0.00	26.3	5.0	7.2	0.00
9	0.00	0.01	0.00	0.03	0.00	29.6	6.0	8.7	0.00
10	0.00	0.00	0.05	0.07	0.06	33.4	13.0	10.2	0.00
Winery wastewater									
1(1)	-	-	-	-	-	-	-	-	-
2(1)	-	-	-	-	-	-	-	-	-
3(1)	-	-	-	-	-	-	-	-	-
4(1)	-	-	-	-	-	-	-	-	-
5(1)	-	-	-	-	-	-	-	-	-
6(1)	-	-	-	-	-	-	-	-	-
7(1)	-	-	-	-	-	-	-	-	-
8	0.51	0.02	0.00	0.17	0.22	42.3	1124.0	167.8	0.28
9(1)	-	-	-	-	-	-	-	-	-
10	0.41	0.11	0.02	0.02	0.07	182.8	1482.0	590.2	0.32

(1) No winery wastewater was applied for this irrigation.

Table 2.52. The pH, EC, COD, NH_4-N, NO_3-N, Total-N, P, Ca, Mg, K, PAR, Na and SAR in raw water used for irrigation of Cabernet Sauvignon at Spruitdrift during the 2020/21 season.

Date	pH	EC (dS/m)	NH_4-N (mg/L)	NO_3-N (mg/L)	Total-N (mg/L)	P (mg/L)	Ca (mg/L)	Mg (mg/L)	K (mg/L)	PAR	Na (mg/L)	SAR
15/11/20	7.2	0.24	0.00	0.00	0.00	0.00	5.5	6.2	0.0	0.00	34.0	2.38
21/01/21	7.2	0.12	0.00	0.14	0.14	0.00	3.3	3.1	0.0	0.00	13.0	1.24
30/03/21	7.4	0.14	0.78	0.00	0.78	0.01	3.7	3.8	2.1	0.11	17.0	1.49

Table 2.53. The B, Mn, Cu, Zn, Fe, Cl, HCO_3, SO_4 and F in raw water used for irrigation of Cabernet Sauvignon at Spruitdrift during the 2020/21 season.

Date	B (mg/L)	Mn (mg/L)	Cu (mg/L)	Zn (mg/L)	Fe (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	SO_4 (mg/L)	F (mg/L)
15/11/20	0.00	0.00	0.00	0.00	0.00	53.0	22.0	17.4	0.00
21/01/21	0.00	0.00	0.00	0.02	0.00	53.0	19.0	6.3	0.00
30/03/21	0.00	0.00	0.00	0.02	0.00	23.2	7.0	8.1	0.00

2.3.4. Amount of elements applied

2017/18 season: The amounts of elements applied *via* the irrigation at Backsberg is given in Tables 2.54 and 2.55.

Table 2.54. The amounts of NH_4-N, NO_3-N, Total-N, P, Ca, Mg, K and Na applied *via* the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Cabernet Sauvignon at Backsberg during the 2017/18 season.

Irrigation no.	NH_4-N (kg/ha)	NO_3-N (kg/ha)	Total-N (kg/ha)	P (kg/ha)	Ca (kg/ha)	Mg (kg/ha)	K (kg/ha)	Na (kg/ha)
Raw water								
1	0.00	0.00	0.00	0.00	0.53	0.72	0.42	3.20
2	120.50	0.00	120.50	0.01	0.98	1.74	1.15	10.28
Total	*120.50*	*0.00*	*120.50*	*0.01*	*1.50*	*2.46*	*1.57*	*13.48*
Winery wastewater								
1	0.00	0.00	0.00	1.79	2.04	1.20	52.82	6.03
2	120.39	0.16	120.55	4.11	5.40	2.33	70.83	11.46
Total	*120.39*	*0.16*	*120.55*	*5.90*	*7.44*	*3.54*	*123.65*	*17.50*
Raw water + winery wastewater								
Total	*240.89*	*0.16*	*241.05*	*5.91*	*8.94*	*5.99*	*125.22*	*30.97*

Table 2.55. The amounts of B, Mn, Cu, Zn, Fe, Cl, HCO_3, SO_4 and F applied *via* the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Cabernet Sauvignon at Backsberg during the 2017/18 season.

Irrigation no.	B (kg/ha)	Mn (kg/ha)	Cu (kg/ha)	Zn (kg/ha)	Fe (kg/ha)	Cl (kg/ha)	HCO_3 (kg/ha)	SO_4 (kg/ha)	F (kg/ha)
Raw water									
1	0.00	0.01	0.00	0.01	0.19	7.79	8.63	1.47	0.00
2	0.00	0.02	0.00	0.00	0.17	18.81	16.03	4.18	0.10
Total	*0.00*	*0.03*	*0.00*	*0.01*	*0.36*	*26.60*	*24.66*	*5.65*	*0.10*
Winery wastewater									
1	0.02	0.02	0.01	0.12	0.71	11.23	0.00	3.92	0.00
2	0.03	0.05	0.00	0.07	1.92	17.77	0.00	2.09	0.03
Total	*0.06*	*0.06*	*0.01*	*0.19*	*2.62*	*29.00*	*0.00*	*6.01*	*0.03*
Raw water + winery wastewater									
Total	*0.06*	*0.09*	*0.01*	*0.20*	*2.99*	*55.60*	*24.66*	*11.66*	*0.14*

The amounts of elements applied *via* the irrigation at Madeba is given in Tables 2.56 to 2.59.

Table 2.56. The amounts of NH_4-N, NO_3-N, Total-N, P, Ca, Mg, K and Na applied *via* the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Shiraz at the sandy loam experiment plot at Madeba during the 2017/18 season.

Irrigation no.	NH_4-N (kg/ha)	NO_3-N (kg/ha)	Total-N (kg/ha)	P (kg/ha)	Ca (kg/ha)	Mg (kg/ha)	K (kg/ha)	Na (kg/ha)
				Raw water				
1	0.00	0.00	0.00	0.00	0.74	0.97	0.22	4.17
2	0.00	0.00	0.00	0.01	1.76	2.35	0.47	10.87
Total	*0.00*	*0.00*	*0.00*	*0.01*	*2.50*	*3.31*	*0.69*	*15.04*
				Winery wastewater				
1	0.00	0.00	0.00	0.40	9.52	2.79	22.62	5.19
2	0.00	0.00	0.00	2.14	18.27	6.62	176.09	19.30
Total	*0.00*	*0.00*	*0.00*	*2.54*	*27.79*	*9.40*	*198.71*	*24.48*
				Raw water + winery wastewater				
Total	*0.00*	*0.00*	*0.00*	*2.55*	*30.30*	*12.71*	*199.40*	*39.52*

Table 2.57. The amounts of B, Mn, Cu, Zn, Fe, Cl, HCO_3, SO_4 and F applied *via* the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Shiraz at the sandy loam experiment plot at Madeba during the 2017/18 season.

Irrigation no.	B (kg/ha)	Mn (kg/ha)	Cu (kg/ha)	Zn (kg/ha)	Fe (kg/ha)	Cl (kg/ha)	HCO_3 (kg/ha)	SO_4 (kg/ha)	F (kg/ha)
					Raw water				
1	0.00	0.00	0.00	0.00	0.14	11.86	7.17	2.21	0.00
2	0.00	0.00	0.01	0.02	0.16	24.63	11.34	4.69	0.08
Total	*0.00*	*0.00*	*0.01*	*0.02*	*0.29*	*36.50*	*18.51*	*6.90*	*0.08*
					Winery wastewater				
1	0.05	0.09	0.01	1.51	0.52	12.41	0.00	7.17	0.00
2	0.22	0.11	0.17	2.61	1.42	33.87	929.87	27.96	0.04
Total	*0.27*	*0.20*	*0.18*	*4.12*	*1.94*	*46.29*	*929.87*	*35.14*	*0.04*
					Raw water + winery wastewater				
Total	*0.27*	*0.20*	*0.19*	*4.13*	*2.24*	*82.78*	*948.38*	*42.03*	*0.12*

Table 2.58. The amounts of NH_4-N, NO_3-N, Total-N, P, Ca, Mg, K and Na applied *via* the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Shiraz at the clay loam experiment plot at Madeba during the 2017/18 season.

Irrigation no.	NH_4-N (kg/ha)	NO_3-N (kg/ha)	Total-N (kg/ha)	P (kg/ha)	Ca (kg/ha)	Mg (kg/ha)	K (kg/ha)	Na (kg/ha)
				Raw water				
1	0.00	0.00	0.00	0.00	0.85	1.11	0.25	4.77
2	0.00	0.00	0.00	0.01	1.59	2.12	0.42	9.81
Total	*0.00*	*0.00*	*0.00*	*0.01*	*2.44*	*3.22*	*0.68*	*14.58*
				Winery wastewater				
1	0.00	0.00	0.00	0.46	10.91	3.19	25.93	5.95
2	0.00	0.00	0.00	2.12	18.11	6.56	174.51	19.13
Total	*0.00*	*0.00*	*0.00*	*2.58*	*29.02*	*9.75*	*200.44*	*25.07*
				Raw water + winery wastewater				
Total	*0.00*	*0.00*	*0.00*	*2.59*	*31.46*	*12.98*	*201.12*	*39.65*

Table 2.59. The amounts of B, Mn, Cu, Zn, Fe, Cl, HCO_3, SO_4 and F applied *via* the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Shiraz at the clay loam experiment plot at Madeba during the 2017/18 season.

Irrig-ation no.	B (kg/ha)	Mn (kg/ha)	Cu (kg/ha)	Zn (kg/ha)	Fe (kg/ha)	Cl (kg/ha)	HCO_3 (kg/ha)	SO_4 (kg/ha)	F (kg/ha)
					Raw water				
1	0.00	0.00	0.00	0.00	0.16	13.60	8.22	2.53	0.00
2	0.00	0.00	0.01	0.01	0.14	22.23	10.23	4.23	0.07
Total	*0.00*	*0.00*	*0.01*	*0.01*	*0.30*	*35.82*	*18.45*	*6.76*	*0.07*
					Winery wastewater				
1	0.06	0.10	0.01	1.73	0.60	14.23	0.00	8.22	0.00
2	0.22	0.11	0.17	2.59	1.41	33.57	921.51	27.71	0.04
Total	*0.28*	*0.21*	*0.18*	*4.31*	*2.01*	*47.80*	*921.51*	*35.93*	*0.04*
					Raw water + winery wastewater				
Total	*0.28*	*0.21*	*0.19*	*4.33*	*2.31*	*83.62*	*939.97*	*42.70*	*0.11*

The amounts of elements applied *via* the irrigation at Lutzville are given in Tables 2.60 and 2.61.

Table 2.60. The amounts of NH_4-N, NO_3-N, Total-N, P, Ca, Mg, K and Na applied *via* the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Shiraz at Lutzville during the 2017/18 season.

Irrigation no.	NH_4-N (kg/ha)	NO_3-N (kg/ha)	Total-N (kg/ha)	P (kg/ha)	Ca (kg/ha)	Mg (kg/ha)	K (kg/ha)	Na (kg/ha)
Raw water								
1	0.06	0.00	0.06	0.00	0.83	0.92	0.32	5.15
2	0.12	0.00	0.12	0.00	2.50	2.54	1.03	13.13
3	0.06	0.00	0.06	0.00	2.18	2.10	0.90	10.34
4	0.00	0.00	0.00	0.01	2.27	2.03	0.95	9.31
5	0.00	0.00	0.00	0.02	4.54	4.45	4.18	24.72
Total	*0.25*	*0.00*	*0.25*	*0.04*	*12.32*	*12.05*	*7.37*	*62.65*
Winery wastewater								
1	0.65	0.00	0.65	1.00	43.28	2.24	61.03	7.07
2	2.75	0.00	2.75	3.93	135.65	13.06	216.21	41.05
3	7.40	0.00	7.40	2.82	116.84	12.20	201.76	41.32
4	14.31	0.00	14.31	2.11	118.95	13.70	226.28	50.07
5	7.75	0.00	7.75	10.98	177.87	12.81	252.33	23.41
Total	*32.86*	*0.00*	*32.86*	*20.83*	*592.59*	*54.00*	*957.60*	*162.93*
Raw water + winery wastewater								
Total	*33.11*	*0.00*	*33.11*	*20.87*	*604.91*	*66.06*	*964.97*	*225.59*

Table 2.61. The amounts of B, Mn, Cu, Zn, Fe, Cl, HCO_3, SO_4 and F applied *via* the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Shiraz at Lutzville during the 2017/18 season.

Irrigation no.	B (kg/ha)	Mn (kg/ha)	Cu (kg/ha)	Zn (kg/ha)	Fe (kg/ha)	Cl (kg/ha)	HCO_3 (kg/ha)	SO_4 (kg/ha)	F (kg/ha)
					Raw water				
1	0.00	0.00	0.00	0.00	0.02	10.68	4.46	1.91	0.03
2	0.00	0.00	0.00	0.00	0.04	24.62	10.67	5.34	0.04
3	0.02	0.00	0.00	0.01	0.04	23.44	9.54	4.80	0.04
4	0.05	0.00	0.00	0.02	0.05	27.05	10.26	5.20	0.05
5	0.00	0.00	0.01	0.00	0.04	54.83	8.99	15.73	0.09
Total	*0.07*	*0.00*	*0.01*	*0.03*	*0.19*	*140.62*	*43.92*	*32.98*	*0.25*
					Winery wastewater				
1	0.09	0.06	0.00	0.01	0.06	8.80	285.37	13.28	0.12
2	0.36	0.07	0.00	0.02	0.24	103.65	916.97	235.88	0.04
3	0.32	0.04	0.00	0.01	0.16	77.80	924.42	458.80	0.14
4	0.35	0.02	0.00	0.00	0.09	63.77	1 121.99	810.63	0.28
5	0.31	0.13	0.04	0.07	1.66	46.74	0.00	84.48	0.13
Total	*1.44*	*0.33*	*0.04*	*0.11*	*2.22*	*300.77*	*3 248.76*	*1 603.07*	*0.72*
					Raw water + winery wastewater				
Total	*1.50*	*0.33*	*0.06*	*0.14*	*2.41*	*441.38*	*3 292.68*	*1 636.05*	*0.97*

The amounts of elements applied *via* the irrigation at Spruitdrift are given in Tables 2.62 and 2.63.

Table 2.62. The amounts of NH_4-N, NO_3-N, Total-N, P, Ca, Mg, K and Na applied *via* the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Cabernet Sauvignon at Spruitdrift during the 2017/18 season.

Irrigation no.	NH_4-N (kg/ha)	NO_3-N (kg/ha)	Total-N (kg/ha)	P (kg/ha)	Ca (kg/ha)	Mg (kg/ha)	K (kg/ha)	Na (kg/ha)
				Raw water				
1	0.00	0.00	0.00	0.02	2.22	2.75	1.21	14.90
2	0.00	0.00	0.00	0.00	1.23	2.07	0.65	10.34
3	0.13	0.00	0.13	0.00	2.61	3.19	1.03	14.29
4	0.00	0.00	0.00	0.00	1.64	1.88	0.64	7.62
5	0.00	0.00	0.00	0.01	1.52	1.76	0.64	6.96
6	20.02	0.00	20.02	0.00	1.88	2.24	0.96	9.79
Total	*20.15*	*0.00*	*20.15*	*0.03*	*11.10*	*13.89*	*5.13*	*63.89*
				Winery wastewater				
1	3.42	0.00	3.42	6.98	32.52	13.29	219.91	314.39
2	6.29	0.00	6.29	4.60	70.64	7.14	155.33	61.72
3	2.01	0.00	2.01	3.60	115.42	10.33	233.76	69.46
4	0.00	0.00	0.00	2.92	83.14	8.66	169.48	47.90
5	7.66	0.00	7.66	9.80	201.20	17.52	145.76	85.40
6	0.00	0.00	0.00	9.18	147.84	14.72	140.82	38.40
Total	*19.37*	*0.00*	*19.37*	*37.09*	*650.76*	*71.67*	*1 065.07*	*617.28*
				Raw water + winery wastewater				
Total	*39.52*	*0.00*	*39.52*	*37.12*	*661.85*	*85.56*	*1 070.20*	*681.17*

Table 2.63. The amounts of B, Mn, Cu, Zn, Fe, Cl, HCO_3, SO_4 and F applied *via* the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Cabernet Sauvignon at Spruitdrift during the 2017/18 season.

Irrigation no.	B (kg/ha)	Mn (kg/ha)	Cu (kg/ha)	Zn (kg/ha)	Fe (kg/ha)	Cl (kg/ha)	HCO_3 (kg/ha)	SO_4 (kg/ha)	F (kg/ha)
					Raw water				
1	0.00	0.00	0.00	0.00	0.00	26.25	13.33	5.25	0.08
2	0.00	0.00	0.00	0.00	0.06	23.84	10.34	4.20	0.03
3	0.00	0.01	0.00	0.00	0.09	26.51	13.93	6.29	0.04
4	0.00	0.01	0.02	0.02	0.04	23.65	11.22	4.01	0.00
5	0.00	0.00	0.00	0.00	0.00	24.00	8.40	5.60	0.00
6	0.00	0.02	0.00	0.00	0.04	23.18	6.80	5.20	0.04
Total	*0.00*	*0.04*	*0.02*	*0.02*	*0.23*	*147.43*	*64.01*	*30.54*	*0.20*
					Winery wastewater				
1	0.45	0.25	0.00	0.02	1.00	114.31	694.38	33.34	0.09
2	0.18	0.06	0.00	0.00	0.52	38.26	496.11	16.16	0.03
3	0.34	0.06	0.00	0.02	0.67	69.64	916.53	23.36	0.04
4	0.18	0.05	0.00	0.00	0.28	68.14	505.79	398.84	0.04
5	0.29	0.12	0.00	0.02	0.64	80.40	522.57	1 145.22	0.00
6	0.35	0.16	0.01	0.02	2.22	64.95	0.00	296.09	0.04
Total	*1.79*	*0.70*	*0.01*	*0.08*	*5.33*	*435.70*	*3135.38*	*1 913.01*	*0.24*
					Raw water + winery wastewater				
Total	*1.79*	*0.74*	*0.02*	*0.10*	*5.56*	*583.12*	*3199.39*	*1 943.56*	*0.44*

2018/19 season: The amounts of elements applied *via* the irrigation at Backsberg is given in Tables 2.64, 2.65, 2.66 and 2.67.

Table 2.64. The amounts of NH_4-N, NO_3-N, Total-N, P, Ca, Mg, K and Na applied *via* the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Cabernet Sauvignon at the Backsberg sand experiment plot during the 2018/19 season.

Irrigation no.	NH_4-N (kg/ha)	NO_3-N (kg/ha)	Total-N (kg/ha)	P (kg/ha)	Ca (kg/ha)	Mg (kg/ha)	K (kg/ha)	Na (kg/ha)
Raw water								
1	0.00	0.00	0.00	0.01	2.72	2.17	1.05	5.26
2	0.00	0.00	0.00	0.06	13.44	2.19	1.70	9.00
3	0.00	0.00	0.00	0.01	1.96	1.45	0.78	4.23
4	0.00	0.00	0.00	0.01	1.69	1.24	1.07	6.14
5	0.00	0.00	0.00	0.01	1.75	1.60	1.28	6.86
Total	*0.00*	*0.00*	*0.00*	*0.09*	*21.56*	*8.65*	*5.88*	*31.49*
Winery wastewater								
1[(1)]	-	-	-	-	-	-	-	-
2[(1)]	-	-	-	-	-	-	-	-
3	4.03	0.00	4.03	4.22	8.42	3.31	70.00	14.16
4	2.28	0.00	2.28	4.55	6.93	2.01	80.70	10.55
5	4.36	0.20	4.56	5.13	5.30	2.67	71.46	13.89
Total	*10.67*	*0.20*	*10.87*	*13.89*	*20.65*	*7.99*	*222.16*	*38.60*
Raw water + winery wastewater								
Total	*10.67*	*0.20*	*10.87*	*13.98*	*42.21*	*16.64*	*228.04*	*70.09*

[(1)] No winery wastewater was applied for this irrigation.

Table 2.65. The amounts of B, Mn, Cu, Zn, Fe, Cl, HCO_3, SO_4 and F applied *via* the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Cabernet Sauvignon at the Backsberg sand experiment plot during the 2018/19 season.

Irrigation no.	B (kg/ha)	Mn (kg/ha)	Cu (kg/ha)	Zn (kg/ha)	Fe (kg/ha)	Cl (kg/ha)	HCO_3 (kg/ha)	SO_4 (kg/ha)	F (kg/ha)
Raw water									
1	0.05	0.00	0.00	0.06	0.16	21.48	25.38	4.33	0.06
2	0.10	0.15	0.00	0.30	0.75	22.50	26.14	5.47	0.00
3	0.00	0.00	0.00	0.03	0.14	4.77	14.87	2.70	0.20
4	0.00	0.01	0.00	0.00	0.08	12.90	5.18	2.07	0.03
5	0.00	0.01	0.00	0.04	0.17	13.66	16.63	2.97	0.03
Total	*0.15*	*0.16*	*0.00*	*0.43*	*1.30*	*75.31*	*88.20*	*17.55*	*0.33*
Winery wastewater									
1[1]	-	-	-	-	-	-	-	-	-
2[1]	-	-	-	-	-	-	-	-	-
3	0.08	0.04	0.01	0.07	1.37	4.90	182.18	5.41	0.17
4	0.00	0.03	0.00	0.06	1.49	24.09	116.68	3.59	0.07
5	0.13	0.03	0.00	0.04	1.73	16.74	159.34	4.03	0.03
Total	*0.21*	*0.11*	*0.01*	*0.17*	*4.59*	*45.73*	*458.20*	*13.03*	*0.27*
Raw water + winery wastewater									
Total	*0.36*	*0.27*	*0.01*	*0.60*	*5.89*	*121.04*	*546.4*	*30.58*	*0.60*

(1) No winery wastewater was applied for this irrigation.

Table 2.66. The amounts of NH_4-N, NO_3-N, Total-N, P, Ca, Mg, K and Na applied *via* the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Cabernet Sauvignon at the Backsberg clay experiment plot during the 2018/19 season.

Irrigation no.	NH_4-N (kg/ha)	NO_3-N (kg/ha)	Total-N (kg/ha)	P (kg/ha)	Ca (kg/ha)	Mg (kg/ha)	K (kg/ha)	Na (kg/ha)
Raw water								
1	0.00	0.00	0.00	0.03	1.37	1.44	0.76	1.75
2	0.00	0.00	0.00	0.00	1.43	1.09	0.87	4.30
3	0.03	0.04	0.07	0.00	2.15	1.75	1.65	9.35
Total	*0.03*	*0.04*	*0.07*	*0.03*	*4.95*	*4.27*	*3.29*	*15.41*
Winery wastewater								
1	3.90	0.00	3.90	3.30	5.82	2.85	48.89	3.65
2	2.86	0.00	2.86	2.79	4.09	1.24	88.78	5.65
3	2.76	0.01	2.77	2.26	3.48	1.34	57.60	5.39
Total	*9.52*	*0.01*	*9.53*	*8.35*	*13.39*	*5.43*	*195.26*	*14.69*
Raw water + winery wastewater								
Total	*9.55*	*0.05*	*9.60*	*8.38*	*18.34*	*9.70*	*198.55*	*30.10*

Table 2.67. The amounts of B, Mn, Cu, Zn, Fe, Cl, HCO_3, SO_4 and F applied *via* the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Cabernet Sauvignon at the Backsberg clay experiment plot during the 2018/19 season.

Irrigation no.	B (kg/ha)	Mn (kg/ha)	Cu (kg/ha)	Zn (kg/ha)	Fe (kg/ha)	Cl (kg/ha)	HCO_3 (kg/ha)	SO_4 (kg/ha)	F (kg/ha)
Raw water									
1	0.05	0.01	0.00	0.01	0.12	8.99	11.02	3.82	0.07
2	0.00	0.02	0.00	0.01	0.11	7.67	8.14	1.92	0.04
3	0.00	0.00	0.01	0.03	0.00	12.28	16.52	3.65	0.07
Total	*0.05*	*0.03*	*0.01*	*0.05*	*0.23*	*28.94*	*35.67*	*9.39*	*0.18*
Winery wastewater									
1	0.08	0.03	0.01	0.30	1.17	19.40	73.19	9.42	0.10
2	0.02	0.02	0.00	0.02	0.86	12.03	121.89	1.34	0.08
3	0.02	0.02	0.00	0.03	0.26	7.06	77.43	0.78	0.11
Total	*0.12*	*0.07*	*0.01*	*0.34*	*2.29*	*38.49*	*272.51*	*11.54*	*0.28*
Raw water + winery wastewater									
Total	*0.18*	*0.10*	*0.02*	*0.39*	*2.52*	*67.43*	*308.19*	*20.93*	*0.46*

The amounts of elements applied *via* the irrigation at Madeba is given in Tables 2.68 to 2.71.

Table 2.68. The amounts of NH_4-N, NO_3-N, Total-N, P, Ca, Mg, K and Na applied *via* the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Shiraz at the Madeba sandy loam experiment plot during the 2018/19 season.

Irrigation no.	NH_4-N (kg/ha)	NO_3-N (kg/ha)	Total-N (kg/ha)	P (kg/ha)	Ca (kg/ha)	Mg (kg/ha)	K (kg/ha)	Na (kg/ha)
Raw water								
1	0.00	0.00	0.00	0.00	2.23	1.57	0.51	3.98
2	0.00	0.00	0.00	0.00	1.24	0.94	0.23	3.82
3	0.00	2.50	0.00	0.00	1.88	1.43	0.84	7.04
Total	*0.00*	*2.50*	*2.50*	*0.00*	*5.35*	*3.94*	*1.58*	*14.84*
Winery wastewater								
1	0.00	0.00	0.00	0.60	16.57	6.35	56.36	10.69
2	0.00	0.00	0.00	0.28	8.84	2.97	52.88	5.37
3	0.17	0.00	0.17	0.05	10.69	4.11	4.38	9.86
Total	*0.17*	*0.00*	*0.17*	*0.93*	*36.09*	*13.44*	*113.62*	*25.93*
Raw water + winery wastewater								
Total	*0.17*	*2.50*	*2.67*	*0.93*	*41.44*	*17.37*	*115.20*	*40.77*

Table 2.69. The amounts of B, Mn, Cu, Zn, Fe, Cl, HCO_3, SO_4 and F applied *via* the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Shiraz at the Madeba sandy loam experiment plot during the 2018/19 season.

Irrig-ation no.	B (kg/ha)	Mn (kg/ha)	Cu (kg/ha)	Zn (kg/ha)	Fe (kg/ha)	Cl (kg/ha)	HCO_3 (kg/ha)	SO_4 (kg/ha)	F (kg/ha)
Raw water									
1	0.03	0.00	0.00	0.00	0.20	5.29	11.32	3.65	0.11
2	0.00	0.00	0.00	0.00	0.12	8.47	5.73	2.29	0.00
3	0.00	0.00	0.00	0.00	0.00	10.62	10.67	2.79	0.07
Total	*0.03*	*0.00*	*0.00*	*0.00*	*0.32*	*24.39*	*27.71*	*8.73*	*0.18*
Winery wastewater									
1	0.16	0.19	0.07	1.11	0.97	105.63	0.00	13.51	0.29
2	0.06	0.13	0.00	0.68	0.85	10.94	0.00	9.55	0.07
3	0.00	0.02	0.00	0.00	0.07	16.25	33.15	97.00	0.13
Total	*0.22*	*0.35*	*0.07*	*1.79*	*1.90*	*132.82*	*33.15*	*120.05*	*0.49*
Raw water + winery wastewater									
Total	*0.25*	*0.35*	*0.07*	*1.79*	*2.21*	*157.21*	*60.86*	*128.78*	*0.66*

Table 2.70. The amounts of NH_4-N, NO_3-N, Total-N, P, Ca, Mg, K and Na applied *via* the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Shiraz at the Madeba clay loam experiment plot during the 2018/19 season.

Irrigation no.	NH_4-N (kg/ha)	NO_3-N (kg/ha)	Total-N (kg/ha)	P (kg/ha)	Ca (kg/ha)	Mg (kg/ha)	K (kg/ha)	Na (kg/ha)
Raw water								
1	0.00	2.68	2.68	0.03	9.10	7.41	2.60	18.72
2	0.00	0.00	0.00	0.00	2.28	1.60	0.52	4.07
3	0.00	0.00	0.00	0.00	1.20	0.91	0.22	3.72
Total	*0.00*	*2.68*	*2.68*	*0.03*	*12.58*	*9.92*	*3.34*	*26.51*
Winery wastewater								
1[(1)]	-	-	-	-	-	-	-	-
2	0.00	0.00	0.00	0.60	16.62	6.37	56.51	10.72
3	0.00	0.00	0.00	0.25	7.92	2.67	47.40	4.82
Total	*0.00*	*0.00*	*0.00*	*0.85*	*24.54*	*9.04*	*103.91*	*15.54*
Raw water + winery wastewater								
Total	*0.00*	*2.68*	*2.68*	*0.88*	*37.12*	*18.96*	*107.25*	*42.05*

[(1)] No winery wastewater was applied for this irrigation.

Table 2.71. The amounts of B, Mn, Cu, Zn, Fe, Cl, HCO_3, SO_4 and F applied *via* the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Shiraz at the Madeba clay loam experiment plot during the 2018/19 season.

Irrigation no.	B (kg/ha)	Mn (kg/ha)	Cu (kg/ha)	Zn (kg/ha)	Fe (kg/ha)	Cl (kg/ha)	HCO_3 (kg/ha)	SO_4 (kg/ha)	F (kg/ha)
Raw water									
1	0.13	0.00	0.00	0.00	0.65	67.73	52.00	18.20	0.13
2	0.03	0.00	0.00	0.00	0.20	5.41	11.56	3.73	0.11
3	0.00	0.00	0.00	0.00	0.12	8.25	5.58	2.23	0.00
Total	*0.16*	*0.00*	*0.00*	*0.00*	*0.97*	*81.39*	*69.14*	*24.16*	*0.24*
Winery wastewater									
1[(1)]	-	-	-	-	-	-	-	-	-
2	0.16	0.19	0.07	1.12	0.97	105.92	0.00	13.54	0.29
3	0.06	0.12	0.00	0.61	0.77	9.81	0.00	8.56	0.06
Total	*0.22*	*0.31*	*0.07*	*1.73*	*1.74*	*115.73*	*0.00*	*22.10*	*0.35*
Raw water + winery wastewater									
Total	*0.38*	*0.31*	*0.07*	*1.73*	*2.71*	*197.12*	*69.14*	*46.26*	*0.59*

[(1)] No winery wastewater was applied for this irrigation.

The amounts of elements applied *via* the irrigation at Lutzville are given in Tables 2.72 and 2.73.

Table 2.72. The amounts of NH_4-N, NO_3-N, Total-N, P, Ca, Mg, K and Na applied *via* the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Shiraz at Lutzville during the 2018/19 season.

Irrigation no.	NH_4-N (kg/ha)	NO_3-N (kg/ha)	Total-N (kg/ha)	P (kg/ha)	Ca (kg/ha)	Mg (kg/ha)	K (kg/ha)	Na (kg/ha)
Raw water								
1	0.00	0.00	0.00	0.03	1.59	1.43	1.91	8.10
2	0.00	0.00	0.00	0.01	2.21	1.60	0.47	6.11
3	0.00	0.00	0.00	0.05	2.72	1.97	0.88	8.84
4	0.00	0.01	0.01	0.00	0.80	0.61	0.34	3.57
Total	*0.00*	*0.01*	*0.01*	*0.09*	*7.32*	*5.61*	*3.60*	*26.62*
Winery wastewater								
1	7.13	0.00	7.13	9.23	89.50	10.57	171.07	41.38
2	24.81	0.00	24.81	13.00	102.98	14.43	260.01	128.13
3A(1)	13.32	0.00	13.32	3.89	61.12	15.08	337.03	97.74
3B(1)	0.00	0.00	0.00	5.05	87.65	9.18	261.73	12.76
4	17.42	0.00	17.42	3.84	253.81	7.13	181.35	10.89
Total	*62.69*	*0.00*	*62.69*	*35.00*	*595.06*	*56.39*	*1 211.20*	*290.90*
Raw water + winery wastewater								
Total	*62.69*	*0.01*	*62.70*	*35.09*	*602.37*	*62.01*	*1 214.80*	*317.52*

(1) Winery wastewater was applied in two batches.

Table 2.73. The amounts of B, Mn, Cu, Zn, Fe, Cl, HCO_3, SO_4 and F applied *via* the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Shiraz at Lutzville during the 2018/19 season.

Irrigation no.	B (kg/ha)	Mn (kg/ha)	Cu (kg/ha)	Zn (kg/ha)	Fe (kg/ha)	Cl (kg/ha)	HCO_3 (kg/ha)	SO_4 (kg/ha)	F (kg/ha)
Raw water									
1	0.00	0.00	0.00	0.00	0.08	19.45	6.75	5.16	0.00
2	0.15	0.00	0.00	0.00	0.06	18.80	7.52	3.76	0.05
3	0.00	0.02	0.00	0.00	0.17	23.73	4.90	4.08	0.00
4	0.00	0.00	0.00	0.00	0.00	0.61	9.01	0.41	0.04
Total	*0.15*	*0.02*	*0.00*	*0.00*	*0.31*	*68.09*	*28.18*	*13.41*	*0.09*
Winery wastewater									
1	0.28	0.12	0.02	0.06	1.84	51.88	0.00	224.53	0.00
2	0.55	0.19	0.01	0.04	1.21	98.23	1 005.83	1 351.30	0.47
3A[(1)]	0.35	0.24	0.00	0.00	0.17	35.69	892.11	40.97	0.04
3B[(1)]	0.42	0.12	0.01	0.07	1.63	18.36	0.00	64.55	0.30
4	0.16	0.07	0.01	0.01	0.60	16.82	446.05	6.01	0.32
Total	*1.75*	*0.73*	*0.05*	*0.18*	*5.46*	*220.98*	*2 343.99*	*1 687.36*	*1.13*
Raw water + winery wastewater									
Total	*1.90*	*0.75*	*0.05*	*0.19*	*5.77*	*289.07*	*2 372.16*	*1 700.77*	*1.22*

[(1)] Winery wastewater was applied in two batches.

The amounts of elements applied *via* the irrigation at Spruitdrift are given in Tables 2.74 and 2.75.

Table 2.74. The amounts of NH_4-N, NO_3-N, Total-N, P, Ca, Mg, K and Na applied *via* the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Cabernet Sauvignon at Spruitdrift during the 2018/19 season.

Irrigation no.	NH_4-N (kg/ha)	NO_3-N (kg/ha)	Total-N (kg/ha)	P (kg/ha)	Ca (kg/ha)	Mg (kg/ha)	K (kg/ha)	Na (kg/ha)
				Raw water				
1	0.00	0.00	0.00	0.03	1.54	1.79	2.21	8.20
2	0.00	0.00	0.00	0.05	1.07	0.91	0.81	4.30
3	0.00	0.00	0.00	0.00	1.68	1.47	0.34	3.68
4(1)	0.00	0.00	0.00	0.03	1.98	1.68	0.54	5.00
5	0.00	0.00	0.00	0.05	3.17	2.66	0.69	9.44
6	0.00	0.00	0.00	0.00	2.56	2.81	0.63	2.56
7	0.00	0.00	0.00	0.05	2.67	2.17	1.08	8.44
8	0.00	0.00	0.00	0.04	2.43	2.23	1.18	5.49
9	0.00	0.06	0.06	0.12	3.01	1.81	4.17	8.34
Total	*0.00*	*0.06*	*0.06*	*0.38*	*20.12*	*17.52*	*11.64*	*55.46*
				Winery wastewater				
1	7.10	0.00	7.10	5.35	54.43	11.79	121.20	89.47
2	1.51	0.00	1.51	4.50	20.70	7.07	115.76	64.21
3	1.03	0.00	1.03	12.30	109.98	14.33	203.08	122.85
4(1)	5.14	0.00	5.14	4.10	15.43	3.09	56.98	79.09
5	9.59	0.00	9.59	5.48	21.32	5.23	88.40	110.05
6	5.74	0.00	5.74	3.63	13.60	3.28	50.29	29.55
7	2.20	0.00	2.20	5.69	0.82	0.34	7.64	0.84
8	1.31	0.00	1.31	7.04	11.11	6.24	97.67	21.09
9	0.29	0.00	0.29	5.04	10.23	3.52	93.49	8.63
Total	*33.91*	*0.00*	*33.91*	*53.13*	*257.62*	*54.89*	*835.51*	*525.77*
				Raw water + winery wastewater				
Total	*33.91*	*0.06*	*33.97*	*53.50*	*277.74*	*72.40*	*846.15*	*581.23*

(1) Fractional ratio of winery wastewater to raw water changed to 0.25.

Table 2.75. The amounts of B, Mn, Cu, Zn, Fe, Cl, HCO_3, SO_4 and F applied *via* the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Cabernet Sauvignon at Spruitdrift during the 2018/19 season.

Irrigation no.	B (kg/ha)	Mn (kg/ha)	Cu (kg/ha)	Zn (kg/ha)	Fe (kg/ha)	Cl (kg/ha)	HCO_3 (kg/ha)	SO_4 (kg/ha)	F (kg/ha)
Raw water									
1	0.00	0.00	0.00	0.00	0.06	18.74	7.91	8.74	0.00
2	0.00	0.01	0.00	0.00	0.00	9.40	7.39	2.69	0.03
3	0.18	0.02	0.00	0.00	0.08	15.49	3.35	3.77	0.00
4(1)	0.21	0.02	0.00	0.00	0.19	14.35	8.91	13.36	0.05
5	0.27	0.09	0.00	0.00	0.39	26.59	16.30	6.00	0.00
6	0.00	0.04	0.00	0.00	0.13	6.75	10.81	4.38	0.13
7	0.00	0.11	0.00	0.03	0.28	23.10	6.78	3.61	0.00
8	0.00	0.03	0.00	0.03	0.10	25.04	16.00	6.26	0.00
9	0.00	0.09	0.00	0.03	0.18	14.27	23.17	3.75	0.15
Total	*0.66*	*0.41*	*0.00*	*0.09*	*1.41*	*153.73*	*100.62*	*52.56*	*0.36*
Winery wastewater									
1	0.18	0.10	0.01	0.16	1.16	58.01	318.07	782.12	0.00
2	0.13	0.10	0.02	0.10	1.90	24.79	0.00	267.97	0.00
3	0.50	0.19	0.03	0.35	4.98	33.52	0.00	96.37	0.00
4(1)	0.13	0.05	0.01	0.10	0.86	13.21	0.00	52.53	0.02
5	0.16	0.07	0.01	0.04	1.20	26.15	397.08	254.25	0.11
6	0.10	0.05	0.01	0.01	0.34	14.18	177.76	135.88	0.04
7	0.17	0.06	0.00	0.13	0.89	15.41	0.00	2.40	0.02
8	0.17	0.08	0.00	0.04	1.19	11.80	0.00	16.72	0.00
9	0.13	0.06	0.00	0.03	1.18	6.42	46.5	9.11	0.00
Total	*1.66*	*0.75*	*0.09*	*0.96*	*13.70*	*203.49*	*939.42*	*1 617.34*	*0.19*
Raw water + winery wastewater									
Total	*2.32*	*1.16*	*0.09*	*1.05*	*15.11*	*357.22*	*1040.04*	*1 669.90*	*0.55*

(1) Fractional ratio of winery wastewater to raw water changed to 0.25.

2019/20 season: The amounts of elements applied *via* the irrigation at Backsberg is given in Tables 2.76 and 2.77.

Table 2.76. The amounts of NH_4-N, NO_3-N, Total-N, P, Ca, Mg, K and Na applied *via* the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Cabernet Sauvignon at the Backsberg sand and clay experiment plots during the 2019/20 season.

Irrigation no.	NH_4-N (kg/ha)	NO_3-N (kg/ha)	Total-N (kg/ha)	P (kg/ha)	Ca (kg/ha)	Mg (kg/ha)	K (kg/ha)	Na (kg/ha)
				Raw water				
1	0.00	0.08	0.08	0.00	3.55	2.64	2.33	13.20
2	0.39	0.00	0.39	0.00	0.85	0.13	0.16	1.35
3	0.98	0.10	1.09	0.00	2.65	1.77	1.85	8.85
4	0.58	0.13	0.71	0.00	2.28	1.40	1.36	6.63
5	0.38	0.00	0.38	0.00	1.74	1.14	1.26	5.69
6	0.06	0.02	0.08	0.00	1.41	1.02	1.02	5.10
Total	*2.40*	*0.32*	*2.72*	*0.00*	*12.48*	*8.09*	*7.99*	*40.81*
				Winery wastewater				
1[(1)]	-	-	-	-	-	-	-	-
2[(1)]	-	-	-	-	-	-	-	-
3[(1)]	-	-	-	-	-	-	-	-
4	9.09	0.00	9.09	3.55	6.18	2.66	43.59	9.58
5	2.44	0.00	2.44	1.75	7.49	2.55	68.61	9.89
6	2.63	0.03	2.66	2.38	8.99	2.46	95.31	8.69
Total	*14.17*	*0.03*	*14.20*	*7.67*	*22.66*	*7.66*	*207.51*	*28.16*
				Raw water + winery wastewater				
Total	*16.56*	*0.35*	*16.92*	*7.67*	*35.15*	*15.75*	*215.50*	*68.97*

[(1)] No winery wastewater was applied for this irrigation.

Table 2.77. The amounts of B, Mn, Cu, Zn, Fe, Cl, HCO_3, SO_4 and F applied *via* the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Cabernet Sauvignon at the Backsberg sand and clay experiment plots during the 2019/20 season.

Irrigation no.	B (kg/ha)	Mn (kg/ha)	Cu (kg/ha)	Zn (kg/ha)	Fe (kg/ha)	Cl (kg/ha)	HCO_3 (kg/ha)	SO_4 (kg/ha)	F (kg/ha)
Raw water									
1	0.00	0.00	0.00	0.03	0.04	18.47	7.61	5.58	0.14
2	0.00	0.00	0.02	0.03	0.00	2.97	2.50	0.00	0.01
3	0.00	0.00	0.00	0.01	0.05	26.95	30.57	1.62	0.07
4	0.00	0.00	0.00	0.03	0.03	9.43	11.41	2.21	0.15
5	0.00	0.00	0.00	0.02	0.03	7.85	9.89	1.89	0.03
6	0.00	0.00	0.01	0.03	0.04	9.30	12.30	3.00	0.04
Total	*0.00*	*0.00*	*0.02*	*0.15*	*0.18*	*74.97*	*74.29*	*14.29*	*0.44*
Winery wastewater									
1[(1)]	-	-	-	-	-	-	-	-	-
2[(1)]	-	-	-	-	-	-	-	-	-
3[(1)]	-	-	-	-	-	-	-	-	-
4	0.05	0.04	0.00	0.01	1.82	15.09	112.53	27.82	0.10
5	0.04	0.04	0.00	0.06	2.19	16.66	84.19	63.82	0.00
6	0.05	0.04	0.00	0.01	2.07	17.08	88.42	60.24	0.04
Total	*0.14*	*0.12*	*0.00*	*0.08*	*6.08*	*48.83*	*285.14*	*151.88*	*0.14*
Raw water + winery wastewater									
Total	*0.14*	*0.12*	*0.02*	*0.23*	*6.26*	*123.80*	*359.42*	*166.17*	*0.58*

[(1)] No winery wastewater was applied for this irrigation.

The amounts of elements applied *via* the irrigation at Madeba is given in Tables 2.78 to 2.81.

Table 2.78. The amounts of NH_4-N, NO_3-N, Total-N, P, Ca, Mg, K and Na applied *via* the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Shiraz at the Madeba sandy loam experiment plot during the 2019/20 season.

Irrigation no.	NH_4-N (kg/ha)	NO_3-N (kg/ha)	Total-N (kg/ha)	P (kg/ha)	Ca (kg/ha)	Mg (kg/ha)	K (kg/ha)	Na (kg/ha)
Raw water								
1	0.08	0.36	0.08	0.00	14.00	11.53	5.76	51.88
2	0.00	0.16	0.00	0.00	13.94	10.27	6.45	45.47
3	1.20	0.00	1.20	0.00	6.71	4.91	2.17	22.67
4	0.99	0.00	0.99	0.00	6.55	4.52	3.51	19.50
5	0.86	0.00	0.86	0.00	6.01	4.17	2.83	18.39
6	0.19	0.05	0.19	0.00	4.59	3.49	2.21	16.27
7	0.47	0.05	0.52	0.00	4.80	3.94	1.08	19.42
Total	*3.79*	*0.63*	*4.42*	*0.00*	*56.60*	*42.83*	*24.02*	*193.60*
Winery wastewater								
1[(1)]	-	-	-	-	-	-	-	-
2[(1)]	-	-	-	-	-	-	-	-
3[(1)]	-	-	-	-	-	-	-	-
4[(1)]	-	-	-	-	-	-	-	-
5[(1)]	-	-	-	-	-	-	-	-
6	3.04	0.04	3.08	0.82	6.61	2.09	37.59	5.39
7	0.27	0.96	1.23	0.12	13.48	4.62	18.10	10.40
Total	*3.31*	*1.00*	*4.31*	*0.94*	*20.09*	*6.71*	*55.69*	*15.79*
Raw water + winery wastewater								
Total	*7.10*	*1.63*	*8.73*	*0.94*	*76.69*	*49.54*	*79.70*	*209.40*

[(1)] No winery wastewater was applied for this irrigation.

Table 2.79. The amounts of B, Mn, Cu, Zn, Fe, Cl, HCO_3, SO_4 and F applied *via* the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Shiraz at the Madeba sandy loam experiment plot during the 2019/20 season.

Irrig-ation no.	B (kg/ha)	Mn (kg/ha)	Cu (kg/ha)	Zn (kg/ha)	Fe (kg/ha)	Cl (kg/ha)	HCO_3 (kg/ha)	SO_4 (kg/ha)	F (kg/ha)
Raw water									
1	0.00	0.00	0.00	0.02	0.00	91.33	27.18	29.61	0.30
2	0.00	0.00	0.00	0.01	0.10	79.73	30.80	24.17	0.30
3	0.00	0.00	0.00	0.05	0.07	40.33	24.56	8.50	0.00
4	0.00	0.00	0.00	0.02	0.05	32.69	28.08	6.54	0.12
5	0.00	0.00	0.00	0.03	0.00	32.53	22.63	5.72	0.03
6	0.00	0.00	0.00	0.01	0.07	27.32	25.57	6.39	0.08
7	0.00	0.00	0.00	0.02	0.00	59	54	16	0.05
Total	*0.00*	*0.00*	*0.00*	*0.14*	*0.29*	*335.52*	*187.95*	*89.57*	*0.84*
Winery wastewater									
1[(1)]	-	-	-	-	-	-	-	-	-
2[(1)]	-	-	-	-	-	-	-	-	-
3[(1)]	-	-	-	-	-	-	-	-	-
4[(1)]	-	-	-	-	-	-	-	-	-
5[(1)]	-	-	-	-	-	-	-	-	-
6	0.02	0.09	0.00	0.01	0.97	9.05	90.83	1.74	0.11
7	0.00	0.10	0.00	0.08	0.46	16.68	68.16	85.49	0.26
Total	*0.02*	*0.20*	*0.00*	*0.09*	*1.44*	*25.72*	*158.99*	*87.23*	*0.37*
Raw water + winery wastewater									
Total	*0.02*	*0.20*	*0.00*	*0.22*	*1.72*	*361.25*	*346.94*	*176.80*	*1.22*

[(1)] No winery wastewater was applied for this irrigation.

Table 2.80. The amounts of NH_4-N, NO_3-N, Total-N, P, Ca, Mg, K and Na applied *via* the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Shiraz at the Madeba clay loam experiment plot during the 2019/20 season.

Irrigation no.	NH_4-N (kg/ha)	NO_3-N (kg/ha)	Total-N (kg/ha)	P (kg/ha)	Ca (kg/ha)	Mg (kg/ha)	K (kg/ha)	Na (kg/ha)
Raw water								
1	0.09	0.41	0.51	0.00	15.98	13.16	6.58	59.22
2	0.00	0.17	0.17	0.00	14.95	11.02	6.92	48.78
3	1.32	0.00	1.32	0.00	7.38	5.40	2.39	24.94
4	0.99	0.00	0.99	0.00	6.55	4.52	3.51	19.50
5	0.86	0.00	0.86	0.00	6.01	4.17	2.83	18.39
6	0.18	0.05	0.22	0.00	4.33	3.29	2.08	15.36
7	0.46	0.05	0.51	0.00	4.72	3.87	1.06	19.07
Total	*3.90*	*0.69*	*4.59*	*0.00*	*59.92*	*45.43*	*25.38*	*205.26*
Winery wastewater								
1[(1)]	-	-	-	-	-	-	-	-
2[(1)]	-	-	-	-	-	-	-	-
3[(1)]	-	-	-	-	-	-	-	-
4[(1)]	-	-	-	-	-	-	-	-
5[(1)]	-	-	-	-	-	-	-	-
6	3.92	0.05	3.97	1.06	8.52	2.69	48.44	6.95
7	0.29	1.02	1.31	0.12	14.33	4.91	19.27	11.04
Total	*4.21*	*1.07*	*5.28*	*1.19*	*22.85*	*7.60*	*67.68*	*18.00*
Raw water + winery wastewater								
Total	*8.11*	*1.76*	*9.87*	*1.19*	*82.77*	*53.04*	*93.06*	*223.26*

[(1)] No winery wastewater was applied for this irrigation.

Table 2.81. The amounts of B, Mn, Cu, Zn, Fe, Cl, HCO_3, SO_4 and F applied *via* the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Shiraz at the Madeba clay loam experiment plot during the 2019/20 season.

Irrig-ation no.	B (kg/ha)	Mn (kg/ha)	Cu (kg/ha)	Zn (kg/ha)	Fe (kg/ha)	Cl (kg/ha)	HCO_3 (kg/ha)	SO_4 (kg/ha)	F (kg/ha)
					Raw water				
1	0.00	0.00	0.00	0.02	0.00	104.24	31.02	33.79	0.34
2	0.00	0.00	0.00	0.01	0.11	85.53	33.05	25.93	0.32
3	0.00	0.00	0.00	0.05	0.07	44.37	27.01	9.35	0.00
4	0.00	0.00	0.00	0.02	0.05	32.69	28.08	6.54	0.12
5	0.00	0.00	0.00	0.03	0.00	32.53	22.63	5.72	0.03
6	0.00	0.00	0.00	0.01	0.07	25.78	24.13	6.03	0.07
7	0.00	0.00	0.00	0.01	0.00	31.05	28.61	8.48	0.03
Total	*0.00*	*0.00*	*0.00*	*0.14*	*0.30*	*356.17*	*194.53*	*95.85*	*0.90*
					Winery wastewater				
1[(1)]	-	-	-	-	-	-	-	-	-
2[(1)]	-	-	-	-	-	-	-	-	-
3[(1)]	-	-	-	-	-	-	-	-	-
4[(1)]	-	-	-	-	-	-	-	-	-
5[(1)]	-	-	-	-	-	-	-	-	-
6	0.03	0.12	0.00	0.01	1.26	11.66	117.07	2.24	0.15
7	0.00	0.11	0.00	0.08	0.49	17.72	72.45	90.87	0.27
Total	*0.03*	*0.23*	*0.00*	*0.09*	*1.75*	*29.38*	*189.51*	*93.11*	*0.42*
					Raw water + winery wastewater				
Total	*0.0.*	*0.23*	*0.00*	*0.24*	*2.04*	*385.56*	*384.05*	*188.96*	*1.33*

[(1)] No winery wastewater was applied for this irrigation.

The amounts of elements applied *via* the irrigation at Lutzville are given in Tables 2.82 and 2.83.

Table 2.82. The amounts of NH_4-N, NO_3-N, Total-N, P, Ca, Mg, K and Na applied *via* the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Shiraz at Lutzville during the 2019/20 season.

Irrigation no.	NH_4-N (kg/ha)	NO_3-N (kg/ha)	Total-N (kg/ha)	P (kg/ha)	Ca (kg/ha)	Mg (kg/ha)	K (kg/ha)	Na (kg/ha)
				Raw water				
1	0.00	6.29	6.29	0.00	6.24	4.37	1.25	24.95
2	0.00	0.13	0.13	0.00	3.34	2.54	0.67	14.52
3	0.00	0.14	0.14	0.00	4.20	3.08	0.79	17.75
4	0.00	0.22	0.22	0.00	3.68	2.74	0.68	12.85
5	1.23	0.00	1.23	0.00	5.41	3.54	1.58	16.78
6	1.13	0.00	1.13	0.16	4.61	2.98	3.71	14.47
7	1.00	0.00	1.00	0.00	2.99	2.17	0.97	11.98
8	0.57	0.00	0.57	0.00	1.68	1.29	0.60	5.61
9	0.02	0.03	0.05	0.00	1.17	1.00	0.74	5.18
10	0.18	0.07	0.25	0.00	1.73	1.35	0.53	7.44
Total	*4.12*	*6.88*	*11.00*	*0.16*	*35.05*	*25.08*	*11.53*	*131.52*
				Winery wastewater				
1[(1)]	-	-	-	-	-	-	-	-
2[(1)]	-	-	-	-	-	-	-	-
3[(1)]	-	-	-	-	-	-	-	-
4[(1)]	-	-	-	-	-	-	-	-
5[(1)]	-	-	-	-	-	-	-	-
6[(1)]	-	-	-	-	-	-	-	-
7	0.50	0.00	0.50	2.03	36.98	3.99	145.01	10.15
8	1.97	0.00	1.97	2.13	78.27	3.21	78.56	6.13
9	6.82	0.00	6.82	4.00	71.91	4.00	206.15	9.99
10	11.59	0.00	11.59	2.49	261.88	12.26	348.10	14.43
Total	*20.88*	*0.00*	*20.88*	*10.65*	*449.04*	*23.46*	*771.81*	*40.70*
				Raw water + winery wastewater				
Total	*25.00*	*6.88*	*31.88*	*10.81*	*484.09*	*48.54*	*789.35*	*172.22*

(1) No winery wastewater was applied for this irrigation.

Table 2.83. The amounts of B, Mn, Cu, Zn, Fe, Cl, HCO_3, SO_4 and F applied *via* the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Shiraz at Lutzville during the 2019/20 season.

Irrigation no.	B (kg/ha)	Mn (kg/ha)	Cu (kg/ha)	Zn (kg/ha)	Fe (kg/ha)	Cl (kg/ha)	HCO_3 (kg/ha)	SO_4 (kg/ha)	F (kg/ha)
Raw water									
1	0.00	0.01	0.00	0.00	0.07	44.29	8.73	10.47	1.33
2	0.00	0.00	0.00	0.00	0.00	26.35	5.81	5.65	0.20
3	0.00	0.02	0.00	0.00	0.00	32.32	8.41	6.72	0.38
4	0.00	0.00	0.00	0.00	0.05	22.88	7.71	5.65	0.29
5	0.00	0.02	0.00	0.03	0.05	31.60	16.78	3.63	0.03
6	0.00	0.02	0.00	0.02	0.23	25.77	17.18	2.66	0.07
7	0.00	0.01	0.00	0.02	0.06	25.15	10.48	1.80	0.00
8	0.00	0.00	0.00	0.01	0.02	12.30	3.45	1.16	0.00
9	0.00	0.01	0.00	0.01	0.07	11.01	8.74	1.62	0.00
10	0.00	0.00	0.00	0.00	0.02	12.75	5.58	3.45	0.00
Total	*0.00*	*0.08*	*0.00*	*0.07*	*0.57*	*244.41*	*92.87*	*42.80*	*2.31*
Winery wastewater									
1[(1)]	-	-	-	-	-	-	-	-	-
2[(1)]	-	-	-	-	-	-	-	-	-
3[(1)]	-	-	-	-	-	-	-	-	-
4[(1)]	-	-	-	-	-	-	-	-	-
5[(1)]	-	-	-	-	-	-	-	-	-
6[(1)]									
7	0.13	0.04	0.07	0.11	0.80	16.86	236.36	11.95	0.14
8	0.07	0.04	0.03	0.02	0.67	24.56	287.96	2.89	0.20
9	0.10	0.04	0.00	0.01	0.68	18.38	411.90	2.80	0.18
10	0.15	0.06	0.01	0.00	0.13	32.10	487.69	295.07	0.13
Total	*0.45*	*0.19*	*0.11*	*0.14*	*2.27*	*91.90*	*1 423.92*	*312.70*	*1.13*
Raw water + winery wastewater									
Total	*0.45*	*0.27*	*0.11*	*0.21*	*2.85*	*336.31*	*1 516.78*	*355.50*	*2.95*

[(1)] No winery wastewater was applied for this irrigation.

2020/21 season: The amounts of elements applied *via* the irrigation at Backsberg is given in Tables 2.84 to 2.87.

Table 2.84. The amounts of NH_4-N, NO_3-N, Total-N, P, Ca, Mg, K and Na applied *via* the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Cabernet Sauvignon at the Backsberg sand experiment plot during the 2020/21 season.

Irrigation no.	NH_4-N (kg/ha)	NO_3-N (kg/ha)	Total-N (kg/ha)	P (kg/ha)	Ca (kg/ha)	Mg (kg/ha)	K (kg/ha)	Na (kg/ha)
Raw water								
1	0.00	0.85	0.85	0.15	6.61	4.56	1.19	22.47
2	0.00	0.11	0.11	0.00	8.44	4.01	1.76	22.51
3	0.00	0.00	0.00	0.18	5.73	4.19	0.00	25.66
4	0.00	0.00	0.00	0.00	10.51	3.60	0.00	18.77
5	0.00	0.00	0.00	0.00	5.23	0.80	0.00	4.00
6	0.00	0.00	0.00	0.02	1.06	0.78	0.60	3.92
7	0.00	0.00	0.00	0.02	0.93	0.66	0.57	3.31
8	0.30	0.00	0.30	0.01	0.77	0.54	0.54	2.82
Total	*0.30*	*0.96*	*1.26*	*0.38*	*39.29*	*19.15*	*4.66*	*103.47*
Winery wastewater								
1[1]	-	-	-	-	-	-	-	-
2[1]	-	-	-	-	-	-	-	-
3[1]	-	-	-	-	-	-	-	-
4[1]	-	-	-	-	-	-	-	-
5	13.77	0.00	13.77	5.39	7.58	2.80	103.43	11.07
6	7.34	0.00	7.34	5.90	19.90	2.65	165.86	10.25
7	6.41	0.00	6.41	5.24	7.79	2.31	139.36	9.81
8	5.63	0.00	5.63	3.79	6.67	1.98	70.56	13.86
Total	*33.15*	*0.00*	*33.15*	*20.33*	*41.94*	*9.73*	*479.22*	*44.99*
Raw water + winery wastewater								
Total	*33.45*	*0.96*	*34.41*	*20.70*	*81.23*	*28.89*	*483.88*	*148.46*

[1] No winery wastewater was applied for this irrigation.

Table 2.85. The amounts of B, Mn, Cu, Zn, Fe, Cl, HCO_3, SO_4 and F applied *via* the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Cabernet Sauvignon at the Backsberg sand experiment plot during the 2020/21 season.

Irrigation no.	B (kg/ha)	Mn (kg/ha)	Cu (kg/ha)	Zn (kg/ha)	Fe (kg/ha)	Cl (kg/ha)	HCO_3 (kg/ha)	SO_4 (kg/ha)	F (kg/ha)
Raw water									
1	0.00	0.00	0.02	1.52	0.00	26.97	36.36	11.69	0.13
2	0.00	4.01	0.00	0.02	0.13	23.56	35.87	9.48	0.00
3	0.00	0.00	0.00	0.00	0.36	26.26	41.06	7.69	0.16
4	0.00	0.04	0.00	0.00	0.21	19.45	29.29	5.17	0.00
5	0.00	0.01	0.00	0.00	0.07	5.33	7.70	1.47	0.00
6	0.00	0.00	0.01	0.03	0.02	5.70	4.22	1.53	0.00
7	0.00	0.01	0.03	0.07	0.03	4.54	3.01	1.35	0.00
8	0.00	0.00	0.00	0.01	0.02	3.95	2.31	1.00	0.00
Total	*0.00*	*4.07*	*0.06*	*1.66*	*0.82*	*115.76*	*159.80*	*39.39*	*0.29*
Winery wastewater									
1(1)	-	-	-	-	-	-	-	-	-
2(1)	-	-	-	-	-	-	-	-	-
3(1)	-	-	-	-	-	-	-	-	-
4(1)	-	-	-	-	-	-	-	-	-
5	0.00	0.02	0.00	0.00	0.38	10.46	202.79	1.92	0.09
6	0.05	0.04	0.00	0.03	0.96	12.00	214.41	25.30	0.14
7	0.05	0.04	0.00	0.01	1.64	11.74	187.84	6.57	0.11
8	0.03	0.03	0.01	0.04	0.87	10.49	119.83	3.69	0.13
Total	*0.14*	*0.13*	*0.01*	*0.07*	*3.86*	*44.70*	*724.87*	*37.48*	*0.46*
Raw water + winery wastewater									
Total	*0.14*	*4.20*	*0.07*	*1.73*	*4.69*	*160.46*	*884.67*	*76.86*	*0.75*

(1) No winery wastewater was applied for this irrigation.

Table 2.86. The amounts of NH_4-N, NO_3-N, Total-N, P, Ca, Mg, K and Na applied *via* the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Cabernet Sauvignon at the Backsberg clay experiment plot during the 2020/21 season.

Irrigation no.	NH_4-N (kg/ha)	NO_3-N (kg/ha)	Total-N (kg/ha)	P (kg/ha)	Ca (kg/ha)	Mg (kg/ha)	K (kg/ha)	Na (kg/ha)
Raw water								
1	0.00	0.11	0.11	0.00	8.44	4.01	1.76	22.51
2	0.00	0.00	0.00	0.18	5.73	4.19	0.00	25.66
3	0.00	0.00	0.00	0.00	10.51	3.60	0.00	18.77
4	0.00	0.00	0.00	0.00	5.23	0.80	0.00	4.00
5	0.00	0.00	0.00	0.02	1.06	0.78	0.60	3.92
6	0.00	0.00	0.00	0.02	0.93	0.66	0.57	3.31
7	0.30	0.00	0.30	0.01	0.77	0.54	0.54	2.82
Total	*0.30*	*0.11*	*0.41*	*0.23*	*32.68*	*14.59*	*3.47*	*80.99*
Winery wastewater								
1[(1)]	-	-	-	-	-	-	-	-
2[(1)]	-	-	-	-	-	-	-	-
3[(1)]	-	-	-	-	-	-	-	-
4	13.77	0.00	13.77	5.39	7.58	2.80	103.43	11.07
5	7.34	0.00	7.34	5.90	19.90	2.65	165.86	10.25
6	6.41	0.00	6.41	5.24	7.79	2.31	139.36	9.81
7	5.63	0.00	5.63	3.79	6.67	1.98	70.56	13.86
Total	*33.15*	*0.00*	*33.15*	*20.33*	*41.94*	*9.73*	*479.22*	*44.99*
Raw water + winery wastewater								
Total	*33.45*	*0.11*	*33.56*	*20.55*	*74.62*	*24.32*	*482.69*	*125.99*

[(1)] No winery wastewater was applied for this irrigation.

Table 2.87. The amounts of B, Mn, Cu, Zn, Fe, Cl, HCO_3, SO_4 and F applied *via* the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Cabernet Sauvignon at the Backsberg clay experiment plot during the 2020/21 season.

Irrigation no.	B (kg/ha)	Mn (kg/ha)	Cu (kg/ha)	Zn (kg/ha)	Fe (kg/ha)	Cl (kg/ha)	HCO_3 (kg/ha)	SO_4 (kg/ha)	F (kg/ha)
					Raw water				
1	0.00	4.01	0.00	0.02	0.13	23.56	35.87	9.48	0.00
2	0.00	0.00	0.00	0.00	0.36	26.26	41.06	7.69	0.16
3	0.00	0.04	0.00	0.00	0.21	19.45	29.29	5.17	0.00
4	0.00	0.01	0.00	0.00	0.07	5.33	7.70	1.47	0.00
5	0.00	0.00	0.01	0.03	0.02	5.70	4.22	1.53	0.00
6	0.00	0.01	0.03	0.07	0.03	4.54	3.01	1.35	0.00
7	0.00	0.00	0.00	0.01	0.02	3.95	2.31	1.00	0.00
Total	*0.00*	*4.07*	*0.04*	*0.14*	*0.82*	*88.79*	*123.45*	*27.70*	*0.16*
					Winery wastewater				
1[(1)]	-	-	-	-	-	-	-	-	-
2[(1)]	-	-	-	-	-	-	-	-	-
3[(1)]	-	-	-	-	-	-	-	-	-
4	0.00	0.02	0.00	0.00	0.38	10.46	202.79	1.92	0.09
5	0.05	0.04	0.00	0.03	0.96	12.00	214.41	25.30	0.14
6	0.05	0.04	0.00	0.01	1.64	11.74	187.84	6.57	0.11
7	0.03	0.03	0.01	0.04	0.87	10.49	119.83	3.69	0.13
Total	*0.14*	*0.13*	*0.01*	*0.07*	*3.86*	*44.70*	*724.87*	*37.48*	*0.46*
					Raw water + winery wastewater				
Total	*0.14*	*4.20*	*0.05*	*0.21*	*4.69*	*133.49*	*848.32*	*65.18*	*0.62*

(1) No winery wastewater was applied for this irrigation.

The amounts of elements applied *via* the irrigation at Madeba is given in Tables 2.88 to 2.91.

Table 2.88. The amounts of NH_4-N, NO_3-N, Total-N, P, Ca, Mg, K and Na applied *via* the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Shiraz at the Madeba sandy loam experiment plot during the 2020/21 season.

Irrigation no.	NH_4-N (kg/ha)	NO_3-N (kg/ha)	Total-N (kg/ha)	P (kg/ha)	Ca (kg/ha)	Mg (kg/ha)	K (kg/ha)	Na (kg/ha)
				Raw water				
1	0.00	0.00	0.00	0.00	10.19	7.90	2.63	37.38
2	0.00	0.00	0.00	0.00	9.91	7.66	0.00	36.03
3	0.00	0.00	0.00	0.00	6.71	5.26	0.00	25.46
4	0.00	0.00	0.00	0.00	4.97	4.07	0.00	21.71
5	0.45	0.12	0.57	0.02	4.11	3.18	2.54	14.17
6	0.00	0.00	0.00	0.00	3.50	2.94	1.59	13.54
Total	*0.45*	*0.12*	*0.57*	*0.02*	*39.39*	*31.01*	*6.76*	*148.28*
				Winery wastewater				
1[1]	-	-	-	-	-	-	-	-
2[1]	-	-	-	-	-	-	-	-
3[1]	-	-	-	-	-	-	-	-
4[1]	-	-	-	-	-	-	-	-
5	1.85	0.00	1.85	0.45	2.53	1.14	18.80	2.21
6	0.00	0.00	0.00	0.00	6.55	2.43	6.06	5.58
Total	*1.85*	*0.00*	*1.85*	*0.45*	*9.08*	*3.57*	*24.86*	*7.79*
				Raw water + winery wastewater				
Total	*2.31*	*0.12*	*2.43*	*0.48*	*48.47*	*34.58*	*31.63*	*156.07*

[1] No winery wastewater was applied for this irrigation.

Table 2.89. The amounts of B, Mn, Cu, Zn, Fe, Cl, HCO_3, SO_4 and F applied *via* the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Shiraz at the Madeba sandy loam experiment plot during the 2020/21 season.

Irrig-ation no.	B (kg/ha)	Mn (kg/ha)	Cu (kg/ha)	Zn (kg/ha)	Fe (kg/ha)	Cl (kg/ha)	HCO_3 (kg/ha)	SO_4 (kg/ha)	F (kg/ha)
Raw water									
1	0.00	0.00	0.00	0.01	0.00	51.73	45.02	17.81	0.00
2	0.00	0.00	0.00	0.01	0.00	48.54	46.83	16.19	0.00
3	0.00	0.00	0.00	0.01	0.00	33.44	33.10	11.95	0.00
4	0.00	0.00	0.00	0.01	0.00	31.11	28.94	9.49	0.10
5	0.00	0.00	0.02	0.03	0.08	20.28	14.66	6.15	0.00
6	0.00	0.00	0.01	0.02	0.00	19.65	11.20	5.87	0.00
Total	*0.00*	*0.00*	*0.03*	*0.09*	*0.08*	*204.77*	*179.77*	*67.47*	*0.10*
Winery wastewater									
1[(1)]	-	-	-	-	-	-	-	-	-
2[(1)]	-	-	-	-	-	-	-	-	-
3[(1)]	-	-	-	-	-	-	-	-	-
4[(1)]	-	-	-	-	-	-	-	-	-
5	0.01	0.02	0.00	0.00	0.02	2.80	40.46	0.93	0.03
6	0.00	0.04	0.00	0.01	0.05	6.45	30.56	2.62	0.08
Total	*0.01*	*0.06*	*0.01*	*0.01*	*0.06*	*9.25*	*71.02*	*3.55*	*0.12*
Raw water + winery wastewater									
Total	*0.01*	*0.06*	*0.04*	*0.10*	*0.15*	*214.02*	*250.79*	*71.01*	*0.22*

[(1)] No winery wastewater was applied for this irrigation.

Table 2.90. The amounts of NH_4-N, NO_3-N, Total-N, P, Ca, Mg, K and Na applied *via* the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Shiraz at the Madeba clay loam experiment plot during the 2020/21 season.

Irrigation no.	NH_4-N (kg/ha)	NO_3-N (kg/ha)	Total-N (kg/ha)	P (kg/ha)	Ca (kg/ha)	Mg (kg/ha)	K (kg/ha)	Na (kg/ha)
Raw water								
1	0.00	0.00	0.00	0.00	10.19	7.90	2.63	37.36
2	0.00	0.00	0.00	0.00	10.38	8.02	0.00	37.76
3	0.00	0.00	0.00	0.00	6.99	5.49	0.00	26.56
4	0.00	0.00	0.00	0.00	4.97	4.07	0.00	21.70
5	0.43	0.11	0.55	0.02	3.93	3.04	2.43	13.55
6	0.00	0.00	0.00	0.00	3.64	3.06	1.65	14.08
Total	*0.43*	*0.11*	*0.55*	*0.02*	*40.10*	*31.57*	*6.71*	*151.00*
Winery wastewater								
1[(1)]	-	-	-	-	-	-	-	-
2[(1)]	-	-	-	-	-	-	-	-
3[(1)]	-	-	-	-	-	-	-	-
4[(1)]	-	-	-	-	-	-	-	-
5	2.11	0.00	2.11	0.51	2.89	1.30	21.42	2.51
6	0.00	0.00	0.00	0.00	6.94	2.57	6.43	5.91
Total	*2.11*	*0.00*	*2.11*	*0.52*	*9.83*	*3.87*	*27.84*	*8.43*
Raw water + winery wastewater								
Total	*2.55*	*0.11*	*2.66*	*0.54*	*49.93*	*35.45*	*34.56*	*159.43*

[(1)] No winery wastewater was applied for this irrigation.

Table 2.91. The amounts of B, Mn, Cu, Zn, Fe, Cl, HCO_3, SO_4 and F applied *via* the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Shiraz at the Madeba clay loam experiment plot during the 2020/21 season.

Irrig-ation no.	B (kg/ha)	Mn (kg/ha)	Cu (kg/ha)	Zn (kg/ha)	Fe (kg/ha)	Cl (kg/ha)	HCO_3 (kg/ha)	SO_4 (kg/ha)	F (kg/ha)
					Raw water				
1	0.00	0.00	0.00	0.01	0.00	51.70	45.00	17.80	0.00
2	0.00	0.00	0.00	0.01	0.00	50.88	49.09	16.97	0.00
3	0.00	0.00	0.00	0.01	0.00	34.88	34.52	12.46	0.00
4	0.00	0.00	0.00	0.01	0.00	31.10	28.93	9.48	0.10
5	0.00	0.00	0.02	0.03	0.08	19.39	14.02	5.88	0.00
6	0.00	0.00	0.01	0.02	0.00	20.44	11.65	6.11	0.00
Total	*0.00*	*0.00*	*0.03*	*0.09*	*0.08*	*208.40*	*183.21*	*68.71*	*0.10*
					Winery wastewater				
1(1)	-	-	-	-	-	-	-	-	-
2(1)	-	-	-	-	-	-	-	-	-
3(1)	-	-	-	-	-	-	-	-	-
4(1)	-	-	-	-	-	-	-	-	-
5	0.01	0.02	0.00	0.00	0.02	3.18	46.09	1.06	0.04
6	0.00	0.04	0.01	0.01	0.05	6.84	32.40	2.77	0.09
Total	*0.01*	*0.06*	*0.01*	*0.01*	*0.07*	*10.02*	*78.49*	*3.83*	*0.13*
					Raw water + winery wastewater				
Total	*0.01*	*0.06*	*0.04*	*0.10*	*0.15*	*218.42*	*261.70*	*72.54*	*0.23*

(1) No winery wastewater was applied for this irrigation.

The amounts of elements applied *via* the irrigation at Lutzville are given in Tables 2.92 and 2.93.

Table 2.92. The amounts of NH_4-N, NO_3-N, Total-N, P, Ca, Mg, K and Na applied *via* the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Shiraz at Lutzville during the 2020/21 season.

Irrigation no.	NH_4-N (kg/ha)	NO_3-N (kg/ha)	Total-N (kg/ha)	P (kg/ha)	Ca (kg/ha)	Mg (kg/ha)	K (kg/ha)	Na (kg/ha)
				Raw water				
1	0.00	0.00	0.00	0.00	5.24	3.49	0.00	21.21
2	0.00	0.00	0.00	0.00	2.76	2.18	0.00	12.37
3	0.00	0.00	0.00	0.00	4.51	3.47	0.00	19.94
4	0.00	0.00	0.00	0.00	4.61	3.39	0.00	18.59
5	0.00	0.00	0.00	0.00	7.19	2.66	0.00	13.67
6	0.00	0.00	0.00	0.00	3.84	2.72	0.00	13.60
7	0.00	0.00	0.00	0.00	3.39	2.22	0.00	11.08
8	0.00	0.00	0.00	0.00	1.85	1.60	1.14	8.01
9	0.00	0.00	0.00	0.00	3.69	3.18	2.44	16.25
10	0.25	0.00	0.25	0.01	2.78	2.12	1.41	10.38
Total	*0.25*	*0.00*	*0.25*	*0.01*	*39.87*	*27.03*	*4.99*	*145.09*
				Winery wastewater				
1[1]	-	-	-	-	-	-	-	-
2[1]	-	-	-	-	-	-	-	-
3[1]	-	-	-	-	-	-	-	-
4[1]	-	-	-	-	-	-	-	-
5[1]	-	-	-	-	-	-	-	-
6[1]	-	-	-	-	-	-	-	-
7[1]	-	-	-	-	-	-	-	-
8	4.47	0.00	4.47	0.21	48.79	5.09	218.5	22.75
9[1]	-	-	-	-	-	-	-	-
10	4.36	0.00	4.36	1.45	205.50	5.65	182.55	17.62
Total	*8.84*	*0.00*	*8.84*	*1.67*	*254.28*	*10.74*	*401.05*	*40.37*
				Raw water + winery wastewater				
Total	*9.09*	*0.00*	*9.09*	*1.68*	*294.16*	*37.77*	*406.04*	*185.46*

[1] No winery wastewater was applied for this irrigation.

Table 2.93. The amounts of B, Mn, Cu, Zn, Fe, Cl, HCO_3, SO_4 and F applied *via* the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation of Shiraz at Lutzville during the 2020/21 season.

Irrigation no.	B (kg/ha)	Mn (kg/ha)	Cu (kg/ha)	Zn (kg/ha)	Fe (kg/ha)	Cl (kg/ha)	HCO_3 (kg/ha)	SO_4 (kg/ha)	F (kg/ha)
					Raw water				
1	0.00	0.00	0.00	0.00	0.10	0.00	21.21	9.72	0.00
2	0.00	0.00	0.00	0.00	0.07	22.99	13.09	5.67	0.00
3	0.00	0.00	0.00	0.00	0.00	32.94	18.21	9.35	0.00
4	0.00	0.02	0.00	0.01	0.00	28.29	20.21	8.24	0.00
5	0.00	0.02	0.00	0.00	0.00	23.45	8.63	5.39	0.00
6	0.00	0.02	0.00	0.00	0.00	19.99	19.99	5.99	0.00
7	0.00	0.00	0.00	0.02	0.00	20.86	12.39	4.69	0.00
8	0.00	0.00	0.00	0.01	0.00	11.08	2.11	3.03	0.00
9	0.00	0.01	0.00	0.02	0.00	21.87	4.43	6.42	0.00
10	0.00	0.00	0.02	0.03	0.02	13.87	5.40	4.23	0.00
Total	*0.00*	*0.07*	*0.02*	*0.09*	*0.19*	*195.35*	*125.67*	*62.72*	*0.00*
					Winery wastewater				
1[(1)]	-	-	-	-	-	-	-	-	-
2[(1)]	-	-	-	-	-	-	-	-	-
3[(1)]	-	-	-	-	-	-	-	-	-
4[(1)]	-	-	-	-	-	-	-	-	-
5[(1)]	-	-	-	-	-	-	-	-	-
6[(1)]	-	-	-	-	-	-	-	-	-
7[(1)]	-	-	-	-	-	-	-	-	-
8	0.15	0.01	0.00	0.05	0.07	12.66	336.42	50.22	0.08
9[(1)]	-	-	-	-	-	-	-	-	-
10	0.14	0.04	0.01	0.01	0.02	60.78	492.79	196.26	0.11
Total	*0.29*	*0.04*	*0.01*	*0.06*	*0.09*	*73.45*	*829.22*	*246.47*	*0.19*
					Raw water + winery wastewater				
Total	0.29	0.11	0.03	0.15	0.28	268.79	954.88	309.20	*0.19*

(1) No winery wastewater was applied for this irrigation.

2.4. CONCLUSIONS

As expected, grapevines growing in the regions with lower mean annual rainfall required more irrigation. The K and Na levels in the undiluted winery wastewater was substantially higher than that in the raw water. Consequently, the PAR of the undiluted winery wastewater was substantially higher than the raw water. With regard to the refinement of the General Authorisations for wineries, the PAR of the wastewater has not yet been adopted as a quality parameter. Considering that results confirm that winery wastewater contains high levels of K, the use of the PAR of the wastewater should be considered as a further indicator of the wastewater quality. However, further research is needed to refine PAR norms for wastewater quality. With regards to anions, HCO_3 and Cl levels was substantially higher in the undiluted winery wastewater compared to the raw water. Taking above-mentioned into consideration, substantial amounts of additional elements were applied to the vineyard *via* the in-field fractional use (augmentation) of winery wastewater with raw water for vineyard irrigation. Given that amounts of K applied *via* the in-field fractional use (augmentation) of winery wastewater with raw water were considerably higher than the grapevine's requirements, the cultivation and removal of a suitable interception crop during summer might be useful to absorb excessive K.

CHAPTER 3: EFFECT OF IN-FIELD FRACTIONAL USE (AUGMENTATION) OF WINERY WASTEWATER WITH RAW WATER ON SOIL CHEMICAL STATUS

3.1. INTRODUCTION

Although there is extensive literature available regarding the effect of irrigation with wastewaters of various origins on soil chemical properties (Hulugalle *et al.*, 2006; Walker & Lin, 2008; Duan *et al.,* 2010; Rana *et al*., 2010; Lado *et al*., 2011; Moraetis *et al*., 2011; Blum *et al*., 2012; Chávez *et al.*, 2012; Barbera *et al.,* 2013*;* Di Bene *et al,.* 2013; Thapliyal *et al.,* 2013), very little is known about the effects of irrigation using augmented winery wastewater on soil chemical status. In Australia, it is estimated that approximately 3 to 5 m^3 of winery wastewater, with high organic load and variable salinity and nutrient levels, is generally produced when a ton of grapes is crushed (Mosse *et al*., 2011). This means that this particular winery generates about 1.1 m^3 of wastewater per ton of grapes crushed. The effects of high concentrations of K application to soils have not been extensively researched and are still unclear (Mosse *et al.*, 2011; Laurenson *et al*., 2012). On the other hand, limited irrigation water supplies could be restricted further in future allocations of irrigation water (Van Zyl & Weber, 1981; Petrie *et al.*, 2004). If winery wastewater could be used to irrigate vineyards with no detrimental impacts on soil chemical status, it could be a possible viable alternative to using either raw river or recycled municipal water.

Land application of wastewater can increase levels of soluble and exchangeable forms of K more rapidly than with conventional inorganic fertilizers (Arienzo *et al.,* 2009). In addition, most of the K in wastewater is available immediately. Irrigation with K-rich wastewater could be beneficial to overall soil fertility, although long-term application could affect soil chemical and physical properties (Laurenson *et al*., 2011; Mosse *et al.*, 2011). A further advantage of using winery wastewater as a source of K over the use of conventional fertiliser is that it could be an efficient recycling practice where the soil has low K. In addition to Na and K ions, winery wastewater can also contain Ca and Mg ions (Mosse *et al*., 2011). Neither of these ions is harmful to soil structure and can ameliorate the impacts of Na *via* their role in reducing the SAR.

According to Kumar *et al.* (2014), both soil K and SAR increased throughout the soil profile where winery wastewater was used for irrigation. The latter practice also resulted in higher Na and K in vineyard soils compared to a control vineyard which was irrigated with river water (Kumar *et al.*, 2006). In a field study, where grapevines were irrigated with simulated winery wastewater, soil Na levels in the 0-20 cm and 20-40 cm layers increased (Mosse *et al*., 2013). The addition of wine to the simulated winery wastewater enhanced K movement to the subsoil. In a field study where grapevines were irrigated with diluted winery wastewater, the element concentrations in an alluvial, sandy soil did not respond to the irrigation with the exception of K and Na (Myburgh & Howell, 2014). This was probably due to the low levels of the other elements applied *via* the irrigation with diluted winery wastewater in relation to the K and Na. Mulidzi (2016) investigated the effect of rainfall on different soils which were irrigated with winery wastewater in a pot experiment. Thereafter, simulated winter rainfall was added to the pots. Leaching of cations, particularly K and Na occurred from only four of the six soils when winter rainfall was simulated. The simulated rainfall was too low for a sandy and a clay soil to allow leaching. Furthermore, more cations were leached from the sandy soils compared to the two heavier soils.

The aim of this study was to determine the effect of in-field fractional use (augmentation) of winery wastewater with raw water for vineyard irrigation on the chemical status of different soils to assess the fitness for use of winery wastewater for irrigation of different soil types with varying rainfall

3.2. MATERIALS AND METHODS

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. 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. 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 (Fig. 3.1). Samples for each depth were analysed for soil chemical parameters by a commercial laboratory (Bemlab, Strand; Labserve, Stellenbosch), according to the methods described by Myburgh and Howell (2014).

Since the amounts of soluble cations were not determined, the amount of exchangeable cations, which is the extractable minus the soluble amounts (Richards, 1954), could not be calculated. Therefore, the cation exchange capacity (CEC) could not be calculated. Most South African laboratories only determine extractable cations due to the tedious process of determining the exchangeable cations and CEC (Conradie, 1994). Therefore, most laboratories calculate the sum of the extractable cations to obtain an estimated CEC, which is also referred to as the S-value. Given the above-mentioned, the ESP and EPP of the soil could not be calculated. However, the extractable sodium percentage (ESP´) was calculated as follows:

$$ESP' = (Na \div S) \times 100 \qquad \text{Eq. 3.1)}$$

where Na is the extractable sodium (cmol$^{(+)}$/kg) and S is the S-value (cmol$^{(+)}$/kg), *i.e.* the sum of the Ca, Mg, K and Na.

The extractable potassium percentage (EPP´) was calculated as follows:

$$EPP' = (K \div S) \times 100 \qquad \text{(Eq. 3.2)}$$

where K is the extractable potassium (cmol$^{(+)}$/kg) and S is the S-value (cmol$^{(+)}$/kg), *i.e.* the sum of the Ca, Mg, K and Na.

The designation ESP´ is used so as not to confuse extractable sodium percentage, which includes both adsorbed Na and Na in solution, with ESP. Likewise, the designation EPP´ is used so as not to confuse extractable potassium percentage, which includes both adsorbed K and K in solution, with EPP.

Figure 3.1. A modified soil auger was used to collect soil samples to 3 m depth at the Lutzville deep sand experiment plot.

3.3. RESULTS AND DISCUSSION

3.3.1. $pH_{(KCl)}$

There was a decrease in soil $pH_{(KCl)}$ at the Backsberg experiment plots following winter rainfall in 2018 (Fig. 3.2). The $pH_{(KCl)}$ of the Madeba clay loam experiment plot was lower in the 60-120 cm soil layer after winter. After winter, subsoil $pH_{(KCl)}$ at the Lutzville deep sand experiment plot decreased to levels similar to baseline values. This was probably due to the leaching of HCO_3^- during rainfall. The soil $pH_{(KCl)}$ of the Spruitdrift shallow sand experiment plot remained unchanged after winter. Soil pH after wastewater application in May 2019 tended to be lower than baseline values but were higher after the winter rainfall period of the 2018/19 season. The soil $pH_{(KCl)}$ of the Backsberg sand experiment plot was low after the winter rainfall of 2020. Furthermore, for the Backsberg clay and Madeba clay loam experiment plots, soil $pH_{(KCl)}$ increased. After wastewater application in May 2021, soil $pH_{(KCl)}$ of the Backsberg sand experiment plot tended to increase but was reduced by the winter rainfall. After the winter of the 2020/21 season, soil $pH_{(KCl)}$ at the Madeba clay loam and Lutzville deep sand experiment plots were lower than that measured after wastewater application.

The baseline values for soil $pH_{(KCl)}$ for the Backsberg sand experiment plot was 6.7, 7.3, 6.9 and 6.1 for the 0-30 cm, 30-60 cm, 60-90 cm and 90-120 cm soil layers, respectively. Soil $pH_{(KCl)}$ at this particular plot was lower at the end of the trial in September 2021 compared to the baseline values (Fig 3.2). The soil $pH_{(KCl)}$ was still within the norm of 5.0 to 7.5 recommended by Saayman (1981) for optimal grapevine growth. The baseline values for soil $pH_{(KCl)}$ for the Backsberg clay experiment plot was 6.1, 6.8, 6.9, 6.6 and 6.3 for the 0-30 cm, 30-60 cm, 60-90 cm, 90-120 cm and 120-150 cm soil layers, respectively. Soil $pH_{(KCl)}$ in the 0-30 cm, 30-60 cm and 60-90 cm soil layers was lower at the end of the trial in September 2021 compared to the baseline values (Fig 3.2) but were still within the norm of 5.0 to 7.5 recommended by Saayman (1981) for optimal grapevine growth. The baseline values for soil $pH_{(KCl)}$ for the Madeba sandy loam experiment plot was 6.5, 6.1, 5.5 and 5.5 for the 0-30 cm, 30-60 cm, 60-90 cm and 90-120 cm soil layers, respectively. Soil $pH_{(KCl)}$ at the end of the trial in September 2021 was lower than the baseline values for the 30-60 cm and 60-90 cm soil layers (Fig. 3.2). The baseline values for soil $pH_{(KCl)}$ for the Madeba clay loam experiment plot was 7.0, 7.2, 7.2, 7.4 and 7.5 for the 0-30 cm, 30-60 cm, 60-90 cm, 90-120 cm and 120-150 cm soil layers, respectively. Soil $pH_{(KCl)}$ was generally lower at the end of the trial in September 2021 compared to the baseline values (Fig. 3.2). The baseline values for soil $pH_{(KCl)}$ for the Lutzville deep sand experiment plot was 6.6, 6.2, 6.0, 5.9, 5.8, 5.9, 6.1, 6.3, 6.3 and 6.9.2, 7.4 and 7.5 for the 0-30 cm, 30-60 cm, 60-90 cm, 90-120 cm, 120-150 cm, 150-180 cm, 180-210 cm, 210-240 cm and 240-270 cm soil layers, respectively. At this particular plot, soil $pH_{(KCl)}$ tended to be higher at the end of the trial in September 2021 compared to the baseline values (Fig. 3.2). The baseline values for $pH_{(KCl)}$ for the Spruitdrift shallow sand experiment plot was

5.9 and 7.0 for the 0-30 cm and 30-60 cm soil layers, respectively. At the end of the trial in September 2021, soil $pH_{(KCl)}$ was lower than baseline values (Fig. 3.2).

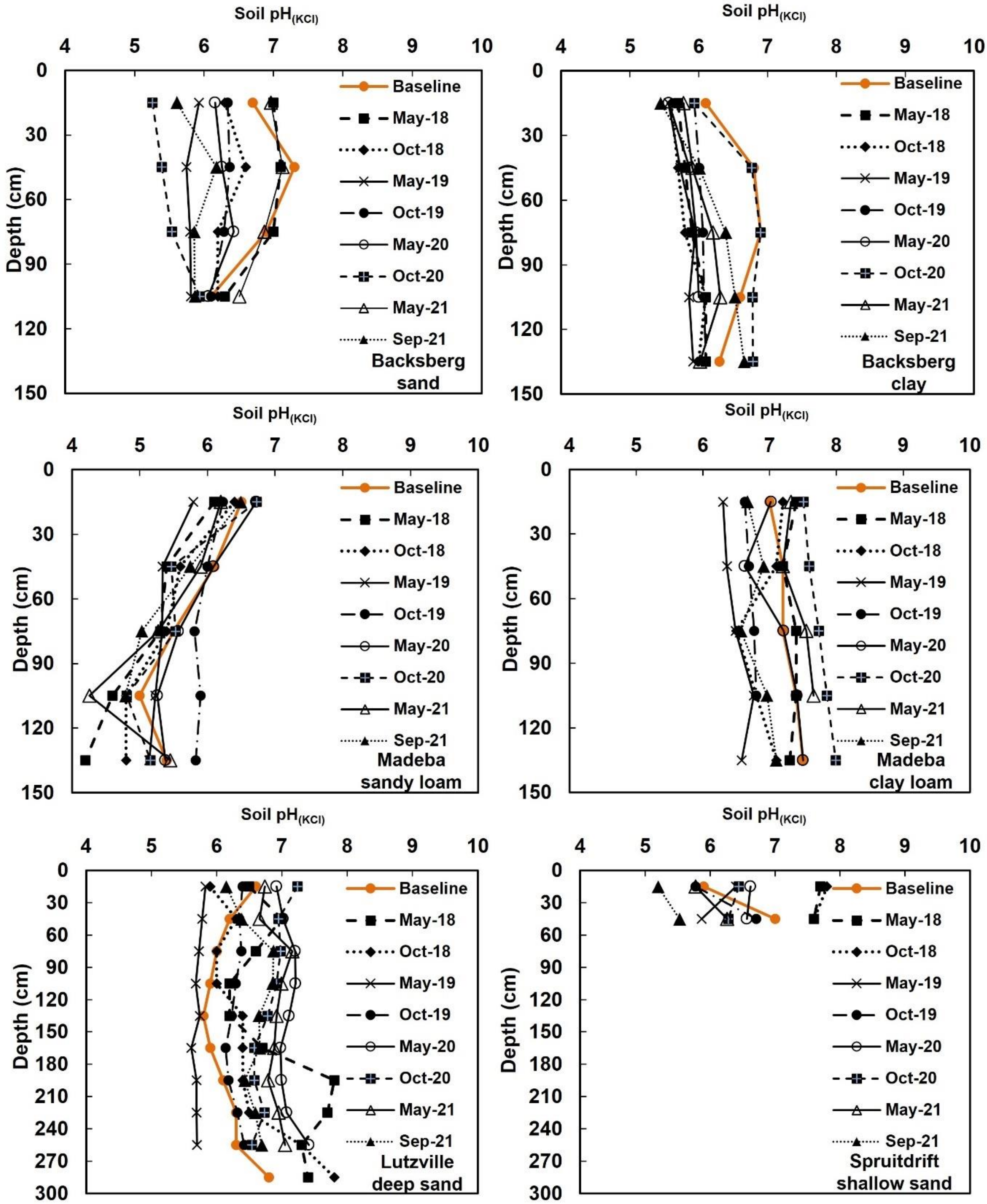

Figure 3.2. Soil $pH_{(KCl)}$ measured at the various experiment plots.

3.3.2. Electrical conductivity of the saturated extract (EC_e)

Winter rainfall in 2018 did not affect EC_e of Coastal region experiment plots (Fig. 3.3). Following winter, salinity levels in the 30-90 cm soil layer of the Madeba sandy loam experiment plot decreased to values below baseline and post-treatment values. At the clay loam plot, subsoil EC_e increased relative to post-treatment values. The EC_e of the Lutzville deep sand experiment plot was similar to the baseline after the winter rainfall period whereas the EC_e of the topsoil decreased at the Spruitdrift shallow sand experiment plot, and salts were leached to the 30-60 cm soil layer. Soil EC_e at the Spruitdrift shallow sand experiment plot after wastewater application in May 2019 was higher than the baseline value. Winter rainfall of the 2018/19 and 2019/20 seasons did not affect EC_e of Coastal region experiment plots with the exception of the deeper soil layers in 2020. Similarly, winter rainfall during 2021 did not affect EC_e of the Coastal region experiment plots or the Lutzville deep sand experiment plot.

The baseline values for EC_e for the Backsberg sand experiment plot was 0.176, 0.093, 0.105 and 0.169 dS/m for the 0-30 cm, 30-60 cm, 60-90 cm and 90-120 cm soil layers, respectively. Soil EC_e at this particular plot at the end of the trial in September 2021 was generally lower compared to these baseline levels (Fig 3.3). This indicated that under the prevailing conditions, 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 soil. The baseline values for EC_e for the Backsberg clay plot was 0.216, 0.197, 0.212, 0.179 and 0.114 dS/m for the 0-30 cm, 30-60 cm, 60-90 cm, 90-120 cm and 120-150 cm soil layers, respectively. Soil EC_e at the end of the trial in September 2021 was similar to these baseline levels (Fig 3.3). The baseline values for EC_e for the Madeba sandy loam experiment plot was 0.540, 0.200, 0.330 and 0.360 dS/m for the 0-30 cm, 30-60 cm, 60-90 cm and 90-120 cm soil layers, respectively. Soil EC_e in the 0-30 cm soil layer was lower than the baseline value (Fig. 3.3). The baseline values for EC_e for the Madeba clay loam experiment plot was 0.431, 0.463, 0.581, 0.893 and 1.136 dS/m for the 0-30 cm, 30-60 cm, 60-90 cm, 90-120 cm and 120-150 cm soil layers, respectively. Soil EC_e levels was higher at this plot at the end of the trial in September 2021 (Fig. 3.3). This trend suggested an accumulation of salts during the grapevine growing season partly due to irrigation in-field fractional use (augmentation) of winery wastewater with raw water which contains salts (Laurenson *et al.*, 2012). In heavier soils, less effective leaching is more likely to result in salt accumulation. The baseline values for EC_e for the Lutzville deep sand experiment plot was 0.097, 0.062, 0.047, 0.060, 0.070, 0.060, 0.080, 0.070 and 0.080 dS/m for the 0-30 cm, 30-60 cm, 60-90 cm, 90-120 cm, 120-150 cm, 150-180 cm, 180-210 cm, 210-240 cm and 240-270 cm soil layers, respectively. Soil EC_e levels at the end of the trial in September 2021 tended to be higher than the baseline values (Fig. 3.3). This suggested an accumulation of salts from the in-field fractional use (augmentation) of winery wastewater with raw water as well as less effective leaching due to lower mean annual rainfall in this particular region. The baseline values for EC_e for the Spruitdrift shallow sand experiment plot was 0.321 and 0.357 dS/m for the 0-30 cm and 30-60 cm soil layers, respectively. Soil EC_e levels at the end of the trial in September 2021 at this particular experiment plot was lower than the baseline values (Fig. 3.3). It should be noted that this particular experiment plot was not irrigated with the in-field fractional use (augmentation) of winery wastewater with raw water for the last two years of the study,

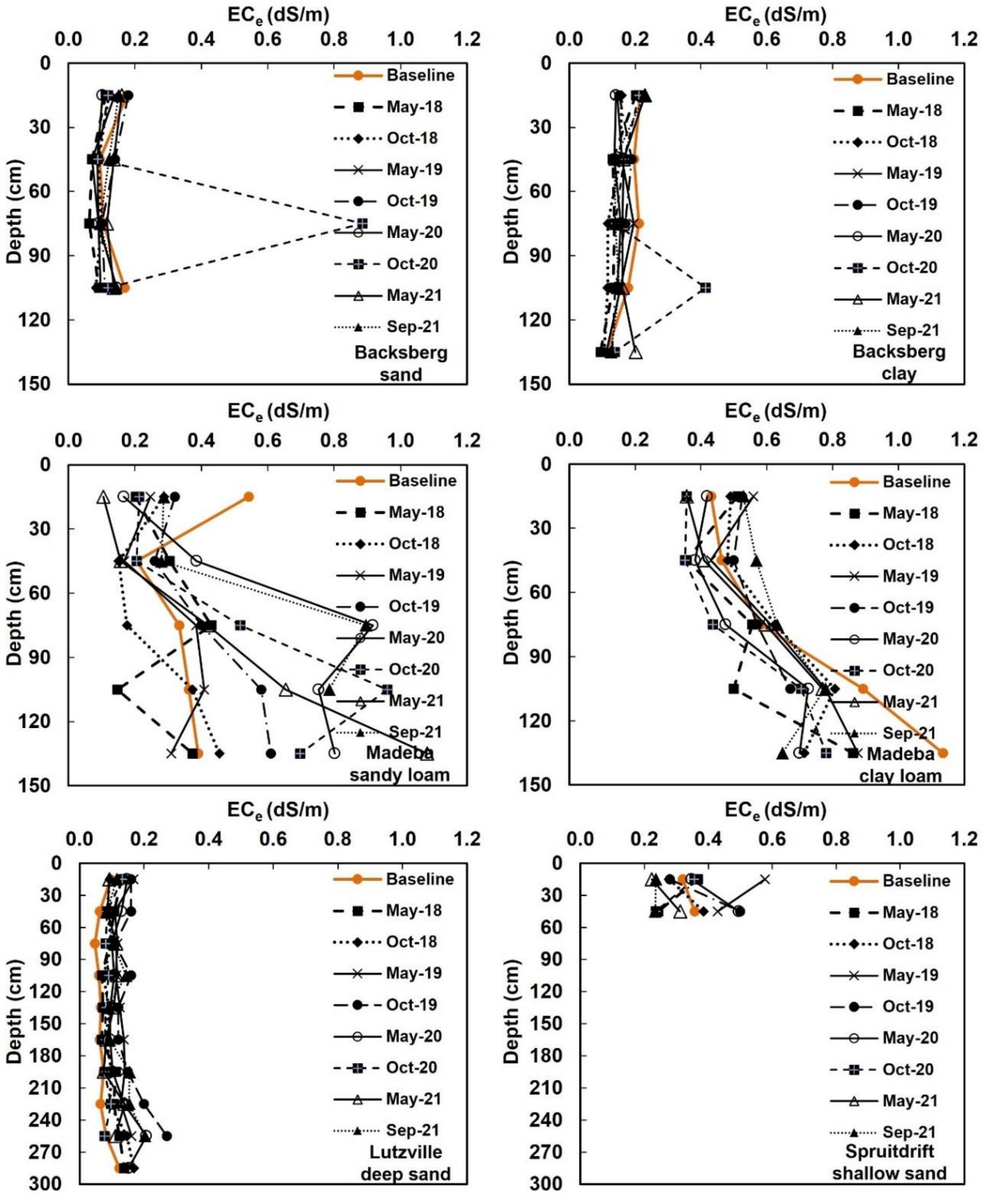

Figure 3.3. Soil EC_e measured at the various experiment plots.

3.3.3. Phosphorus (Bray II)

Levels of P after winter in the experiment plots at Backsberg were similar to baseline levels (Fig. 3.4). Experiment plots at Madeba showed an increase in Bray II P after winter rainfall. Despite the application of 30 kg/ha P *via* the irrigation water at the Lutzville deep sand experiment plot (Refer to Chapter 2), soil Bray II P after winter was similar to baseline levels. Bray II P in the topsoil at Spruitdrift increased substantially compared to the baseline. This was probably due to the application of over 40 kg/ha P *via* the irrigation water (Refer to Chapter 2). Higher $pH_{(KCl)}$ of this plot could have increased the soluble forms of P in the soil and limited the formation of insoluble Ca-phosphates (Mulidzi, 2016). After wastewater application in the 2018/19 season, P levels at Spruitdrift experiment plot increased substantially. Levels of P after winter in the 2018/19 season were lower than baseline levels

The baseline values for P for the Backsberg sand experiment plot was 63, 59, 50 and 32 mg/kg for the 0-30 cm, 30-60 cm, 60-90 cm and 90-120 cm soil layers, respectively. Soil P levels were lower at this plot at the end of the trial in September 2021 (Fig. 3.4). The baseline values for P for the Backsberg clay experiment plot was 69, 44, 26, 17 and 2 mg/kg for the 0-30 cm, 30-60 cm, 60-90 cm, 90-120 cm and 120-150 cm soil layers, respectively. Soil P levels were lower at this plot were also at the end of the trial in September 2021 (Fig. 3.4). The baseline values for P for the Madeba sandy loam experiment plot was 245, 170, 62 and 22 mg/kg for the 0-30 cm, 30-60 cm, 60-90 cm and 90-120 cm soil layers, respectively. Soil P at the end of the trial was substantially lower than the baseline value (Fig. 3.4). The baseline values for P for the Madeba clay loam experiment plot was 49, 28, 25, 16 and 10 mg/kg for the 0-30 cm, 30-60 cm, 60-90 cm, 90-120 cm and 120-150 cm soil layers, respectively. Soil P levels were higher at this plot at the end of the trial in September 2021 (Fig. 3.4). This trend suggested an accumulation of salts during the grapevine growing season partly due to irrigation with the in-field fractional use (augmentation) of winery wastewater with raw water which contains salts (Laurenson *et al.*, 2012). In heavier soils, less effective leaching is more likely to result in salt accumulation. The baseline values for P for the Lutzville deep sand experiment plot was 22, 10, 6, 4, 4, 3, 3, 5 and 3 mg/kg for the 0-30 cm, 30-60 cm, 60-90 cm, 90-120 cm, 120-150 cm, 150-180 cm, 180-210 cm, 210-240 cm and 240-270 cm soil layers, respectively. Soil P levels at the end of the trial in September 2021 tended to be lower than the baseline values (Fig. 3.4). The baseline values for P for the Spruitdrift shallow sand experiment plot was 29 and 52 mg/kg for the 0-30 cm and 30-60 cm soil layers, respectively. Soil P levels at the end of the trial in September 2021 at this particular plot was similar to the baseline value in the 0-30 cm soil layer (Fig. 3.4).

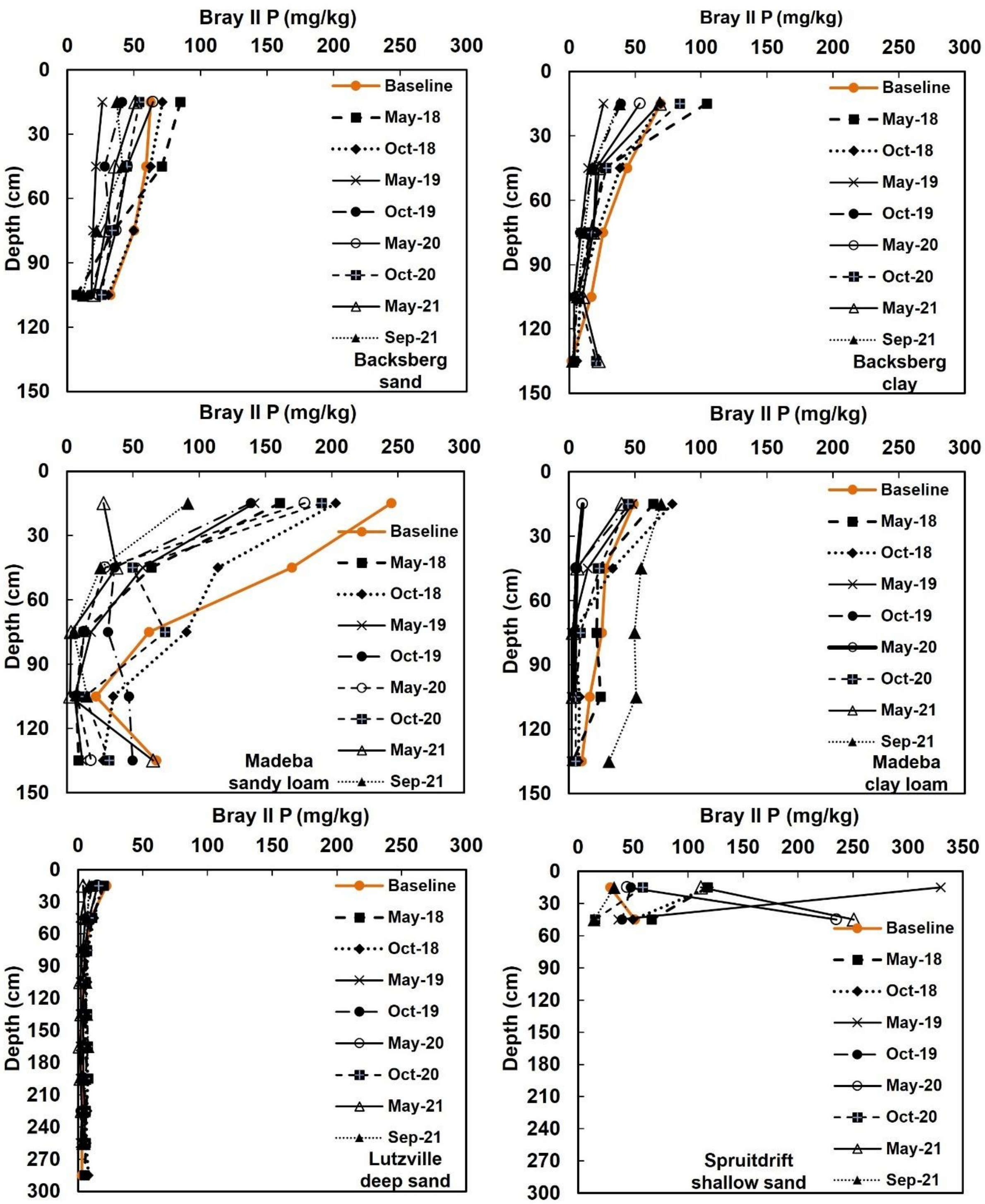

Figure 3.4. Soil Bray-II P measured at the various experiment plots.

3.3.4. Calcium

Soil Ca levels at the Backsberg sand experiment plot remained comparable to the baseline at the end of the winter of 2018 (Fig. 3.5). Soil Ca levels at the Backsberg clay experiment plot at the end of winter were similar to levels measured after wastewater irrigation. At the Madeba experiment plots, it appeared that irrigation water and rainfall, along with grapevine uptake, effectively removed Ca from the soil. At the Lutzville deep sand experiment plot there was a slight accumulation of Ca in the 270-300 cm soil layer after the winter rainfall period. After winter, soil Ca levels at the Spruitdrift shallow sand experiment plot remained relatively unchanged. Therefore, it can be assumed that the rainfall in this region was not able to leach Ca from the soil at this plot. After wastewater application in May 2019, Ca levels at the Spruitdrift experiment plot increased substantially. Soil Ca levels at the Backsberg clay and Madeba experiment plots at the end of winter in the 2018/19 season were similar to levels measured after wastewater irrigation. Soil Ca levels at the Backsberg sand, and Madeba sandy loam and Lutzville experiment plots at the end of winter in the 2019/20 season were similar to levels measured after wastewater irrigation. In the 2021/21 season, soil Ca at the Backsberg sand experiment plot increased after wastewater irrigation but decreased after the winter rainfall. The soil Ca level in the 0-30 cm soil layer of the Backsberg clay experiment plot decreased after the winter rainfall. Soil Ca levels at the Lutzville deep sand experiment plot at the end of winter in the 2020/21 season was similar to levels measured after wastewater irrigation.

The baseline values for soil Ca for the Backsberg sand experiment plot was 2.69, 2.91, 2.42 and 2.91 cmol$^{(+)}$/kg for the 0-30 cm, 30-60 cm, 60-90 cm and 90-120 cm soil layers, respectively. Soil Ca at this particular plot at the end of the trial in September 2021 was higher in certain soil layers compared to these baseline levels (Fig 3.5). This indicated that under the prevailing conditions, irrigation with the in-field fractional use (augmentation) of winery wastewater with raw water lead to a long-term accumulation of salts in the soil in some soil layers. The baseline values for Ca for the Backsberg clay experiment plot was 3.44, 4.52, 5.26, 3.65 and 2.06 cmol$^{(+)}$/kg for the 0-30 cm, 30-60 cm, 60-90 cm, 90-120 cm and 120-150 cm soil layers, respectively. Soil Ca at the end of the trial in September 2021 was lower than the baseline values in the 0-30, 30-60 and 60-90 cm soil layers but higher in the 90-120 and 120-150 cm soil layers (Fig 3.5). The baseline values for Ca for the Madeba sandy loam experiment plot was 9.25, 4.29, 2.68 and 2.01 cmol$^{(+)}$/kg for the 0-30 cm, 30-60 cm, 60-90 cm and 90-120 cm soil layers, respectively. Soil Ca in the 0-30 and 30-60 cm soil layers was lower than the baseline values (Fig. 3.5). The baseline values for Ca for the Madeba clay loam experiment plot was 15.09, 14.83, 15.92, 17.69 and 16.12 cmol$^{(+)}$/kg for the 0-30 cm, 30-60 cm, 60-90 cm, 90-120 cm and 120-150 cm soil layers, respectively. Soil Ca levels was generally lower at this plot at the end of the trial in September 2021 compared to the baseline values (Fig. 3.5). The baseline values for Ca for the Lutzville deep sand experiment plot was 1.48, 1.18, 1.19, 1.09, 1.12, 1.25, 1.31, 1.33 and 1.18 cmol$^{(+)}$/kg for the 0-30 cm, 30-60 cm, 60-90 cm, 90-120 cm, 120-150 cm, 150-180 cm, 180-210 cm, 210-240 cm and 240-270 cm soil layers, respectively. Soil Ca levels at the end of the trial in September 2021 tended to be higher in all soil layers compared to the baseline values (Fig. 3.5). This indicated that under the prevailing conditions, irrigation with the in-field fractional use (augmentation) of winery wastewater with raw water in this low rainfall region lead to a long-term accumulation of salts in the soil. The baseline values for Ca for the Spruitdrift shallow sand experiment plot was 3.66 and 5.67 cmol$^{(+)}$/kg for the 0-30 cm and 30-60 cm soil layers, respectively. Soil Ca levels were lower than baseline values until the end of the trial in September 2021 (Fig. 3.5).

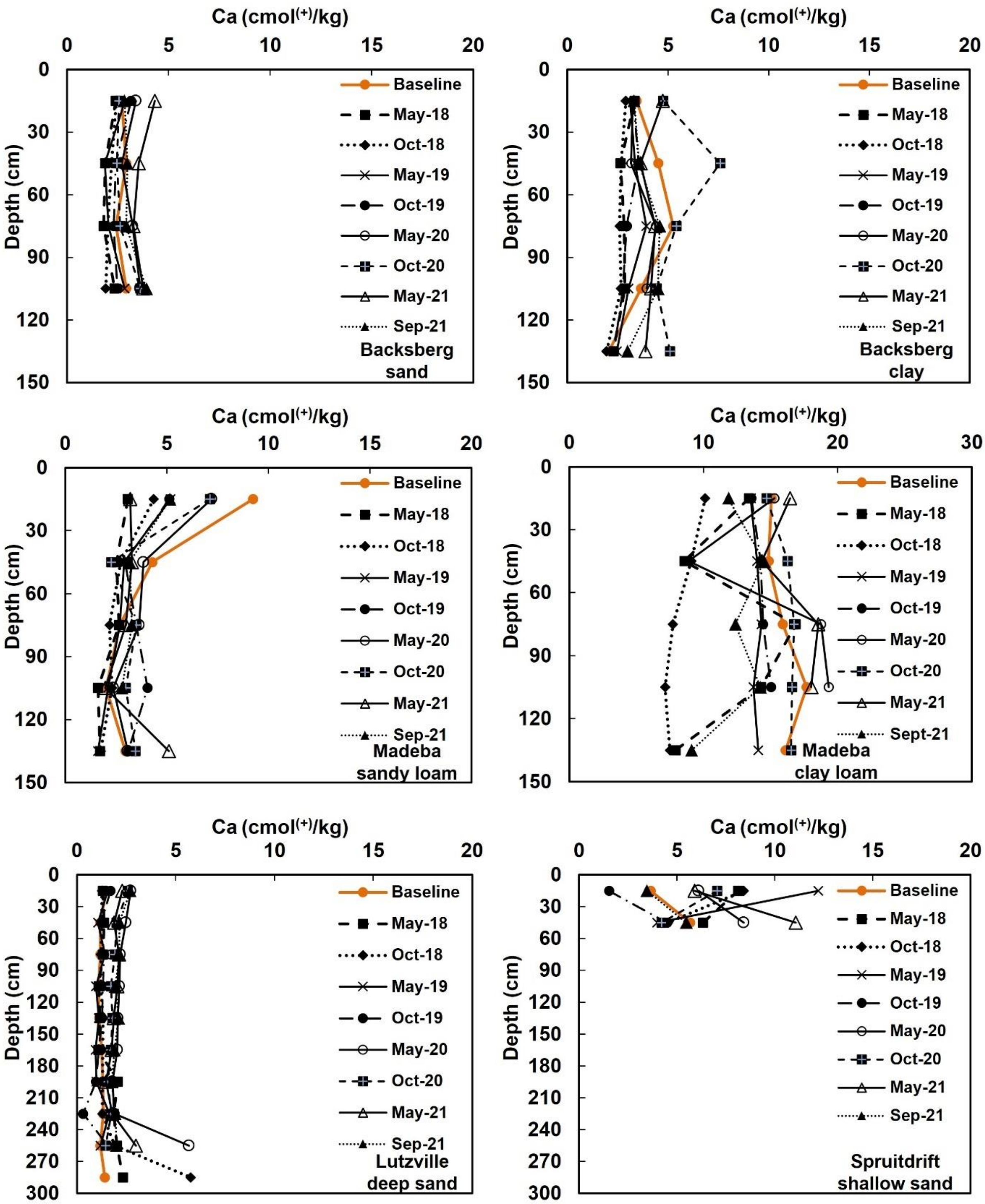

Figure 3.5. Soil extractable Ca measured at the various experiment plots.

3.3.5. Magnesium

Soil Mg levels of the Backsberg experiment plots remained relatively unchanged after winter rainfall of 2018 (Fig. 3.6). With the exception of a slight increase below 90 cm, Mg levels at the Madeba sandy loam experiment plot remained relatively unchanged after winter. There was a substantial increase of Mg in the Madeba clay loam experiment plot after winter. At this stage, there is no plausible explanation for the observed increase. At the Lutzville deep and Spruitdrift shallow sand experiment plots, soil Mg was similar to baseline values, but higher than values reported for May 2018. Reasons for the increases after the rainfall period are still unclear. Soil Mg increased substantially at the Spruitdrift shallow sand experiment plot after wastewater application in May 2019. Soil Mg levels of the Backsberg clay experiment plot remained relatively unchanged and were lower at the Madeba experiment plots after winter rainfall in October 2019. Soil Mg levels at all the experiment plots remained relatively unchanged or lower after winter rainfall in October 2020 compared to after wastewater irrigation in May 2020. After wastewater irrigation during the 2020/21 season, soil Mg at the Backsberg clay experiment plot increased.

The baseline values for soil Mg for the Backsberg sand experiment plot was 0.45, 0.27, 0.24 and 0.41 cmol$^{(+)}$/kg for the 0-30 cm, 30-60 cm, 60-90 cm and 90-120 cm soil layers, respectively. Soil Mg in the 0-30 cm soil layer at this particular plot at the end of the trial in September 2021 was similar to these baseline levels (Fig 3.6). However, soil Mg in the deeper soil layers in September 2021 was higher than the baseline values. For the Backsberg clay experiment plot, the baseline values for Mg was 0.65, 0.52, 0.40, 0.39 and 0.56 cmol$^{(+)}$/kg for the 0-30 cm, 30-60 cm, 60-90 cm, 90-120 cm and 120-150 cm soil layers, respectively. Soil Mg at the end of the trial in September 2021 was similar or higher compared to these baseline levels (Fig 3.6). The baseline values for Mg for the Madeba sandy loam experiment plot was 3.03, 1.77, 1.37 and 1.48 cmol$^{(+)}$/kg for the 0-30 cm, 30-60 cm, 60-90 cm and 90-120 cm soil layers, respectively. Soil Mg in the 0-30 cm and 30-60 cm soil layers was lower than the baseline value (Fig. 3.6). The baseline values for Mg for the Madeba clay loam experiment plot was 2.73, 2.45, 2.92, 3.24 and 3.59 cmol$^{(+)}$/kg for the 0-30 cm, 30-60 cm, 60-90 cm, 90-120 cm and 120-150 cm soil layers, respectively. Soil Mg levels was higher at this plot at the end of the trial in September 2021 (Fig. 3.6). This trend suggested an accumulation of salts during the grapevine growing season partly due to irrigation with the in-field fractional use (augmentation) of winery wastewater with raw water (Laurenson *et al.*, 2012). Furthermore, in heavier soils, less effective leaching is more likely to result in salt accumulation. The baseline values for Mg for the Lutzville deep sand experiment plot was 0.90, 1.12, 1.49, 1.54, 1.68, 1.88, 2.11, 2.30 and 2.37 cmol$^{(+)}$/kg for the 0-30 cm, 30-60 cm, 60-90 cm, 90-120 cm, 120-150 cm, 150-180 cm, 180-210 cm, 210-240 cm and 240-270 cm soil layers, respectively. Soil Mg levels at the end of the trial in September 2021 tended to be lower than the baseline values up to a depth of 210 cm (Fig. 3.6). The baseline values for Mg for the Spruitdrift shallow sand experiment plot was 3.07 and 3.98 cmol$^{(+)}$/kg for the 0-30 cm and 30-60 cm soil layers, respectively. Soil Mg levels were lower than the baseline values at the end of the trial in September 2021 (Fig. 3.6).

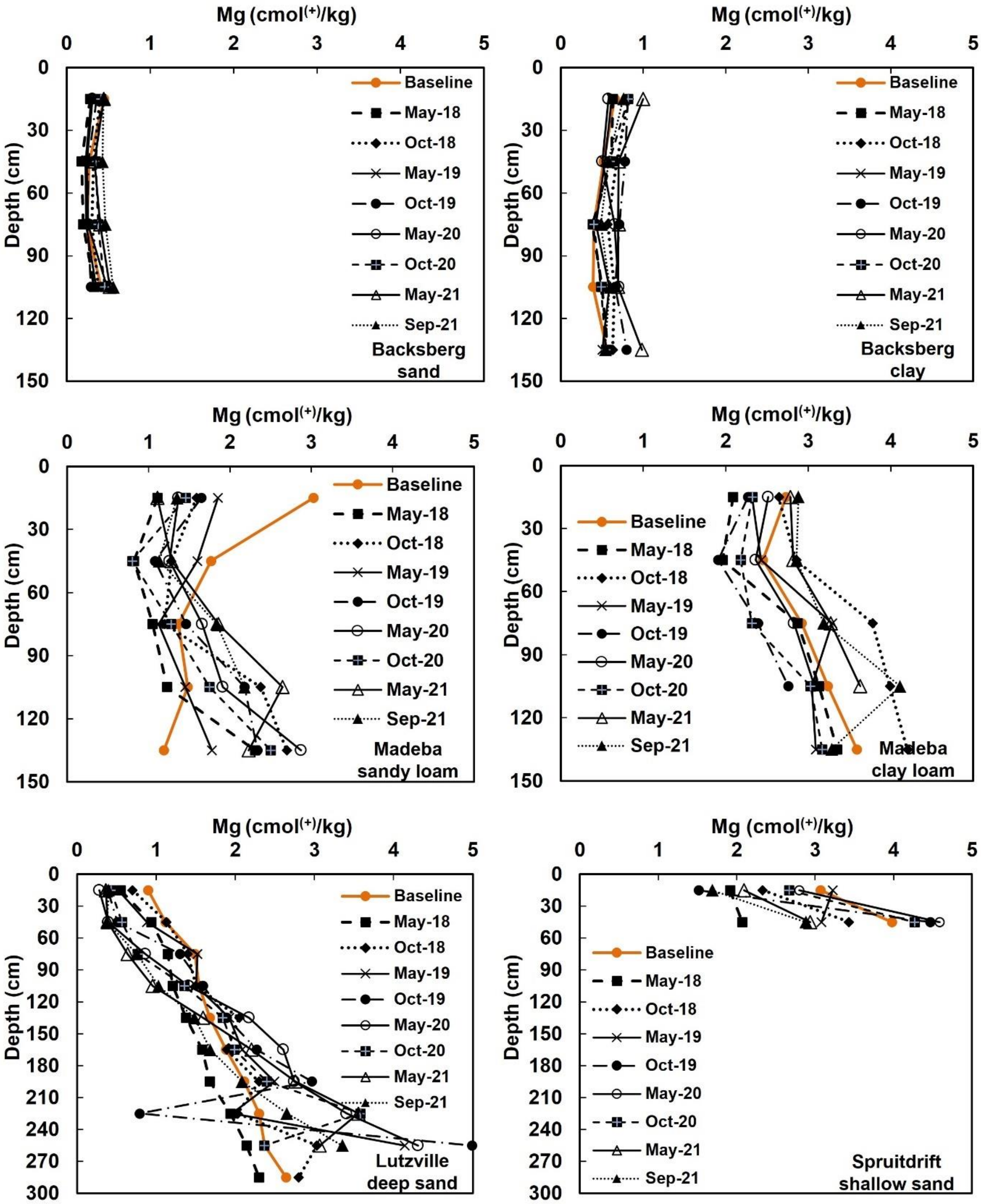

Figure 3.6. Soil extractable Mg measured at the various experiment plots.

3.3.6. Potassium and EPP´

There was a slight increase in plant-available K of the 0-30 cm and 30-60 cm soil layers of the Backsberg clay experiment plot after the winter of 2018. The K levels were higher at the Madeba experiment plots after winter. At the end of winter, the application of over 1 000 kg/ha K *via* the irrigation water (Refer to Chapter 2) resulted in a substantial increase in extractable K in the topsoil of the Lutzville experiment plot. The application of 1 200 kg/ha K at the Spruitdrift shallow sand experiment plot (Refer to Chapter 2) increased topsoil extractable K. The greater accumulation of K in the soils of this region was a result of higher amounts of K applied *via* the irrigation water in conjunction with lower winter rainfall. After winter in the 2018/19 season, K levels at Madeba experiment plots were similar to levels in May 2019. After winter in the 2019/20 season, K levels at all the experiment plots were similar to levels in May 2020. In the 2020/21 season, soil K increased after wastewater application in all the experiment plots.

The baseline values for soil K for the Backsberg sand experiment plot was 0.13, 0.06, 0.04 and 0.06 cmol$^{(+)}$/kg for the 0-30 cm, 30-60 cm, 60-90 cm and 90-120 cm soil layers, respectively. Soil K at this particular plot at the end of the trial in September 2021 was higher to these baseline levels for all the soil layers (Fig 3.7). This indicated that under the prevailing conditions, irrigation with the in-field fractional use (augmentation) wastewater lead to an accumulation of salts even in the sandy soil in the higher rainfall region. The baseline values for soil K for the Backsberg clay experiment plot was 0.23, 0.19, 0.13, 0.10 and 0.09 cmol$^{(+)}$/kg for the 0-30 cm, 30-60 cm, 60-90 cm, 90-120 cm and 120-150 cm soil layers, respectively. Soil K at the end of the trial in September 2021 was higher than these baseline levels up to a depth of 90 cm (Fig 3.7). The accumulation of the K was substantially higher in the clay compared to the sand. In heavier soils, less effective leaching is more likely to result in salt accumulation. The baseline values for soil K for the Madeba sandy loam experiment plot was 0.35, 0.33, 0.24 and 0.26 cmol$^{(+)}$/kg for the 0-30 cm, 30-60 cm, 60-90 cm and 90-120 cm soil layers, respectively. Soil K in all soil layers was higher than the baseline values (Fig. 3.7). The baseline values for EC_e for the Madeba clay loam experiment plot was 0.55, 0.37, 0.47, 0.43 and 0.55 cmol$^{(+)}$/kg for the 0-30 cm, 30-60 cm, 60-90 cm, 90-120 cm and 120-150 cm soil layers, respectively. Soil K at the end of the trial in September 2021 was substantially higher compared to the baseline values (Fig. 3.7). The accumulation of the K was substantially higher in the clay loam compared to the sandy loam. In heavier soils, less effective leaching is more likely to result in salt accumulation. The baseline values for soil K for the Lutzville deep sand experiment plot was 0.36, 0.27, 0.23, 0.22, 0.24, 0.26, 0.25, 0.31 and 0.29 cmol$^{(+)}$/kg for the 0-30 cm, 30-60 cm, 60-90 cm, 90-120 cm, 120-150 cm, 150-180 cm, 180-210 cm, 210-240 cm and 240-270 cm soil layers, respectively. Soil K levels at the end of the trial in September

2021 tended to be higher than the baseline values up to a depth of 180 cm (Fig. 3.7). The greater accumulation of K in the soils of this region was a result of higher amounts of K applied *via* the irrigation water in conjunction with lower winter rainfall. The baseline values for soil K for the Spruitdrift shallow sand experiment plot was 0.38 and 0.357 cmol$^{(+)}$/kg for the 0-30 cm and 30-60 cm soil layers, respectively. Soil K levels were lower than baseline values at the end of the trial in September 2021 (Fig. 3.7). This was expected given that no winery wastewater had been applied at this particular plot for the last two seasons of the study.

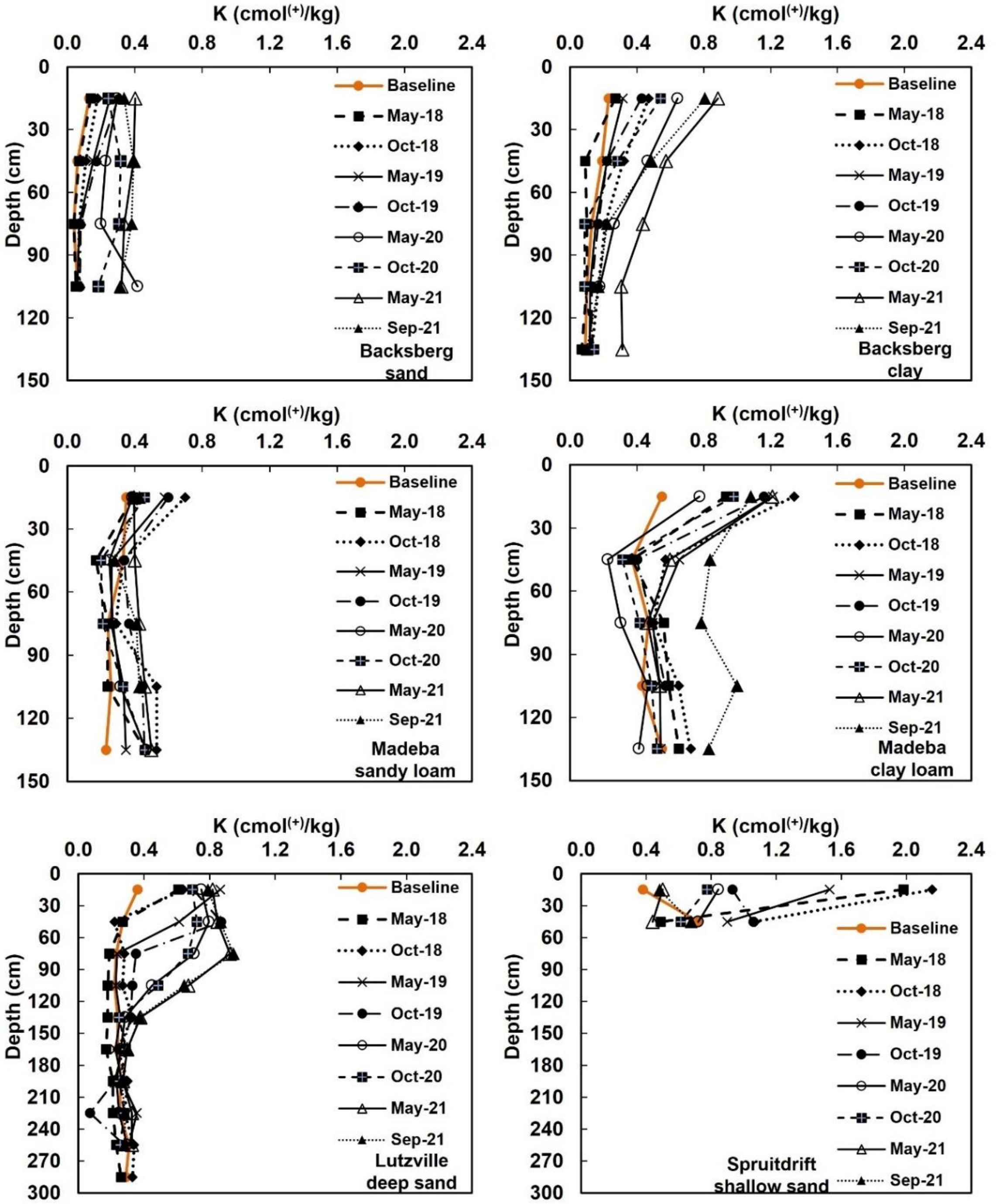

Figure 3.7. Soil extractable K measured at the various experiment plots.

Compared to the baseline, there was a slight increase in EPP´ throughout the soil profile at the Backsberg sand experiment plot at the end of winter in 2018 (Fig. 3.8). Similarly, EPP´ at the Backsberg clay experiment plot increased after the winter rainfall period. The EPP´ at the Madeba experiment plots also increased substantially after winter compared to the baseline. The EPP´ in the 0-30 cm soil layer of the Lutzville deep sand experiment plot after winter increased by more than 10% compared to the baseline values. A similar trend was observed for the Spruitdrift shallow sand experiment plot. After wastewater application in May 2019, EPP´ increased at the Backsberg sand and Lutzville deep sand experiment plots. After winter rainfall in October 2019, EPP´ at the Backsberg experiment plots were similar to after wastewater irrigation. The EPP´ at the Spruitdrift shallow sand experiment plot was higher than after wastewater application. After winter rainfall in October 2020, EPP´ at the Backsberg clay experiment plot was substantially lower than after wastewater irrigation. After wastewater application in May 2021, EPP´ increased at the Backsberg sand and clay, Madeba sandy loam as well as Lutzville deep sand experiment plots.

The baseline values for soil EPP´ for the Backsberg sand experiment plot was 3.93, 1.82, 1.45 and 1.74% for the 0-30 cm, 30-60 cm, 60-90 cm and 90-120 cm soil layers, respectively. Soil EPP´ at this particular plot at the end of the trial in September 2021 was higher to these baseline levels for all the soil layers (Fig 3.8). The greater accumulation of K in the soils of this region was a result of higher amounts of K applied *via* the irrigation water in the 2020/21 season. It should be noted that in the Western Cape fruit industry, the recommended ratio of exchangeable K is 3 to 4% of the cation exchange capacity (Conradie, 1994). The baseline values for soil EPP´ for the Backsberg clay experiment plot was 5.28, 3.61, 2.23, 2.38 and 3.26% for the 0-30 cm, 30-60 cm, 60-90 cm, 90-120 cm and 120-150 cm soil layers, respectively. Soil EPP´ at the end of the trial in September 2021 was higher than these baseline levels up to a depth of 90 cm (Fig 3.8). The higher soils EPP´ was a result of higher amounts of K applied *via* the irrigation water in the 2020/21 season. The baseline values for soil EPP´ for the Madeba sandy loam experiment plot was 2.71, 5.02, 5.23 and 6.19% for the 0-30 cm, 30-60 cm, 60-90 cm and 90-120 cm soil layers, respectively. Soil EPP´ in all the soil layers was higher than the baseline values (Fig. 3.8). The baseline values for EPP´ for the Madeba clay loam experiment plot was 2.94, 2.04, 2.35, 1.93 and 2.59% for the 0-30 cm, 30-60 cm, 60-90 cm, 90-120 cm and 120-150 cm soil layers, respectively. Soil EPP´ at the end of the trial in September 2021 was higher compared to the baseline values (Fig. 3.8). This trend suggested an accumulation of salts during the grapevine growing season due to irrigation with winery wastewater which contains salts (Laurenson *et al.*, 2012). In heavier soils, less effective leaching is more likely to result in salt accumulation. The baseline values for soil EPP´ for the Lutzville deep sand experiment plot was 12.86, 10.31, 7.74, 7.56, 7.72, 6.96, 6.91, 6.31 and 7.87% for the 0-30 cm, 30-60 cm, 60-90 cm, 90-120 cm, 120-150 cm, 150-180 cm, 180-210 cm, 210-240 cm and 240-270 cm soil layers, respectively. Soil EPP´at the end of the trial in September 2021 tended to be higher up to a depth of 180 cm compared to the baseline values (Fig. 3.8). The baseline values for EPP´ for the Spruitdrift shallow sand experiment plot was 5.11 and 6.66% for the 0-30 cm and 30-60 cm soil layers, respectively. Soil EPP´ levels in September 2021 were slightly higher than baseline values (Fig. 3.8).

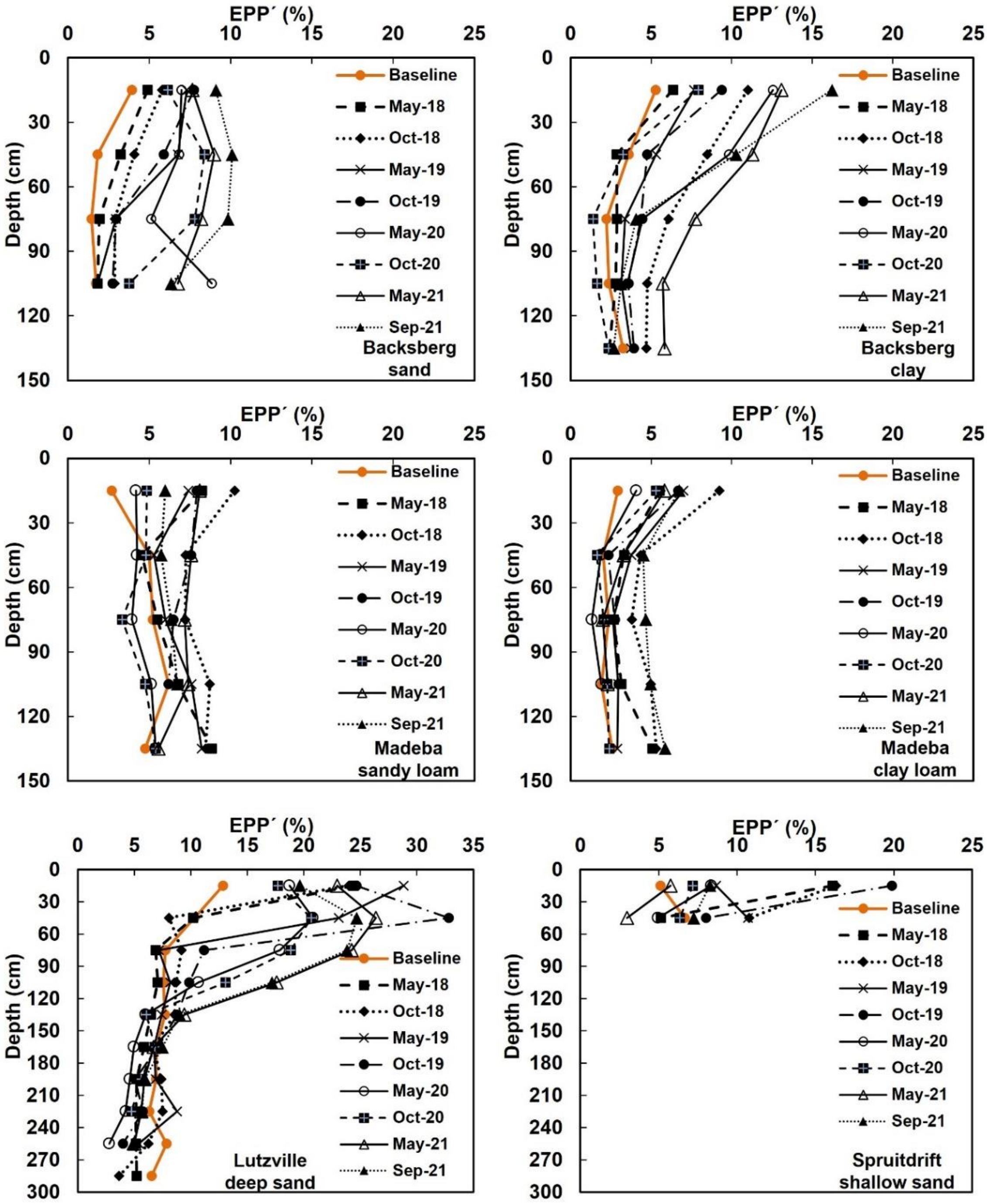

Figure 3.8. Soil EPP´ measured at the various experiment plots.

3.3.7. Sodium and ESP´

No Na accumulated in the Backsberg experiment plots after wastewater application in the 2017/18 season (Fig. 3.9), but this could be due to the application of only two irrigations (Refer to Chapter 2) and rainfall in April and May. After the winter of 2018, there was a substantial increase of soil Na below 90 cm and 60 cm for the Madeba sandy loam and clay experiment plots, respectively. A slight increase of soil Na occurred below 30 cm soil depth following the winter rainfall period at the Lutzville deep sand and Spruitdrift shallow sand experiment plots. There was a substantial increase in soil Na at the Spruitdrift shallow sand experiment plot after wastewater application in May 2019. This was likely due to the substantial amounts of Na applied *via* the irrigation water given the extremely high Na content of the winery wastewater at this particular plot (Refer to Chapter 2). After the winter rainfall of the 2018/19 season, there was a slight increase of soil Na below 30 cm soil depth following the winter rainfall period at the Lutzville deep sand experiment plot but a substantial increase in the case of the Spruitdrift shallow sand experiment plot. After the winter rainfall of the 2019/20 season, soil Na at most experiment plots was similar to after wastewater application in May 2020.

The baseline values for soil Na for the Backsberg sand experiment plot was 0.04, 0.05, 0.05 and 0.05 cmol$^{(+)}$/kg for the 0-30 cm, 30-60 cm, 60-90 cm and 90-120 cm soil layers, respectively. Soil Na at this particular plot at the end of the trial in September 2021 was higher to these baseline levels for all the soil layers (Fig 3.9). This indicated that under the prevailing conditions, irrigation with in-field fractional use (augmentation) of winery wastewater with raw water lead to an accumulation of salts in the soil despite being in a higher rainfall region. The baseline values for soil Na for the Backsberg clay experiment plot was 0.04, 0.04, 0.05, 0.06 and 0.05 cmol$^{(+)}$/kg for the 0-30 cm, 30-60 cm, 60-90 cm, 90-120 cm and 120-150 cm soil layers, respectively. Soil Na at the end of the trial in September 2021 was higher than these baseline levels for all the soil layers (Fig 3.9). The baseline values for soil Na for the Madeba sandy loam experiment plot was 0.29, 0.19, 0.30 and 0.45 cmol$^{(+)}$/kg for the 0-30 cm, 30-60 cm, 60-90 cm and 90-120 cm soil layers, respectively. With the exception of the 0-30 cm soil layer, soil Na was higher than the baseline values (Fig. 3.9). The baseline values for soil Na for the Madeba clay loam experiment plot was 0.34, 0.48, 0.70, 0.89 and 0.95 cmol$^{(+)}$/kg for the 0-30 cm, 30-60 cm, 60-90 cm, 90-120 cm and 120-150 cm soil layers, respectively. Soil Na at the end of the trial in September 2021 was lower compared to the baseline values (Fig. 3.9). The baseline values for soil Na for the Lutzville deep sand experiment plot was 0.06, 0.05, 0.06, 0.06, 0.07, 0.08, 0.08, 0.08 and 0.08 cmol$^{(+)}$/kg for the 0-30 cm, 30-60 cm, 60-90 cm, 90-120 cm, 120-150 cm, 150-180 cm, 180-210 cm, 210-240 cm and 240-270 cm soil layers, respectively. Soil Na at the end of the trial in September 2021 was higher compared to the baseline values (Fig. 3.9). The baseline values for soil Na for the Spruitdrift shallow sand experiment plot was 0.32 and 0.44 cmol$^{(+)}$/kg for the 0-30 cm and 30-60 cm soil layers, respectively. Soil Na levels at the end of the trial in September 2021 were lower than the baseline values (Fig. 3.9).

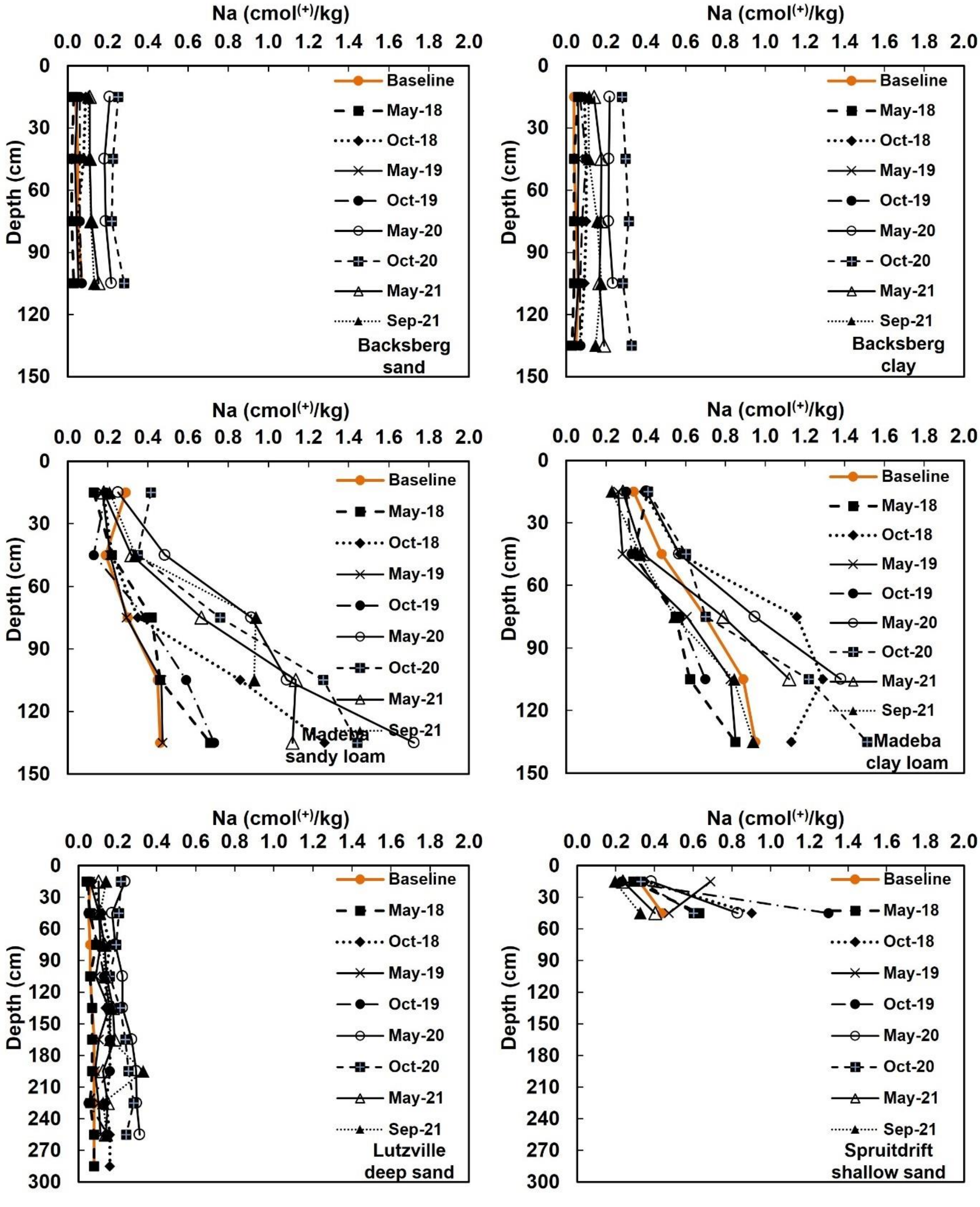

Figure 3.9. Soil extractable Na measured at the various experiment plots.

There was a minimal increase in ESP´ at the Backsberg experiment plots after the 2018 winter rainfall period (Fig. 3.10). For the Madeba sandy loam experiment plot, ESP´ decreased slightly after winter, except below 120 cm depth where ESP´ increased. A similar increase in the subsoil was observed at the Madeba clay loam experiment plot after winter. However, the increase was less pronounced than that of the Madeba sandy loam experiment plot, and ESP´ levels remained below 10%. Soil ESP´ at the Lutzville deep sand experiment plot increased after winter. Compared to the baseline, ESP´ in the 30-60 cm soil layer of the Spruitdrift shallow sand experiment plot increased by approximately 5% after the winter of 2018. After the winter rainfall in 2019, there was a minimal increase in ESP´ at the Backsberg experiment plots. After wastewater application in May 2020, ESP´ increased at all experiment plots and remained similar after the winter rainfall of 2020.

The baseline values for soil ESP´ for the Backsberg sand experiment plot was 1.21, 1.52, 1.82 and 2.03% for the 0-30 cm, 30-60 cm, 60-90 cm and 90-120 cm soil layers, respectively. Soil ESP´ at this particular plot at the end of the trial in September 2021 was higher compared to these baseline levels for all the soil layers (Fig 3.10). The baseline values for soil ESP´ for the Backsberg clay experiment plot was 0.92, 0.76, 0.86, 1.43 and 1.81% for the 0-30 cm, 30-60 cm, 60-90 cm, 90-120 cm and 120-150 cm soil layers, respectively. Soil ESP´ at the end of the trial in September 2021 was higher than these baseline levels for all the soil layers (Fig 3.10). The baseline values for soil ESP´ for the Madeba sandy loam experiment plot was 2.24, 2.89, 6.54 and 10.71% for the 0-30 cm, 30-60 cm, 60-90 cm and 90-120 cm soil layers, respectively. Soil ESP´ in all the soil layers was higher than the baseline values (Fig. 3.10). The baseline values for soil ESP´ for the Madeba clay loam experiment plot was 1.82, 2.65, 3.50, 4.00 and 4.48% for the 0-30 cm, 30-60 cm, 60-90 cm, 90-120 cm and 120-150 cm soil layers, respectively. Soil ESP´ at the end of the trial in September 2021 was similar compared to the baseline values (Fig. 3.10). The baseline values for soil ESP´ for the Lutzville deep sand experiment plot was 2.14, 1.91, 2.02, 2.06, 2.25, 2.32, 2.13, 2.02 and 2.03% for the 0-30 cm, 30-60 cm, 60-90 cm, 90-120 cm, 120-150 cm, 150-180 cm, 180-210 cm, 210-240 cm and 240-270 cm soil layers, respectively. Soil ESP´ at the end of the trial in September 2021 tended to be higher compared to the baseline values (Fig. 3.10). The baseline values for soil ESP´ for the Spruitdrift shallow sand experiment plot was 4.31 and 4.07% for the 0-30 cm and 30-60 cm soil layers, respectively. Soil ESP´ levels the end of the trial in September 2021 were lower than the baseline values (Fig. 3.10). It should be noted that the ESP´ of all the experiment plots at the end of the trial did not exceed the critical threshold of 15% for sustainable agricultural use *(*Laker, 2004; Seilsepour *et al.*, 2009).

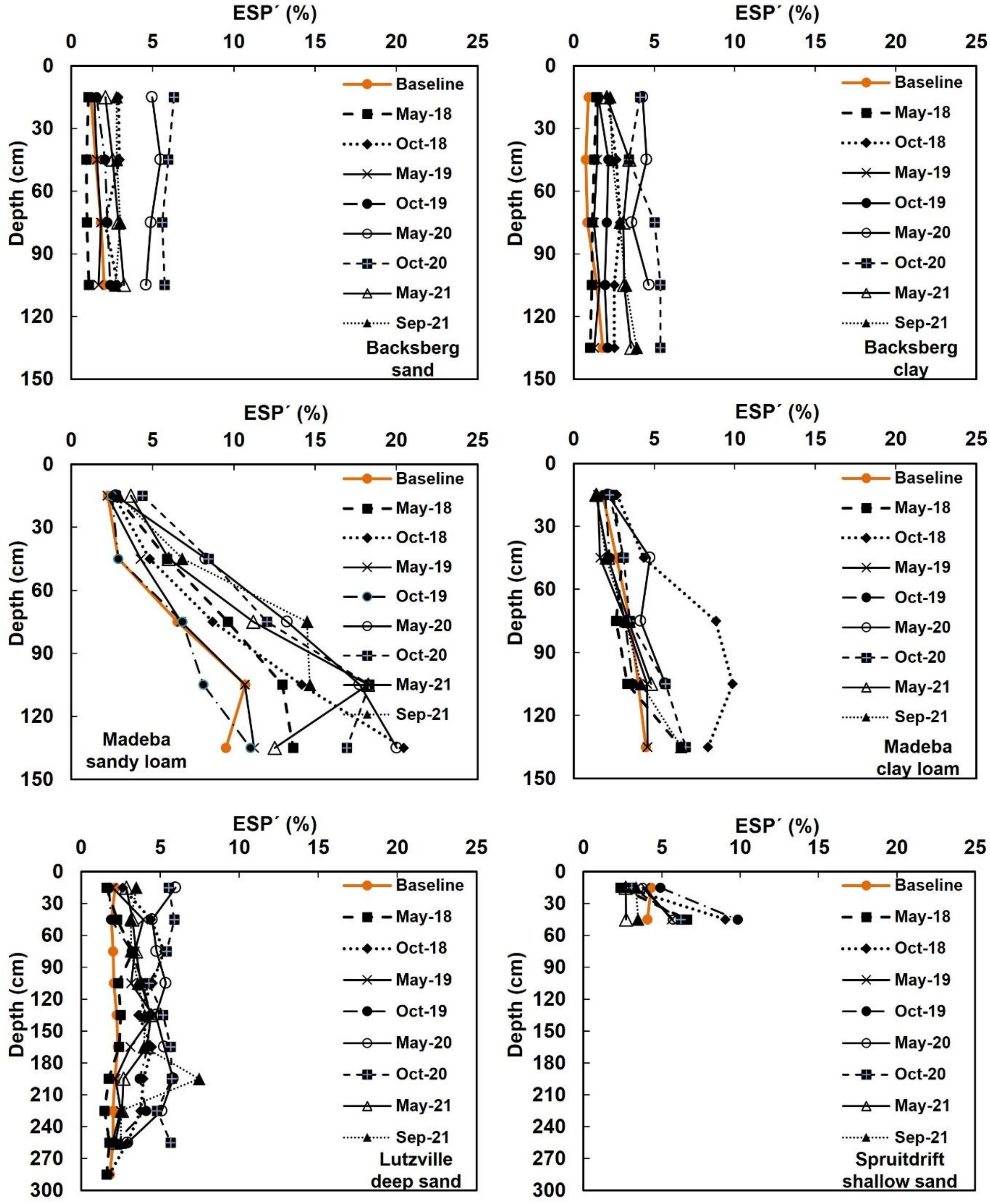

Figure 3.10. Soil ESP´ measured at the various experiment plots.

3.3.8. Organic carbon and trace elements

No trends with regard to soil B, Cu, Fe, Mn, Zn, S and % SOC were observed (data not shown).

3.3.9. Experiment plots compared to their respective controls

At the end of the trial in September 2021, soil $pH_{(KCl)}$ was higher for the experiment plots irrigated with wastewater compared to their respective controls (Fig. 3.11). The soil $pH_{(KCl)}$ of all the experiment plots was still within the norm of 5.0 to 7.5 recommended by Saayman (1981) for optimal grapevine growth. Where winery wastewater was diluted to 3 000 mg/L COD in a field study at Rawsonville, soil $pH_{(KCl)}$ increased at bud break after winter rainfall (Myburgh & Howell, 2014). In contrast, irrigation with winery wastewater did not have a pronounced effect on soil $pH_{(KCl)}$ (Mulidzi, 2016; Mulidzi *et al.*, 2019).

Since irrigation using winery wastewater generally increases soil K and Na, soil pH will consequently increase *via* alkaline hydrolyses. This reaction is primarily caused by the hydrolysis of exchangeable cations in soils, *e.g.* K_{ex} and Na_{ex}, or salts, *e.g.* $CaCO_3$, $MgCO_3$ and Na_2CO_3 (Abrol *et al.*, 1988). Hydrogen ions are inactivated by exchange adsorption in the place of exchangeable K and Na. These displaced cations do not inactivate the hydroxide anions (OH^-), which in turn cause soil pH to increase (Abrol *et al.*, 1988). The extent to which exchangeable cations hydrolyse depends on their ability to compete with H^+ for exchange sites. Exchangeable Ca and Mg are more tightly adsorbed to the exchange complex than K and Na (Abrol *et al.*, 1988). Therefore, K and Na are more readily hydrolyzed and produce a higher pH than do exchangeable Ca or Mg. Hydrolysis of exchangeable Ca and Mg, in fact, is so limited that it results in a soil having only a mildly alkaline reaction. In the present study, excessive soil K after wastewater application in conjunction with winter rainfall could have induced alkaline hydrolysis, thereby increasing soil $pH_{(KCl)}$ of the experiment plots at bud break compared to the respective controls.

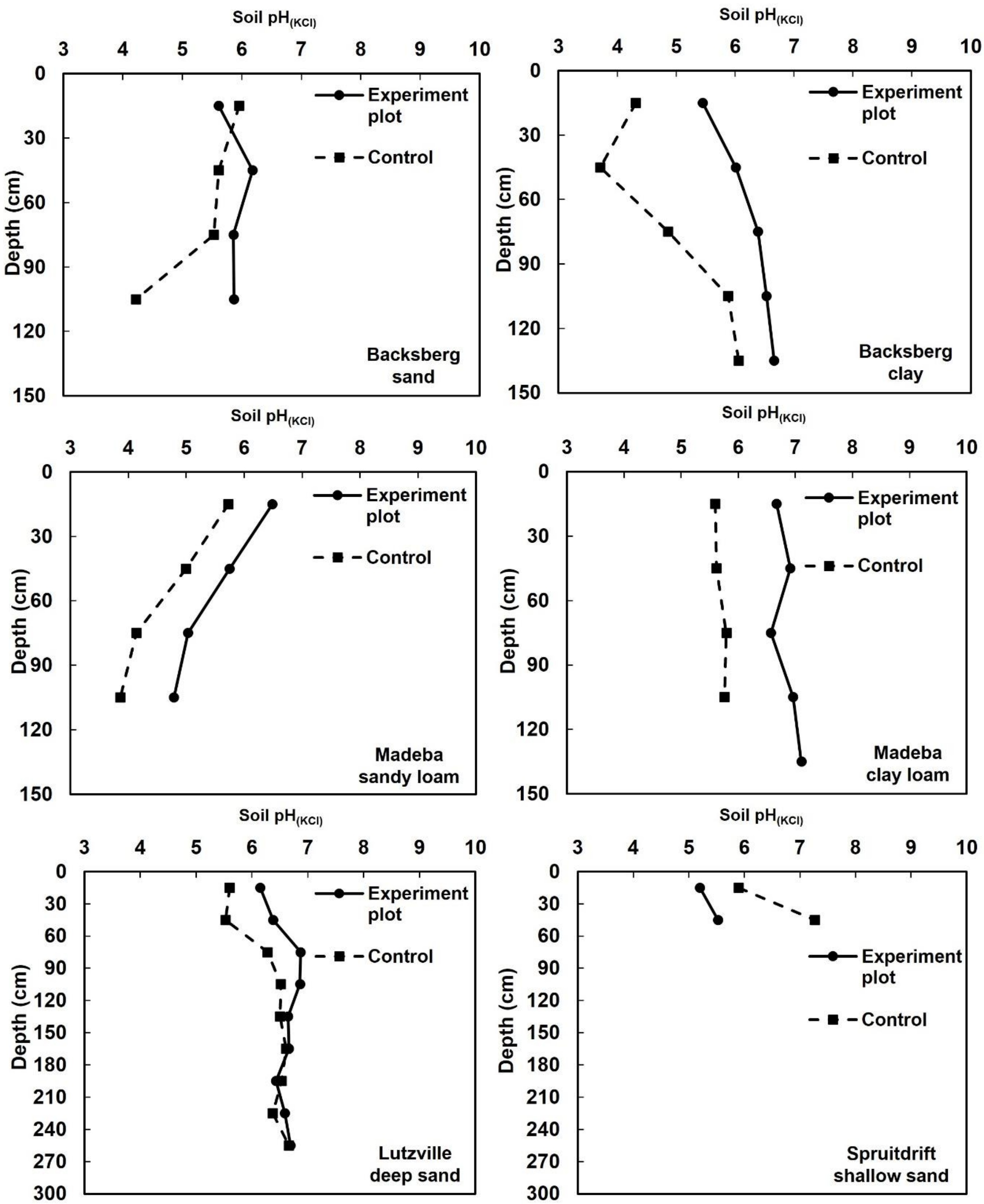

Figure 3.11. Soil pH$_{(KCl)}$ measured at the experiment plots and controls at the end of the trial in September 2021.

At the end of the trial in September 2021, soil 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 (Fig. 3.12). This indicated that under the prevailing conditions, 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. Mulidzi *et al.* (2019) also reported that their results indicated that high irrigation plus rainfall must have leached some of the salts applied *via* the winery wastewater irrigation beyond 90 cm depth, particularly in the last two winters of that particular study. Soil EC_e of the Madeba sandy loam experiment plot was lower than that of its control whereas for the Madeba clay loam experiment plot, soil EC_e of the experiment plot was higher compared to its respective control (Fig. 3.12). This trend suggested an accumulation of salts during the grapevine growing season partly due to irrigation with augmented winery wastewater which contains salts (Laurenson *et al.*, 2012). Furthermore, in heavier soils, less effective leaching is more likely to result in salt accumulation.

At the end of the trial in September 2021, soil P of the Backsberg sand experiment plot was higher than of the control whereas the soil P of the Backsberg clay experiment plot was similar compared to its respective control (Fig. 3.13). Soil of the Madeba clay loam experiment plot was higher compared to its control (Fig. 3.13).

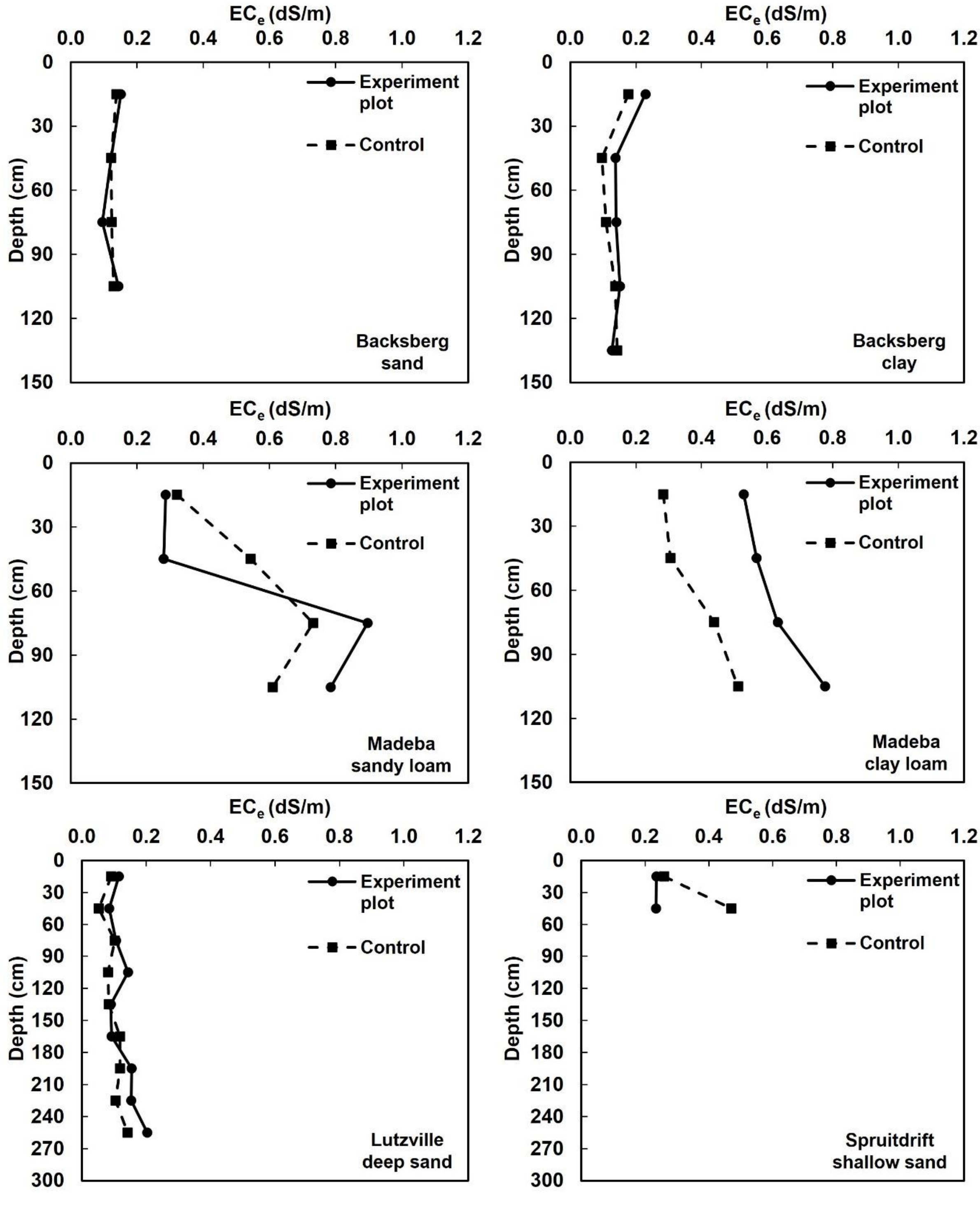

Figure 3.12. Soil EC_e measured at the experiment plots and controls at the end of the trial in September 2021.

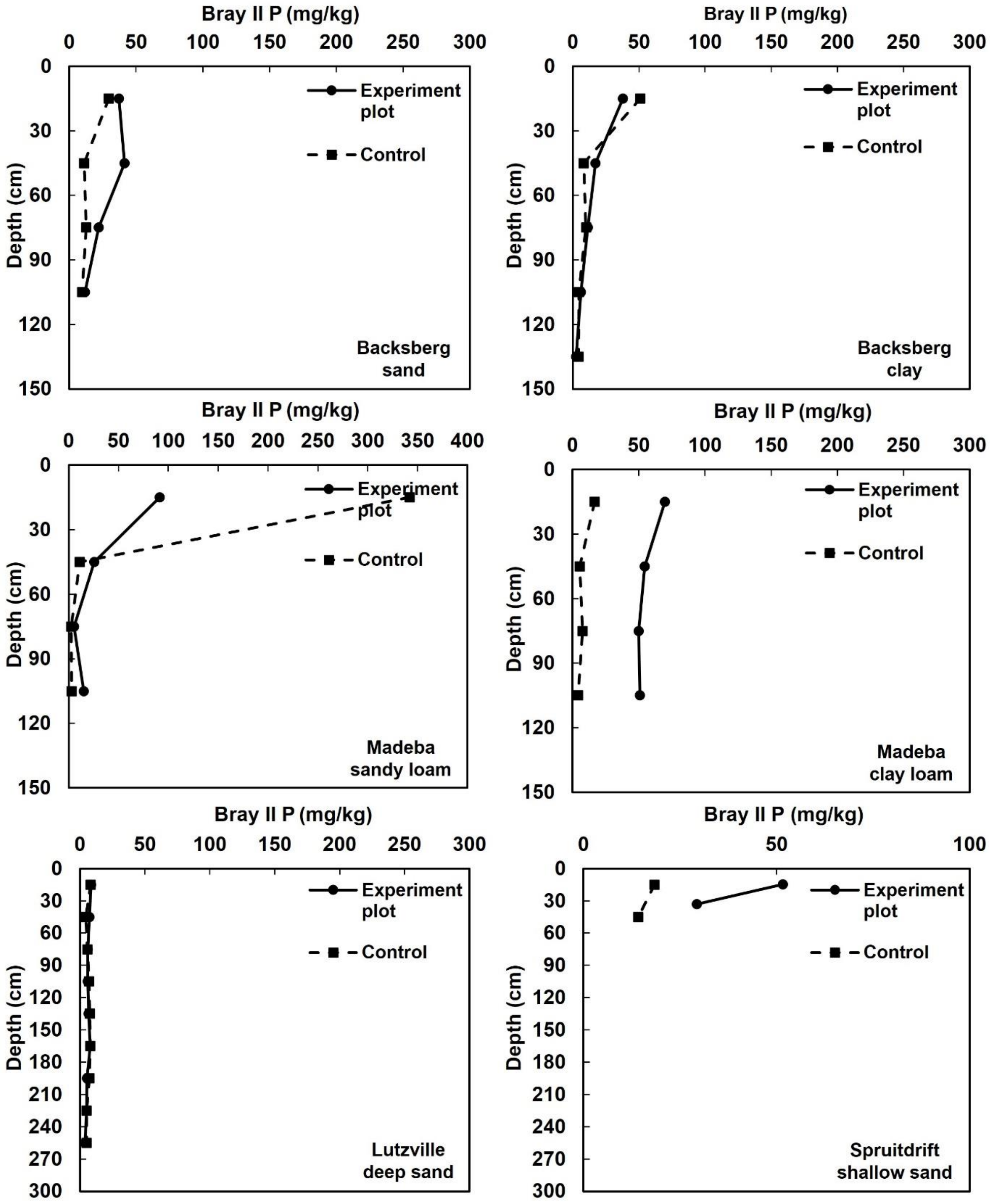

Figure 3.13. Soil P measured at the experiment plots and controls at the end of the trial in September 2021.

At the end of the trial in September 2021, soil Ca was higher for the Backsberg clay and Madeba clay loam experiment plots irrigated with wastewater compared to their respective controls (Fig. 3.14). This trend suggested an accumulation of salts during the grapevine growing season partly due to irrigation with augmented winery wastewater which contains salts (Laurenson *et al.*, 2012) in the heavier soils.

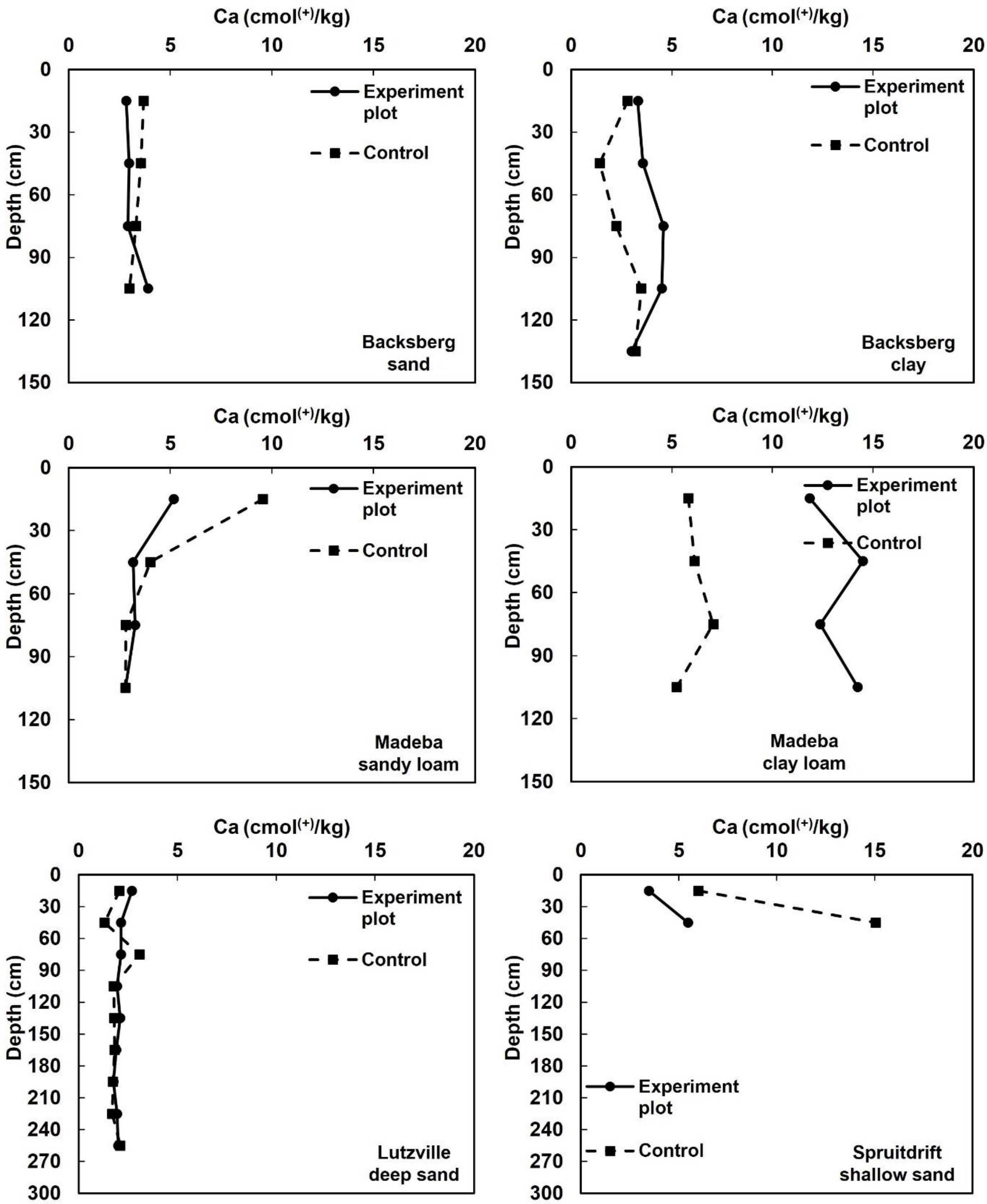

Figure 3.14. Soil Ca measured at the experiment plots and controls at the end of the trial in September 2021.

At the end of the trial in September 2021, soil Mg was slightly higher for the Backsberg clay experiment plot, and substantially higher for the Madeba clay loam experiment plots irrigated with wastewater compared to their respective controls (Fig. 3.15). As in the case for soil Ca, this indicated an accumulation of salts during the grapevine growing season partly due to irrigation with augmented winery wastewater which contains salts (Laurenson *et al.*, 2012). In heavier soils, less effective leaching is more likely to result in salt accumulation.

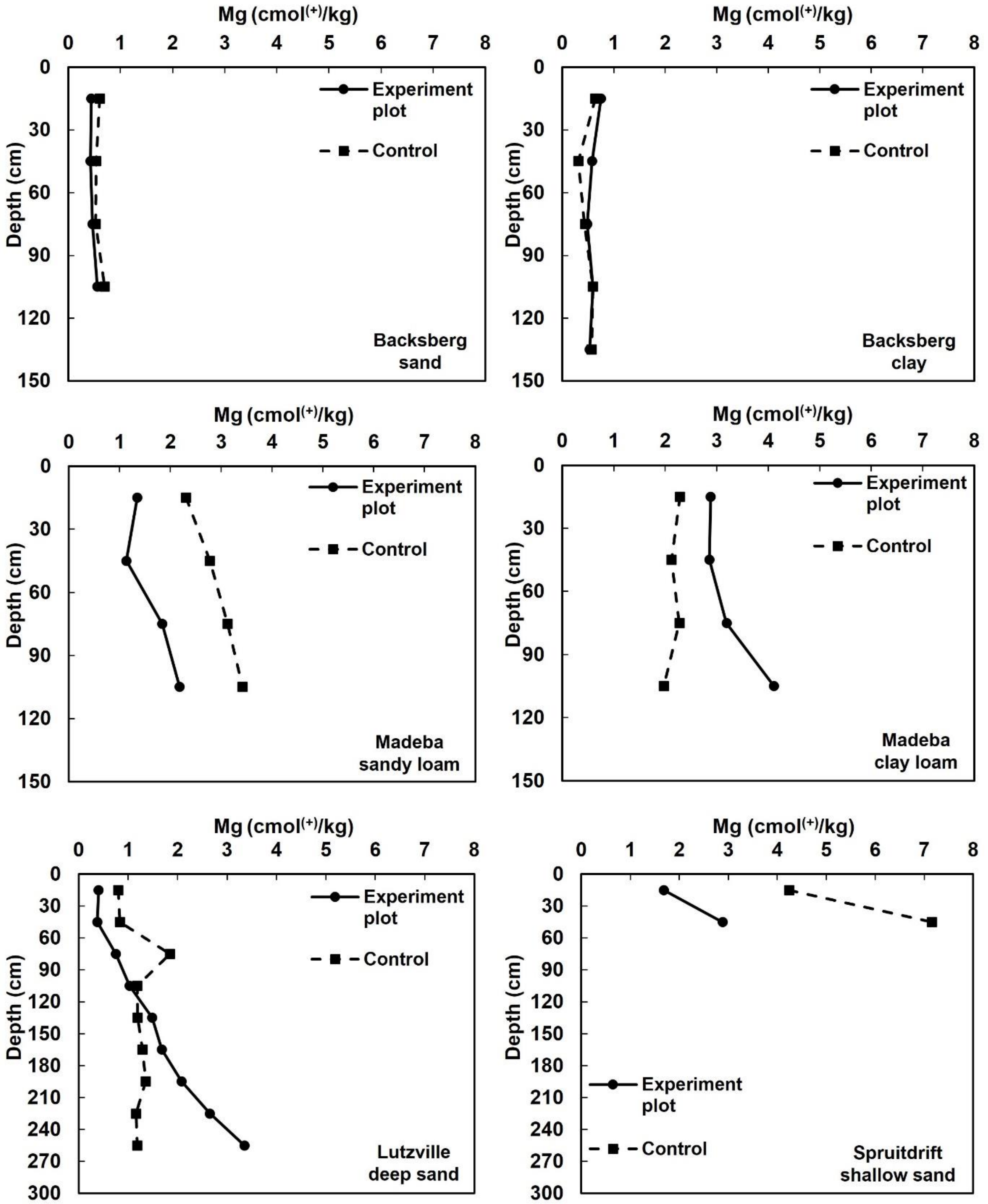

Figure 3.15. Soil Mg measured at the experiment plots and controls at the end of the trial in September 2021.

At the end of the trial in September 2021, soil K was substantially higher for all of the experiment plots irrigated with wastewater compared to their controls (Fig. 3.16). This trend indicated an accumulation of K during the grapevine growing season partly due to irrigation with augmented winery wastewater which contains salts (Laurenson *et al.*, 2012). In heavier soils, less effective leaching is more likely to result in salt accumulation. Mulidzi *et al.* (2020) reported that winter rainfall could not leach basic cations, particularly K and Na, from two of six soils in a pot study as the amount of the simulated rainfall was too low. Furthermore, more cations leached from a sandy soil compared to clayey soils. These trends indicated that the leaching would be a function of soil texture, as could be expected, as well as rainfall. The simulation with low rainfall events indicated that the basic cations are more likely to accumulate in soils if climate change results in lower winter rainfall in these regions. It was previously reported in a study representing the worst-case scenario, *i.e.* large amounts of wastewater disposed of on a small surface, particularly during harvest and in winter that land application of winery wastewater resulted in the accumulation of high levels of K in the soil (Mulidzi *et al.*, 2018). In a field study where the re-use of winery wastewater for irrigation was investigated with micro-sprinkler irrigated Cabernet Sauvignon/99 Richter in the Breede River Valley region of South Africa, soil K also increased (Myburgh & Howell, 2014; Howell *et al.*, 2018). Similar results with regard to an accumulation of soil K in response to irrigation with winery wastewater have been reported previously. Where winery wastewater was used for irrigation for over 30 years, an accumulation of K was reported (Mosse *et al*., 2012). Likewise, soil surface K increased where winery wastewater was used for irrigation of two soils typical of the South Eastern Australia Riverine plains for three years (Quale *et al.,* 2010). However, there were no changes in sub-soil K due to slow mobility of K in the soils, which contained *c.* 50% to 60% clay. Soil K levels were also higher in vineyards which were irrigated with winery wastewater compared to control vineyard soils (Kumar *et al.*, 2006). Furthermore, land application of wastewater can increase the levels of soluble and exchangeable forms of K more rapidly than conventional, inorganic fertilizers (Arienzo *et al.*, 2009). In the only field study of its kind, where simulated winery wastewater was used for vineyard irrigation, the addition of wine to the wastewater enhanced K movement to the sub-soil (Mosse *et al.*, 2012). Although the fate of K in soils and grapevines irrigated with winery wastewater has received limited attention (Laurenson *et al.,* 2012), it is almost certain that high soil K could lead to an increase in K uptake by grapevines. This could have negative consequences on grapevine responses, such as musts with high pH, malate concentrations and poor colour (Jackson & Lombard, 1993; Mpelasoka *et al.*, 2003; Kodur, 2011). However, the effect of soil K on K concentrations in must is often negligible unless excessive amounts are applied (Jackson & Lombard, 1993).

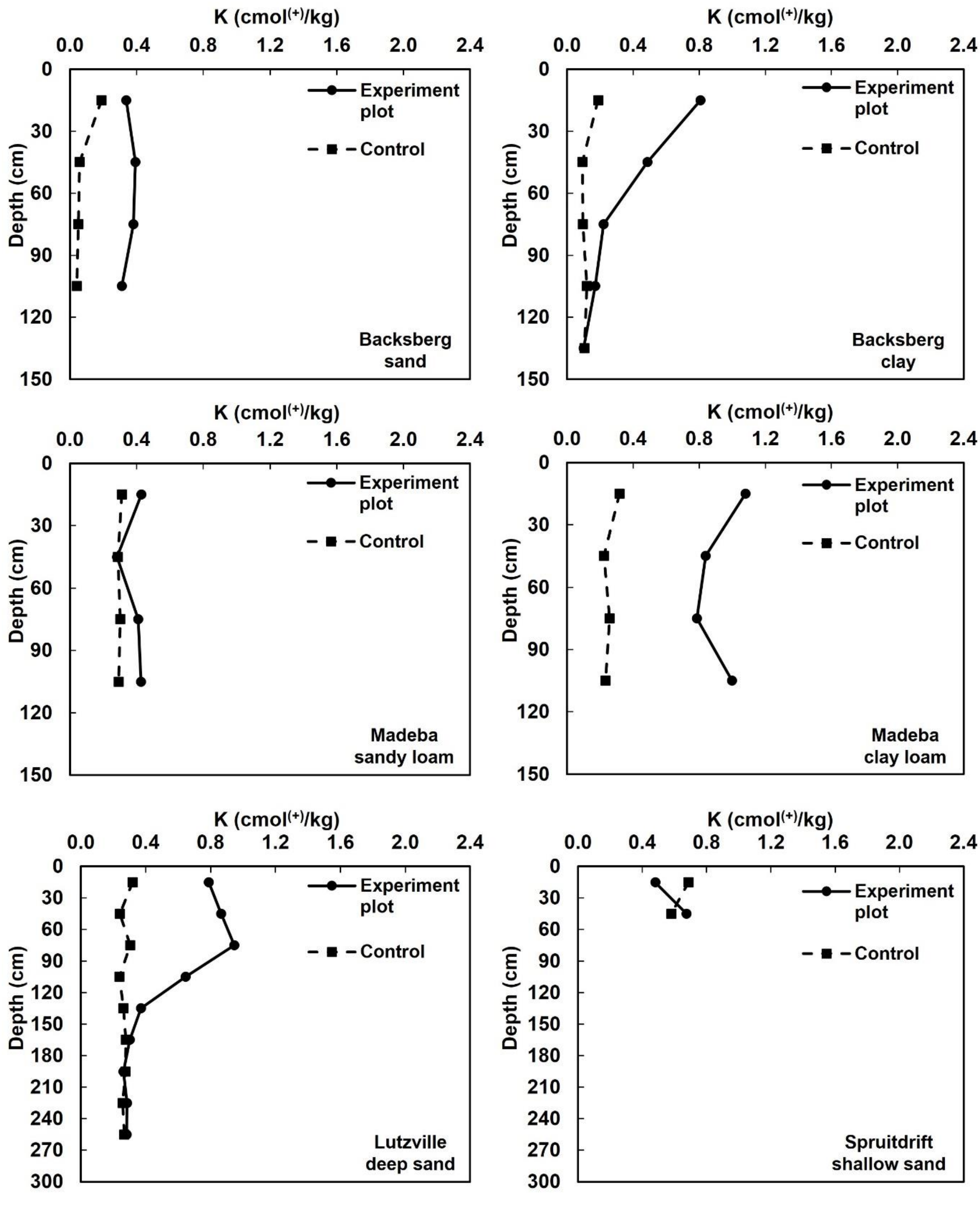

Figure 3.16. Soil K measured at the experiment plots and controls at the end of the trial in September 2021.

At the end of the trial in September 2021, soil EPP´ was substantially higher for all of the experiment plots irrigated with wastewater compared to their controls (Fig. 3.17).

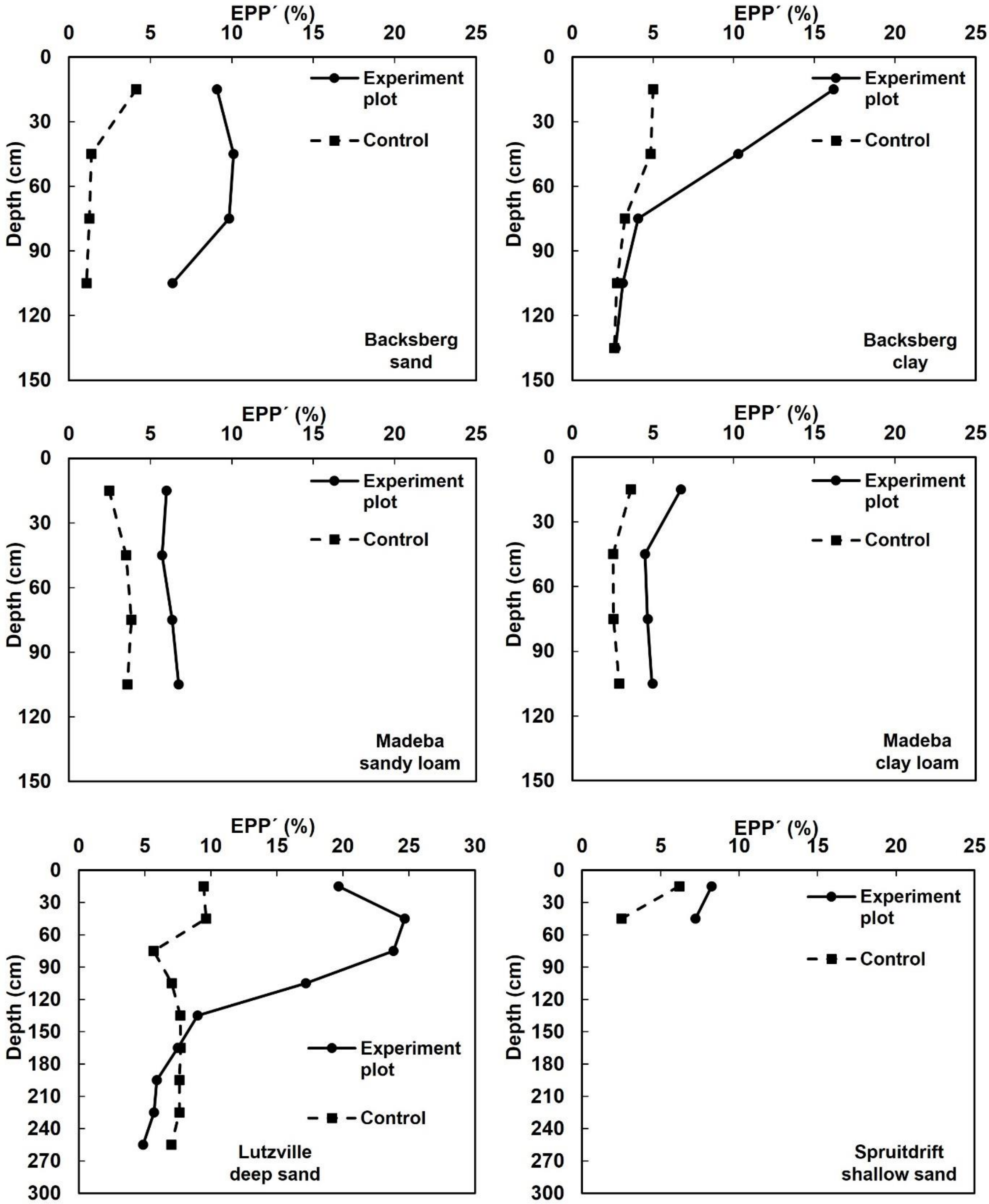

Figure 3.17. Soil EPP´ measured at the experiment plots and controls at the end of the trial in September 2021.

At the end of the trial in September 2021, soil Na of all the experiment plots was similar or lower compared to their respective controls (Fig. 3.18). This indicated that there was sufficient leaching of Na at all the experiment plots, regardless of soil texture. In contrast, it was previously reported that winter rainfall could not leach Na from two of six soils in a pot study as the amount of the simulated rainfall was too low to achieve leaching (Mulidzi, 2016; Mulidzi *et al.*, 2020).

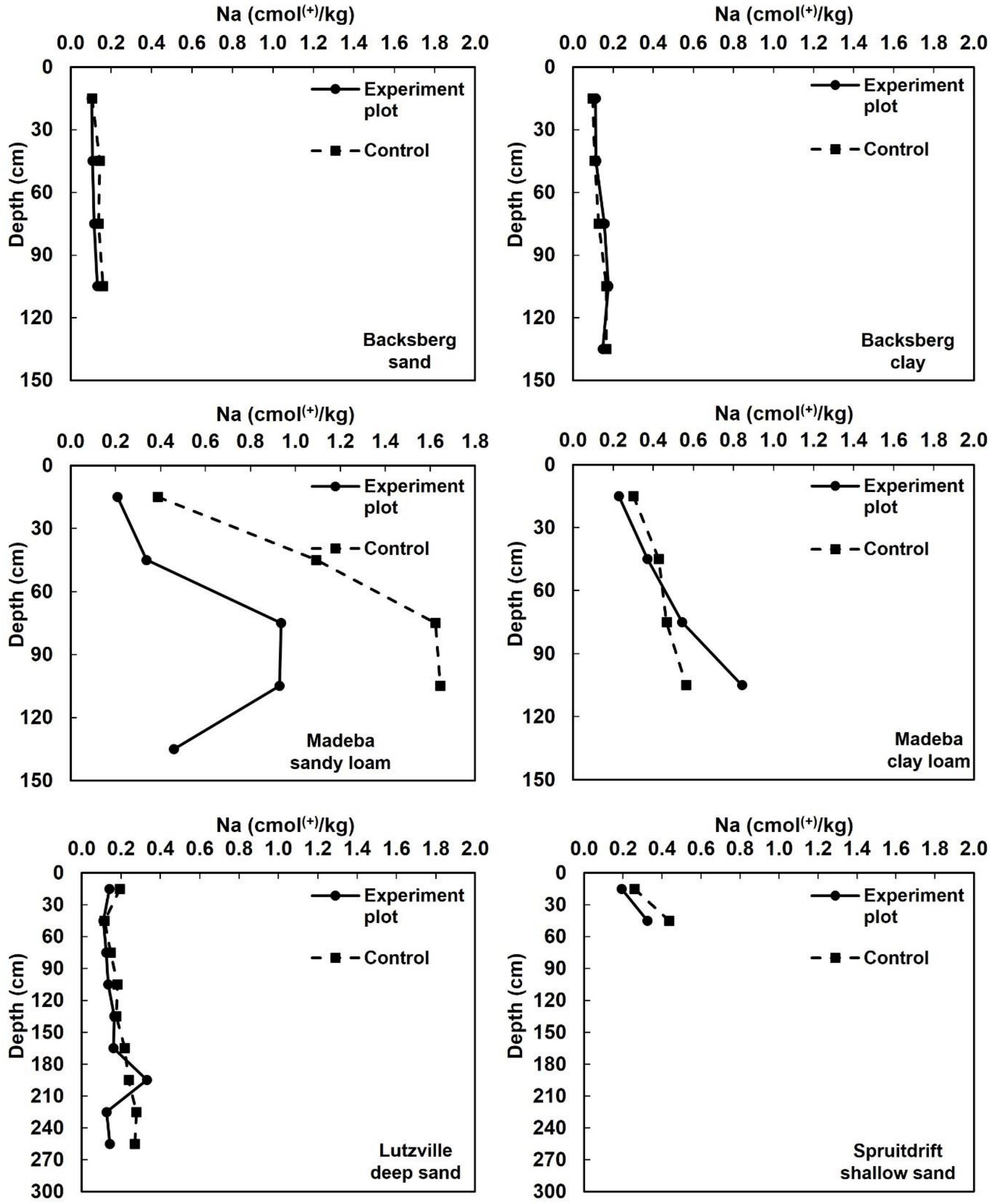

Figure 3.18. Soil Na measured at the experiment plots and controls at the end of the trial in September 2021.

At the end of the trial in September 2021, soil ESP´ of all the experiment plots irrigated with wastewater was similar or lower compared to their respective controls (Fig. 3.19).

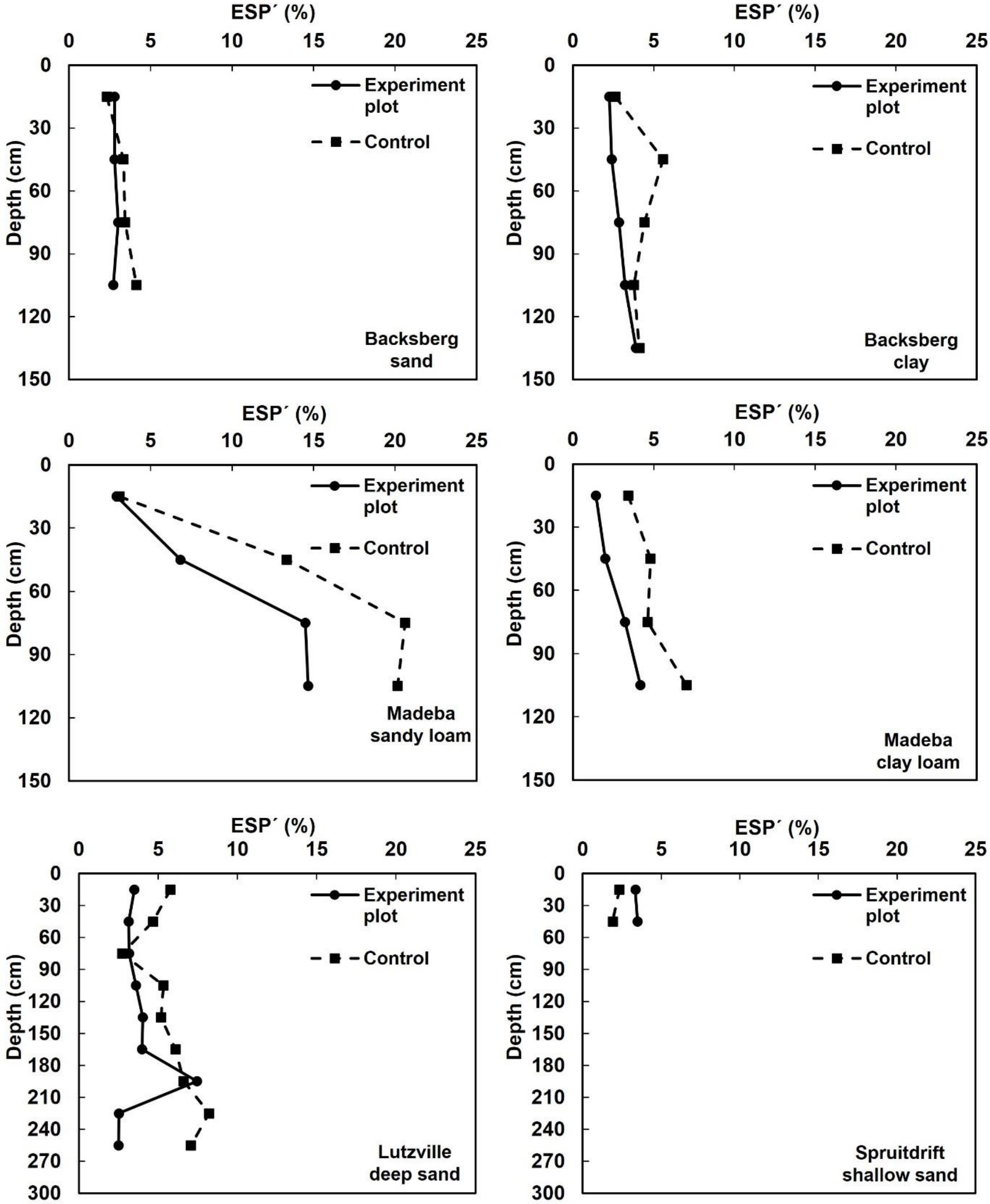

Figure 3.19. Soil ESP´ measured at the experiment plots and controls at the end of the trial in September 2021.

3.4. CONCLUSIONS

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 experiment plot compared to the sandy loam one. 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 Ca, Mg, K and Na had accumulated to such an extent that the wastewater irrigation had to be terminated after two seasons.

At the end of the trial 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. Soil EC_e of the Backsberg sand experiment plot was similar to that of the block whereas soil EC_e of the Backsberg clay 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 irrigated with wastewater compared to their respective controls. Soil K was substantially higher for all of the experiment plots irrigated with wastewater 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.

CHAPTER 4: EFFECT OF IN-FIELD FRACTIONAL USE (AUGMENTATION) OF WINERY WASTEWATER WITH RAW WATER ON GRAPEVINE WATER STATUS, GROWTH AND YIELD

4.1. INTRODUCTION

Although there is extensive literature available regarding the irrigation of grapevines with saline water (Walker *et al*., 1997; Stevens *et al*., 1999; Ben-Asher *et al*., 2006; Paranychianakis & Angelakis, 2008; Stevens *et al.*, 2011; Walker *et al.*, 2015; Walker *et al.*, 2016), very little is known about the effects of irrigation using augmented winery wastewater on grapevine, juice and wine responses. Recent studies have shown that approximately 3 to 5 m^3 of winery wastewater, with high organic load and variable salinity and nutrient levels, is generally produced when a ton of grapes is crushed (Mosse *et al.*, 2011). On the other hand, limited irrigation water supplies could be restricted further in future allocations of irrigation water (Van Zyl & Weber, 1981; Petrie *et al.*, 2004). It was previously reported that irrigation of grapevines using winery wastewater augmented up to a maximum COD level of 3 000 mg/L did not affect vegetative growth or any of the yield components compared to the raw water control (Myburgh & Howell, 2014b). Consequently, the water use and water status of the grapevines was not affected by the wastewater irrigation under the given conditions. There was also a lack of response in element content in the leaves and shoots. Hirzil *et al.* (2017) reported that where winery wastewater was used for irrigation of two vineyards in California, there was an accumulation of K and Na where the wastewater had been applied. In addition, leaves of the grapevines receiving the winery wastewater contained more Na and Mg and less K and Ca than the control. Unfortunately no data pertaining to grapevine yield and its' parameters were presented by the authors.

If winery wastewater could be used to irrigate vineyards, with no detrimental impacts on either grapevines or subsequent wine quality and chemical composition, it could be a possible viable alternative to abstracting raw water from natural resources. Therefore, the objective of this study was to determine the effect of irrigation with in-field fractional use (augmentation) of winery wastewater with raw water on grapevine water status, growth, grapevine chemical status and yield. In addition to this, guidelines as to what limits of quality criteria, *e.g.* level of COD, EC or SAR, for the in-field fractional use (augmentation) of winery wastewater with raw water would allow re-use with no negative consequences on grapevine and yield responses.

4.2. MATERIALS AND METHODS

4.2.1. Soil water content

The SWC was measured by means of the neutron scattering technique. Three Polyvinyl chloride (PVC) access tubes were installed on the grapevine row (Fig. 4.1) at each of the six experiment plots before irrigation applications commenced. The count ratios obtained from the neutron probe were calibrated against volumetric soil water content. The mean SWC of each experiment plot was calculated as an average of SWC measured at the three individual access tubes. Measurements were taken in 30 cm increments up to a depth of 90 cm in all experiment plots and up to 180 cm in plots where deeper measurements were possible. Measurements were taken once every two to three weeks as well as before and after every irrigation application.

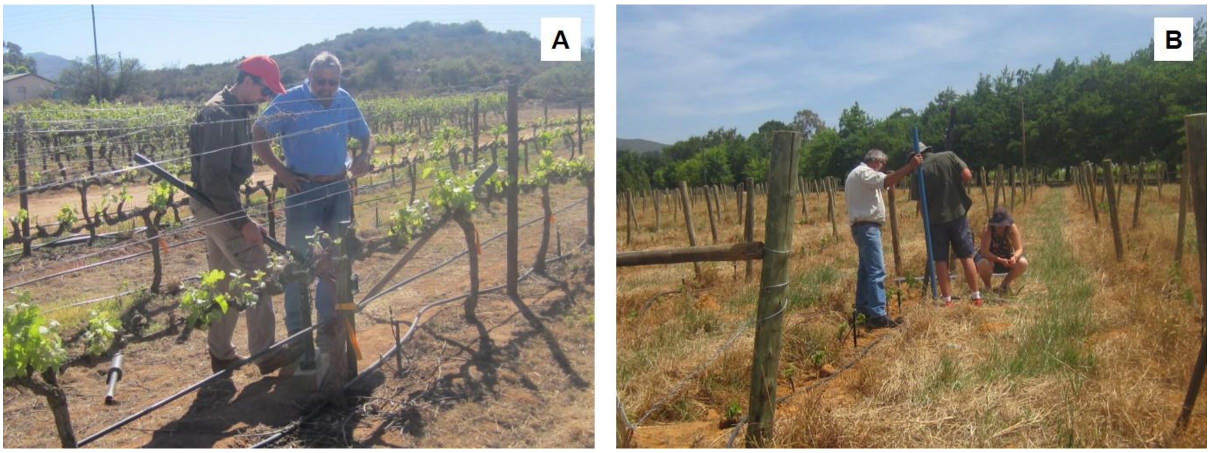

Figure 4.1. Planting neutron probe pipes at the (A) Madeba and (B) Backsberg farms.

4.2.2. Grapevine water status

Grapevine water status was quantified by measuring Ψ_S in mature, unscathed leaves on primary shoots by means of the pressure chamber technique (Scholander *et al.*, 1965), according to the protocol described by Myburgh (2010). For the Ψ_S measurements, five leaves were covered in aluminium bags (Choné *et al.*, 2001; Myburgh, 2010) for at least one hour before Ψ_S measurements were carried out. The Ψ_S was measured prior to harvest during the 2017/18 and 2018/19 seasons.

4.2.3. Vegetative growth

The experiment grapevines in the Breede River and Lower Olifants River regions were pruned to two bud spurs in July and August 2017. The baseline cane mass per grapevine was determined at pruning using a hanging balance. To quantify growth vigour in each season, cane mass at pruning (July) was weighed per experiment plot using a hanging balance. Shoot mass per experiment plot (kg) was converted to tons per hectare. Each of the selected vineyards had an experiment plot that was irrigated with winery wastewater and this was compared to the rest of the surrounding vineyard block which acted as the control. The cane mass of the control was also measured in the 2018/19, 2019/20 and 2020/21 seasons.

4.2.3.1. Grapevine chemical status

In order to allow maximum exposure to the wastewater *via* the irrigation, leaf samples were collected prior to harvest. Thirty mature, unscathed leaves opposite a bunch on the second spur were collected per experiment plot. Shoot samples consisting of four primary canes per experiment plot were collected at pruning in July. At the end of the last season, permanent wood samples were collected at all the experiment plots. Leaf and shoot N, P, K, Ca, Mg, Na, Mn, Fe, Cu, Zn and B contents were determined by a commercial laboratory (BEMLAB, Strand & Labserve, Stellenbosch) as described previously (Myburgh & Howell, 2014b). Leaves and shoots were also sampled from the control in the 2019/20 and 2020/21 seasons.

4.2.4. Yield components

The grapes were harvested as close as possible to a total soluble solids (TSS) value of 24°B. Ten bunches were randomly picked at harvest in order to determine berry mass. Fifteen berries were sampled from each of the ten selected bunches to obtain a sample size of 150 berries per experiment plot. Berries were picked at different positions along the longitudinal bunch axis. The berry samples were weighed in the laboratory to determine mean berry mass. At harvest, all bunches of the experiment grapevines of each experiment plot were picked and counted. Grapes were weighed using top loader mechanical balance to obtain the total mass per experiment plot. The number of bunches per grapevine was calculated by dividing the total number of bunches per experiment plot by the number of experiment grapevines per plot. Grape mass per grapevine (kg/grapevine) was calculated and converted to yield (t/ha). Yield components in the control were also measured in the 2018/19, 2019/20 and 2020/21 seasons.

4.3. RESULTS AND DISCUSSION

4.3.1. Soil water content

2017/18 season: Two irrigations using the in-field fractional use (augmentation) of winery wastewater with raw water were applied to the sand (Fig. 4.2) and clay (Fig. 4.3) experiment plots at Backsberg farm.

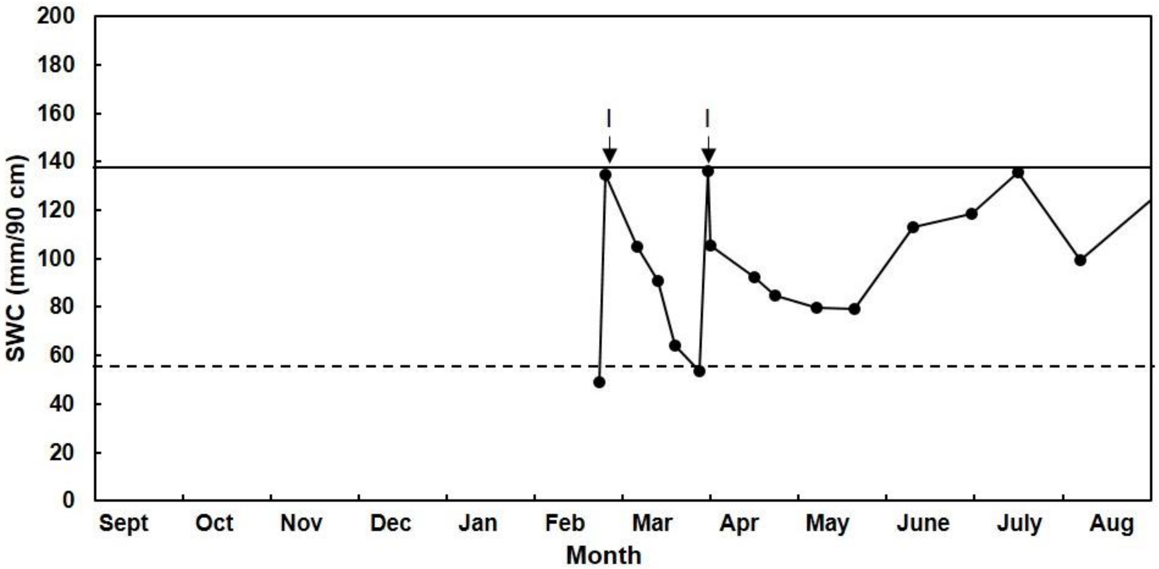

Figure 4.2. Variation in SWC during the 2017/18 season where the in-field fractional use (augmentation) of winery wastewater with raw water was used to irrigate young Cabernet Sauvignon grapevines in a sandy soil at Backsberg farm. (I is winery wastewater irrigation).

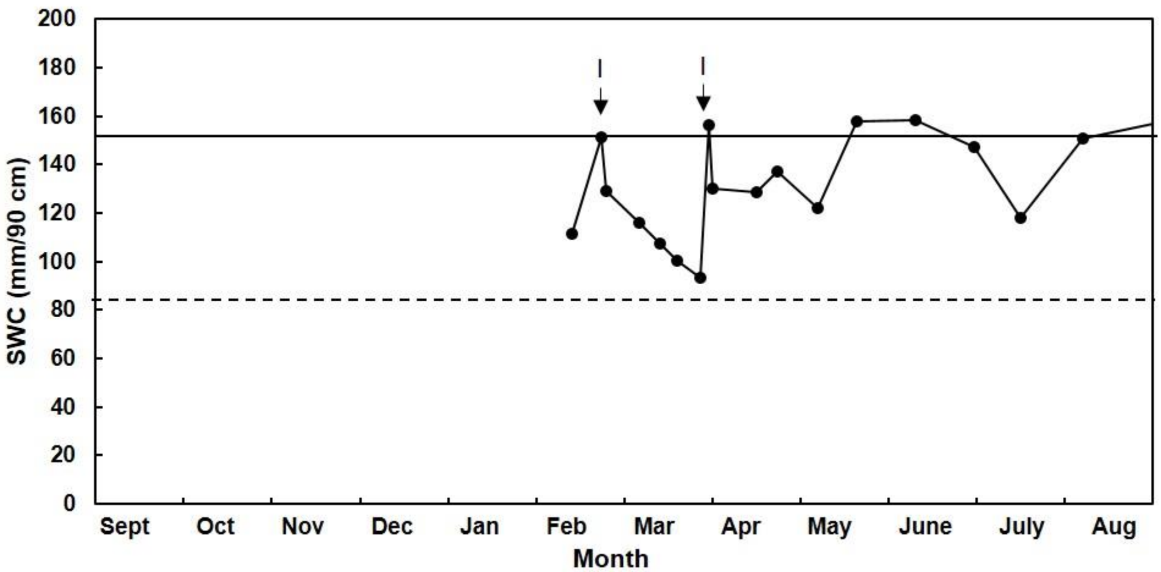

Figure 4.3. Variation in SWC during the 2017/18 season where the in-field fractional use (augmentation) of winery wastewater with raw water was used to irrigate young Cabernet Sauvignon grapevines in a clay soil at Backsberg farm. (I is winery wastewater irrigation).

Two irrigations using the in-field fractional use (augmentation) of winery wastewater with raw water were applied to the sandy loam (Fig. 4.4) and clay loam (Fig. 4.5) experiment plots at Madeba farm.

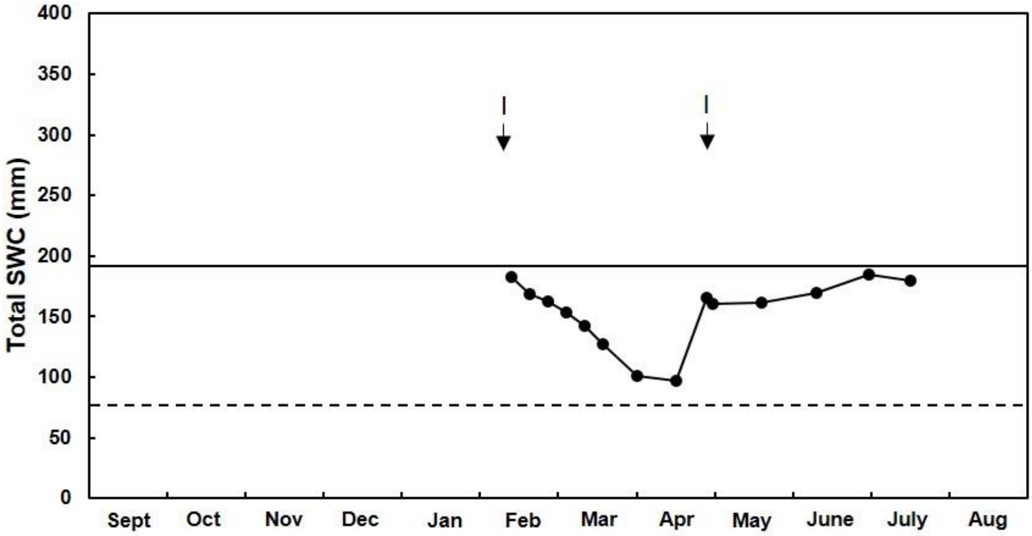

Figure 4.4. Variation in SWC during the 2017/18 season where the in-field fractional use (augmentation) of winery wastewater with raw water was used to irrigate Shiraz grapevines in a sandy loam soil on Madeba farm. (I is winery wastewater irrigation).

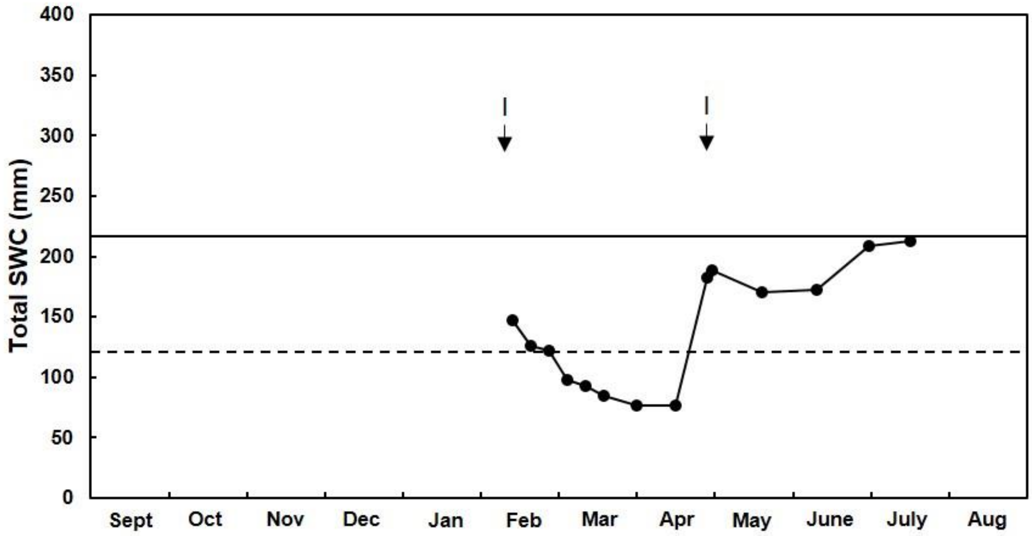

Figure 4.5. Variation in SWC during the 2017/18 season where the in-field fractional use (augmentation) of winery wastewater with raw water was used to irrigate Shiraz grapevines in a clay loam soil near Madeba farm. (I is winery wastewater irrigation).

Since the Ψ_S had not yet achieved its target value at Lutzville winery by 19 December, the soil was allowed to dry out further (Fig. 4.6). At Spruitdrift, a second irrigation was applied on 20 and 21 December (Fig. 4.7). Irrigation with winery wastewater was applied at both sites from 9 to 10 January 2018. In total, five and six irrigations were applied at the Lutzville and Spruitdrift experiment plots, respectively.

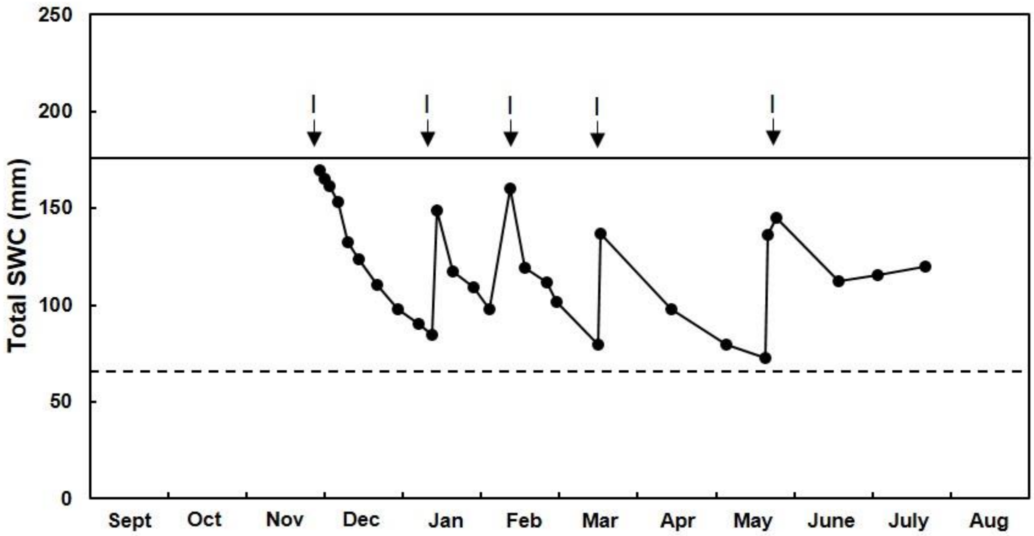

Figure 4.6. Variation in SWC during the 2017/18 season where the in-field fractional use (augmentation) of winery wastewater with raw water was used to irrigate Shiraz grapevines near Lutzville winery. (I is winery wastewater irrigation).

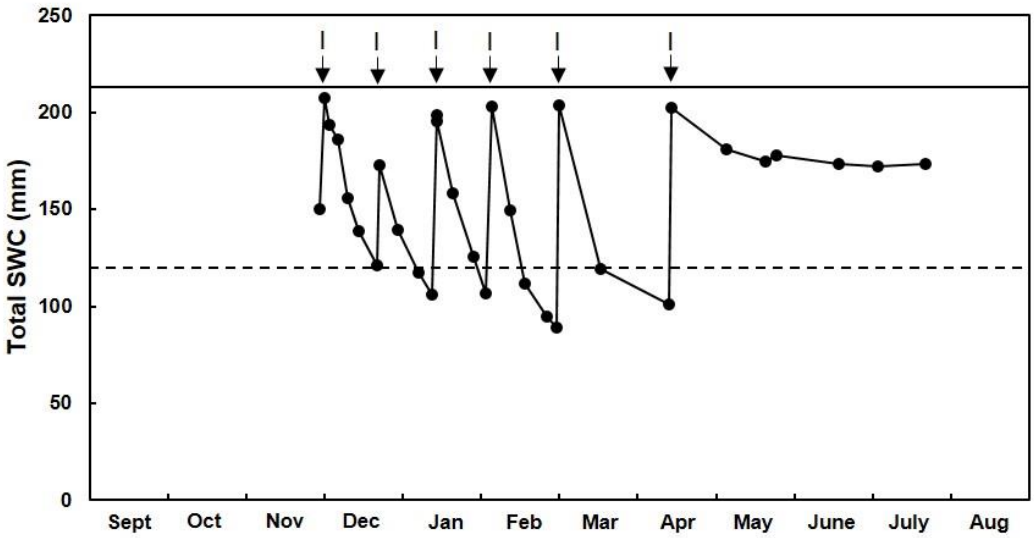

Figure 4.7. Variation in SWC during the 2017/18 season where the in-field fractional use (augmentation) of winery wastewater with raw water was used to irrigate Cabernet Sauvignon grapevines near Spruitdrift winery. (I is winery wastewater irrigation).

2018/19 season: Three irrigations using the in-field fractional use (augmentation) of winery wastewater with raw water were applied to the sandy (Fig. 4.8) and clay (Fig. 4.9) experiment plots at Backsberg farm. Irrigation commenced earlier in the season for the sandy experiment plot (Fig. 4.8).

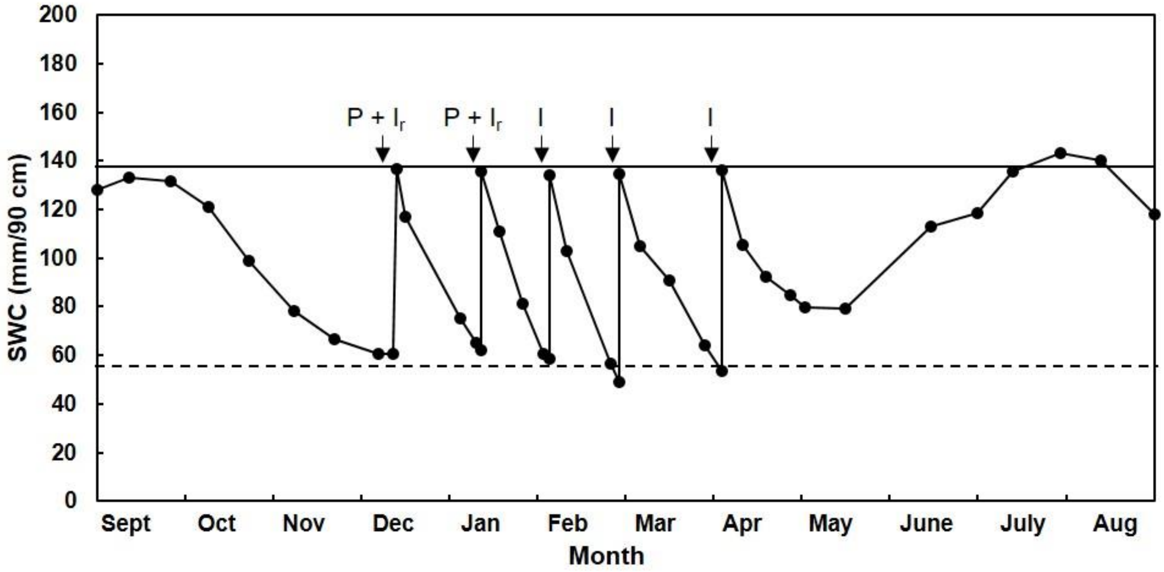

Figure 4.8. Variation in SWC during the 2018/19 season where the in-field fractional use (augmentation) of winery wastewater with raw water was used to irrigate young Cabernet Sauvignon grapevines in a sandy soil at Backsberg (P is precipitation, I_r is raw water irrigation & I is winery wastewater irrigation).

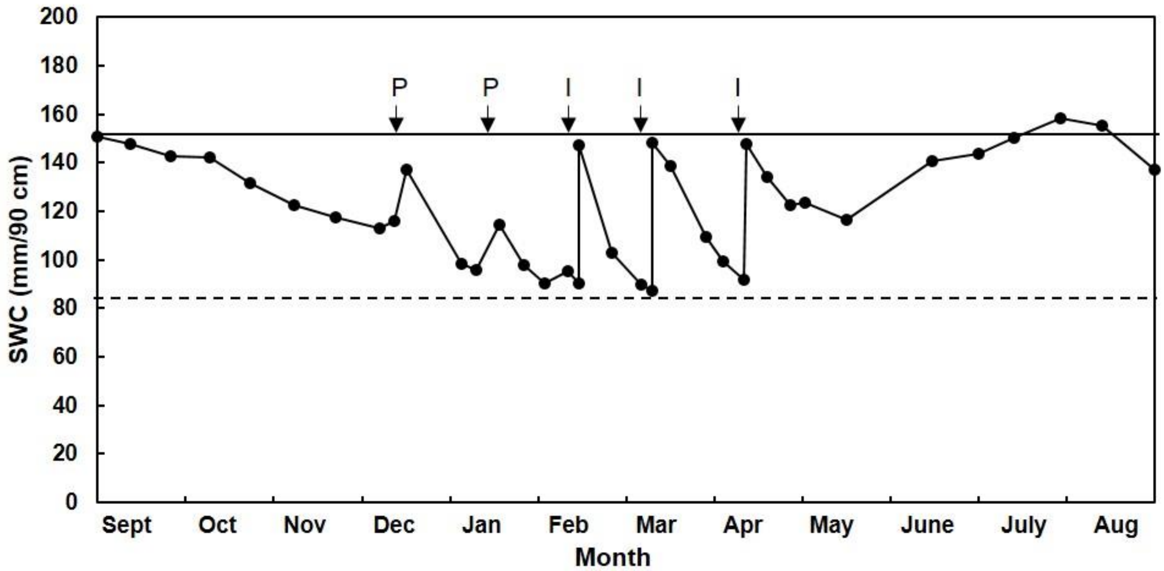

Figure 4.9. Variation in SWC during the 2018/19 season where the in-field fractional use (augmentation) of winery wastewater with raw water was used to irrigate young Cabernet Sauvignon grapevines in a clay soil at Backsberg (P is precipitation & I is winery wastewater irrigation).

Three and two irrigations using the in-field fractional use (augmentation) of winery wastewater with raw water were applied to the sandy loam (Fig. 4.10) and clay loam (Fig. 4.11) experiment plots, respectively, at Madeba farm.

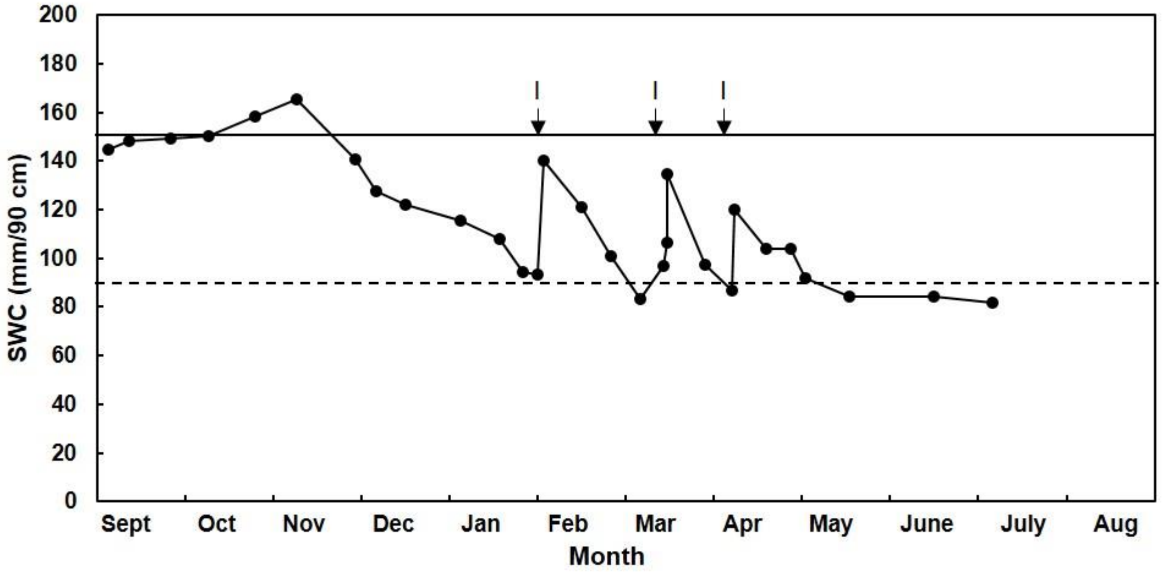

Figure 4.10. Variation in SWC during the 2018/19 season where the in-field fractional use (augmentation) of winery wastewater with raw water was used to irrigate Shiraz grapevines in a sandy loam soil on Madeba farm (I is winery wastewater irrigation).

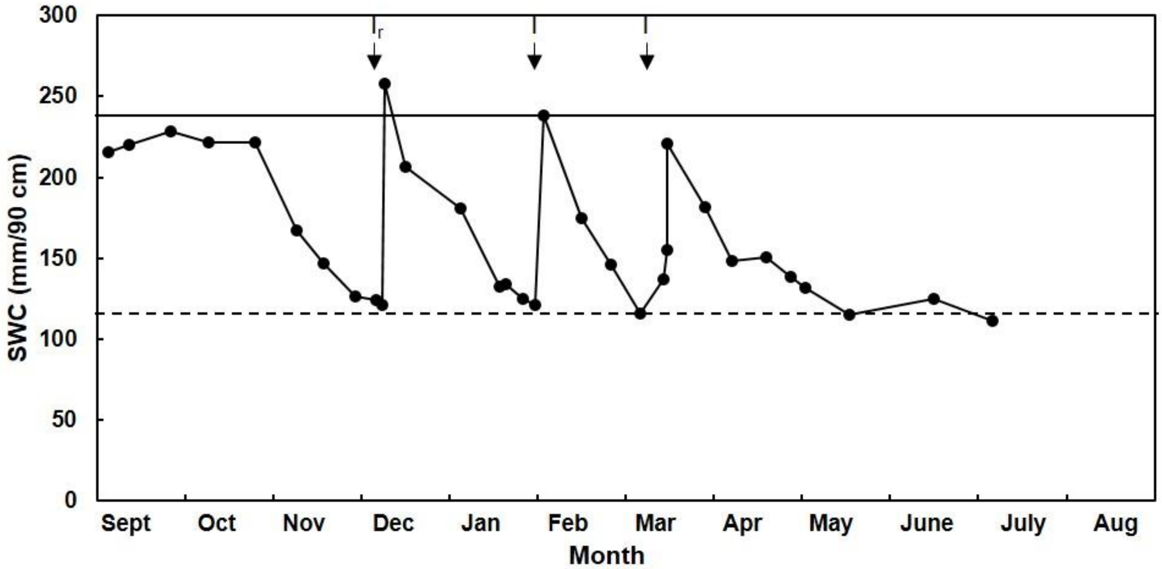

Figure 4.11. Variation in SWC during the 2018/19 season where the in-field fractional use (augmentation) of winery wastewater with raw water was used to irrigate Shiraz grapevines in a clay loam soil near Madeba farm (I_r is raw water irrigation & I is winery wastewater irrigation).

Irrigation with winery wastewater was applied at both experiment plots in the Lower Olifants River region at the beginning of the season in late August (Figs. 4.12 & 4.13). In total, four irrigations were applied at the Lutzville deep sand experiment plot (Fig. 4.12).

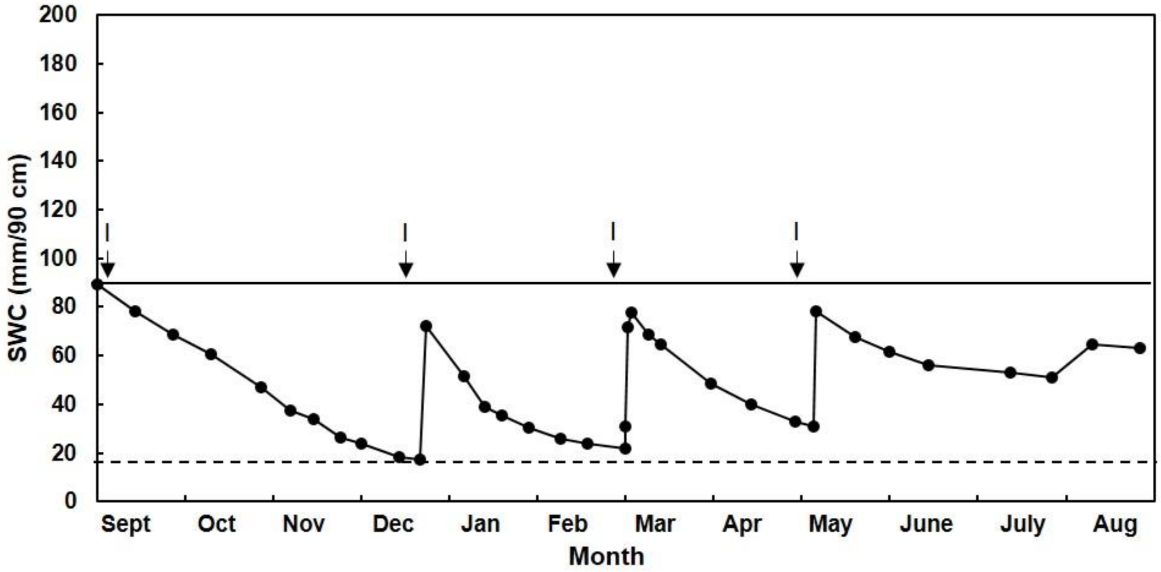

Figure 4.12. Variation in SWC during the 2018/19 season where the in-field fractional use (augmentation) of winery wastewater with raw water was used to irrigate Shiraz grapevines near Lutzville winery (I is winery wastewater irrigation).

Visual observation in the Spruitdrift vineyard in early December 2019 revealed that the grapevines were growing poorly. After consideration of the EC of the winery wastewater, it was decided to decrease the ratio of winery wastewater to raw water. In this regard, from December 2019, a ratio of 25% wastewater to 75% raw water was applied, *i.e.* a fractional ratio of 0.25. In total, nine irrigations were applied to the grapevines (Fig. 4.13).

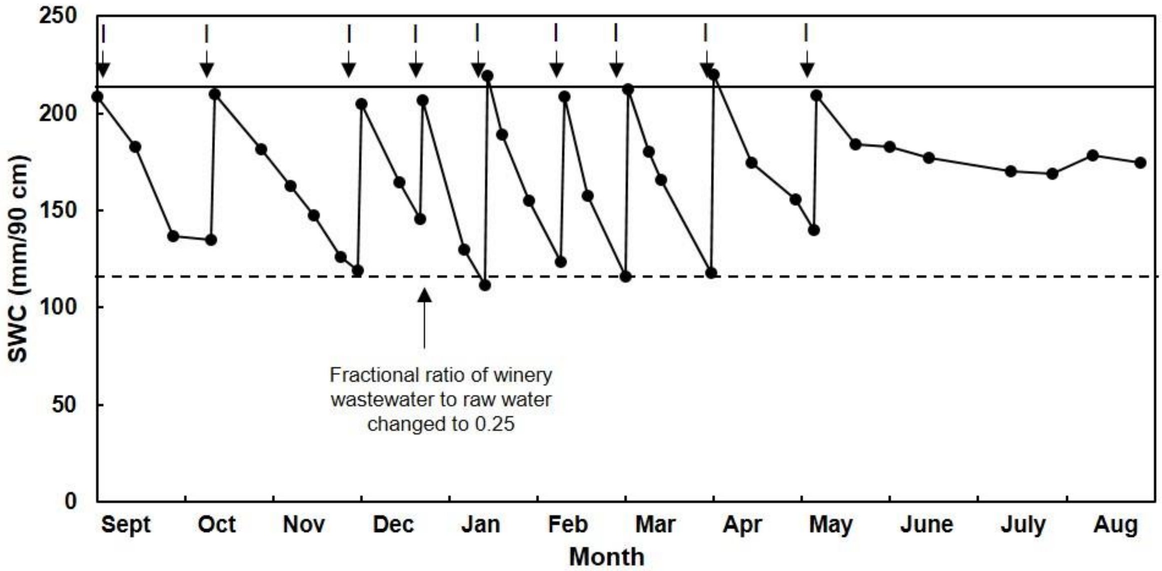

Figure 4.13. Variation in SWC during the 2018/19 season where the in-field fractional use (augmentation) of winery wastewater with raw water was used to irrigate Cabernet Sauvignon grapevines near Spruitdrift winery (I is winery wastewater irrigation).

2019/20 season: Three irrigations using the in-field fractional use (augmentation) of winery wastewater with raw water were applied to the sandy (Fig. 4.14) and clay (Fig. 4.15) experiment plots at Backsberg farm.

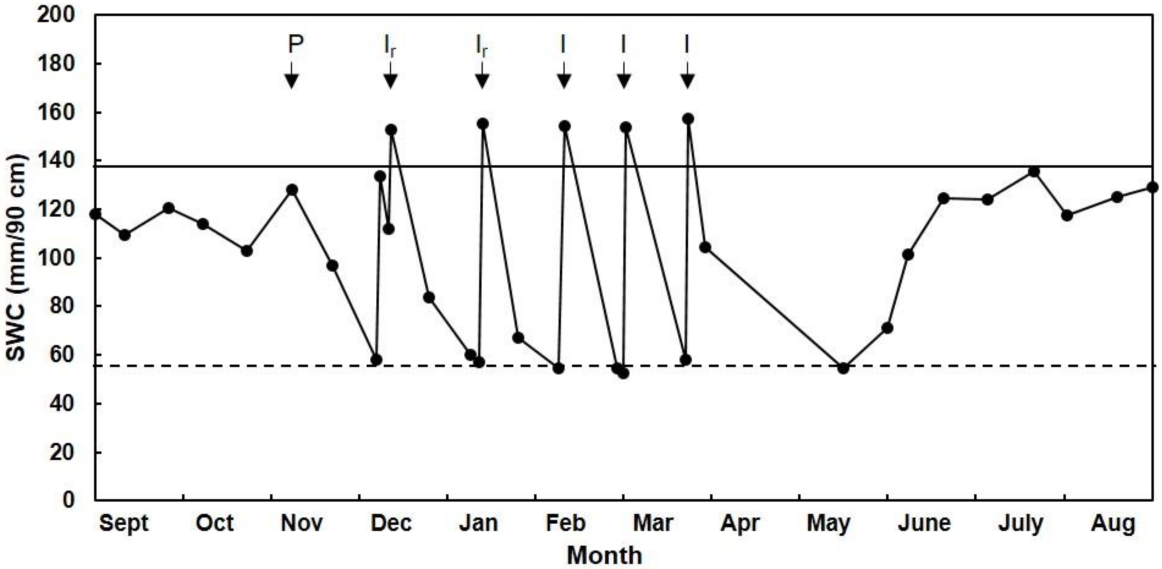

Figure 4.14. Variation in SWC during the 2019/20 season where the in-field fractional use (augmentation) of winery wastewater with raw water was used to irrigate young Cabernet Sauvignon grapevines in a sandy soil at Backsberg (P is precipitation, I_r is raw water irrigation & I is winery wastewater irrigation).

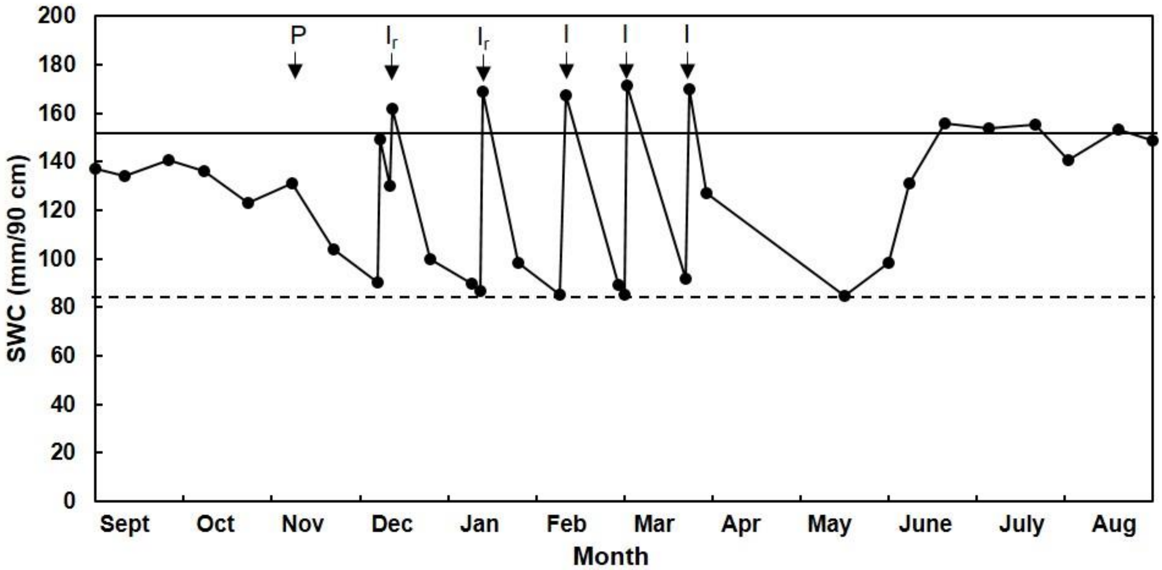

Figure 4.15. Variation in SWC during the 2019/20 season where the in-field fractional use (augmentation) of winery wastewater with raw water was used to irrigate young Cabernet Sauvignon grapevines in a clay soil at Backsberg (P is precipitation, I_r is raw water irrigation & I is winery wastewater irrigation).

Two irrigations using the in-field fractional use (augmentation) of winery wastewater with raw water were applied to the sandy loam (Fig. 4.16) and clay loam (Fig. 4.17) experiment plots, respectively, at Madeba farm.

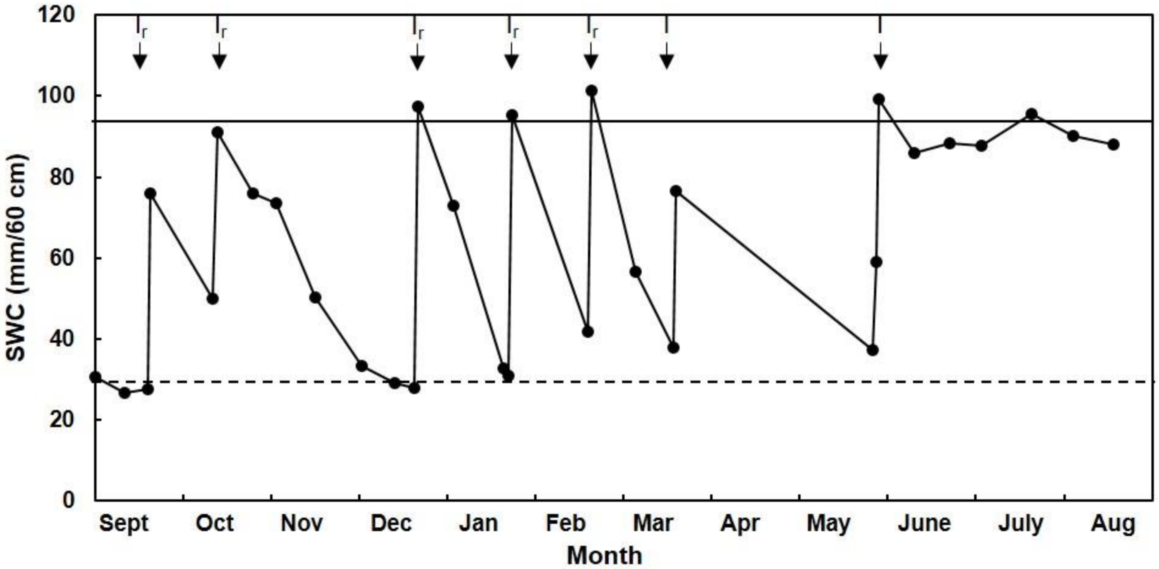

Figure 4.16. Variation in SWC during the 2019/20 season where the in-field fractional use (augmentation) of winery wastewater with raw water was used to irrigate Shiraz grapevines in a sandy loam soil on Madeba farm (I_r is raw water irrigation & I is winery wastewater irrigation).

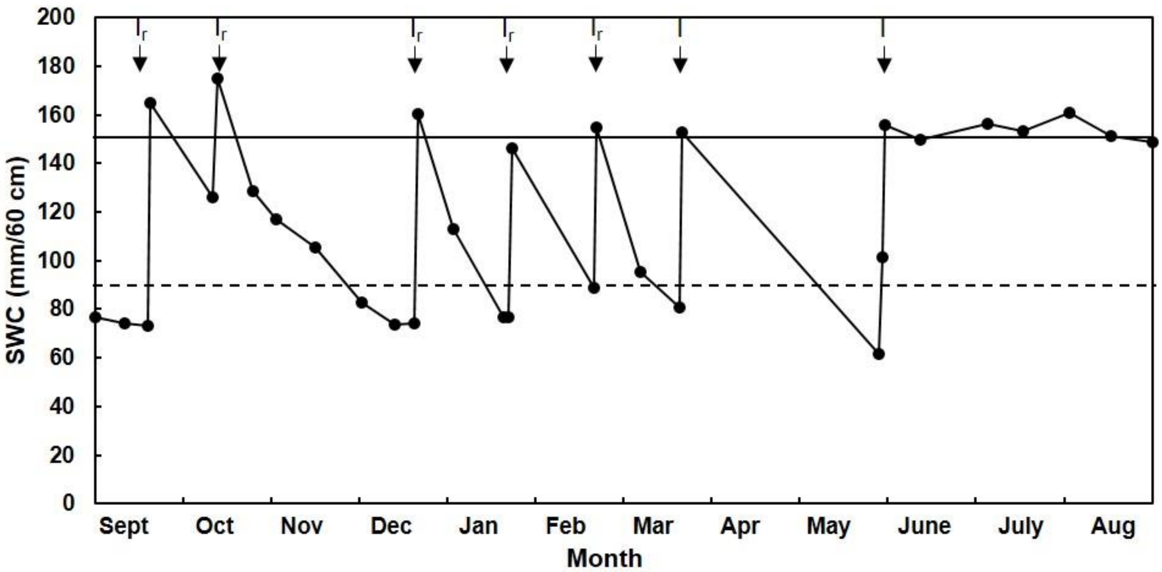

Figure 4.17. Variation in SWC during the 2019/20 season where the in-field fractional use (augmentation) of winery wastewater with raw water was used to irrigate Shiraz grapevines in a clay loam soil near Madeba farm (I_r is raw water irrigation & I is winery wastewater irrigation).

Irrigation with winery wastewater was applied at the Lutzville deep sand experiment plot from January 2020. In total, four irrigations using the in-field fractional use (augmentation) of winery wastewater with raw water were applied in this particular season (Fig. 4.18).

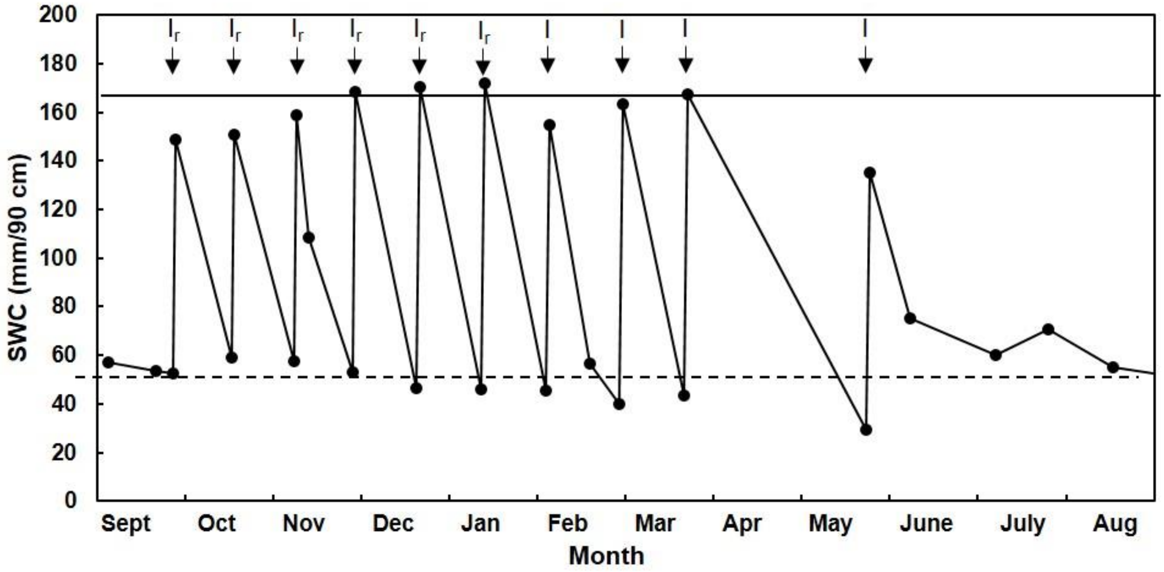

Figure 4.18. Variation in SWC during the 2019/20 season where the in-field fractional use (augmentation) of winery wastewater with raw water was used to irrigate Shiraz grapevines near Lutzville winery (I_r is raw water irrigation & I is winery wastewater irrigation).

Given the extremely poor performance of the grapevines in the previous seasons at Spruitdrift vineyard, wastewater irrigation at this particular experiment plot had to be terminated from the beginning of the 2019/20 season to prevent any further damage. Thereafter, the vineyard was irrigated according to the grower's schedule to facilitate the recovery of the grapevines (Fig. 4.19).

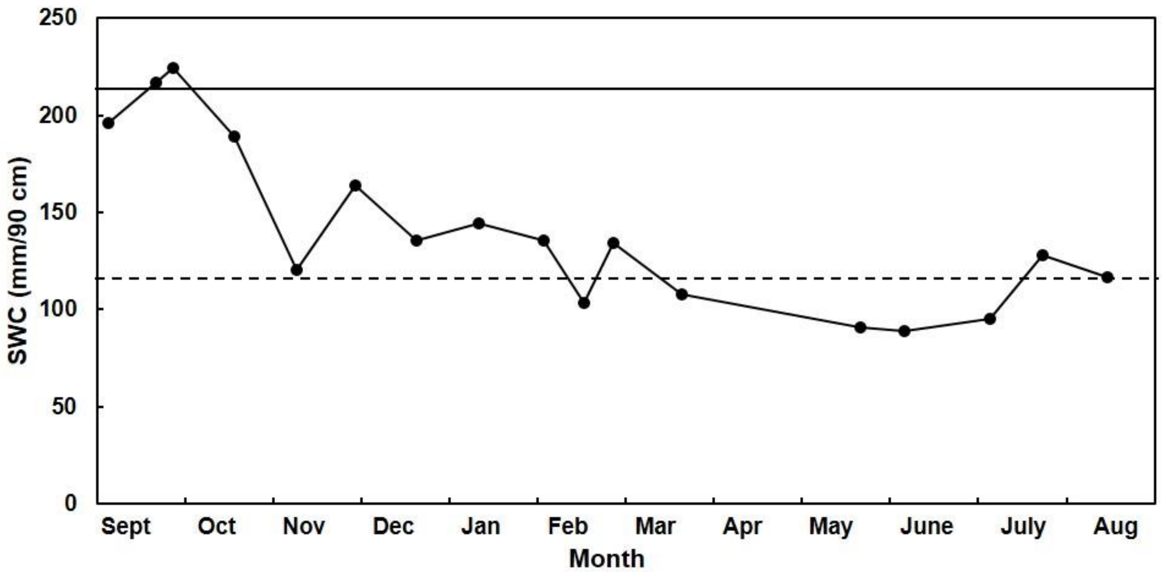

Figure 4.19. Variation in SWC during the 2019/20 season where the Cabernet Sauvignon vineyard was irrigated according to the grower's schedule at Spruitdrift.

2020/21 season: Winery wastewater was only available at Backsberg from early February 2021. Therefore, until then, where the experiment plots required irrigation, they were irrigated with raw water. As soon as wastewater became available at these sites, the in-field fractional use (augmentation) of winery wastewater with raw water for vineyard irrigation commenced. Four and three raw water irrigations were applied to the sandy and clay experiment plots at Backsberg farm (Figs. 4.20 & 4.21), respectively. Four irrigations using the in-field fractional use (augmentation) of winery wastewater with raw water were applied to the sandy (Fig. 4.20) and clay (Fig. 4.21) experiment plots.

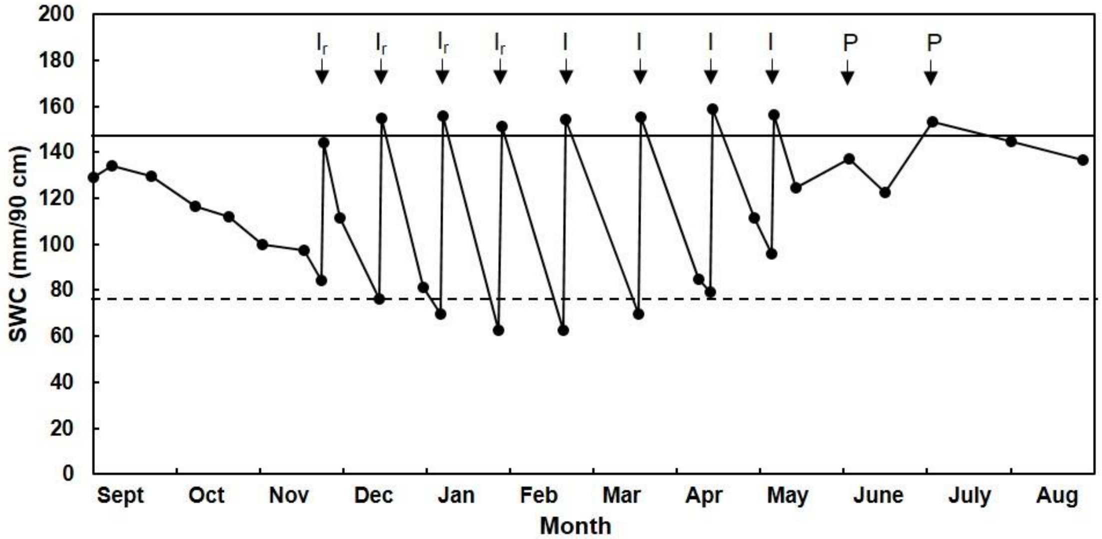

Figure 4.20. Variation in SWC during the 2020/21 season where the in-field fractional use (augmentation) of winery wastewater with raw water was used to irrigate young Cabernet Sauvignon grapevines in a sandy soil at Backsberg (P is precipitation, I_r is raw water irrigation & I is winery wastewater irrigation).

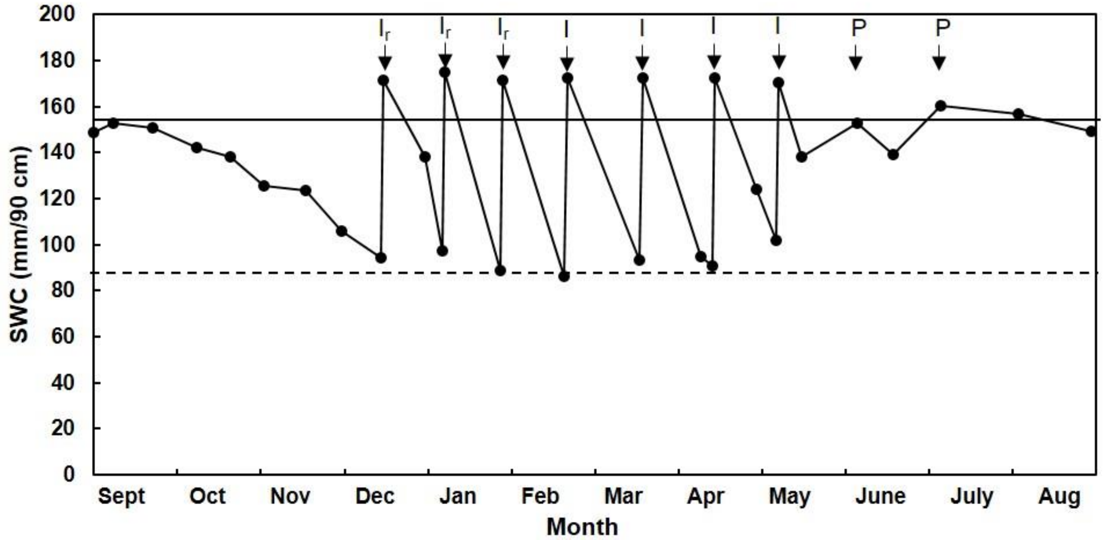

Figure 4.21. Variation in SWC during the 2020/21 season where the in-field fractional use (augmentation) of winery wastewater with raw water was used to irrigate young Cabernet Sauvignon grapevines in a clay soil at Backsberg (P is precipitation, I_r is raw water irrigation & I is winery wastewater irrigation).

Two irrigations using the in-field fractional use (augmentation) of winery wastewater with raw water were applied to the sandy loam (Fig. 4.22) and clay loam (Fig. 4.23) experiment plots, respectively, at Madeba farm.

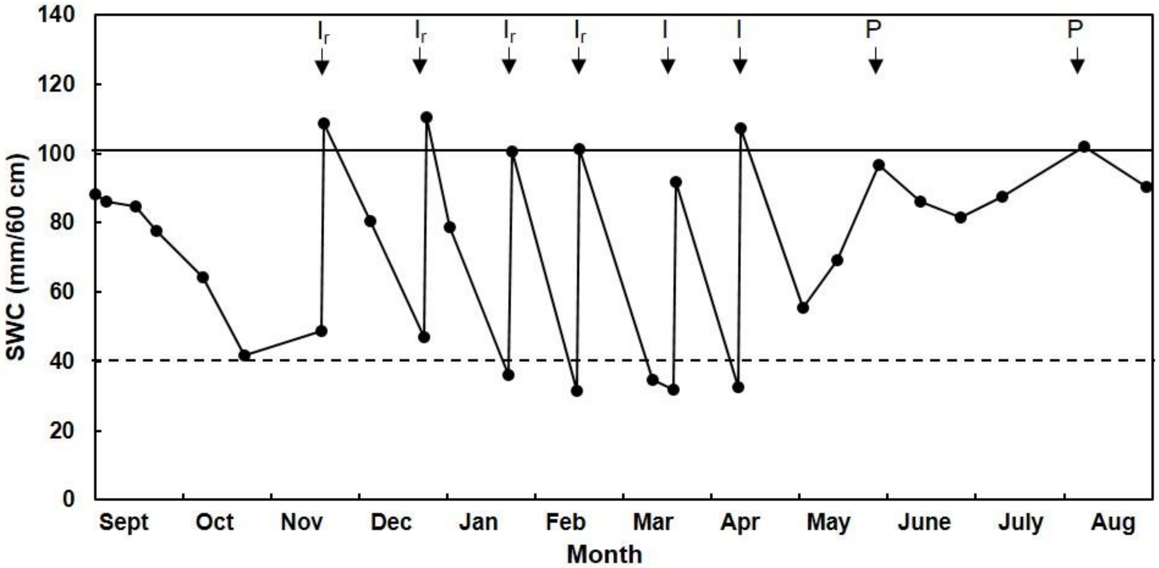

Figure 4.22. Variation in SWC during the 2020/21 season where the in-field fractional use (augmentation) of winery wastewater with raw water was used to irrigate Shiraz grapevines in a sandy loam soil on Madeba farm (P is precipitation, I_r is raw water irrigation & I is winery wastewater irrigation).

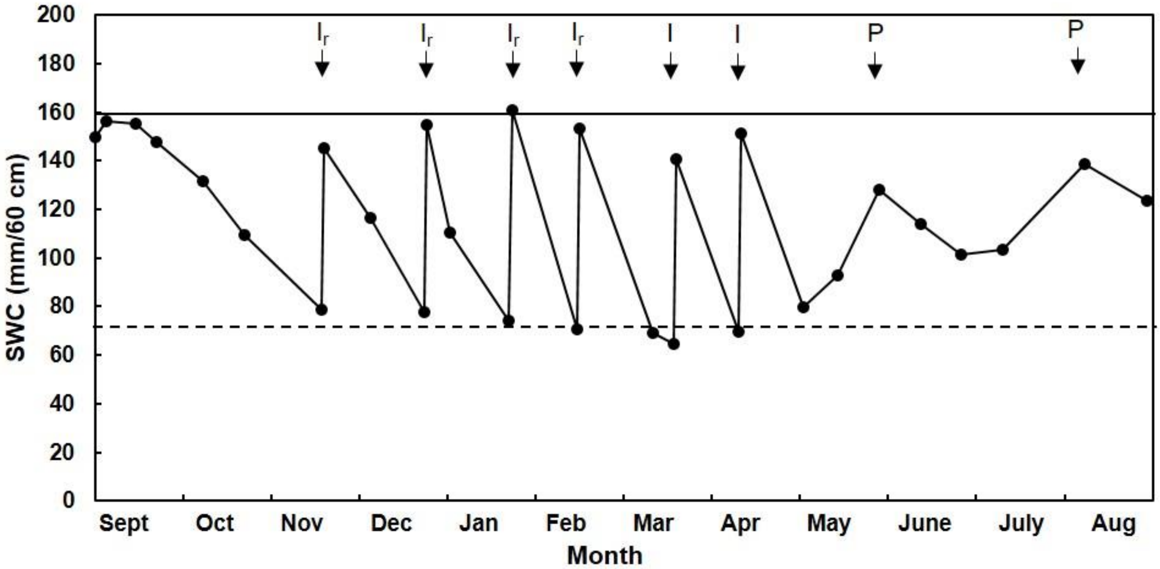

Figure 4.23. Variation in SWC during the 2020/21 season where the in-field fractional use (augmentation) of winery wastewater with raw water was used to irrigate Shiraz grapevines in a clay loam soil near Madeba farm (P is precipitation, I_r is raw water irrigation & I is winery wastewater irrigation).

Two irrigations using the in-field fractional use (augmentation) of winery wastewater with raw water were applied at Lutzville during the 2020/21 season (Fig. 4.24).

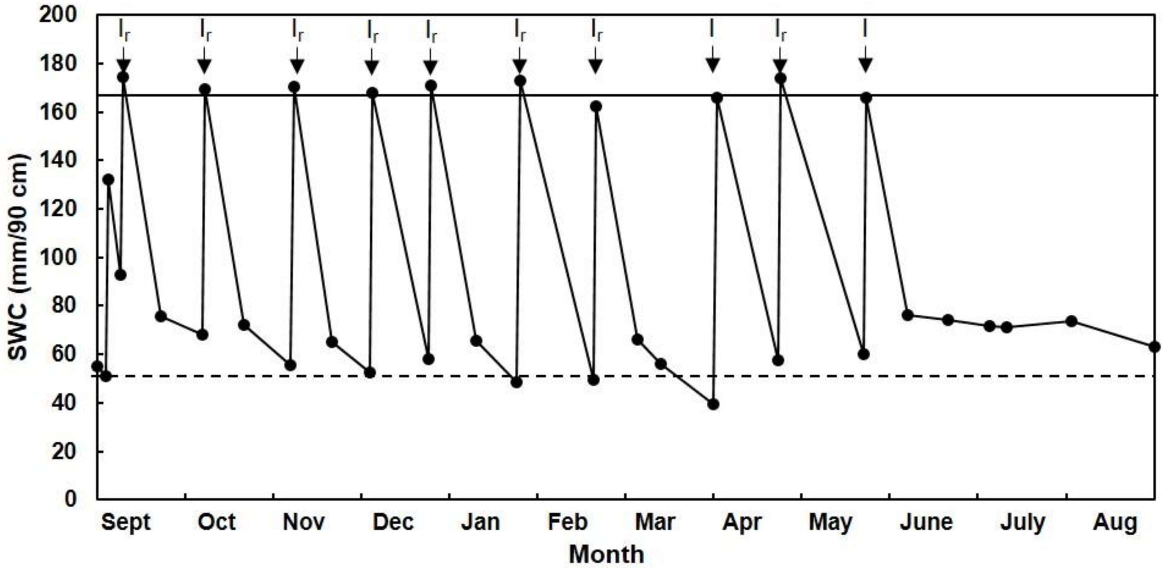

Figure 4.24. Variation in SWC during the 2020/21 season where the in-field fractional use (augmentation) of winery wastewater with raw water was used to irrigate Shiraz grapevines near Lutzville winery (I_r is raw water irrigation & I is winery wastewater irrigation).

The vineyard at Spruitdrift was irrigated according to the grower's schedule to facilitate the recovery of the grapevines (Fig. 4.25).

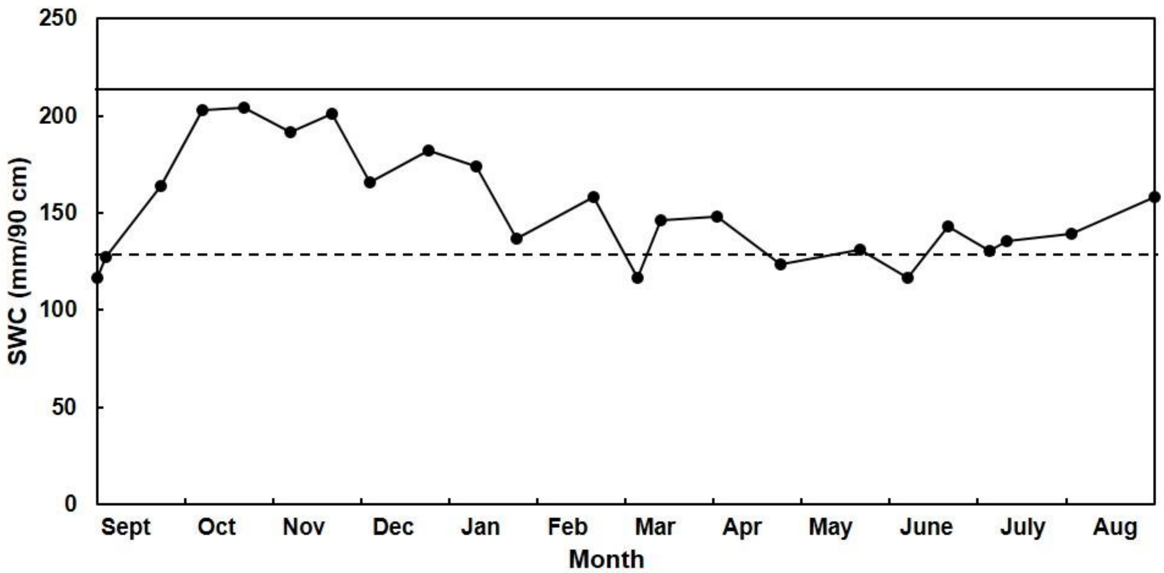

Figure 4.25. Variation in SWC during the 2020/21 season where the Cabernet Sauvignon vineyard was irrigated according to the grower's schedule at Spruitdrift.

4.3.2. Grapevine water status

The Ψ_S was measured prior to harvest in the 2017/18 (Fig. 4.26) and 2018/19 seasons (Fig. 4.27). Despite the Madeba clay loam experiment plot experiencing more water constraints compared to the Madeba sandy loam experiment plot during this period in the 2017/18 season

(Fig. 4.26), the Ψ_S measured at both these experiment plots were still within the range of -1.1 MPa to -1.65 MPa which designates moderate water constraints in Shiraz grapevines (Myburgh, 2018 and references therein). In the 2018/19 season, the Ψ_S measured at both these experiment plots (Fig. 4.27) prior to harvest was in the high water constraint class for Shiraz grapevines (Myburgh, 2018 and references therein). According to water constraint thresholds for Shiraz grapevines (Myburgh, 2018 and references therein), grapevines at the Lutzville deep sand experiment plot experienced low and moderate water constraints prior to harvest in the 2017/18 and 2018/19 seasons, respectively (Figs. 4.26 & 4.27). Similar results were reported by Bruwer (2010) for drip irrigated Cabernet Sauvignon grapevines in a sandy soil near Lutzville. The lower water constraints were attributed to cooler atmospheric conditions which was likely influenced by the proximity of the vineyards to the Atlantic Ocean. Furthermore, the lower water constraints experienced at this plot would probably have resulted in higher yields and lower wine quality (Myburgh *et al*., 2016). Despite the application of winery wastewater with relatively high salinity (Refer to Chapter 2), the in-field fractional use (augmentation) of winery wastewater with raw water used to irrigate grapevines did not negatively affect grapevine water status at this particular experiment plot. These results were similar to a previous study which indicated that irrigation with winery wastewater diluted to 3 000 mg/L COD did not affect the water status of Cabernet Sauvignon grapevines in a sandy alluvial soil in the Breede River region (Myburgh & Howell, 2014b). At harvest in the 2017/18 season, the grapevines at the Spruitdrift shallow sand experiment plot were exposed to water constraints below -1.4 MPa (Fig. 4.26), which is the lower limit that classifies high water constraints in Cabernet Sauvignon grapevines (Myburgh *et al*., 2016). These results were considerably lower than Ψ_S of -0.73 MPa to -1.28 MPa previously reported for Cabernet Sauvignon grapevines in a sandy loam soil near Vredendal (Bruwer, 2010). At harvest in the 2018/19 season, the grapevines at the Spruitdrift shallow sand experiment plot were exposed to high water constraints (Fig. 4.27).

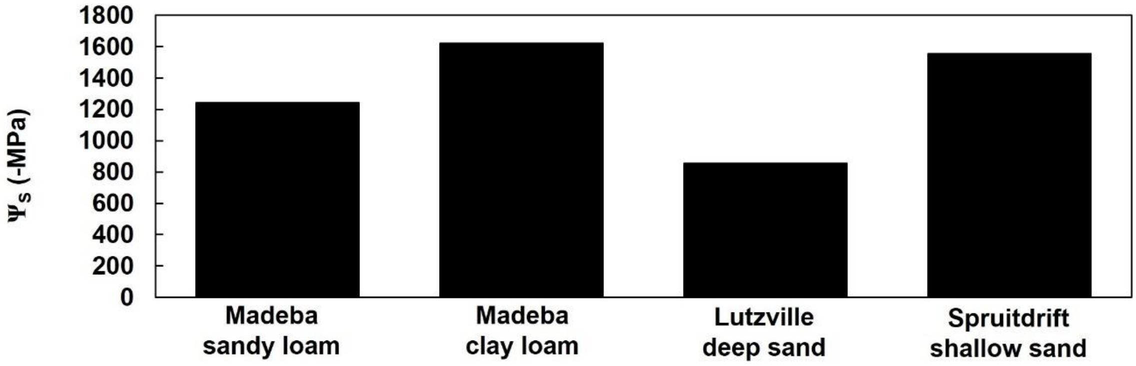

Figure 4.26. The midday stem water potential measured prior to harvest during the 2017/18 season where the in-field fractional use (augmentation) of winery wastewater with raw water was used to irrigate grapevines.

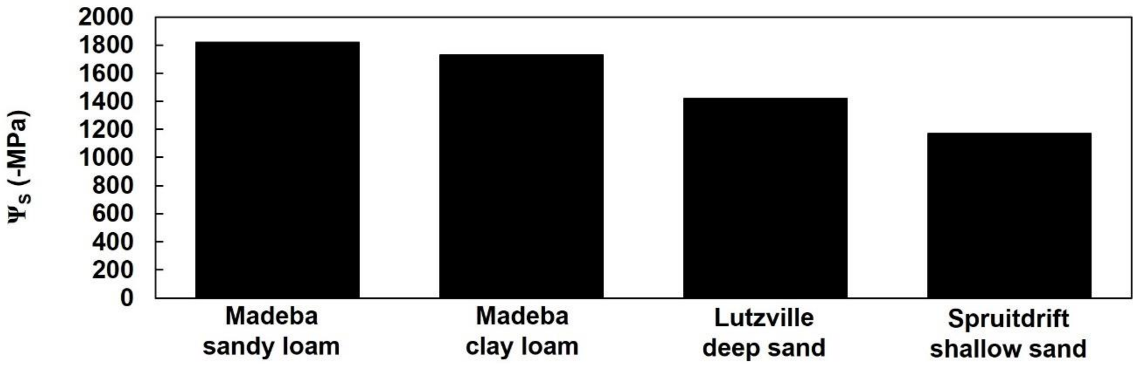

Figure 4.27. The midday stem water potential measured prior to harvest during the 2018/19 season where the in-field fractional use (augmentation) of winery wastewater with raw water was used to irrigate grapevines.

4.3.3. Vegetative growth

Following one season of irrigation with the in-field fractional use (augmentation) of winery wastewater with raw water, cane mass decreased at both experiment plots in the Lower Olifants River region (Fig. 4.28). However, the decline was more pronounced at the Spruitdrift shallow sand experiment plot. The mass of the grapevines at the Madeba sandy loam and clay loam experiment plots differed substantially prior to the in-field fractional use (augmentation) of winery wastewater with raw water. The reason for this difference is still uncertain. However, soil compaction due to tractor traffic is more likely to occur at the Madeba clay loam experiment plot due to the heavier soil texture. Therefore, the lower vegetative growth may have been the result of restricted root development. Compared to the baseline values, cane mass at both Madeba experiment plots remained unchanged after the 2017/18 season. The lack of difference was to be expected since only two irrigations were applied at these experiment plots during the 2017/18 season. In addition, after the irrigations were applied (Refer to Chapter 2), the EC_e of the soils were below the range of 0.7 to 1.5 dS/m which is the proposed salinity threshold for vineyards in the Breede River region (Myburgh &

Howell, 2014b). Furthermore, the high water constraints experienced by the grapevines at the Madeba clay loam experiment plot did not seem to have a negative effect on grapevine vegetative growth. Since the grapevines in the Coastal region were only planted in September 2017, baseline cane mass was not determined at these experiment plots prior to the in-field fractional use (augmentation) of winery wastewater with raw water.

Cane mass at pruning was substantially lower in the 2018/19 season compared to the baseline values measured during July 2017 (Fig. 4.28). Cane mass at the Lutzville deep sand experiment plot showed a progressive decline since the start of the project. At pruning in the winter of 2019, cane mass at the Spruitdrift shallow sand experiment plot showed a substantial decline from the baseline value. The cane mass of the experiment plot at Spruitdrift was also substantially lower than the control. At Madeba, there was a decline in cane mass in July 2019 for the sandy loam experiment plot and a substantial decline in the cane mass for the clay loam experiment plot. The cane mass of the Madeba clay loam experiment plot was substantially lower than the control. The general decline of cane mass after two seasons of the in-field fractional use (augmentation) of winery wastewater with raw water at the experiment plots was a matter of concern. Since grapevine growth is quite sensitive to adverse environmental conditions, this trend raised questions about the sustainability of using wastewater for irrigation irrespective of wastewater quality.

Although cane mass at the Lutzville deep sand experiment plot had shown a progressive decline since the start of the project, the application of more water in the 2019/20 season improved cane mass in July 2020 (Fig. 4.28). Cane mass at Spruitdrift showed a substantial decline from the baseline value (Fig. 4.28) but had started to recover given that there was no in-field fractional use (augmentation) of winery wastewater with raw water at this experiment plot during the season. The growth at this particular site, however, was still substantially lower compared to the control. At Madeba, there was a substantial decline in cane mass in July 2020 for the sandy loam experiment plot whereas the cane mass of the clay loam experiment plot was similar to the previous season (Figs. 4.28). The cane mass of the experiment plot at Madeba clay loam was still substantially lower than the control.

At the end of the trial in 2021, the cane mass of the Lutzville deep sand and Madeba sandy loam experiment plots was comparable to the baseline values measured at the beginning of the trial. However, the cane mass at the Madeba clay loam and Spruitdrift shallow sand 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 these grapevines.

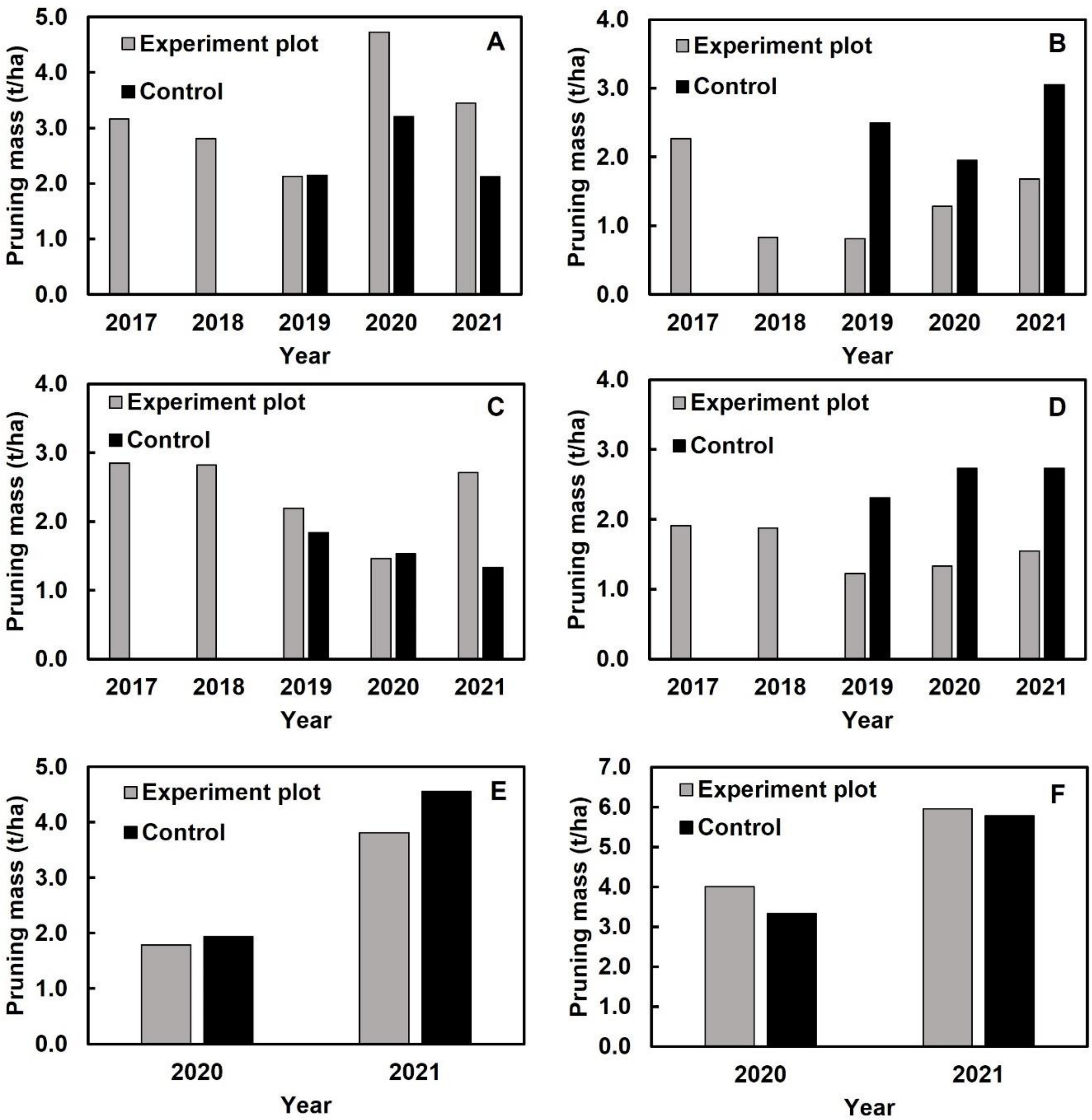

Figure 4.28. Effect of in-field fractional use (augmentation) of winery wastewater with raw water on pruning mass measured for (A) deep sand at Lutzville, (B) shallow sand at Spruitdrift, (C) sandy loam at Madeba, (D) clay loam at Madeba, (E) sand at Backsberg and (F) clay at Backsberg in 2017, 2018, 2019, 2020 and 2021.

4.3.3.1. Grapevine leaf chemical status

2017/18 season: According to the norms for grapevine nutrient levels in leaves (Conradie, 1994), *i.e.* 1.6% to 2.7% for N, 0.14% to 0.55% for P, 0.65% to 1.3% for K, 1.2% to 2.2% for Ca, and 0.16% to 0.55% for Mg, none of the macro elements were at deficient levels (Fig. 4.29). The levels of N in the leaf blades of the grapevines (Fig. 4.28A) at the Backsberg experiment plots were above the recommended range of 1.6% to 2.7% for N in grapevine leaves (Conradie, 1994). This was probably the result of the over application of N *via* the irrigation water to the newly established grapevines at these experiment plots (Refer to Chapter 2). Except for the grapevines at the Backsberg sand experiment plot (Fig. 4.29B), all of the experiment grapevines had P contents within the recommended range of 0.14% to 0.55% for grapevine leaf blades (Conradie, 1994). Furthermore, a trend of increasing leaf blade P content occurred in the case of grapevines planted on the heavier textured soils (Fig. 4.29B). Leaf blade K ranged between 0.55% and 1.42% (Fig 4.29C). Despite the high amounts of K applied (Refer to Chapter 2), the experiment grapevines at both experiment plots in the Breede River region had leaf blade K levels below the minimum recommended norm of 0.65% (Conradie, 1994). Most of the K is absorbed by grapevines before the onset of véraison (Conradie, 1981). Therefore, it is possible that the K applied *via* the irrigation water at these experiment plots was applied too late in the season to have had an effect on leaf K levels. Similar results were reported by Myburgh and Howell (2014b) for Cabernet Sauvignon grapevines irrigated with diluted winery wastewater in the Breede River region. The grapevines at the Lutzville deep sand experiment plot had K contents above the maximum recommended norm of 1.3% for grapevine leaf blades (Conradie, 1994). Since the grapevines at this particular experiment plot were irrigated before the onset of véraison, the irrigation water supplied large amounts of K during the period of active K uptake (Refer to Chapter 2). This resulted in an accumulation in the leaves.

With the exception of the Lutzville deep sand experiment plot, leaf blade Ca levels were relatively similar for all the experiment plots (Fig. 4.29D). The high Ca content of the grapevine leaves at the Lutzville deep sand experiment plot exceeded the threshold value of 2.2% Ca recommended by Conradie (1994). In contrast to other studies (Morris & Cawthon, 1982; Mosse *et al*., 2013; Myburgh & Howell, 2014b), the excessive application of K at this particular experiment plot (Refer to Chapter 2) did not suppress Ca uptake. The high leaf blade Ca concentrations at the Lutzville deep sand experiment plot was probably caused by the substantial amount of Ca applied *via* the irrigation water during the 2017/18 season (Refer to Chapter 2).

Apart from the Madeba sandy loam experiment plot (Fig. 4.29E), grapevines had leaf blade Mg levels within the recommended range of 0.16% to 0.55% (Conradie, 1994). It is still uncertain why the grapevines at the Madeba sandy loam experiment plot had particularly high leaf blade Mg contents, since the amount of Mg applied *via* the irrigation water was similar for the two experiment plots in the Breede River region (Refer to Chapter 2), but appreciably lower compared to amounts applied in the Lower Olifants River region (Refer to Chapter 2).

Leaf blade Na levels at the Madeba and Lutzville experiment plots were substantially higher compared to the other experiment plots (Fig. 4.29F). Increased leaf Na contents with an increase in EC_w was reported for Colombar grapevines in the Breede River region (Moolman *et al*., 1999). The authors also reported a more rapid increase in leaf Na content above EC_w levels of 3.5 dS/m. Since the winery wastewater applied at the Madeba and Lutzville experiment plots frequently had EC_w values exceeding 3.5 dS/m (Refer to Chapter 2), the accumulation of Na in the leaves at the Madeba and Lutzville experiment plots may be ascribed to the high salinity irrigation water. Furthermore, Na uptake by grapevines can be influenced by rootstock cultivar (Walker *et al*., 2004). A recent study by Saritha *et al*. (2017) indicated that Ramsey accumulated considerable amounts of Na in the leaf blades when irrigated with different Cl-salt solutions. Since the Shiraz grapevines at the Lutzville deep sand experiment plot was grafted onto Ramsey, the higher Na accumulation by these grapevines may be explained by higher Na uptake by the rootstock compared to the other experiment plots. However, the leaf Na levels at all the experiment plots were still well below the maximum threshold value 0.25% (Conradie, 1994). Moolman *et al*. (1999) reported that leaf damage can occur at Na levels as low as 0.17%. Leaf Na contents at all the experiment plots were below this threshold value (Fig. 4.29F), therefore no leaf scorching was expected.

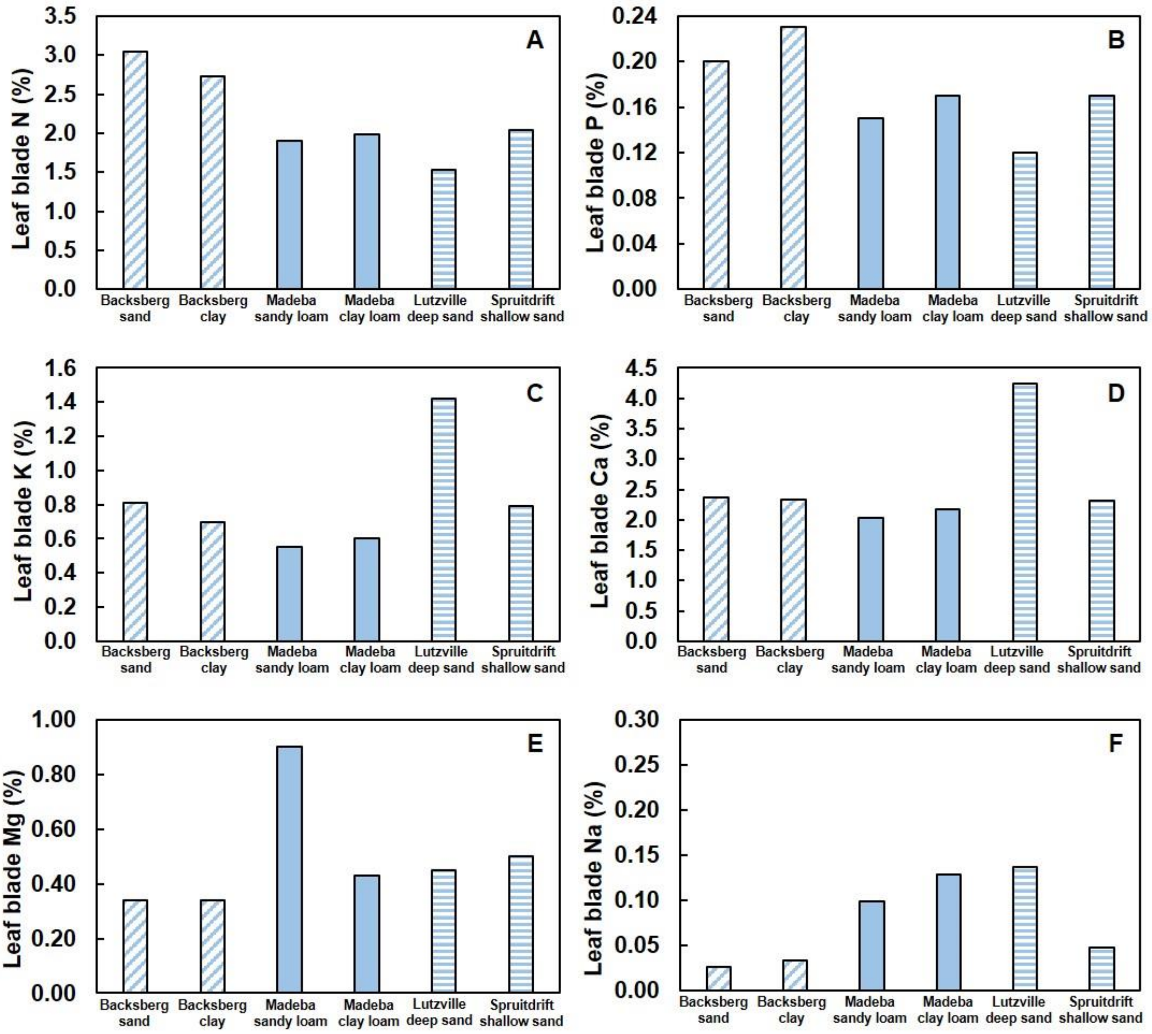

Figure 4.29. Variation in leaf blade element contents at harvest in the 2017/18 season where the in-field fractional use (augmentation) of winery wastewater with raw water was used to irrigate grapevines.

2018/19 season: According to the norms for grapevine nutrient levels in leaves (Conradie, 1994), *i.e.* 1.6% to 2.7% for N, 0.14% to 0.55% for P, 0.65% to 1.3% for K, 1.2% to 2.2% for Ca, and 0.16% to 0.55% for Mg, none of the macro elements were at deficient levels during the season (Fig. 4.30). The levels of N in the leaf blades of the grapevines (Fig. 4.30A) at all the experiment plots were within the recommended range of 1.6% to 2.7% for N in grapevine leaves (Conradie, 1994). All of the experiment grapevines had P contents (Fig. 4.30B) within the recommended range of 0.14% to 0.55% for grapevine leaf blades (Conradie, 1994). Furthermore, there was still a trend of increasing leaf blade P content in the case of grapevines planted on the heavier textured soils at Madeba. Leaf blade K ranged between 0.66% and 1.09% (Fig 4.30C).

The high Ca content of the grapevine leaves at the Madeba and Lutzville deep sand experiment plots (Fig. 4.30D) exceeded the threshold value of 2.2% Ca recommended by Conradie (1994). In contrast to other studies (Morris & Cawthon, 1982; Mosse *et al*., 2013; Myburgh & Howell, 2014b), the excessive application of K at these particular experiment plots (Refer to Chapter 2) did not suppress Ca uptake. The high leaf blade Ca concentrations at the Lutzville deep sand experiment plot was probably caused by the substantial amount of Ca applied *via* the irrigation water during the 2018/19 season (Refer to Chapter 2).

Apart from the Madeba clay loam experiment plot (Fig. 4.30E), grapevines at all the experiment plots had leaf blade Mg levels within the recommended range of 0.16% to 0.55% (Conradie, 1994). For the Backsberg and Madeba sandy loam experiment plots, leaf blade Mg tended to decrease (Fig. 4.30E). This indicated a possible K-induced suppression of Mg absorption (Saayman, 1981). Similar results were reported by Morris *et al.* (1980) where grapevines were fertilized with excessive amounts of K. Large applications of K have been known to reduce Mg to deficiency levels (Morris & Cawthon, 1982 and references therein), and it is possible that a K-induced Mg deficiency could develop from continued use of high levels of K (Morris *et al.*, 1980). Where Seyval Blanc grapevines were growing in four nutrient solutions, petiole Mg decreased in response to increasing K (Wolf *et al.*, 1983). Likewise, when 45 kg K was applied per ha compared to no K, leaf blade and petiole Mg decreased (Conradie & Saayman, 1989). However, increasing K from 45 kg/ha to 90 kg/ha did not induce further Mg reductions.

Leaf blade Na levels at the Madeba and Spruitdrift experiment plots were substantially higher compared to the other experiment plots (Fig. 4.30F). However, the leaf Na levels at all the experiment plots were still well below the maximum threshold value 0.25% (Conradie, 1994).

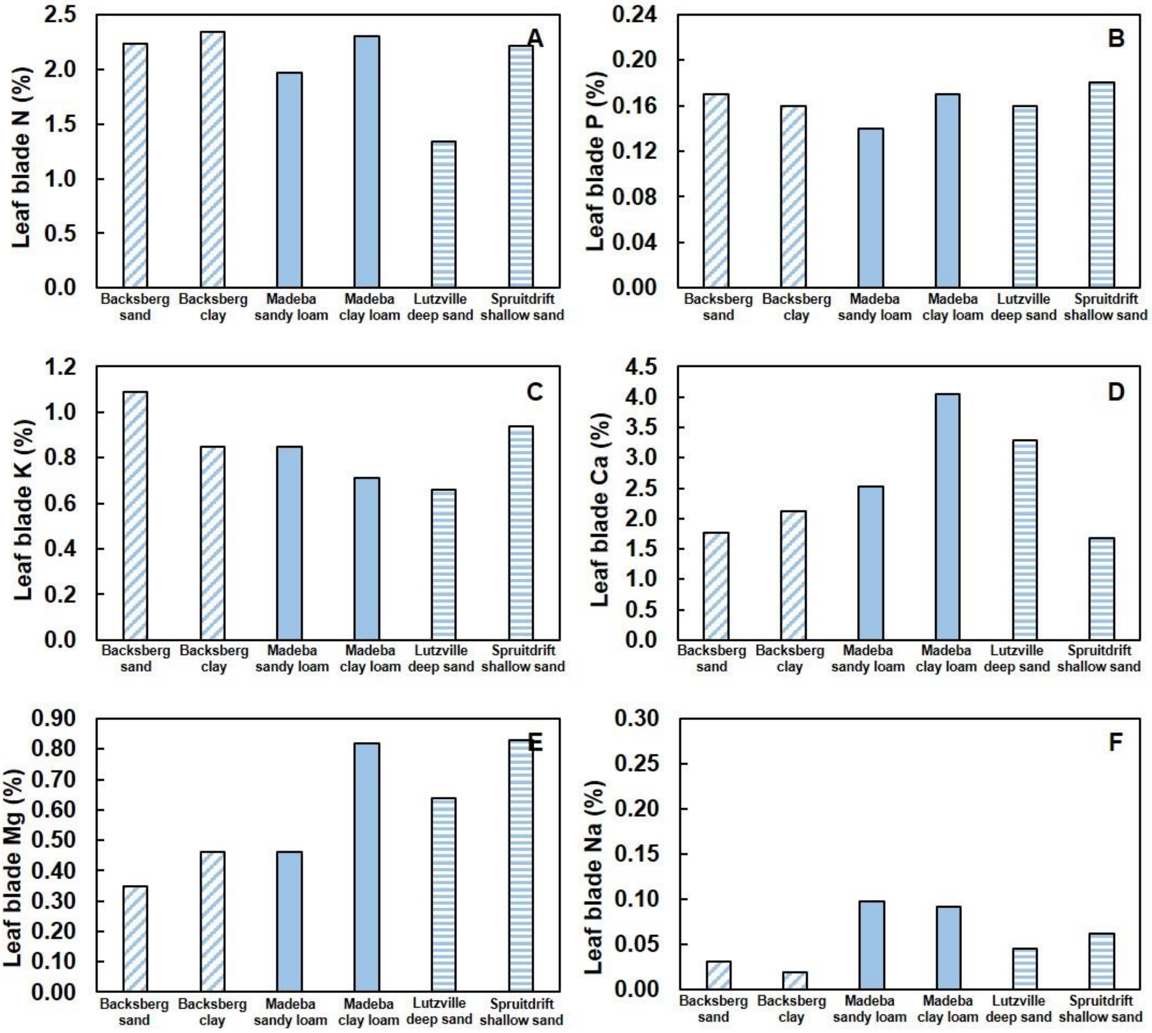

Figure 4.30. Variation in leaf blade element contents at harvest in the 2018/19 season where the in-field fractional use (augmentation) of winery wastewater with raw water was used to irrigate grapevines.

2019/20 season: The levels of N in the leaf blades of the grapevines at the Madeba experiment plots were within the recommended range of 1.6% to 2.7% for N in grapevine leaves (Conradie, 1994) whereas the N levels were slightly lower than the norm for the other experiment plots (Fig. 4.31A). With the exception of the Backsberg sand experiment plot (Fig. 4.31B), all of the experiment grapevines had P contents within the recommended range of 0.14% to 0.55% for grapevine leaf blades (Conradie, 1994). Leaf blade K ranged between 0.37% and 0.86% (Fig 4.31C).

With the exception of the Spruitdrift shallow sand experiment plot (Fig. 4.31D), leaf blade Ca levels exceeded the threshold value of 2.2% Ca recommended by Conradie (1994). Grapevines at all the experiment plots had leaf blade Mg levels within the recommended range of 0.16% to 0.55% (Conradie, 1994). For the Backsberg and Madeba sandy loam experiment plots, leaf blade Mg still tended to decrease (Fig. 4.31E). Leaf blade Na levels at the Madeba and Spruitdrift experiment plots were still substantially higher compared to the other experiment plots (Fig. 4.31F). However, the leaf Na levels at all the experiment plots were still well below the maximum threshold value 0.25% (Conradie, 1994).

Leaf blade N was 1.73%, 1.90%, 1.70%, 1.93%, 1.17% and 1.61% for the Backsberg sand, Backsberg clay, Madeba sandy loam, Madeba clay loam, Lutzville deep sand and Spruitdrift shallow sand controls, respectively. The leaf blade N was higher at the Backsberg control compared to the experiment plot. Leaf blade P was 0.08%, 0.14%, 0.17%, 0.21%, 0.15% and 0.12% for the Backsberg sand, Backsberg clay, Madeba sandy loam, Madeba clay loam, Lutzville deep sand and Spruitdrift shallow sand controls, respectively. Despite no wastewater application at the Spruitdrift experiment plot during the 2019/20 season, the experiment plot had higher leaf blade P compared to the control section. Leaf blade K was 0.70%, 0.76%, 0.37%, 0.47%, 0.80% and 0.47% for the Backsberg sand, Backsberg clay, Madeba sandy loam, Madeba clay loam, Lutzville deep sand and Spruitdrift shallow sand controls, respectively. Leaf blade K was higher at the Backsberg experiment plots where the in-field fractional use (augmentation) of winery wastewater with raw water was used for vineyard irrigation compared to the control which had received no wastewater. Despite large amounts of K applied *via* the irrigation water of the Lutzville experiment plot, grapevines had lower leaf blade K than the control. Despite no wastewater application at the Spruitdrift experiment plot during the 2019/20 season, the experiment plot had substantially higher leaf blade K compared to the control section. Leaf blade Ca was 2.60%, 2.03%, 2.49%, 2.81%, 2.03% and 1.59% for the Backsberg sand, Backsberg clay, Madeba sandy loam, Madeba clay loam, Lutzville deep sand and Spruitdrift shallow sand controls, respectively. Leaf blade K of the Backsberg clay, Madeba clay loam and Lutzville deep sand experiment plots were higher compared to the respective controls. Leaf blade Mg was 0.37%, 0.41%, 0.32%, 0.34%, 0.56% and 0.50% for the Backsberg sand, Backsberg clay, Madeba sandy loam, Madeba clay loam, Lutzville deep sand and Spruitdrift shallow sand controls, respectively. Leaf blade Mg was lower in the Backsberg experiment plots compared to the respective controls. The Madeba clay loam experiment plot had higher leaf blade Mg than the control. Despite no wastewater application at the Spruitdrift experiment plot during the 2019/20 season, the experiment plot had substantially higher leaf blade Mg compared to the control section. Leaf blade Na was 0.037%, 0.021%, 0.114%, 0.066%, 0.055% and 0.043% for the Backsberg sand, Backsberg clay, Madeba sandy loam, Madeba clay loam, Lutzville deep sand and Spruitdrift shallow sand controls, respectively. The Madeba clay loam experiment plot had higher leaf blade Na than the control. Despite no wastewater application at the Spruitdrift experiment plot during the 2019/20 season, the experiment plot had higher leaf blade Na compared to the control which was only irrigated with raw water.

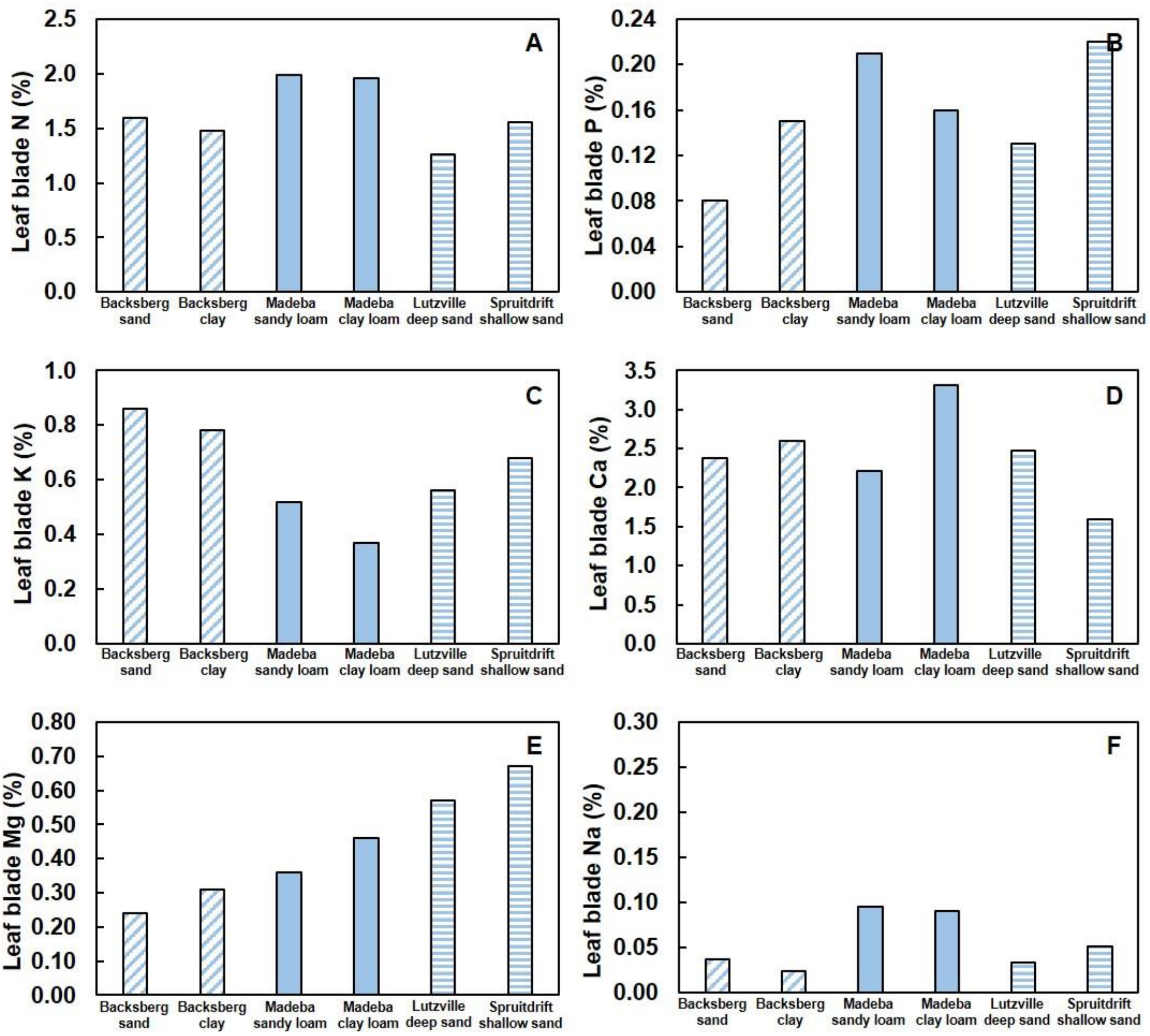

Figure 4.31. Variation in leaf blade element contents at harvest in the 2019/20 season where the in-field fractional use (augmentation) of winery wastewater with raw water was used to irrigate grapevines.

2020/21 season: The levels of N in the leaf blades of the grapevines (Fig. 4.32) at the Madeba experiment plots were within the recommended range of 1.6% to 2.7% for N in grapevine leaves (Conradie, 1994) whereas the N levels were slightly lower than the norm for the other experiment plots (Fig. 4.32A). All of the experiment grapevines had P contents within the recommended range of 0.14% to 0.55% for grapevine leaf blades (Conradie, 1994). Leaf blade K ranged between 0.57% and 1.13% (Fig 4.32C).

With the exception of the Spruitdrift shallow sand experiment plot, leaf blade Ca levels (Fig. 4.32D) exceeded the threshold value of 2.2% Ca recommended by Conradie (1994). The high leaf blade Ca concentrations at the Lutzville deep sand experiment plot was probably caused by the substantial amount of Ca applied *via* the irrigation water during the 2017/18 season (Refer to Chapter 2). Grapevines at all the experiment plots had leaf blade Mg levels within the recommended range of 0.16% to 0.55% (Conradie, 1994). For the Backsberg and Madeba sandy loam experiment plots, leaf blade Mg still tended to decrease (Fig. 4.32E). Leaf blade Na levels at the Madeba and Spruitdrift experiment plots were still substantially higher compared to the other experiment plots (Fig. 4.32F). However, the leaf Na levels at all the experiment plots were still well below the maximum threshold value 0.25% (Conradie, 1994).

Leaf blade N was 1.73%, 1.49%, 1.55%, 1.73%, 1.22% and 1.50% for the Backsberg sand, Backsberg clay, Madeba sandy loam, Madeba clay loam, Lutzville deep sand and Spruitdrift shallow sand controls, respectively. The leaf blade N was higher for the experiment plots compared to the controls for all the vineyards with the exception of Backsberg sand. Leaf blade P was 0.17%, 0.13%, 0.26%, 0.21%, 0.19% and 0.17% for the Backsberg sand, Backsberg clay, Madeba sandy loam, Madeba clay loam, Lutzville deep sand and Spruitdrift shallow sand controls, respectively. The leaf blade P was higher for the experiment plots compared to the controls for all the sites with the exception of Madeba. Despite no wastewater application at the Spruitdrift shallow sand experiment plot during the 2020/21 season, the experiment plot still had higher leaf blade P compared to the control. Leaf blade K was 0.44%, 0.66%, 0.69%, 0.81%, 0.67% and 0.75% for the Backsberg sand, Backsberg clay, Madeba sandy loam, Madeba clay loam, Lutzville deep sand and Spruitdrift shallow sand controls, respectively. Leaf blade K was substantially higher at the Backsberg experiment plots where the in-field fractional use (augmentation) of winery wastewater with raw water was used for vineyard irrigation compared to the controls which had received no wastewater. Despite large amounts of application of K at Lutzville, the experiment plot had similar leaf blade K to the control. Despite no wastewater application at the Spruitdrift experiment plot during the 2019/20 season, the experiment plot had substantially higher leaf blade K compared to the control section.

Leaf blade Ca was 2.60%, 2.10%, 2.57%, 3.11%, 2.57% and 1.82% for the Backsberg sand, Backsberg clay, Madeba sandy loam, Madeba clay loam, Lutzville deep sand and Spruitdrift shallow sand controls, respectively. Leaf blade K of the all the experiment plots except the Spruitdrift one were higher compared to the controls. Leaf blade Mg was 0.43%, 0.39%, 0.36%, 0.47%, 0.45% and 0.47% for the Backsberg sand, Backsberg clay, Madeba sandy loam, Madeba clay loam, Lutzville deep sand and Spruitdrift shallow sand controls, respectively. Leaf blade Mg was still lower in the Backsberg experiment plots compared to the respective controls. The Madeba experiment plots had higher leaf blade Mg than the respective controls. Leaf blade Mg from the Lutzville deep sand experiment plot was higher compared to those from the control. Despite no wastewater application at the Spruitdrift experiment plot during the 2020/21 season, the experiment plot had substantially higher leaf blade Mg compared to the control. Leaf blade Na was 0.028%, 0.032%, 0.164%, 0.069%, 0.053% and 0.058% for the Backsberg sand, Backsberg clay, Madeba sandy loam, Madeba clay loam, Lutzville deep sand and Spruitdrift shallow sand controls, respectively. The Madeba clay loam experiment plot had higher leaf blade Na than the control.

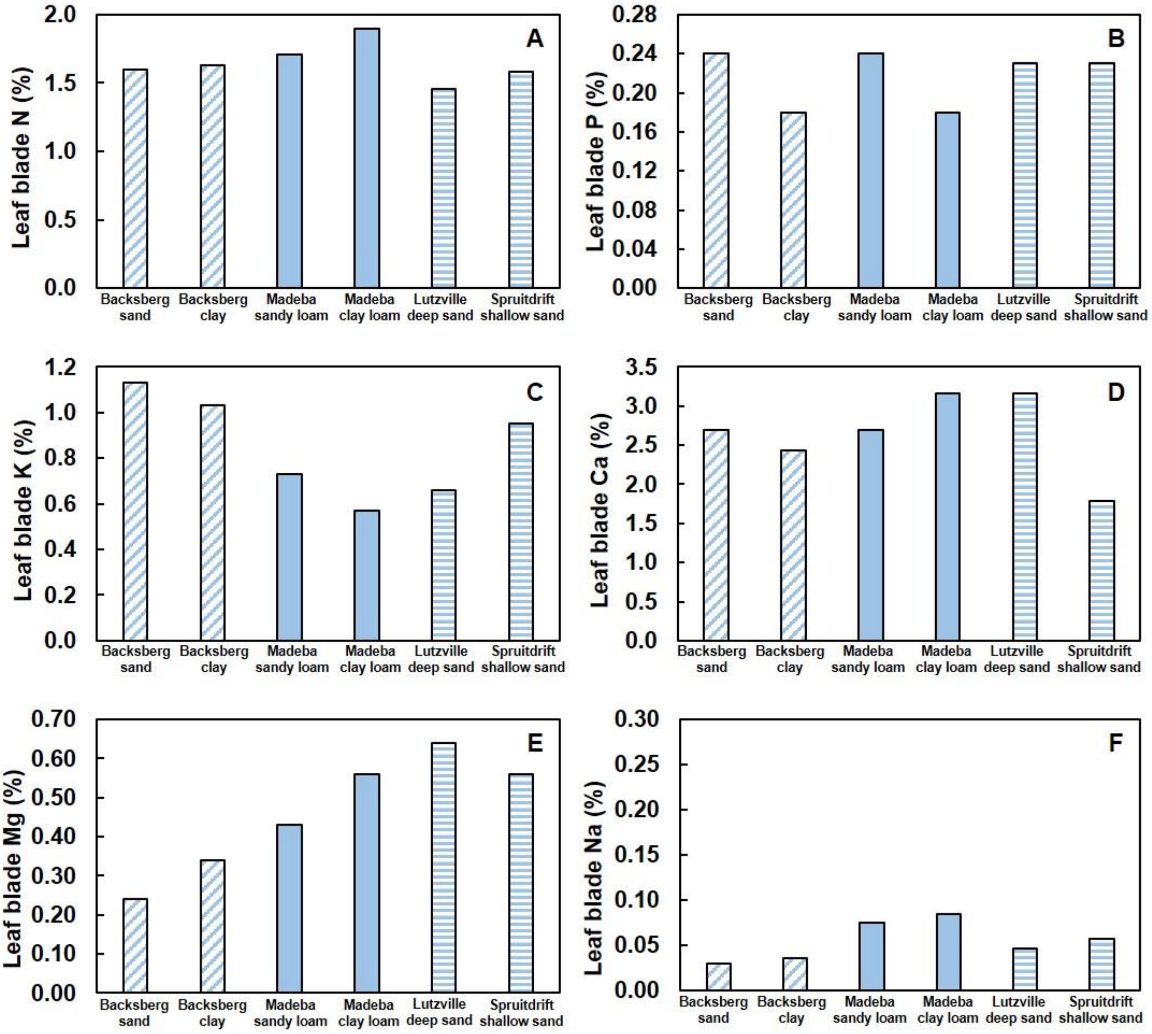

Figure 4.32. Variation in leaf blade element contents at harvest in the 2020/21 season where the in-field fractional use (augmentation) of winery wastewater with raw water was used to irrigate grapevines.

4.3.3.2. Grapevine shoot chemical status

2017/18 season: Grapevine shoot N levels of both of the Madeba, as well as the Spruitdrift shallow sand experiment plots (Fig. 4.33A) exceeded the recommended threshold value of 0.9% (Saayman, 1981 and references therein). Since no N was applied *via* the irrigation water at the experiment plots at Madeba (Refer to Chapter 2), the accumulation of N by these grapevines can't be related to the irrigation water. In contrast, high amounts of N applied *via* the irrigation water (Refer to Chapter 2), and poor vegetative growth (Fig. 4.28) at the Spruitdrift shallow sand experiment plot may have reduced N metabolization and subsequently resulted in higher shoot N accumulations at pruning. The shoot P contents of the grapevines at the Madeba clay loam and Lutzville deep sand experiment plots (Fig. 4.33B) were within the range of 0.05-0.15% recommended for grapevines (Saayman, 1981 and references therein). In contrast, the grapevine shoot P contents at all the other experiment plots were above this range (Fig. 4.33B). Shoot K contents (Fig. 4.33C) were within the range of 0.4-0.7% recommended for grapevine shoots (Saayman, 1981 and references therein).

Except for the grapevines at the Spruitdrift shallow sand experiment plot (Fig. 4.33D), shoot Ca contents at all the experiment plots were above the recommended range of 0.3-0.6% (Saayman, 1981 and references therein). However, the shoot Ca content of the grapevines at the Spruitdrift shallow sand experiment plot was within the recommended range. Grapevines in the Breede River and Lower Olifants River regions accumulated more Mg in their shoots compared to grapevines in the Coastal region (Fig. 4.33E). In fact, shoot Mg levels in grapevines of the former experiment plots exceeded the maximum concentration of 0.25% recommended for grapevine shoots at pruning (Saayman, 1981 and references therein). This may be a result of the higher amounts of Mg applied *via* the irrigation water at these experiment plots (Refer to Chapter 2).

Grapevine shoot Na levels of the experiment plots (Fig. 4.33F) were within the recommended range of 0.02-0.50% (Saayman, 1981). Therefore, irrigation using in-field fractionally applied winery wastewater with raw water for one season did not pose a sodicity risk to grapevines under the prevailing conditions. This agrees with previous results reported for Cabernet Sauvignon grapevines irrigated using winery wastewater diluted to 3 000 mg/L COD in the Breede River region (Myburgh & Howell, 2014b). In contrast, Mosse *et al*. (2013) observed a substantial increase in petiole Na levels of Shiraz grapevines irrigated using Na-based artificial winery wastewater.

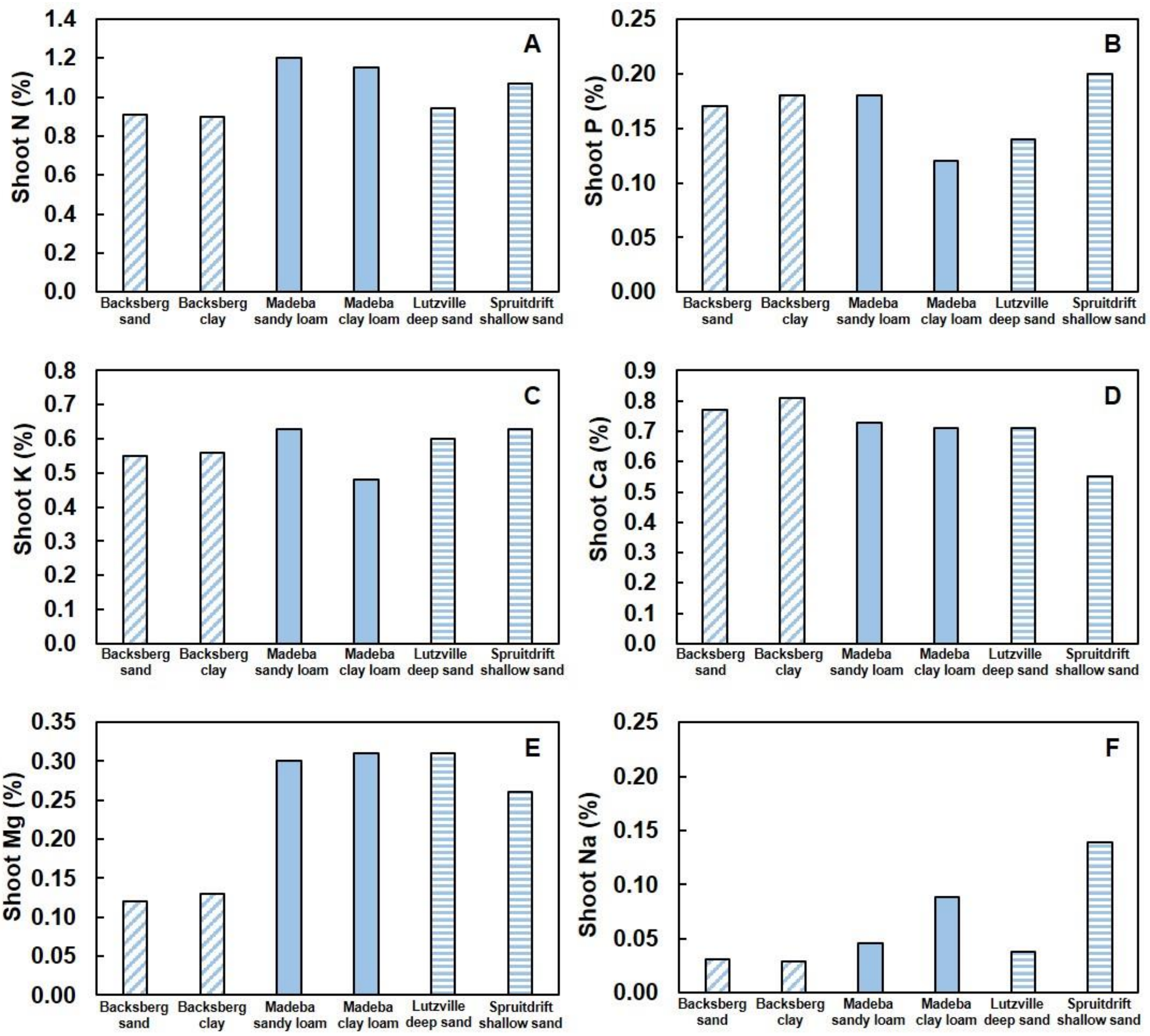

Figure 4.33. Variation in shoot element contents at pruning in the 2017/18 season where the in-field fractional use (augmentation) of winery wastewater with raw water was used to irrigate grapevines.

2018/19 season: With the exception of the Lutzville deep sand experiment plot, grapevine shoot N levels (Fig. 4.34A) exceeded the recommended threshold value of 0.9% (Saayman, 1981 and references therein). The shoot P contents (Fig. 4.34B) of the grapevines at all the experiment plots were within the range of 0.05-0.15% recommended for grapevines (Saayman, 1981 and references therein). Shoot Ca contents (Fig. 4.34D) at all the experiment plots were above the recommended range of 0.3-0.6% (Saayman, 1981 and references therein). Grapevines in the Breede River and Lower Olifants River regions accumulated more Mg in their shoots compared to grapevines in the Coastal region (Fig. 4.34E). In fact, shoot Mg levels in grapevines of most of the experiment plots exceeded the maximum concentration of 0.25% recommended for grapevine shoots at pruning (Saayman, 1981 and references therein). Grapevine shoot Na levels at the Spruitdrift experiment plot was substantially higher than at the other experiment plots (Fig. 4.34F).

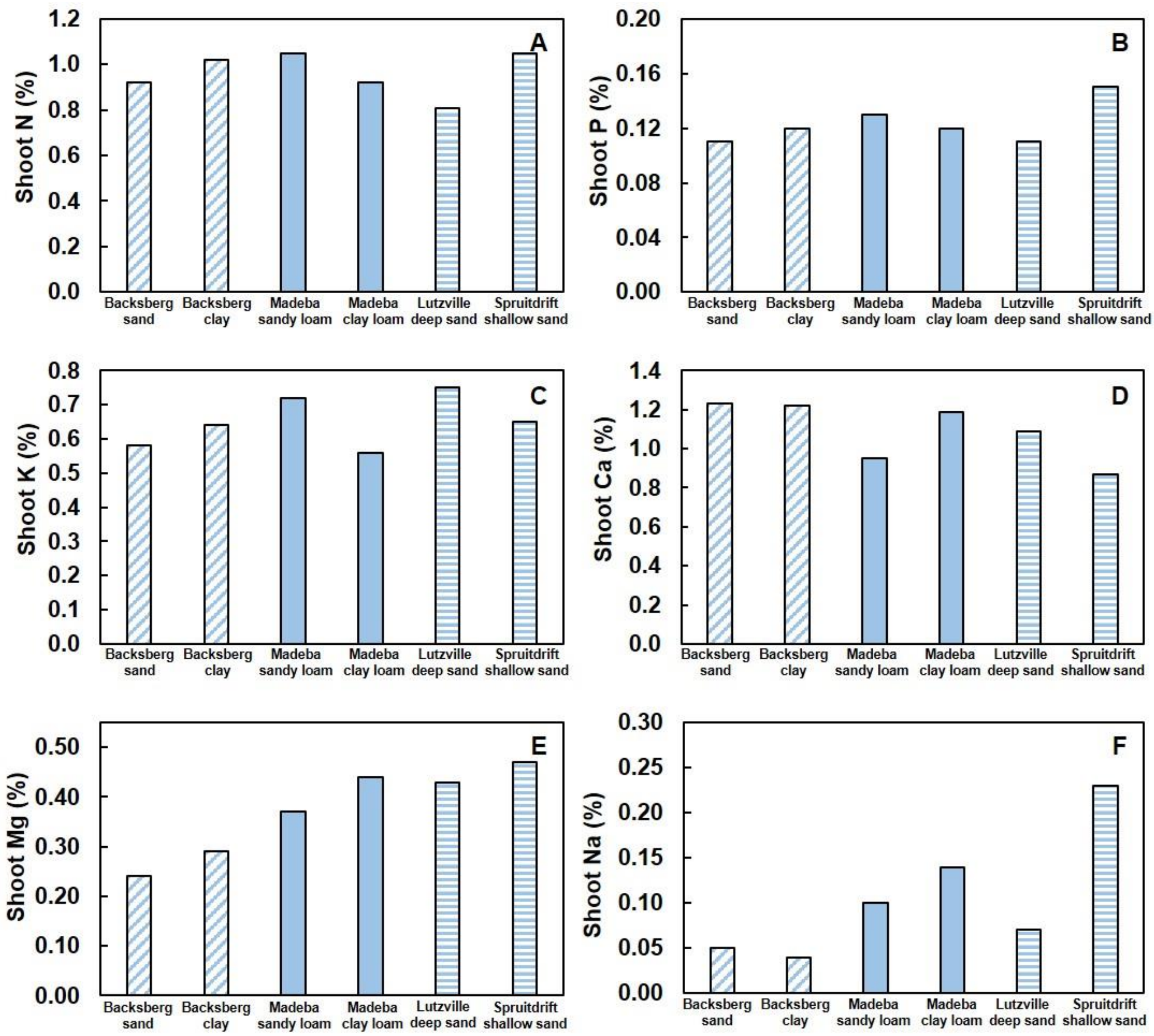

Figure 4.34. Variation in shoot element contents at pruning in the 2018/19 season where the in-field fractional use (augmentation) of winery wastewater with raw water was used to irrigate grapevines.

2019/20 season: With the exception of the Madeba clay loam experiment plot, most of the grapevine shoot N levels (Fig. 4.35A) were below the recommended threshold value of 0.9% (Saayman, 1981 and references therein). The shoot P contents of the grapevines were within the range of 0.05-0.15% recommended for grapevines (Saayman, 1981 and references therein). Shoot Ca contents (Fig. 4.35D) at most of the experiment plots were within the recommended range of 0.3-0.6% (Saayman, 1981 and references therein). Grapevines in the Breede River and Lower Olifants River regions accumulated more Mg in their shoots compared to grapevines in the Coastal region (Fig. 4.35E). However, shoot Mg levels in grapevines of most of the experiment plots were below the maximum concentration of 0.25% recommended for grapevine shoots at pruning (Saayman, 1981 and references therein). Grapevine shoot Na levels at the Spruitdrift shallow sand experiment plot was still substantially higher than at the other experiment plots despite no wastewater being applied at this particular experiment plot in the 2019/20 season (Fig. 4.35F).

Shoot N levels were 0.60%, 0.66%, 0.83%, 0.82%, 0.56% and 0.66% for the Backsberg sand, Backsberg clay, Madeba sandy loam, Madeba clay loam, Lutzville deep sand and Spruitdrift shallow sand controls, respectively. Shoot N levels were higher at the Madeba clay loam experiment plot compared to the control. Shoot P levels were 0.13%, 0.11%, 0.18%, 0.17%, 0.12% and 0.13% for the Backsberg sand, Backsberg clay, Madeba sandy loam, Madeba clay loam, Lutzville deep sand and Spruitdrift shallow sand controls, respectively. Despite no wastewater application at the Spruitdrift experiment plot during the 2019/20 season, the experiment plot had higher shoot P levels compared to the control. Shoot K levels were 0.53%, 0.52%, 0.52%, 0.63%, 0.58% and 0.51% for the Backsberg sand, Backsberg clay, Madeba sandy loam, Madeba clay loam, Lutzville deep sand and Spruitdrift shallow sand controls, respectively. With the exception of the Madeba clay loam experiment plot, shoot K levels were higher at experiment plots where the in-field fractional use (augmentation) of winery wastewater with raw water was used for vineyard irrigation compared to the control which had received no wastewater. Shoot Ca levels were 0.70%, 0.63%, 0.63%, 0.58%, 0.48% and 0.46% for the Backsberg sand, Backsberg clay, Madeba sandy loam, Madeba clay loam, Lutzville deep sand and Spruitdrift shallow sand controls, respectively. Shoot Ca of the Backsberg sand experiment plot was higher compared to the control. Shoot Mg levels were 0.18%, 0.20%, 0.24%, 0.25%, 0.25% and 0.20% for the Backsberg sand, Backsberg clay, Madeba sandy loam, Madeba clay loam, Lutzville deep sand and Spruitdrift shallow sand controls, respectively. Shoot Mg levels were lower in the Backsberg experiment plots compared to the respective controls. The Madeba clay loam experiment plot had higher leaf blade Mg than the control. Despite no wastewater application at the Spruitdrift shallow sand experiment plot during the 2019/20 season, the experiment plot had higher shoot Mg levels compared to the control. Shoot Na levels were 0.028%, 0.024%, 0.054%, 0.033%, 0.033% and 0.032% for the Backsberg sand, Backsberg clay, Madeba sandy loam, Madeba clay loam, Lutzville deep sand and Spruitdrift shallow sand controls, respectively. The Madeba clay loam experiment plot had higher shoot Na levels than the control. Despite no wastewater application at the Spruitdrift shallow sand experiment plot during the 2019/20 season, the experiment plot had higher shoot Na levels compared to the control section.

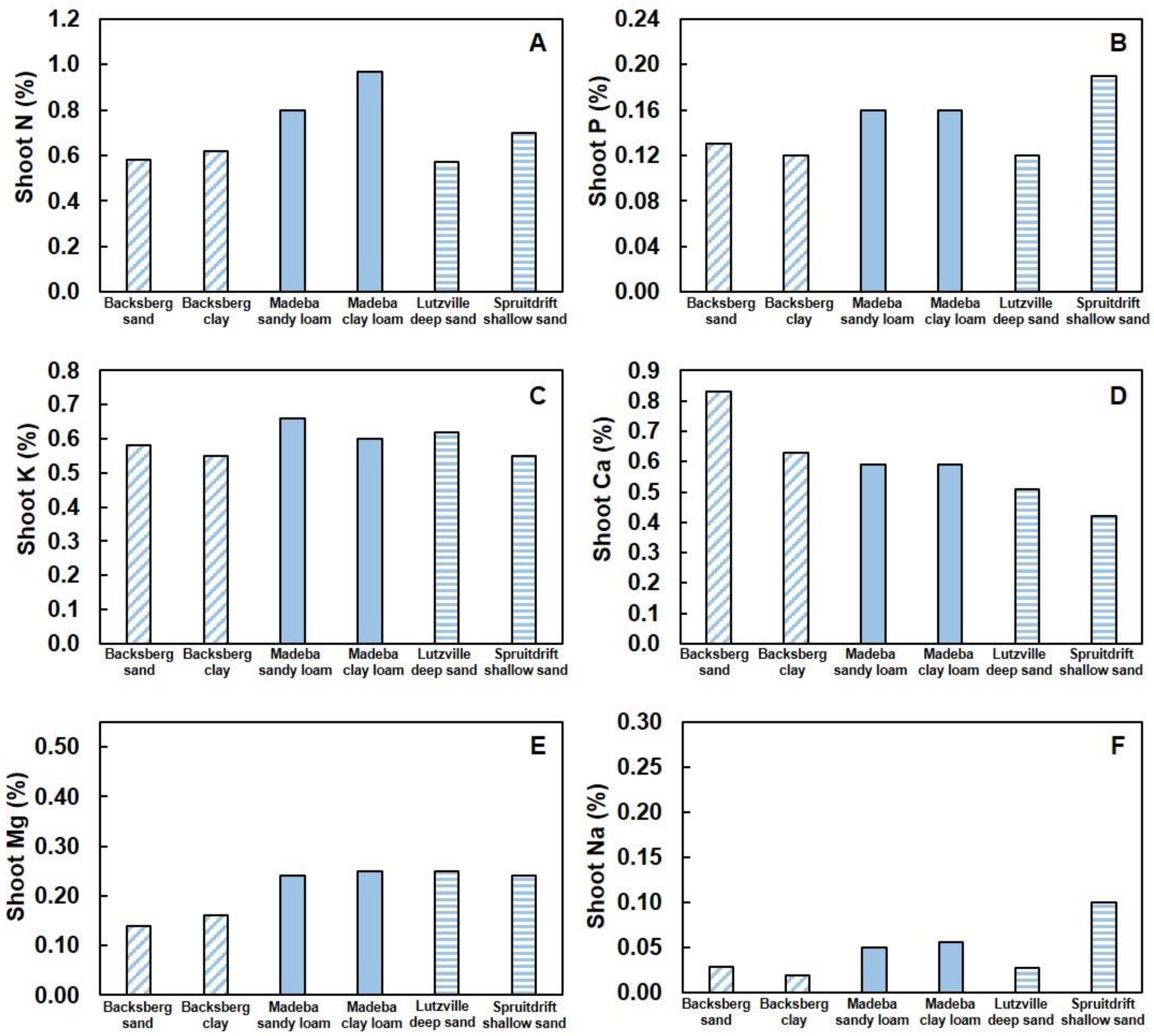

Figure 4.35. Variation in shoot element contents at pruning in the 2019/20 season where the in-field fractional use (augmentation) of winery wastewater with raw water was used to irrigate grapevines.

2020/21 season: With the exception of the Madeba experiment plots, the grapevine shoot N levels (Fig. 4.36A) were below the recommended threshold value of 0.9% (Saayman, 1981 and references therein). The shoot P contents of the grapevines (Fig. 4.36B) were within the range of 0.05-0.15% recommended for grapevines (Saayman, 1981 and references therein). Shoot Ca contents (Fig. 4.36D) of all the experiment plots were within the recommended range of 0.3-0.6% (Saayman, 1981 and references therein). Grapevines in the Breede River and Lower Olifants River regions accumulated more Mg in their shoots compared to grapevines in the Coastal region (Fig. 4.36E). However, shoot Mg levels in grapevines of most of the experiment plots were below the maximum concentration of 0.25% recommended for grapevine shoots at pruning (Saayman, 1981 and references therein).

Shoot N levels were 0.64%, 0.75%, 1.02%, 0.94%, 0.62% and 0.81% for the Backsberg sand, Backsberg clay, Madeba sandy loam, Madeba clay loam, Lutzville deep sand and Spruitdrift shallow sand controls, respectively. Shoot N levels were higher at the Madeba clay loam experiment plot compared to the control. Shoot P levels were 0.09%, 0.11%, 0.16%, 0.14%, 0.11% and 0.14% for the Backsberg sand, Backsberg clay, Madeba sandy loam, Madeba clay loam, Lutzville deep sand and Spruitdrift shallow sand controls, respectively. The experiment plots had higher shoot P levels compared to the controls. Shoot K levels were 0.36%, 0.53%, 0.50%, 0.65%, 0.53% and 0.54% for the Backsberg sand, Backsberg clay, Madeba sandy loam, Madeba clay loam, Lutzville deep sand and Spruitdrift shallow sand controls, respectively. With the exception of the Madeba clay loam experiment plot, shoot K levels were similar or higher at the experiment plots where the in-field fractional use (augmentation) of winery wastewater with raw water was used for vineyard irrigation compared to the control that had received no wastewater. Shoot Ca levels were 0.43%, 0.46%, 0.49%, 0.56%, 0.48% and 0.43% for the Backsberg sand, Backsberg clay, Madeba sandy loam, Madeba clay loam, Lutzville deep sand and Spruitdrift shallow sand controls, respectively. Shoot Ca of the Backsberg sand experiment plot was higher compared to the control. Shoot Mg levels were 0.14%, 0.15%, 0.21%, 0.21%, 0.20% and 0.17% for the Backsberg sand, Backsberg clay, Madeba sandy loam, Madeba clay loam, Lutzville deep sand and Spruitdrift shallow sand controls, respectively. Shoot Mg levels were lower in the Backsberg experiment plots compared to the respective controls. The Madeba clay loam experiment plot had higher leaf blade Mg than the control. Shoot Na levels were 0.056%, 0.042%, 0.077%, 0.055%, 0.045% and 0.068% for the Backsberg sand, Backsberg clay, Madeba sandy loam, Madeba clay loam, Lutzville deep sand and Spruitdrift shallow sand controls, respectively. The Madeba clay loam experiment plot had higher shoot Na levels than the control.

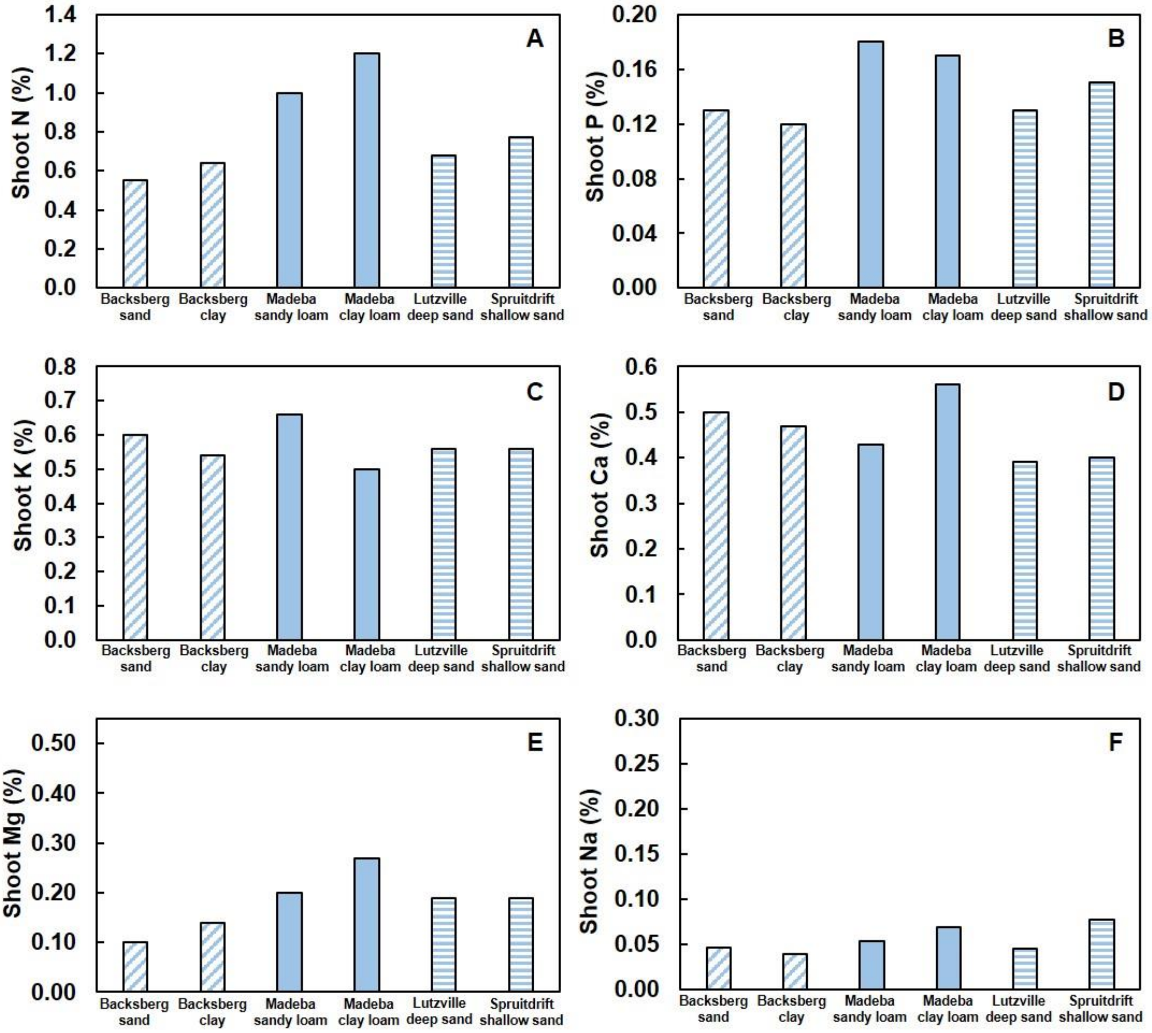

Figure 4.36. Variation in shoot element contents at pruning in the 2020/21 season where the in-field fractional use (augmentation) of winery wastewater with raw water was used to irrigate grapevines.

4.3.3.3. Grapevine permanent wood chemical status

The grapevine permanent wood element contents are given in Figure 4.37. Levels of N and K in the permanent wood was similar for all the experiment plots. Grapevines in the Breede River region accumulated more Mg in their permanent wood compared to grapevines in the Coastal region or Lower Olifants River region (Fig. 4.37E).

Permanent wood N levels were 0.59%, 0.47%, 0.49%, 0.58%, 0.66% and 0.50% for the Backsberg sand, Backsberg clay, Madeba sandy loam, Madeba clay loam, Lutzville deep sand and Spruitdrift shallow sand controls, respectively. Permanent wood N levels were higher at the Backsberg clay, Madeba sand and Spruitdrift shallow sand experiment plots compared to the respective controls. Permanent wood P levels were 0.13%, 0.10%, 0.08%, 0.08%, 0.07% and 0.09% for the Backsberg sand, Backsberg clay, Madeba sandy loam, Madeba clay loam, Lutzville deep sand and Spruitdrift shallow sand controls, respectively. The Madeba sandy loam, Lutzville deep sand and Spruitdrift shallow sand experiment plots had higher permanent wood P levels compared to the control sections. Permanent wood K levels were 0.48%, 0.37%, 0.34%, 0.34%, 0.31% and 0.42% for the Backsberg sand, Backsberg clay, Madeba sandy loam, Madeba clay loam, Lutzville deep sand and Spruitdrift shallow sand controls, respectively. With the exception of the Backsberg sand experiment plot, permanent wood K levels were similar or higher at the experiment plots where the in-field fractional use (augmentation) of winery wastewater with raw water was used for vineyard irrigation compared to the control that had received no wastewater. Permanent wood Ca levels were 0.68%, 0.44%, 0.66%, 0.69%, 0.81% and 0.65% for the Backsberg sand, Backsberg clay, Madeba sandy loam, Madeba clay loam, Lutzville deep sand and Spruitdrift shallow sand controls, respectively. Permanent wood Ca of the Backsberg clay experiment plot was higher compared to the control. Permanent wood Mg levels were 0.23%, 0.17%, 0.21%, 0.14%, 0.15% and 0.23% for the Backsberg sand, Backsberg clay, Madeba sandy loam, Madeba clay loam, Lutzville deep sand and Spruitdrift shallow sand controls, respectively. Permanent wood Mg levels were lower in the Backsberg experiment plots compared to the respective controls. The Madeba clay loam experiment plot had substantially higher permanent wood Mg than the control. Permanent wood Na levels were 0.087%, 0.068%, 0.055%, 0.016%, 0.021% and 0.069% for the Backsberg sand, Backsberg clay, Madeba sandy loam, Madeba clay loam, Lutzville deep sand and Spruitdrift shallow sand controls, respectively. The Madeba clay loam experiment plot had substantially higher permanent wood Na levels compared to the control.

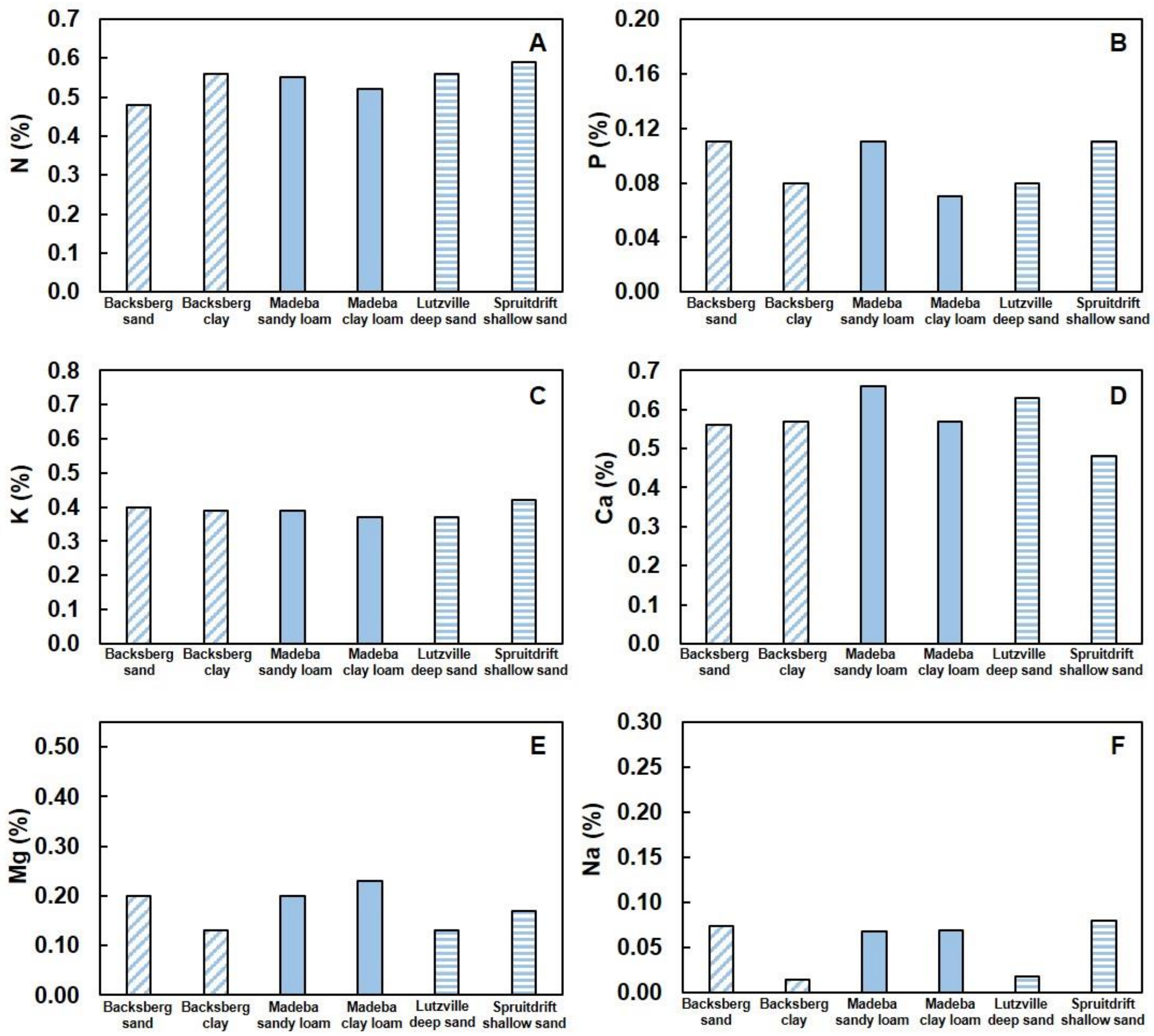

Figure 4.37. Variation in permanent wood element contents at pruning in the 2020/21 season where the in-field fractional use (augmentation) of winery wastewater with raw water was used to irrigate grapevines.

4.3.4. Yield components

Bunches per grapevine: In the 2017/18 season, fertility ranged from 14 to 55 bunches per grapevine at the Spruitdrift shallow sand experiment plot and the clay loam experiment plot at Madeba (Fig. 4.38A), respectively. The low fertility at the Spruitdrift shallow sand experiment plot was probably caused by unfavourable atmospheric conditions during bunch initiation in the preceding year. In the 2018/19 season, fertility ranged from 2 to 55 bunches per grapevine at the Spruitdrift shallow sand and Lutzville deep sand experiment plots (Fig. 4.38A), respectively. The low fertility at the Spruitdrift shallow sand experiment plot was probably caused by unfavourable atmospheric conditions during bunch initiation in the preceding year as well as saline soil conditions during winter. At three of the experiment plots, the number of bunches was substantially lower at harvest in 2018 compared to harvest at 2019 (Fig. 4.38A). In the 2019/20 season, fertility amounted to 21 to 54 bunches per grapevine at the Backsberg sand, Madeba clay loam and Lutzville deep sand experiment plots, respectively (Fig. 4.38A).

The number of bunches was substantially lower at harvest in 2020 compared to harvest at 2018 and 2019 for the Madeba clay loam experiment plot (Fig. 4.38A). In the 2020/21 season, fertility amounted to 21 to 68 bunches per grapevine at the Spruitdrift shallow sand and Lutzville deep sand experiment plots, respectively (Fig. 4.38A).

Berry mass: In the 2017/18 season, berry size ranged from 0.65 g to 1.81 g per berry (Fig. 4.38B). In the 2018/19 season, berry mass ranged from 0.93 g to 1.40 g per berry. With the exception of the Spruitdrift shallow sand experiment plot, the berry mass was lower at harvest in the 2018/19 season compared to the 2017/18 season. In the 2019/20 season, berry mass ranged from 0.94 g to 1.52 g per berry. With the exception of the Spruitdrift shallow sand experiment plot, the berry mass was lower at harvest in the 2018/19 and 2019/20 seasons compared to the 2017/18 season. Berry mass ranged from 1.33 g to 1.97 g per berry in the 2020/21 season (Fig. 4.38B). Although Mosse *et al.* (2013) observed some differences in berry weight at harvest where different artificial winery wastewaters were used for vineyard irrigation, these differences were very small and no conclusions could be made. Similarly, the use of undiluted winery wastewater for vineyard irrigation at Oxford Landing had no detrimental effect on berry size (Kumar *et al.*, 2014). In contrast, in a similar study at Angaston by the same researchers, the use of undiluted winery wastewater for vineyard irrigation consistently reduced berry weight substantially. It could be that the quality of the winery wastewater differed between the two sites. Mean berry mass at harvest of 1.2 g/berry and 1.5 g/berry is comparable to values for drip irrigated Cabernet Sauvignon in the Breede River valley (Roux, 2005). Where Cabernet is subjected to severe water constraints, *i.e.* Ψ_L below 1.6 MPa, berry mass is expected to be *c.* 1 g/berry (Bruwer, 2010; Mehmel, 2010). In the case of Shiraz, mean berry mass at harvest of 1.2-1.4 g/berry is comparable to values for drip irrigated Shiraz in the Breede River valley (Lategan & Howell, 2016).

Bunch mass: In the 2017/18 season, lower berry mass reported in Figure 4.38B reflected in substantially smaller bunches and lower yield for the shallow sand experiment plot at Spruitdrift compared to the other experiment plots. The lower berry mass in the 2018/19 season (Fig. 4.38C) also reflected in substantially smaller bunches for all the experiment plots. Bunches at Madeba sandy loam and clay loam experiment plot were smaller in the 2019/20 season compared to the 2017/18 and 2018/19 seasons (Fig. 4.38C) but bunches at the Lutzville deep sand experiment plot were bigger in the 2019/20 season compared to the 2018/19 season. Bunches at all experiment plots were bigger at all the experiment plots in the 2020/21 season compared to the other seasons (Fig. 4.38C).

Yield: In the 2017/18 season, grapes were harvested on 14 February 2018 at the Spruitdrift shallow sand experiment plot, and on 27 February 2018 at the Lutzville deep sand experiment plot. Given that the sugar content of the grapes at Madeba was at the optimal stage for winemaking, grapes for winemaking were harvested on 6 March 2018. The rest of the grapes were harvested on 20 March 2018 to obtain the yield masses. The low yield measured at the Spruitdrift shallow sand experiment plot was most likely due to the prevailing drought in the region. It has been speculated that the Spruitdrift winery lost almost 50% of their grapes in this particular season. In the 2018/19 season, grapes were harvested on 14 February 2019 at the Spruitdrift shallow sand experiment plot, 6 March 2019 at Madeba and on 7 March 2019 at the Lutzville deep sand experiment plot. Yield at all the experiment plots was substantially lower in the 2018/19 season compared to the 2017/18 one (Fig. 4.38D). The yield was so low at Spruitdrift that not enough grapes could be harvested to make experimental wine. The extremely low yield measured at the Spruitdrift shallow sand experiment plot was most likely due to the prevailing drought in the region as well as the excessive amounts of elements applied *via* the irrigation (Refer to Chapter 2). Given the low levels of rainfall in the region, excessive salts applied were also not leached from the soil during the winter period. In the 2019/20 season, grapes were harvested on 14 February 2020 at the Spruitdrift shallow sand experiment plot, 25 February 2020 at Backsberg, 28 February 2020 at Madeba and on 4 March 2019 at the Lutzville deep sand experiment plot, respectively. Yield at the Spruitdrift and Lutzville experiment plots was higher in the 2019/20 season compared to the 2018/19 season (Fig. 4.38D). It was evident in this season that the yield at the Madeba experiment plots was becoming progressively lower. Grapes were harvested on 3 March 2021 at the Spruitdrift shallow sand experiment plot, 4 March 2021 at the Backsberg sand experiment plot, 9 March 2021 at Madeba and on 11 March 2021 at the Lutzville deep sand experiment plot, respectively. Unfortunately the Backsberg clay experiment plot was harvested by the farm. Yield at all of the experiment plots was higher in the 2020/21 season compared to the 2019/20 season (Fig. 4.38D).

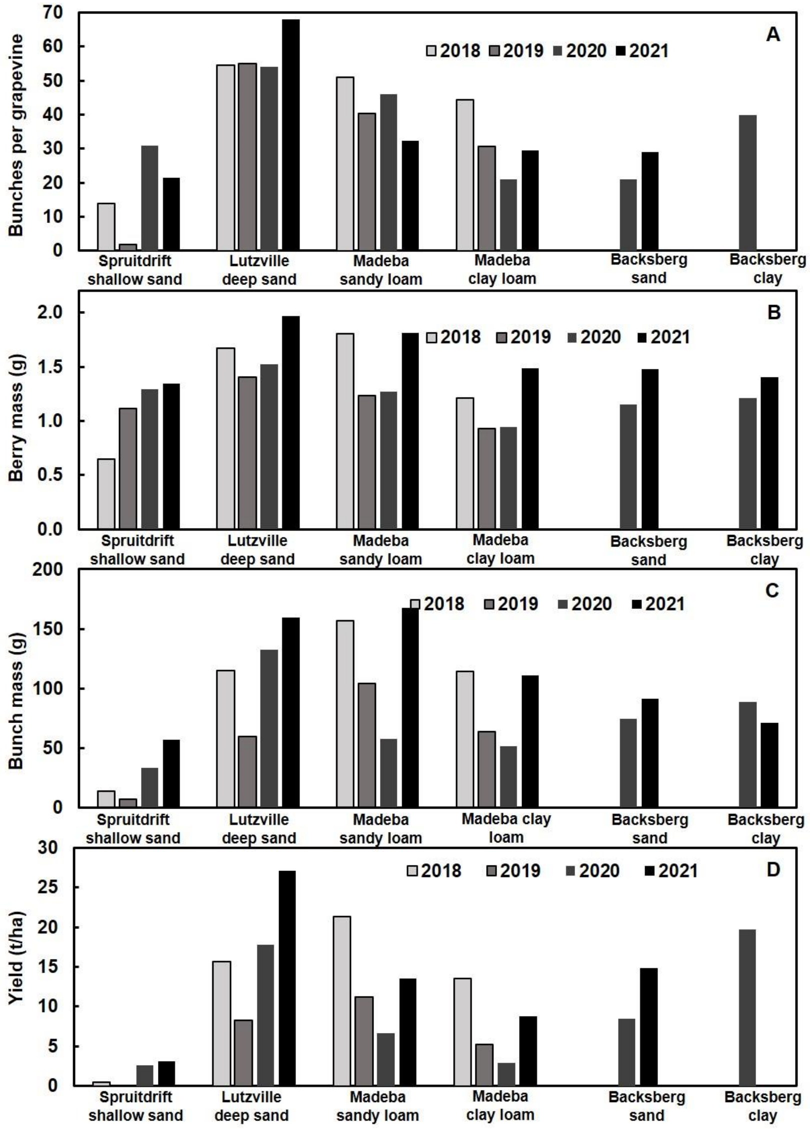

Fig. 4.38. Effect of in-field fractional use of winery wastewater with raw water on (A) bunches per grapevine, (B) berry mass, (C) bunch mass and (D) yield of Shiraz and Cabernet Sauvignon at harvest in 2018, 2019, 2020 and 2021.

Comparison of the experiment plots and the respective controls: In the 2018/19 season, the lower berry mass and bunch mass of the experiment plots reflected in substantially lower yield for the experiment plot compared to the control (Fig. 4.39).

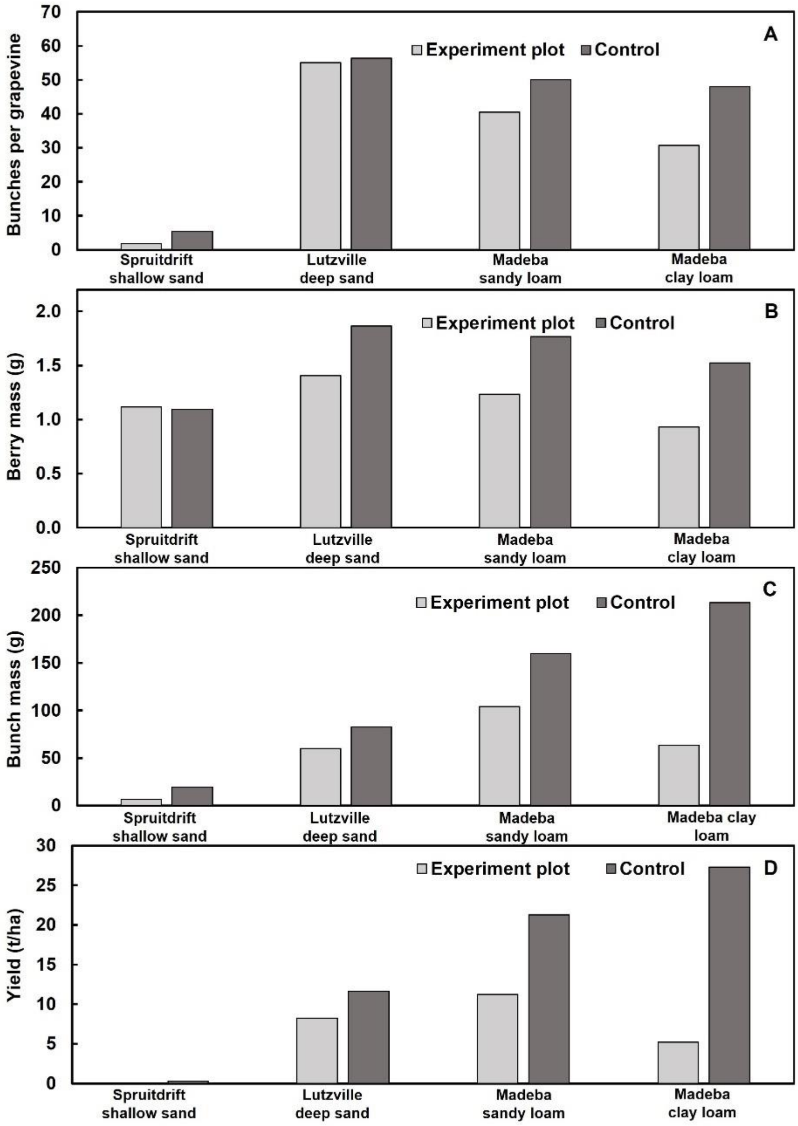

Fig. 4.39. Effect of in-field fractional use of winery wastewater with raw water on (A) bunches per grapevine, (B) berry mass, (C) bunch mass and (D) yield of Shiraz and Cabernet Sauvignon at harvest in 2019.

In the 2019/20 season, the higher berry mass and bunch mass of some of the experiment plots reflected in higher yields for some of the experiment plots compared to the respective controls (Fig. 4.40). The yield at the Spruitdrift shallow sand experiment plot was still substantially lower compared to the control section. Substantially more yield was obtained for the Lutzville deep sand experiment plot compared to the control. Results confirmed visual observations from the producer at Lutzville who indicated to the project team that the experiment section looked much better than the rest of the vineyard which represented the control. The yield of the Madeba clay loam experiment plot was substantially lower compared to the control.

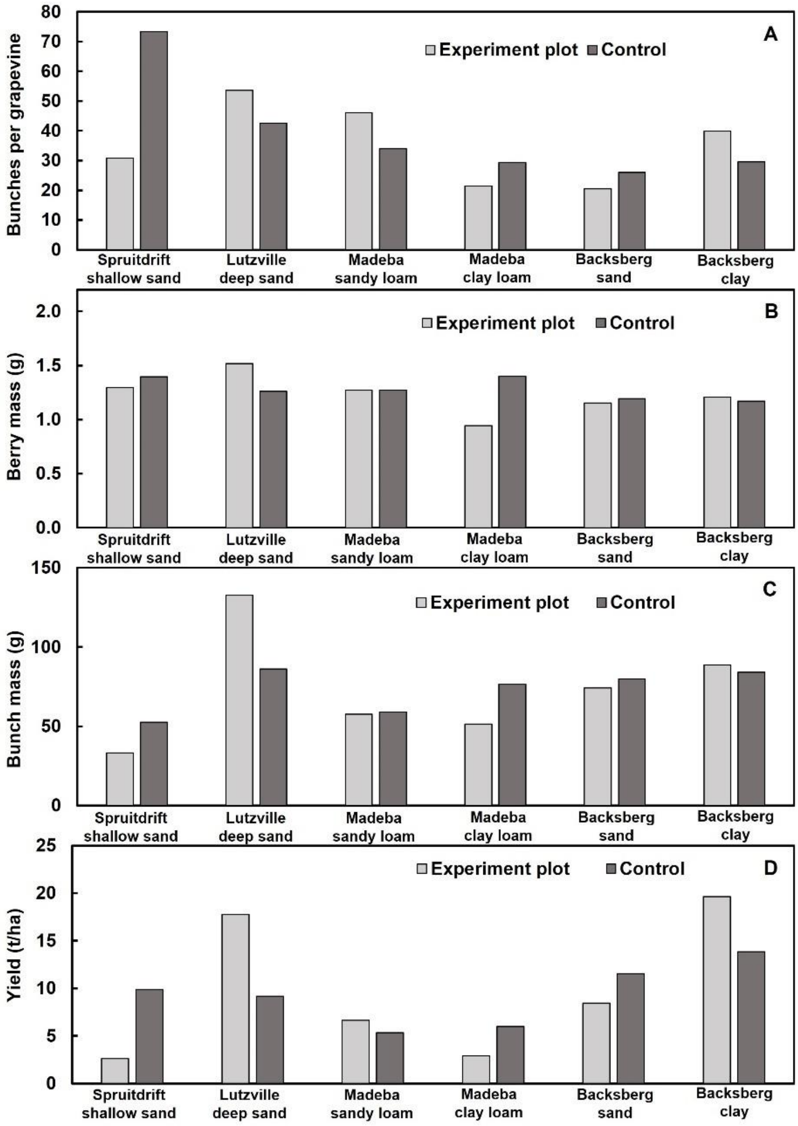

Fig. 4.40. Effect of in-field fractional use of winery wastewater with raw water on (A) bunches per grapevine, (B) berry mass, (C) bunch mass and (D) yield of Shiraz and Cabernet Sauvignon at harvest in 2020.

In the 2020/21 season, the higher berry mass and bunch mass of some of the experiment plots reflected in higher yields for some of the experiment plots compared to their respective controls (Fig. 4.41). The yield at the Spruitdrift shallow sand experiment plot was similar to the control which 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. Substantially more yield was still obtained for the Lutzville deep sand experiment plot compared to the control. The yield of the Madeba clay loam experiment plot was still substantially lower compared to the control.

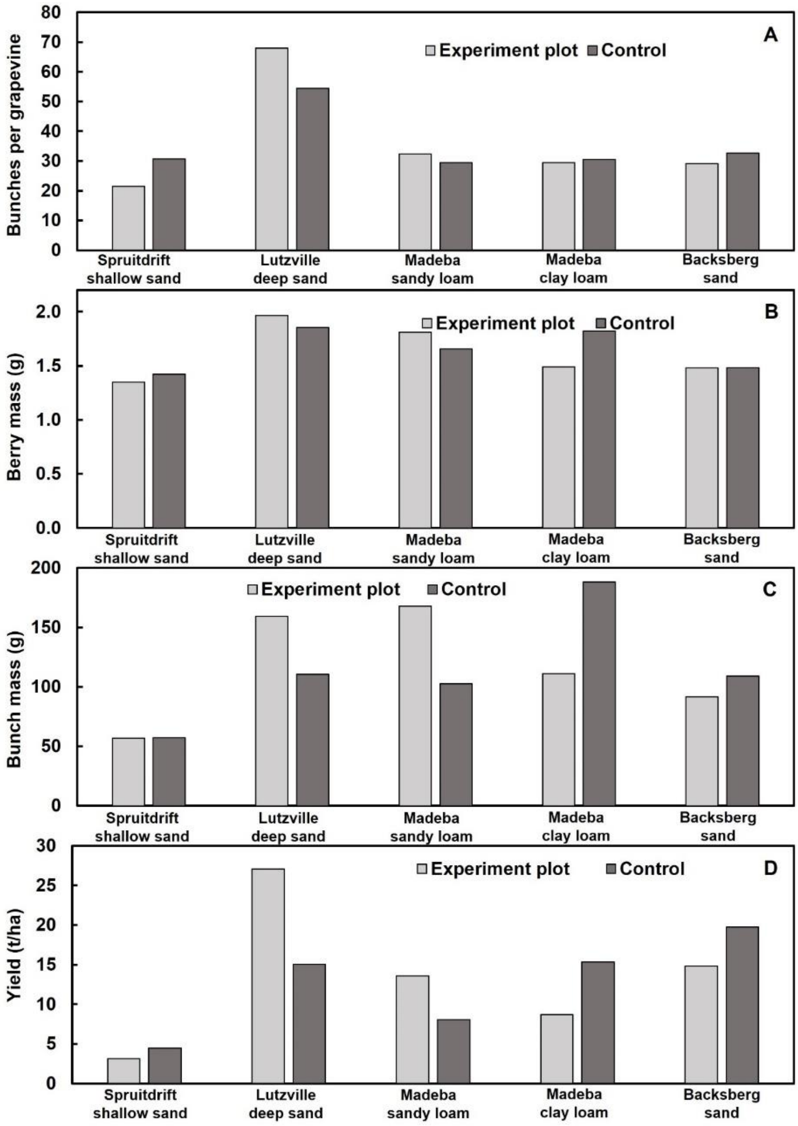

Fig. 4.41. Effect of in-field fractional use of winery wastewater with raw water on (A) bunches per grapevine, (B) berry mass, (C) bunch mass and (D) yield of Shiraz and Cabernet Sauvignon at harvest in 2021.

4.4. CONCLUSIONS

Despite the high amounts of K applied *via* the in-field fractional use (augmentation), the experiment 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 also had higher leaf blade Na than the control. This suggested that under the prevailing conditions at that 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 part of this particular experiment plot, 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 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 Spruitdrift, *i.e.* lower mean annual rainfall and shallow sand, yield was so low 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 Spruitdrift winery was most likely due to the very low rainfall in the region due to drought as well as the excessive amounts 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 them compared to the respective controls. Results indicated that the grapevines at the Spruitdrift experiment plot had recovered to a certain extent after receiving only 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.

CHAPTER 5: EFFECT OF IN-FIELD FRACTIONAL USE (AUGMENTATION) OF WINERY WASTEWATER WITH RAW WATER ON JUICE AND WINE CHARACTERISTICS

5.1. INTRODUCTION

Although there is extensive literature available regarding the irrigation of grapevines with saline water very little is known about the effects of re-using winery wastewater on juice and wine quality characteristics. Winery wastewater contains high numbers of microorganisms, ranging from 105 to 108 colony forming units per millilitre (Jourjon *et al*., 2005). Dominant yeast species are *Saccharomyces cerevisiae*, *Candida intermedia, Hanseniaspora uvarum* and *Pichia membranaefaciens* (Malandra *et al.,* 2003). Winery wastewater also contains high lactic acid bacteria and acetic acid bacteria populations (Jourjon *et al*., 2005). Consequently, if contact is made between winery wastewater and grapes during irrigation, some microbes could survive on grape berries and end up in grape must and wine. If certain unfavourable microbes are transferred from the wastewater into the juice and wine, wine composition and quality may be negatively affected. Winery wastewater has a foul smell due to the conversion of organic compounds to, among others, methane under anaerobic conditions (McCarty, 1964). If these off-odours are transferred onto or into berries and the resulting wines, it may result in tainted wines.

If winery wastewater irrigation is applied, for example through overhead irrigation, contact between irrigation water and bunches is inevitable. Grapevines exposed to smoke between véraison and harvest caused a 'smoke taint' in the resulting wines (Kennison *et al.*, 2009). Likewise, wines made from grapevines which are situated nearby *Eucalyptus* tree plantations, has been found to obtain higher *Eucalyptus*-like or minty characters, which may be obtained from the trees (Novak, 2002; Van Leeuwen *et al*., 2007). If these odours are transferred from the atmosphere onto or into grapes and the resulting wines, the sharp, foul odour of winery wastewater may quite possibly be transferred onto or into grapes and wine if direct contact is made between wastewater and berries. In a study where bunches were deliberately sprayed with diluted winery wastewater, a winery wastewater-like odour was detected in the wines, and their spicy character reduced (Schoeman, 2012). This research highlights the importance of avoiding contact between grapes and winery wastewater.

Where Shiraz grapevines were irrigated with sewage water, there were also no differences with regard to wine quality (McCarthy & Downton, 1981). Likewise, although there were slight differences with regard to wine colour and tannin content where winery wastewater was used for vineyard irrigation, there were no differences in the sensorial evaluation of the wines (Kumar *et al.*, 2014). Irrigation of grapevines using diluted winery wastewater did not have detrimental effects on juice characteristics with regards to ripeness parameters, ion content as well as wine sensorial quality (Myburgh & Howell, 2014). Hirzil *et al.* (2017) reported that where winery wastewater was used for irrigation of two vineyards in California, there was no difference in wines from a control and where grapevines were irrigated with winery wastewater.

If winery wastewater could be used to irrigate vineyards, with no detrimental impacts on either juice and wine characteristics, it could be a possible viable alternative to using raw river or municipal water. Therefore, the objective of this study was to determine the effect of irrigation with in-field fractional use (augmentation) of winery wastewater with raw water on juice and wine characteristics. In addition to this, guidelines as to what limits of quality criteria, *e.g.* level of COD, EC or SAR, for the in-field fractional use (augmentation) of winery wastewater with raw water would allow reuse with no negative consequences on juice and wine characteristics.

5.2. MATERIALS AND METHODS

5.2.1. Juice characteristics

Grape samples were collected at harvest from all experiment plots, and analysed for TSS, total titratable acidity (TTA) and pH according to standard procedures at the AGRI-Food Analytics Laboratory, Infruitec-Nietvoorbji Institute of the Agricultural Research Council (ARC) near Stellenbosch. Juice was obtained by gently crushing berries sampled at harvest and the resultant juice squeezed through cheese cloth. To determine juice P, K, Ca, Mg and Na, juice samples were analysed by a commercial laboratory according to methods described previously (Myburgh & Howell, 2014). Each of the vineyards had an experiment plot that was irrigated with winery wastewater and this was compared to the rest of the surrounding vineyard block which acted as the control in the 2019/20 and 2020/21 seasons.

5.2.2. Wine characteristics

Grapes were harvested when they reached the target sugar content of 24°B. Wines were made from the grapes (*c.* 40 kg) of each experiment plot according to the standard procedure for making red wine used by the experimental winery at ARC Infruitec-Nietvoorbij. After seven months, the wines were evaluated sensorially by a panel of at least 12 industry experts. Wines were evaluated on an unmarked line scale of 100 mm for wine colour, overall intensity, vegetative character, berry character, spicy character, acidity, body, astringency and overall quality. The panel was also asked to give an indication of the occurrence of off-flavours (off-odours and off-tastes) and any other atypical red wine characteristics. The wines were analysed for standard chemical parameters using the Alpha II FT-IR Wine Analyser (Bruker, Germany) at the AGRI-Food Analytics Laboratory, Infruitec-Nietvoorbji Institute of the Agricultural Research Council (ARC) near Stellenbosch.

5.3. RESULTS AND DISCUSSION

5.3.1. Juice characteristics

Grapes were harvested as close as possible to 24°B as logistically possible (Fig. 5.1A). In the 2017/18 season, juice TTA was similar for the Madeba sandy loam, Lutzville deep sand and Spruitdrift shallow sand experiment plots (Fig. 5.1B). Juice TTA was lower at Madeba clay loam. This was most likely due to higher TSS. Juice pH was similar for all the experiment plots (Fig. 5.1C).

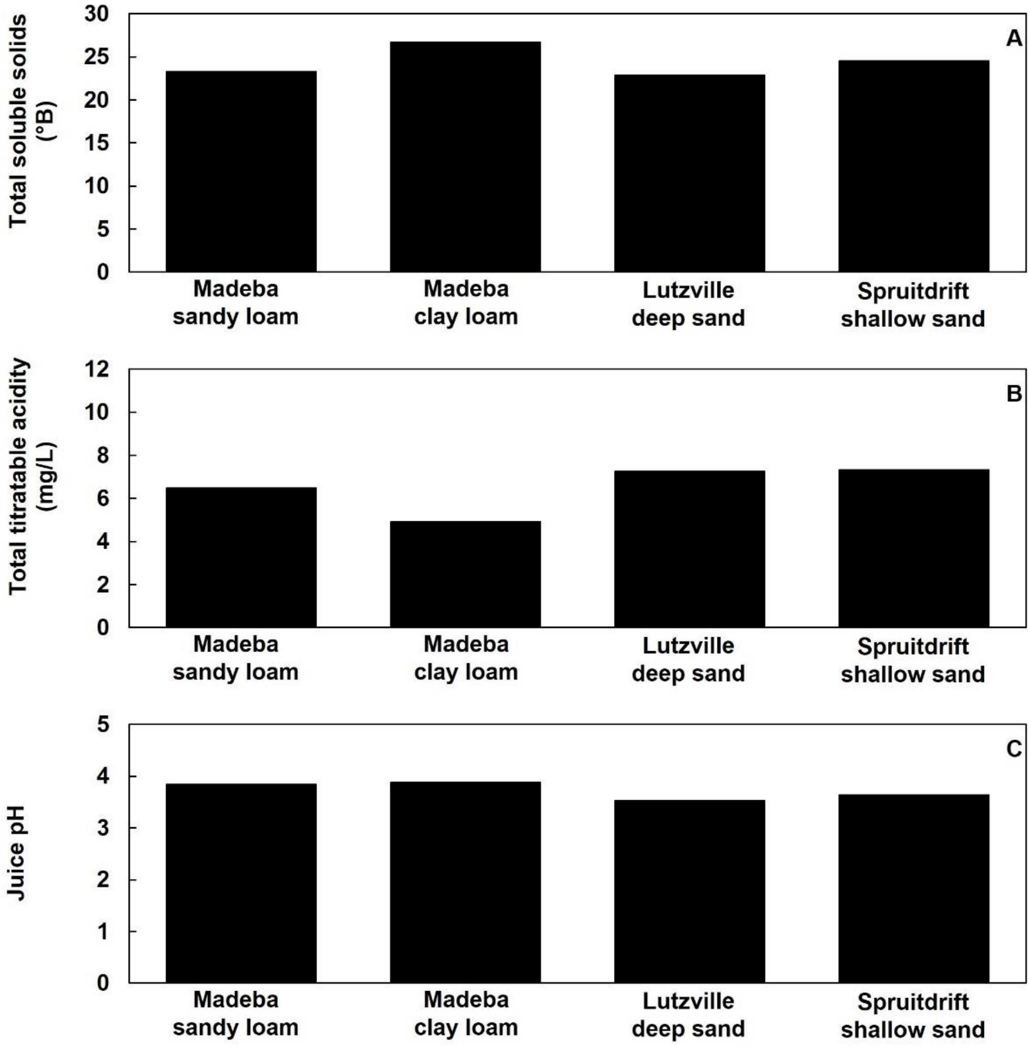

Figure 5.1. Variation in total soluble solids, titratable acidity and juice pH at harvest in the 2017/18 season where the in-field fractional use (augmentation) of winery wastewater with raw water was used to irrigate grapevines.

In the 2018/19 season, grapes were harvested as close as possible to 24°B as was logistically possible with the exception for the Spruitdrift shallow sand experiment plot (Fig. 5.2A). The few grapes that there were at the Spruitdrift shallow sand experiment plot were harvested relatively early to avoid yield losses. Juice TTA was similar for the Madeba sandy loam and clay loam and Lutzville deep sand experiment plots (Fig. 5.2B). Due to the early harvest, juice TTA was considerably higher at the Spruitdrift shallow sand experiment plot. Juice pH was similar for all the experiment plots with the exception of the Spruitdrift shallow sand experiment plot where the high total titratable acidity resulted in lower pH (Fig. 5.2C).

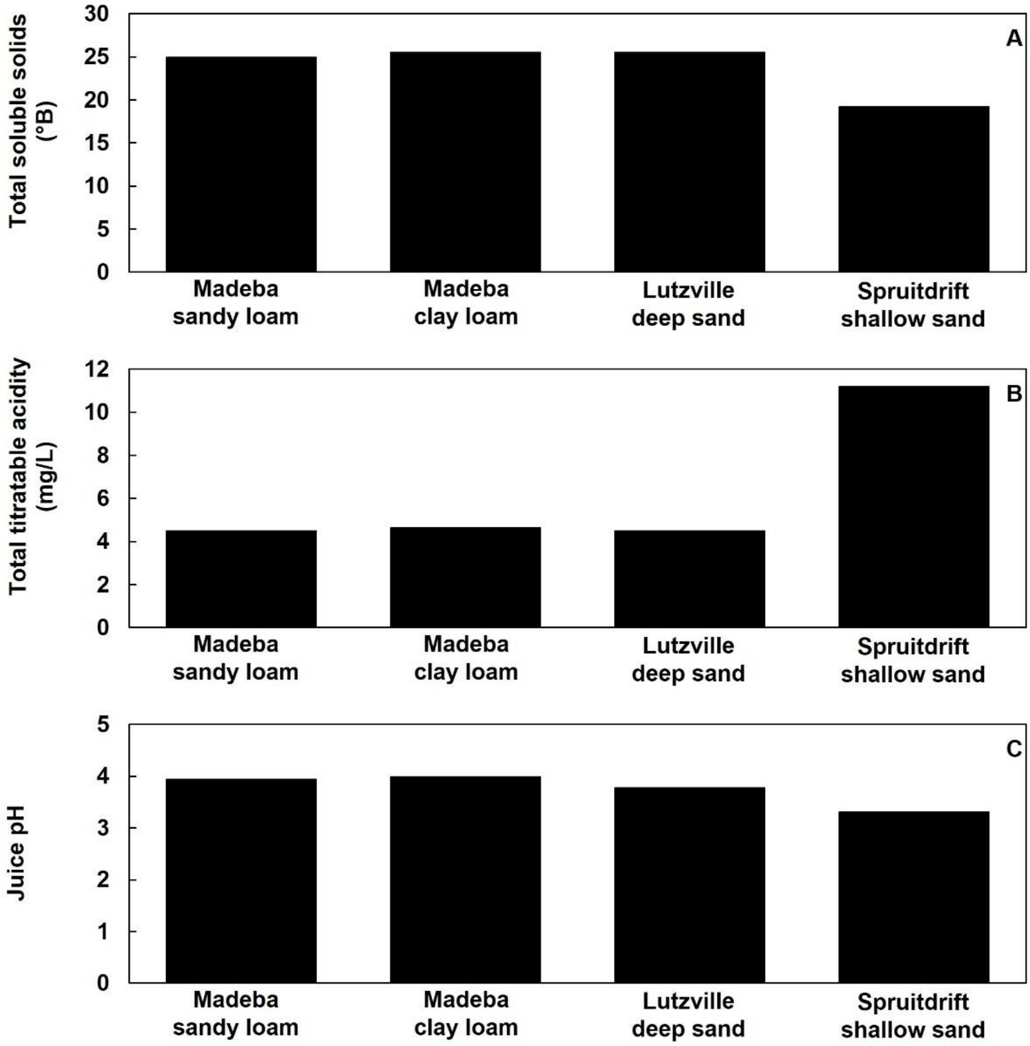

Figure 5.2. Variation in total soluble solids, titratable acidity and juice pH at harvest in the 2018/19 season where the in-field fractional use (augmentation) of winery wastewater with raw water was used to irrigate grapevines.

In the 2019/20 season, grapes at Spruitdrift were harvested relatively early to avoid yield losses (Fig. 5.3A). Juice TTA was similar for the Backsberg and Madeba sandy loam experiment plots (Fig. 5.3B). Due to the early harvest, juice TTA was higher at Spruitdrift. Juice pH was similar for all the experiment plots with the exception of the Madeba experiment plots (Fig. 5.3C).

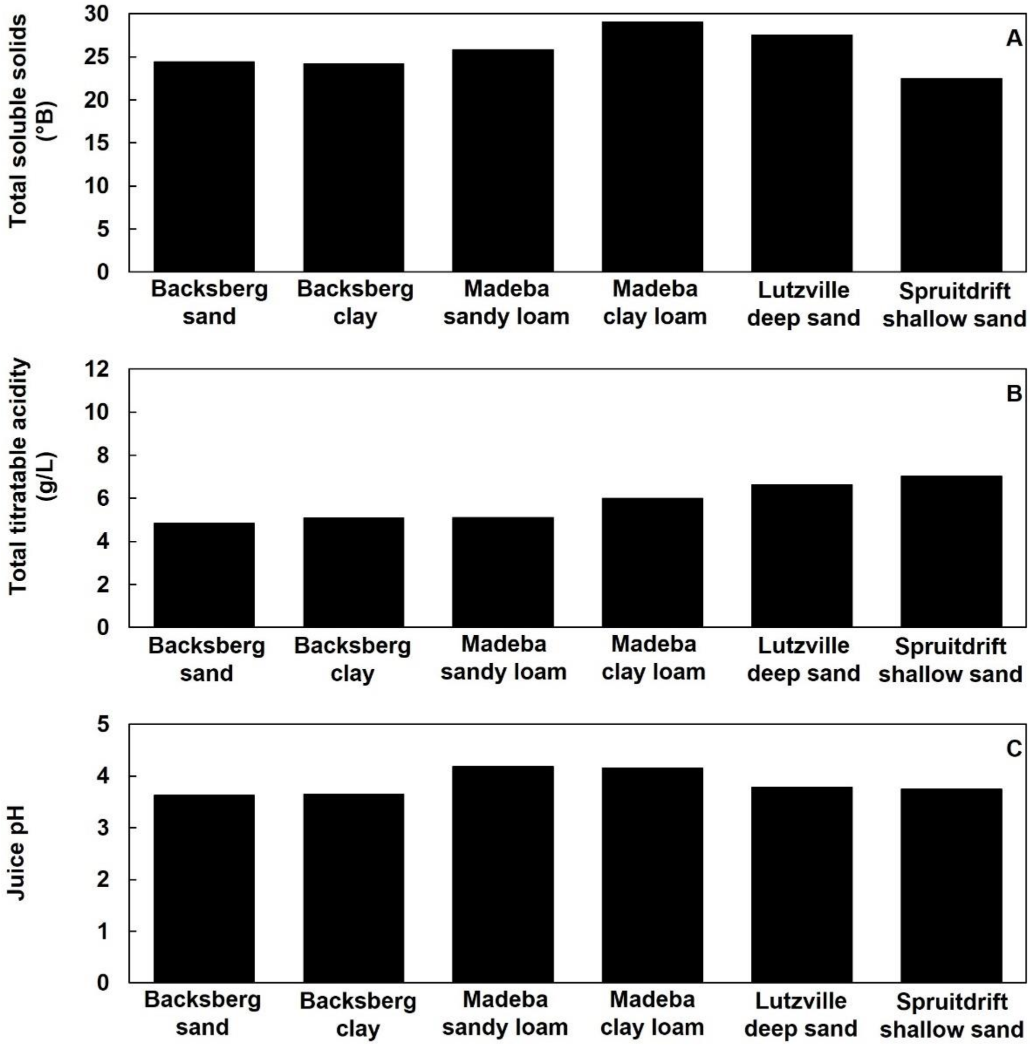

Figure 5.3. Variation in total soluble solids, titratable acidity and juice pH at harvest in the 2019/20 season where the in-field fractional use (augmentation) of winery wastewater with raw water was used to irrigate grapevines.

Grapes were harvested as close as possible to 24°B as logistically possible in the 2020/21 season (Fig. 5.4A). Juice TTA was similar for the Backsberg and Lutzville and Spruitdrift experiment plots (Fig. 5.4B). Juice pH was similar for all the experiment plots (Fig. 5.4C).

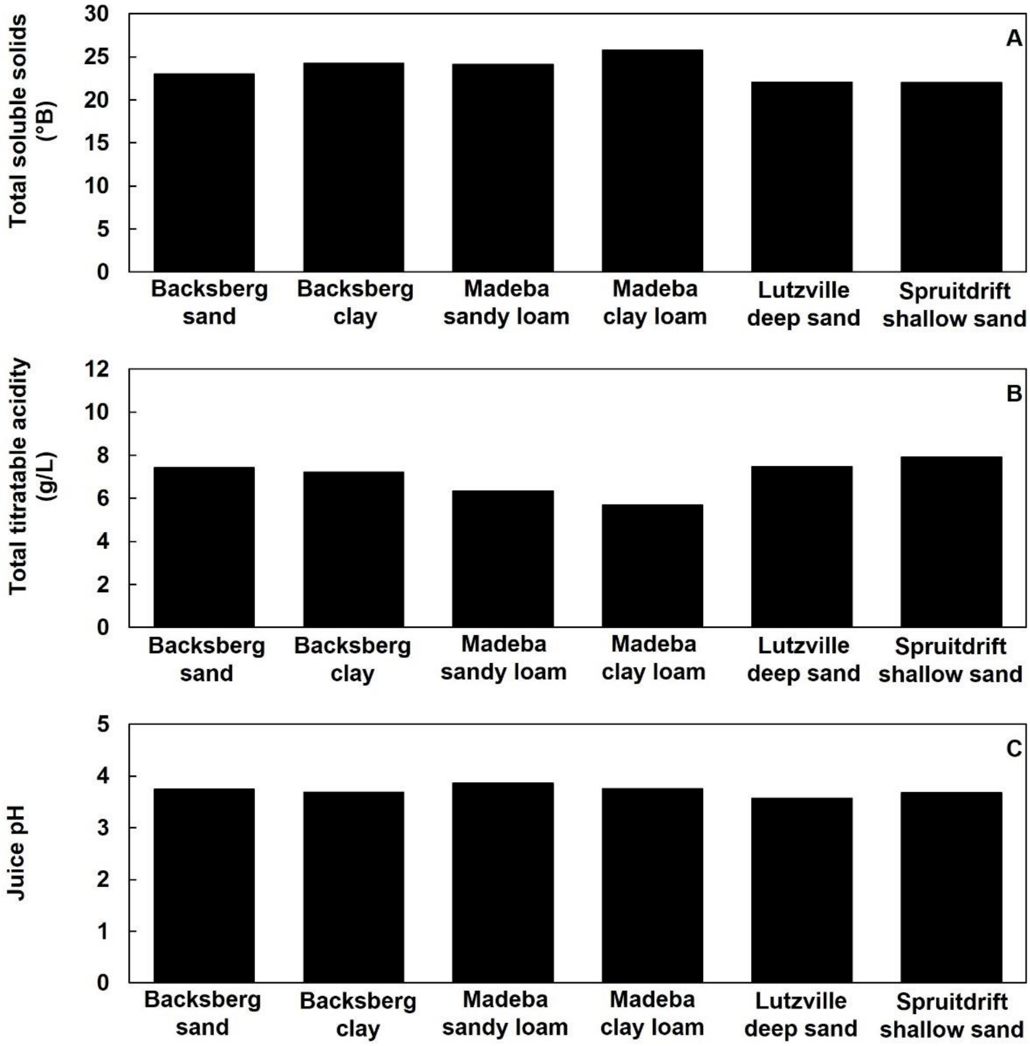

Figure 5.4. Variation in total soluble solids, titratable acidity and juice pH at harvest in the 2020/21 season where the in-field fractional use (augmentation) of winery wastewater with raw water was used to irrigate grapevines.

Juice element contents for the 2017/18 season is given in Figure 5.5. In this particular season, no Na was detected in the juice (data not shown).

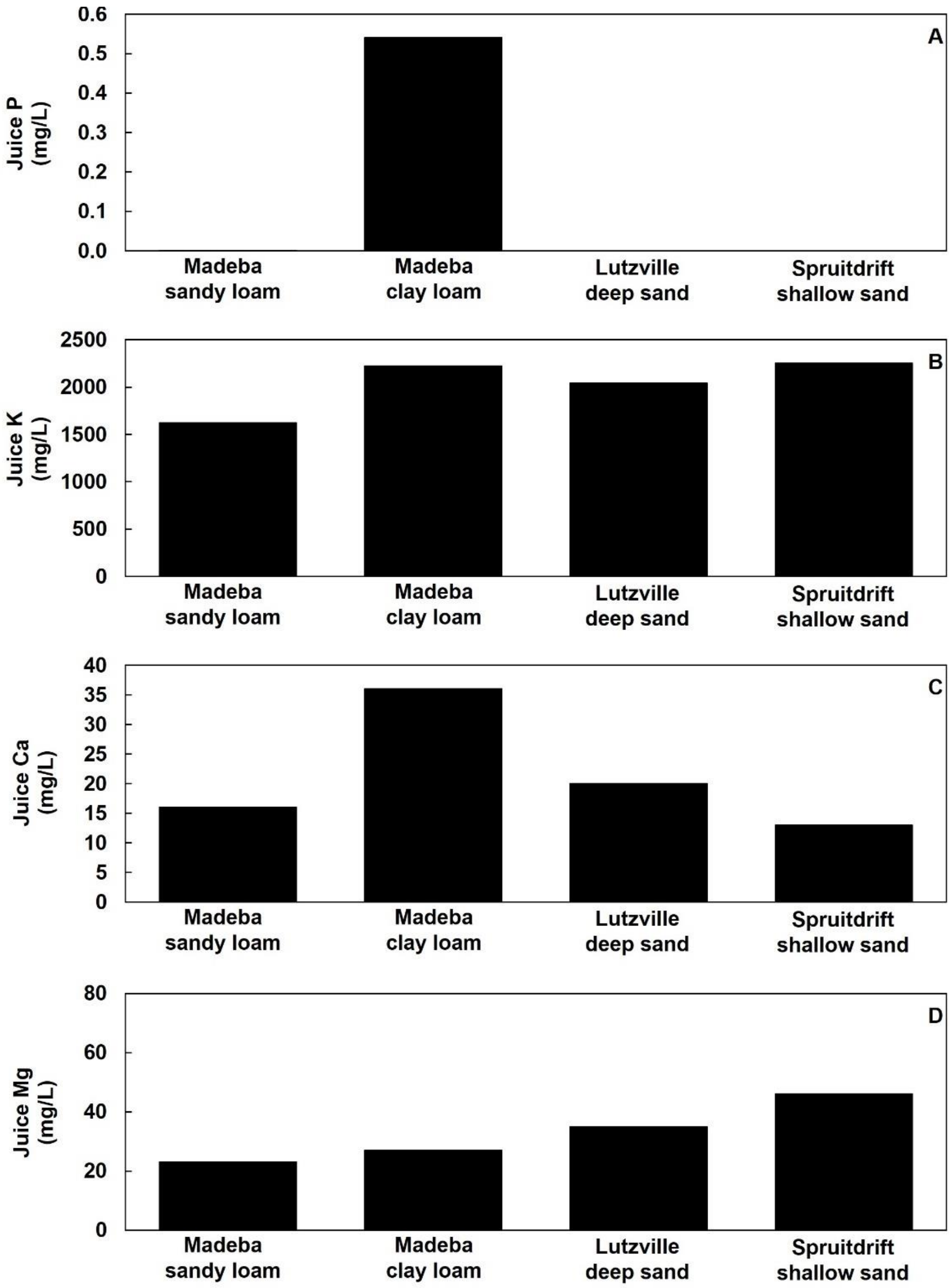

Figure 5.5. Variation in juice element contents at harvest in the 2017/18 season where the in-field fractional use (augmentation) of winery wastewater with raw water was used to irrigate grapevines.

In the 2018/19 season, for the grapevines in all experiment plots, juice element contents were in line with the norms, except for the Na at the Spruitdrift shallow sand experiment plot (Fig. 5.6). The latter was likely caused by the high Na content in the winery wastewater (Refer to Chapter 2). Furthermore, juice Ca was lowest at the Spruitdrift shallow sand experiment plot. It was previously reported that sodic soil conditions could cause high concentrations of Na in grapevine tissue and concomitantly reduce Ca concentrations (McCarthy & Downton, 1981; Stevens *et al*., 2011 and references therein).

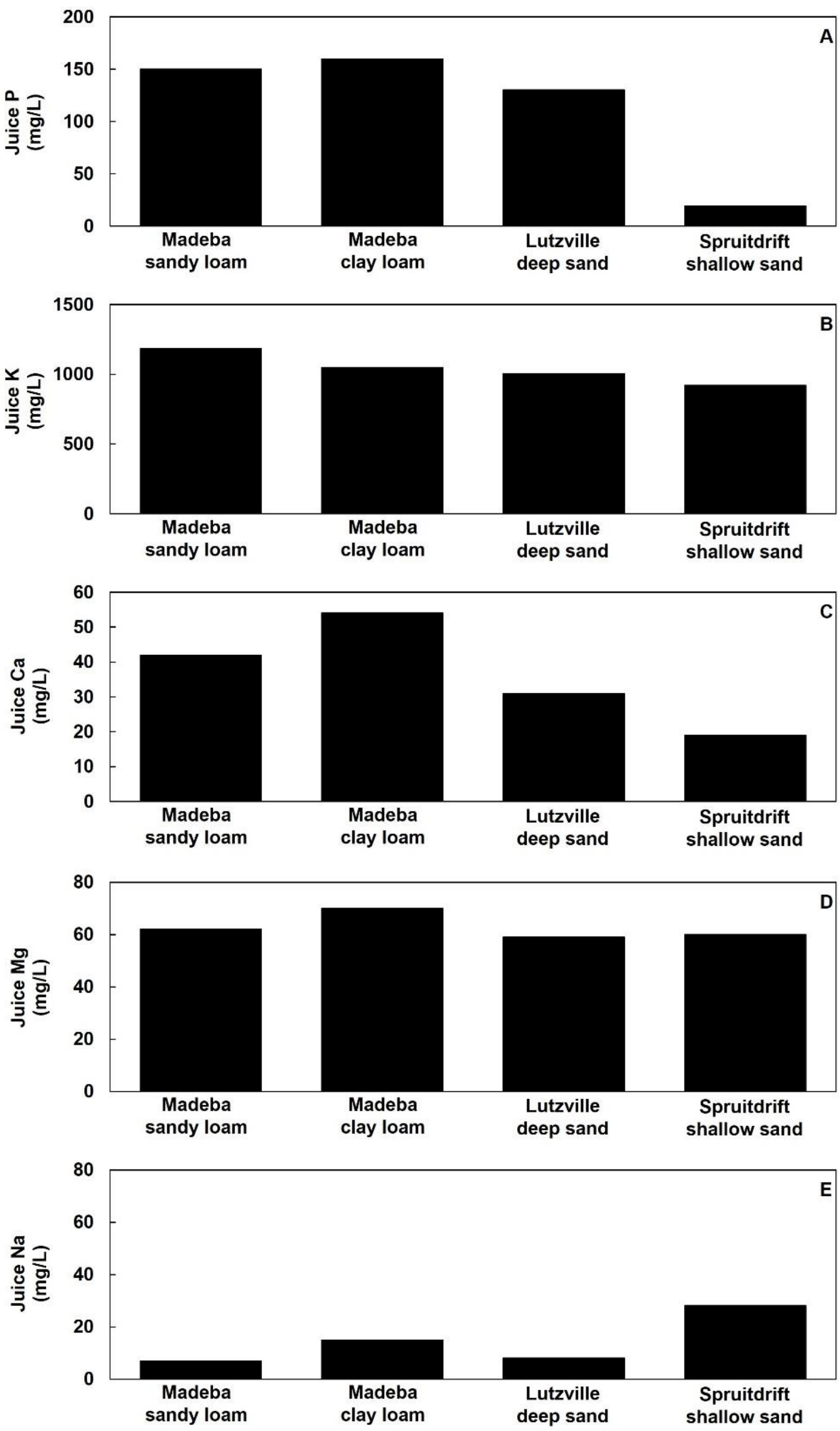

Figure 5.6. Variation in juice element contents at harvest in the 2018/19 season where the in-field fractional use (augmentation) of winery wastewater with raw water was used to irrigate grapevines.

In the 2019/20 season, juice P and K was lowest at the Backsberg sand experiment plot and highest at the Madeba sandy loam experiment plot (Figs. 5.7A & B). Juice Ca and Mg was highest at the Lutzville deep sand experiment plot (Figs. 5.7C & D). Although the Spruitdrift grapevines were not irrigated with the in-field fractional use (augmentation) of winery wastewater with raw water in this particular season, juice Na was still the highest and juice Ca the lowest of all the experiment plots (Fig. 5.7E).

Juice P levels were 0.41%, 0.36%, 0.73%, 0.80%, 0.66% and 0.45% for the Backsberg sand, Backsberg clay, Madeba sandy loam, Madeba clay loam, Lutzville deep sand and Spruitdrift shallow sand controls, respectively. Juice K levels were 4.49%, 4.94%, 4.41%, 4.80%, 4.57% and 5.46% for the Backsberg sand, Backsberg clay, Madeba sandy loam, Madeba clay loam, Lutzville deep sand and Spruitdrift shallow sand controls, respectively. Juice K of the Madeba experiment plots was higher than the respective control. Despite substantial amounts of K being applied *via* the irrigation water at Lutzville, juice K of the experiment plot and control was similar. Juice Ca levels were 0.15%, 0.12%, 0.23%, 0.26%, 0.30% and 0.16% for the Backsberg sand, Backsberg clay, Madeba sandy loam, Madeba clay loam, Lutzville deep sand and Spruitdrift shallow sand controls, respectively. Despite substantial amounts of Ca being applied *via* the irrigation water at Lutzville (Refer to Chapter 2) juice Ca of the experiment plot and control was similar. Juice Mg levels were 0.20%, 0.22%, 0.24%, 0.24%, 0.33% and 0.25% for the Backsberg sand, Backsberg clay, Madeba sandy loam, Madeba clay loam, Lutzville deep sand and Spruitdrift shallow sand controls, respectively. Juice Mg of the Madeba sandy loam and Lutzville deep sand experiment plots was higher than the respective controls. Juice Na levels were 700 mg/kg, 600 mg/kg, 1300 mg/kg, 900 mg/kg, 700 mg/kg and 900 mg/kg for the Backsberg sand, Backsberg clay, Madeba sandy loam, Madeba clay loam, Lutzville deep sand and Spruitdrift shallow sand controls, respectively. Despite no wastewater application at the Spruitdrift experiment plot during the 2019/20 season, it had higher juice Na levels compared to the control section.

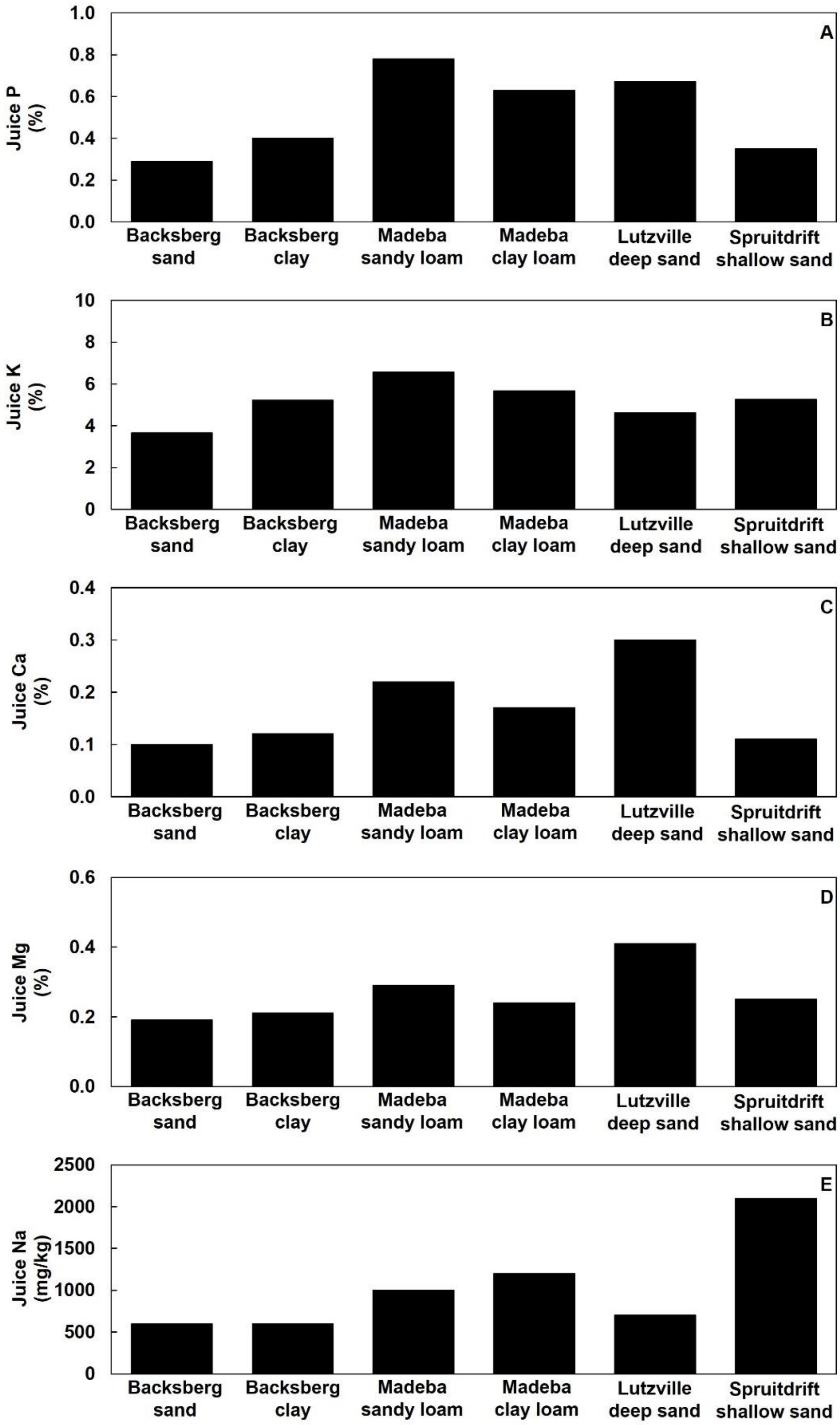

Figure 5.7. Variation in juice element contents at harvest in the 2019/20 season where the in-field fractional use (augmentation) of winery wastewater with raw water was used to irrigate grapevines.

In the 2020/21 season, juice P and K was similar at all the experiment plots (Figs. 5.8A & B). Juice Ca was highest at the Backsberg clay experiment plot (Figs. 5.8C). Despite substantial differences in leaf Mg at harvest (Refer to Chapter 4), juice Mg was similar at all the experiment plots (Figs. 5.8D).

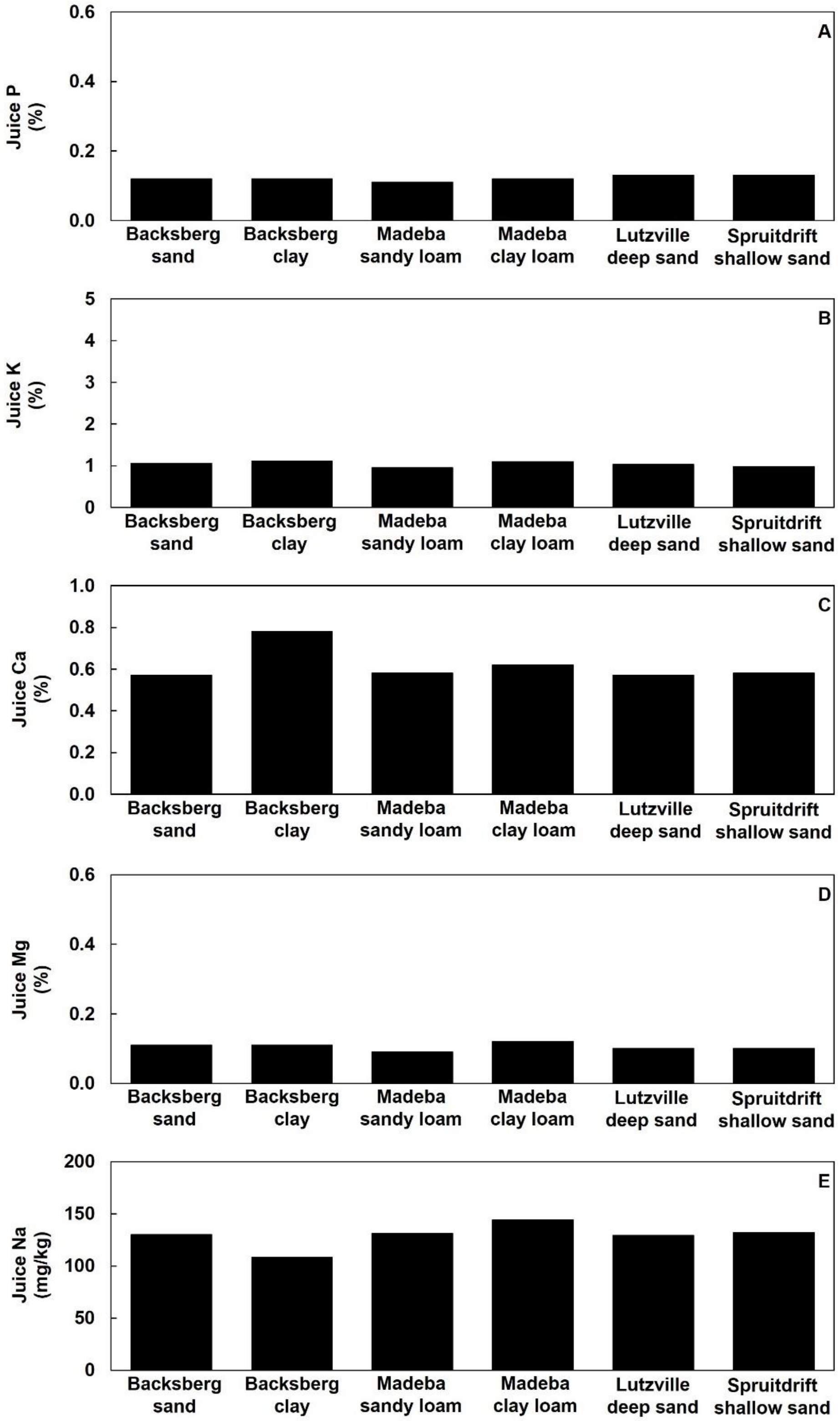

Figure 5.8. Variation in juice element contents at harvest in the 2020/21 season where the in-field fractional use (augmentation) of winery wastewater with raw water was used to irrigate grapevines.

Juice P levels were 0.13%, 0.14%, 0.15%, 0.14%, 0.11% and 0.10% for the Backsberg sand, Backsberg clay, Madeba sandy loam, Madeba clay loam, Lutzville deep sand and Spruitdrift shallow sand controls, respectively. Only the experiment plots in the Lower Olifants River region had higher juice P compared to the respective controls. Juice K levels were 1.07%, 1.08%, 1.22%, 1.09%, 0.96% and 0.96% for the Backsberg sand, Backsberg clay, Madeba sandy loam, Madeba clay loam, Lutzville deep sand and Spruitdrift shallow sand controls, respectively. Juice Ca levels were 0.53%, 0.56%, 0.73%, 0.59%, 0.55% and 0.61% for the Backsberg sand, Backsberg clay, Madeba sandy loam, Madeba clay loam, Lutzville deep sand and Spruitdrift shallow sand controls, respectively. Despite substantial amounts of Ca applied *via* the irrigation water at Lutzville, juice Ca of the experiment plot and control was similar. Juice Mg levels were 0.10%, 0.11%, 0.13%, 0.10%, 0.10% and 0.11% for the Backsberg sand, Backsberg clay, Madeba sandy loam, Madeba clay loam, Lutzville deep sand and Spruitdrift shallow sand controls, respectively. Juice Mg of the Backsberg sand and Madeba clay loam experiment plots was higher than the respective controls. Juice Na levels were 700 mg/kg, 600 mg/kg, 1300 mg/kg, 900 mg/kg, 700 mg/kg and 900 mg/kg for the Backsberg sand, Backsberg clay, Madeba sandy loam, Madeba clay loam, Lutzville deep sand and Spruitdrift shallow sand controls, respectively. Juice Na of the Madeba clay loam experiment plots was higher than the respective controls.

5.3.2. Wine characteristics

The wine produced at Spruitdrift had the best colour (Fig. 5.9A) and overall intensity (Fig. 5.9B). The Spruitdrift and Lutzville wines tended to have a strong berry-like character (Fig. 5.9C). The stronger berry-like rather than spicy character of these wines were consistent with Cabernet Sauvignon wine made from grapes produced in warmer localities such as Klawer which is also in the Lower Olifants River region (Bruwer, 2010). The wines had no wastewater associated off-flavours (Fig. 5.9D) and there were no consistent trends in wastewater associated off-flavours and -tastes, thereby confirming that no contaminants were transferred from the wastewater into the wines. This was expected since visual observations revealed that bunches were not wetted with undiluted winery wastewater during the in-field fractional use (augmentation). Perusal of the scorecards also revealed that members of the tasting panel were highly inconsistent with respect to their perception of off-tastes. The observed off-odours and off-tastes were all related to frequently occurring off-odours and off-tastes in wines such as volatile acidity and bitterness. Wine quality was the best at Spruitdrift (Fig. 5.9F).

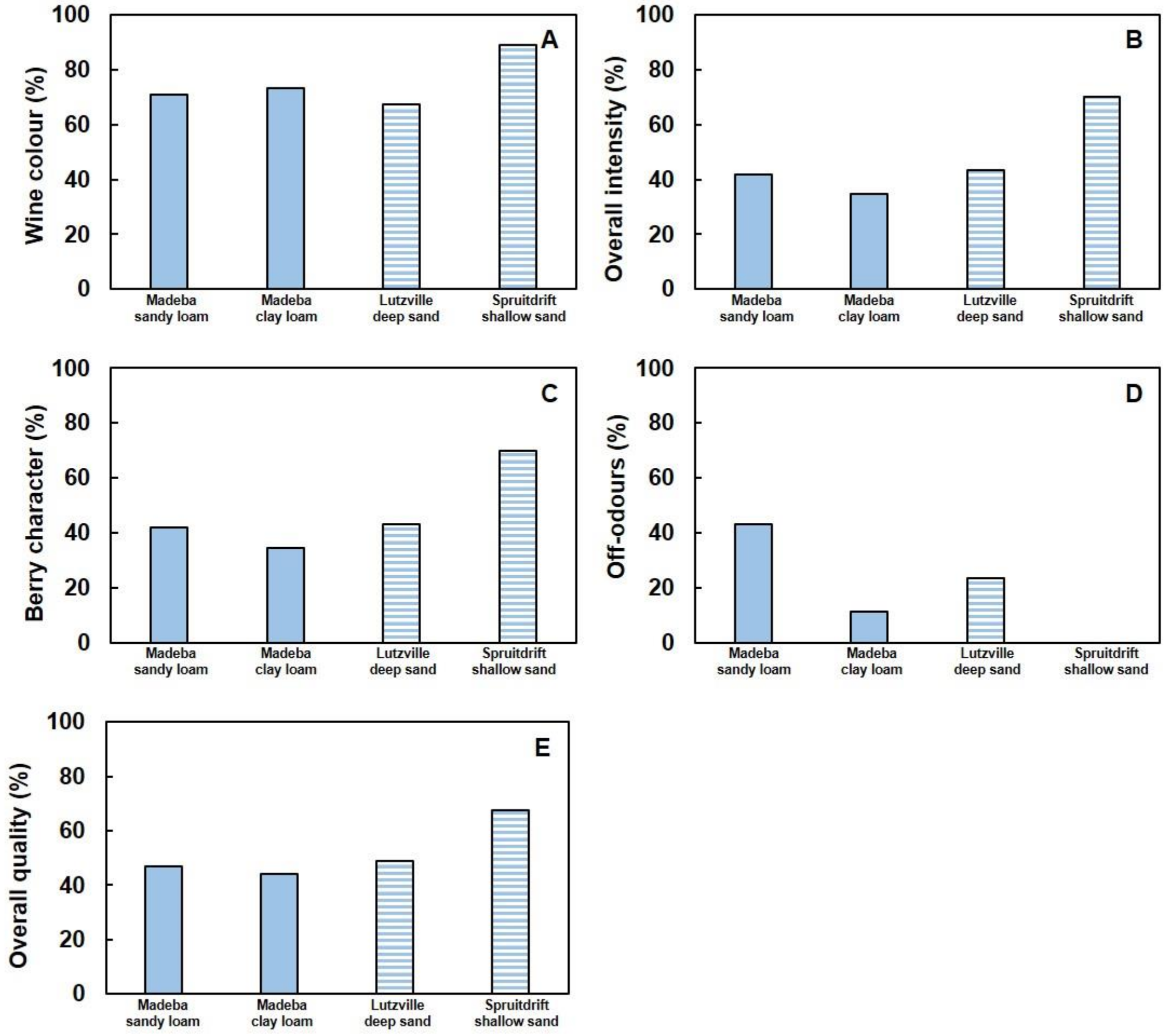

Figure 5.9. The wine (A) colour, (B) overall intensity, (C) berry character, (D) off-odours and (E) overall quality of wines where the in-field fractional use (augmentation) of winery wastewater with raw water was used for vineyard irrigation in the 2017/18 season.

Wine acidity, body, astringency and off-tastes are given in Figure 5.10. Perusal of the scorecards also revealed that members of the tasting panel were highly inconsistent with respect to their perception of off flavours and off-tastes. The observed off-odours and off-tastes were all related to frequently occurring off-odours and off-tastes in wines such as volatile acidity and bitterness.

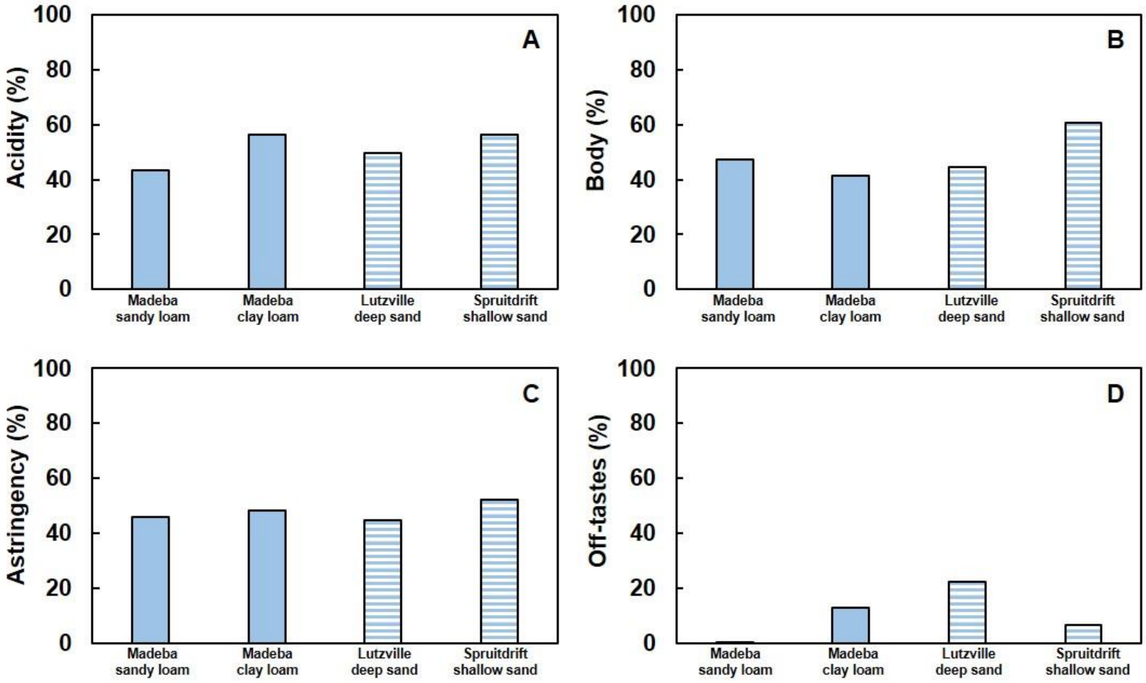

Figure 5.10. The wine (A) acidity, (B) body, (C) astringency and (D) off-tastes where the fractional use (augmentation) of winery wastewater with raw water was used for vineyard irrigation in the 2017/18 season.

In the 2017/18 season, the wine produced at Madeba clay loam had the best colour (Fig. 5.11A) but overall intensity and berry character of the wines was similar (Figs. 5.11B & C). The wines had no wastewater associated off-flavours (Fig. 5.11D). Wine quality was similar at all the experiment plots (Fig. 5.11E). Wine acidity, body, astringency and off-tastes are given in Figure 5.12.

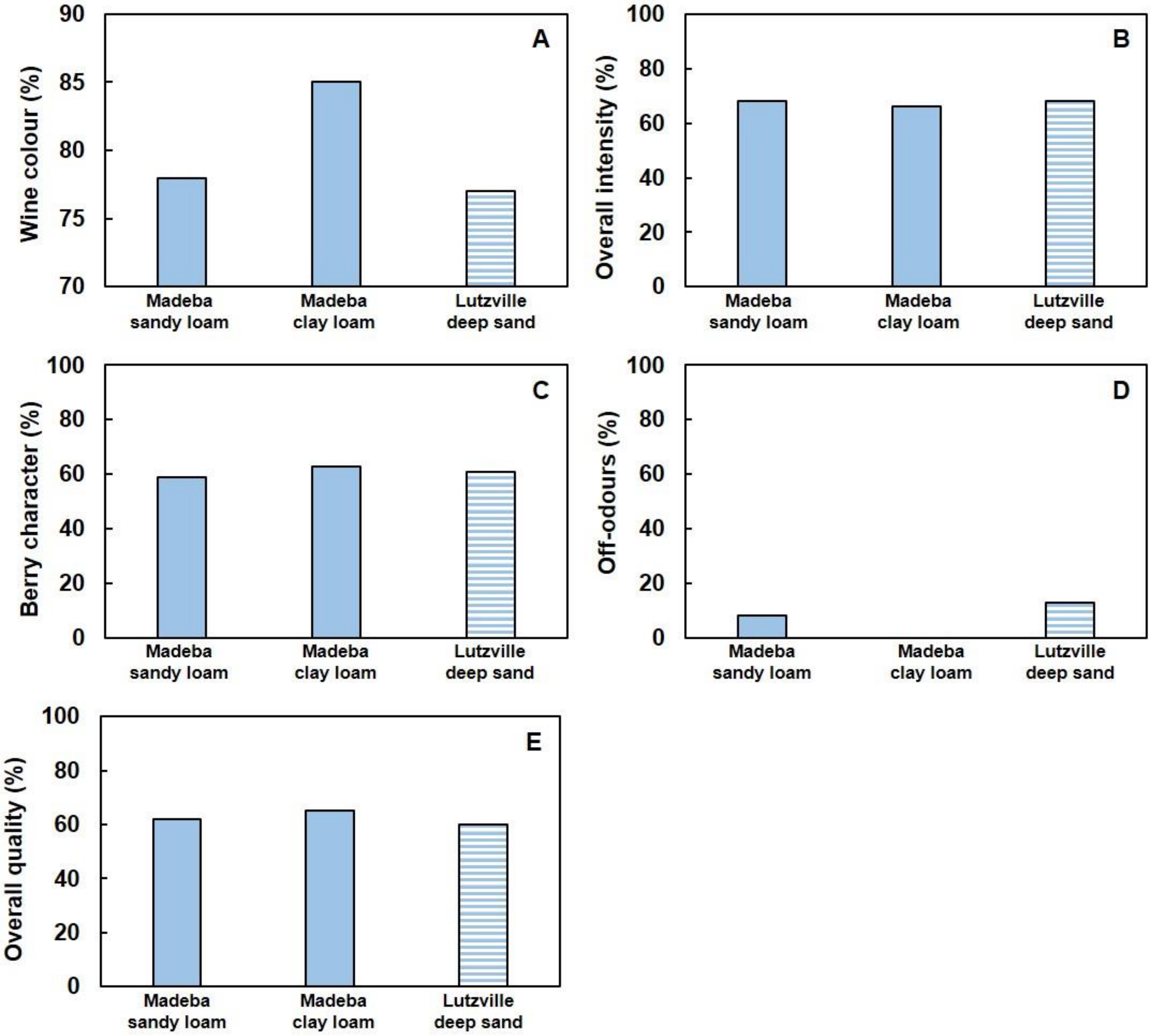

Figure 5.11. The wine (A) colour, (B) overall intensity, (C) berry character, (D) off-odours and (E) overall quality of wines where the in-field fractional use (augmentation) of winery wastewater with raw water was used for vineyard irrigation in the 2018/19 season.

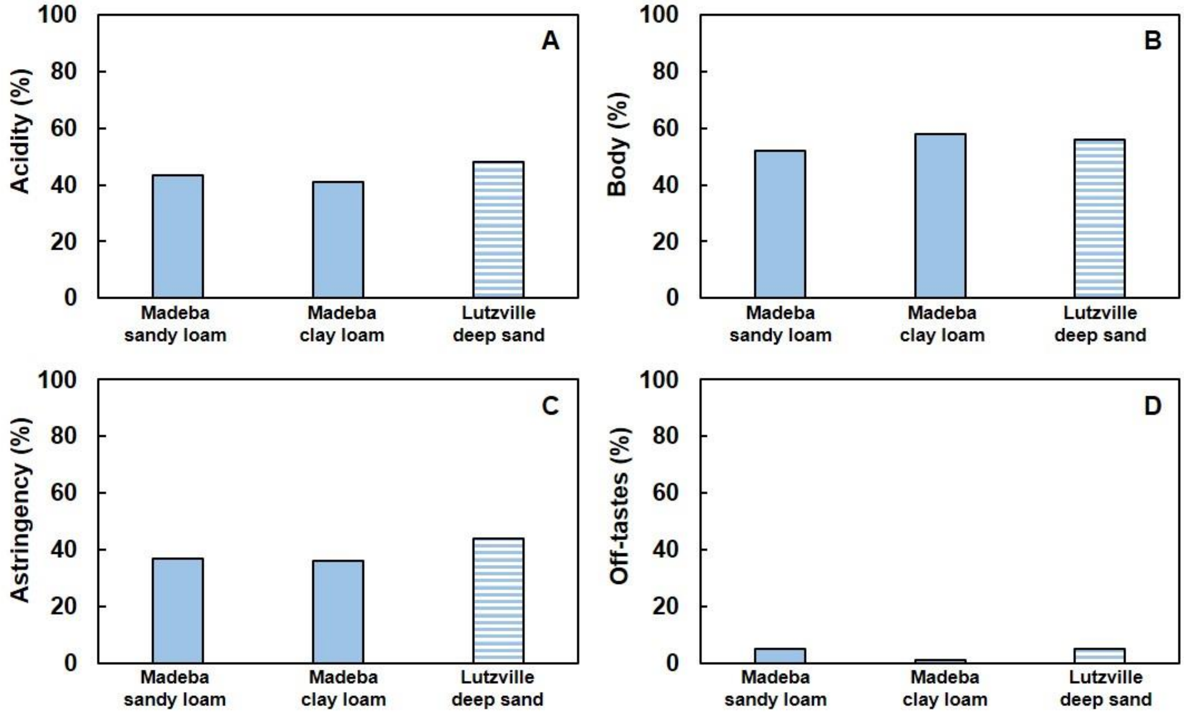

Figure 5.12. The wine (A) acidity, (B) body, (C) astringency and (D) off-tastes where the in-field fractional use (augmentation) of winery wastewater with raw water was used for vineyard irrigation in the 2018/19 season.

In the 2019/20 season, the wine produced for Madeba clay loam had the poorest colour (Fig. 5.13A) but overall intensity and berry character of the wines was similar (Figs. 513B & 5.13C). With the exception of Madeba clay loam experiment plot, the wines had no off-flavours (Fig. 5.13D). Wine quality was similar at all the experiment plots with the exception of the Madeba clay loam experiment plot (Fig. 5.13E). Wine acidity, body, astringency and off-tastes are given in Figure 5.14.

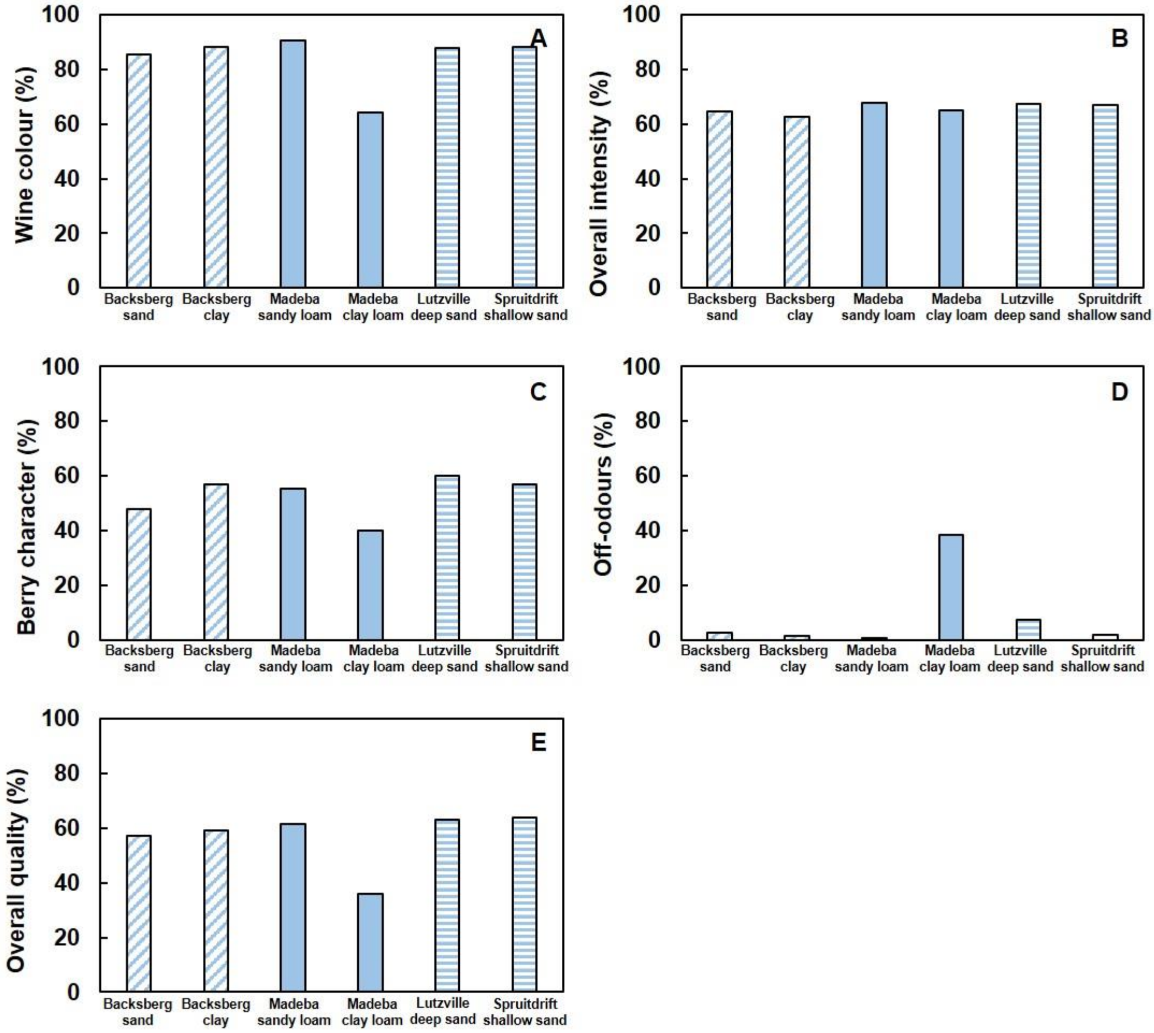

Figure 5.13. The wine (A) colour, (B) overall intensity, (C) berry character, (D) off-odours and (E) overall quality of wines where the in-field fractional use (augmentation) of winery wastewater with raw water was used for vineyard irrigation in the 2019/20 season.

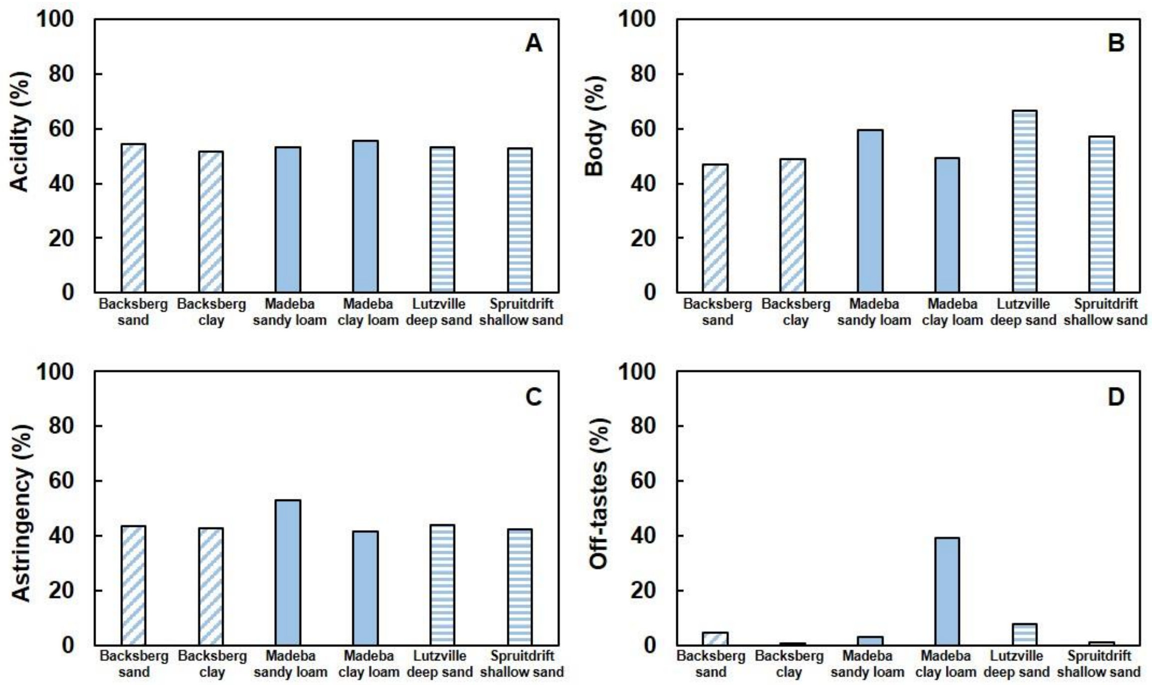

Figure 5.14. The wine (A) acidity, (B) body, (C) astringency and (D) off-tastes where the in-field fractional use (augmentation) of winery wastewater with raw water was used for vineyard irrigation in the 2019/20 season.

In the 2020/21 season, the wine produced for Lutzville deep sand had the poorest colour (Fig. 5.15A). This was expected given the high yield at this specific experiment plot. The wines had no off-flavours (Fig. 5.15D). Wine quality was lower at the Lutzville deep sand experiment plot compared to the rest of the experiment plots (Fig. 5.15E). Wine acidity, body, astringency and off-tastes are given in Figure 5.16.

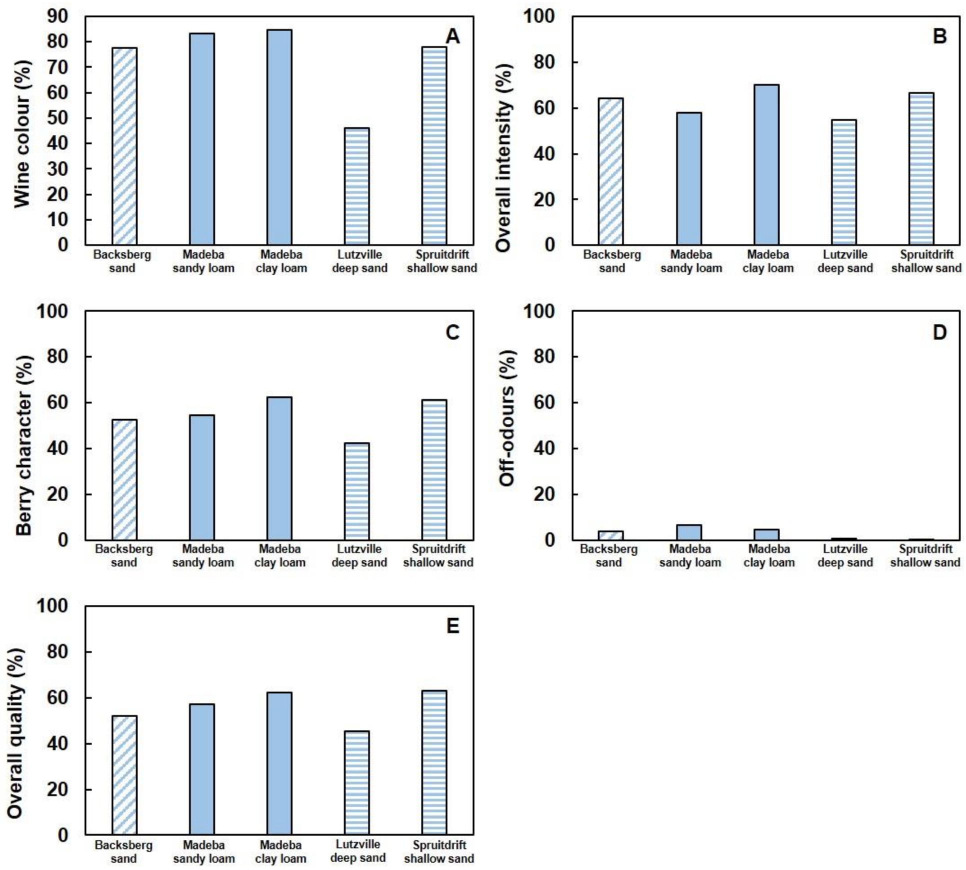

Figure 5.15. The wine (A) colour, (B) overall intensity, (C) berry character, (D) off-odours and (E) overall quality of wines where the in-field fractional use (augmentation) of winery wastewater with raw water was used for vineyard irrigation in the 2020/21 season.

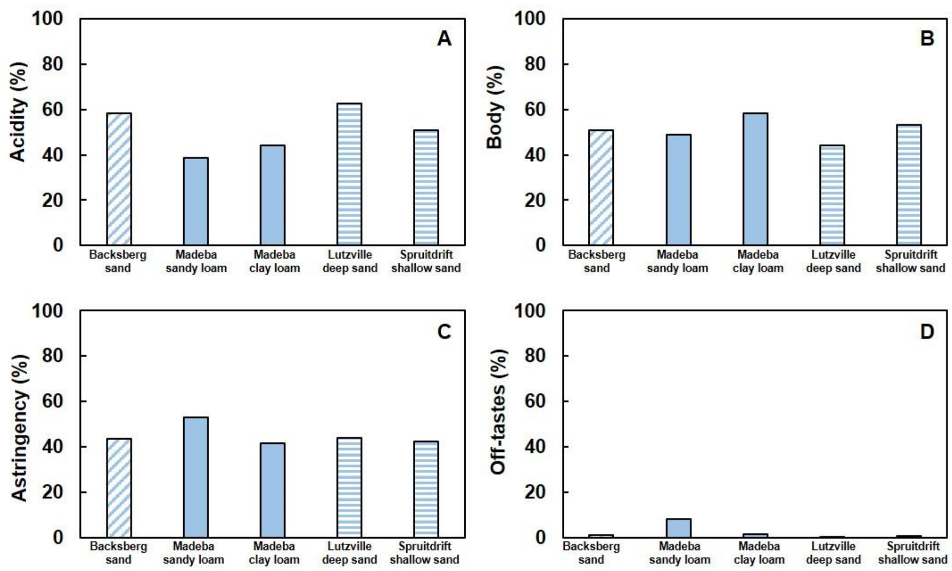

Figure 5.16. The wine (A) acidity, (B) body, (C) astringency and (D) off-tastes where the in-field fractional use (augmentation) of winery wastewater with raw water was used for vineyard irrigation in the 2020/21 season.

In the 2017/18 season, wine pH was 3.85, 3.95, 3.71 and 4.02 for the Madeba sandy loam, Madeba clay loam, Lutzville deep sand and Spruitdrift shallow sand experiment plots, respectively. In the 2018/19 season, wine pH was 4.05, 3.95 and 3.77 for the Madeba sandy loam, Madeba clay loam and Spruitdrift shallow sand experiment plots, respectively. In the 2019/20 season, wine pH was 3.57, 3.59, 4.06, 4.01, 3.80 and 3.97 for the Backsberg sand, Backsberg clay, Madeba sandy loam, Madeba clay loam, Lutzville deep sand and Spruitdrift shallow sand experiment plots, respectively. In the 2020/21 season, wine pH was 3.68, 4.27, 4.14, 3.71 and 3.91 for the Backsberg sand, Madeba sandy loam, Madeba clay loam, Lutzville deep sand and Spruitdrift shallow sand experiment plots, respectively.

The wine Na element contents for the duration of the study ranged from 17 mg/L to 105 mg/L. In a study carried out in Robertson, Moolman *et al*. (1998) reported wine Na contents that ranged from 40 mg/L to 190 mg/L. Much higher values were reported for Australian Shiraz wine Na that ranged from 78 mg/L to 533 mg/ (Walker *et al.*, 2003). However, the legal limit for wine Na in South Africa is 100 mg/L (Department of Water Affairs & Forestry, 1996). Wine Na for the Spruitdrift shallow sand experiment plot was 105 mg/L in the first season thus higher than this norm in the first season and the Madeba clay loam experiment plot had wine Na contents of 102 mg/L in the second season. However, due to the termination of the wastewater irrigation after two seasons the wine Na level at the Spruitdrift shallow sand experiment plot declined to 43 mg/L in the 2020/21 season. Therefore, 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 conformed to statutory requirements with regard to Na content. This was specifically notable in regions with lower rainfall. Moolman *et al*. (1998) reported wine Cl that ranged from 50 mg/L to 160 mg/L, whereas much higher values of 98 mg/L to 1788 mg/L were reported for Shiraz in Australia (Walker *et al.*, 2003). The Australian legal limit for wine Cl content is 606 mg/L (Leske *et al*., 1997). Based on this norm, Cl contents in the wines from the Madeba clay loam experiment plot were high and ranged from 269 mg/L to 671 mg/L. Although wine P, K, Mg, Na and Cl^- were higher in response to irrigation with sewage water, concentrations were not excessively high (McCarthy & Downton, 1981). In contrast, wine Na and Cl were substantially higher where sewage water was used for vineyard irrigation.

5.4. CONCLUSIONS

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.

CHAPTER 6: 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

6.1. INTRODUCTION

After two seasons of using the in-field fractional use (augmentation) of winery wastewater with raw water for vineyard irrigation at the Spruitdrift shallow sand experiment plot, the low yield and poor vegetative growth was a matter of great concern (Refer to Chapter 4). Although the fractional ratio was changed from 0.5 to 0.25 in the 2018/19 season, it was evident that large amounts of elements were still being applied *via* the irrigation and it did not seem sustainable to apply larger volumes of irrigation to increase the yield. Furthermore, results from the soil analyses after winter 2018 confirmed that in this region of low winter rainfall, that excessive salts applied *via* the irrigation were not leached sufficiently in winter. Similar results were reported by Mulidzi (2016) in a pot study. Taking above-mentioned into consideration, the in-field fractional use (augmentation) of winery wastewater with raw water for vineyard irrigation at the Spruitdrift shallow sand experiment plot had to be terminated at the end of the 2018/19 season to prevent further damage of the grapevines. It is well known that irrigation with saline water can have a detrimental effect on grapevines (McCarthy, 1981; McCarthy & Downton, 1981) due to accumulation of elements within the grapevine.

Given the substantial amounts of elements applied *via* the in-field fractional use (augmentation) of winery wastewater with raw water for vineyard irrigation in the Lower Olifants River region together with the low mean annual rainfall, the objective of this study was to make an assessment of the below- and above-ground chemical status of the grapevines growing in the Lower Olifants River region. The termination of the fractional use (augmentation) of winery wastewater with raw water for vineyard irrigation at the Spruitdrift shallow sand experiment plot and the irrigation thereof for two years with raw water according to the producer's schedule also gave the project team the opportunity to assess the permanent wood structure at the end of the study to give an indication of the recovery, if any, in terms of element accumulation in the permanent wood parts.

6.2. MATERIALS AND METHODS

6.2.1. Soil

Soil samples were taken from the 0-30 cm, 30-60 cm and 60-90 cm layers in September 2019 at Spruitdrift. Samples were analysed as discussed in Chapter 4. Each of the vineyard blocks had an experiment plot that was or had been irrigated with winery wastewater and this was compared to the rest of the surrounding vineyard block which acted as the control.

6.2.2. Roots

Qualification of the root systems was carried out before bud break in September 2019 at the Spruitdrift shallow sand experiment plot. Thereafter, soil profile pits were dug and soil carefully removed from the pit and placed onto a sieve. Roots were separated from the soil and placed into bags. Samples were collected at the Lutzville experiment plot and control in May 2021. Samples were collected from the experiment plots and controls. Roots were carefully washed and dried and analysed by a commercial laboratory.

6.2.3. Permanent wood

Permanent wood was sampled at the Spruitdrift shallow sand experiment plot and control in September 2019 as well as July 2021. Permanent wood was sampled at the Lutzville deep sand experiment plot and control in July 2021. Samples were analysed as discussed in Chapter 4.

6.3. RESULTS AND DISCUSSION

6.3.1. Roots

It was evident that the previously drip irrigated root systems in the experiment plot did not adapt to the full surface micro-sprinkler irrigation when wastewater irrigation began (Fig. 6.1). Furthermore, grapevine roots in the experiment plot where the in-field fractional use (augmentation) of winery wastewater with raw water was used for vineyard irrigation tended to be poorer compared to roots of grapevines in the block where only raw water was applied.

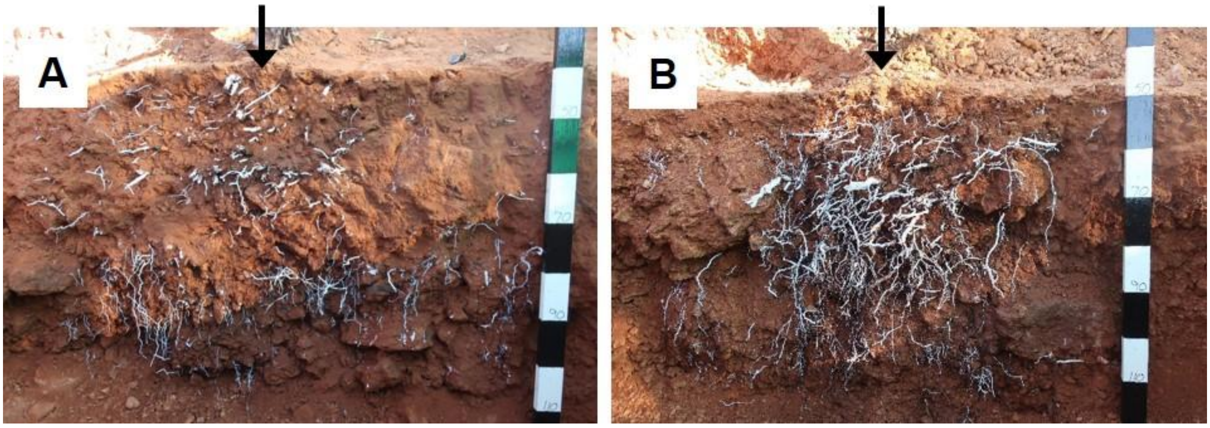

Figure 6.1. Grapevine root systems (A) in the experiment plot where the in-field fractional use (augmentation) of winery wastewater with raw water was used for vineyard irrigation and (B) in the control where raw water was applied. Arrows indicate position of the grapevine trunks.

Analyses showed that the soil K of the Spruitdrift site measured in September 2019 was considerably higher in the experiment plot compared to grapevines in the control to a depth of 90 cm (Fig. 6.2). In contrast, the soil Na only tended to be higher to a depth of 60 cm, in the root zone (Fig. 6.2). This suggested that the raw water irrigation had leached the Na beyond the root depth. In this case, the Na was probably released over time as the parent material weathered after soil preparation. It should be noted that the soil Na in the 30-60 cm layer of the experiment plot was above the proposed norm of 0.4 cmol/kg where negative grapevine responses can be expected (Conradie, personal communication).

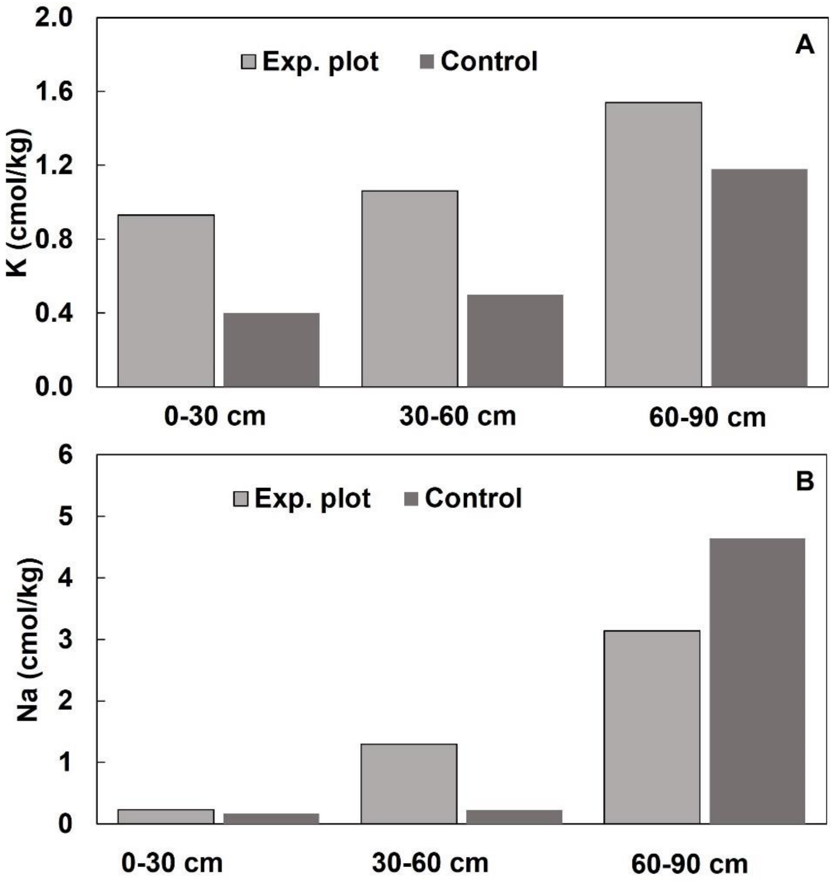

Figure 6.2. Levels of (A) soil K and (B) Na in the experiment plot and control, respectively, in September 2019 at Spruitdrift.

Results indicated that the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation promoted the accumulation of N and P in the roots of the Spruitdrift experiment grapevines (Fig. 6.3).

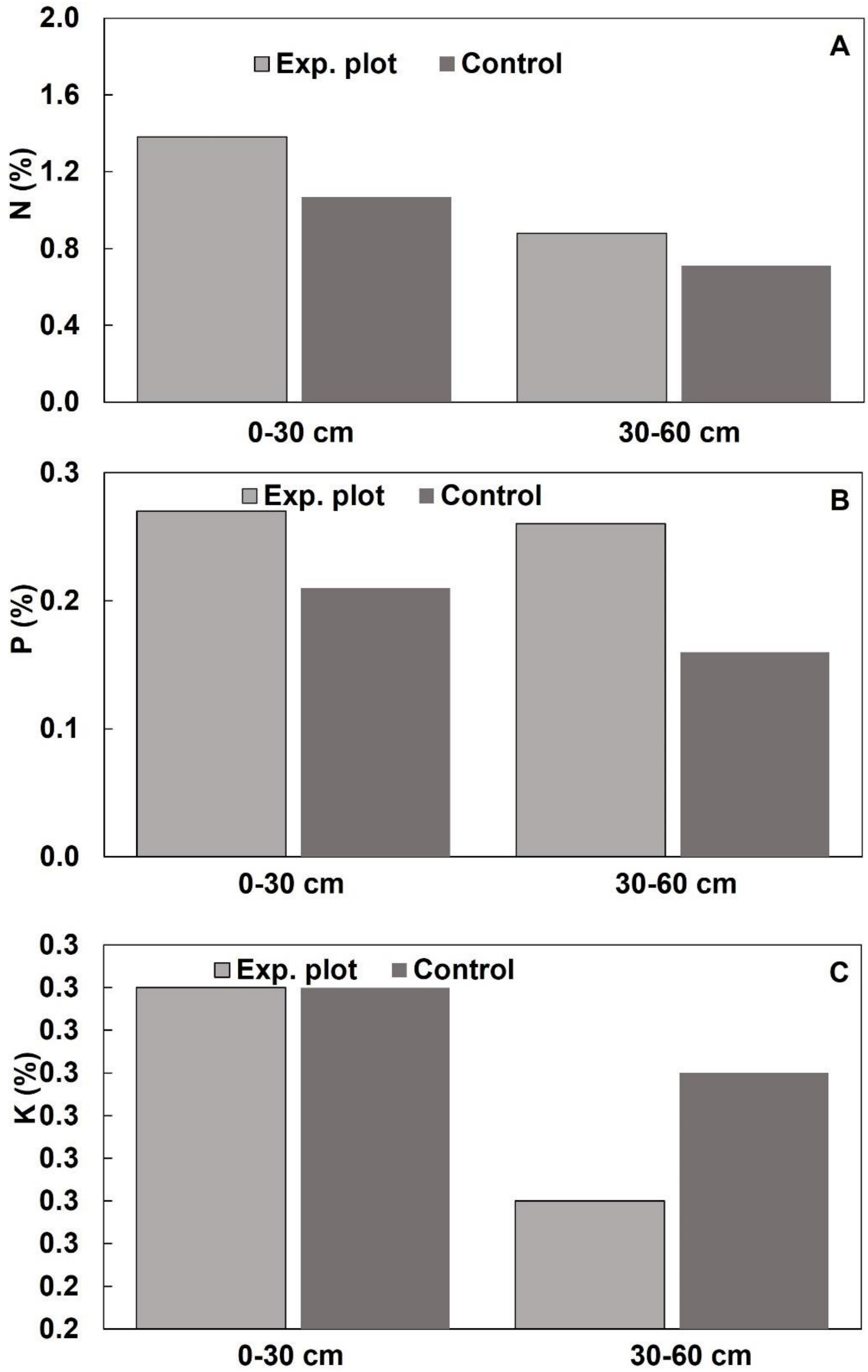

Figure 6.3. Variation in (A) N, (B) P and (C) K in the grapevine roots sampled from 0-30 cm and 30-60 cm soil depth layers at Spruitdrift.

Furthermore, the Na and Cl in grapevine roots (Fig. 6.4) sampled from the experiment plot was substantially higher compared to those that of the control which had been irrigated with raw water only (Fig. 6.4).

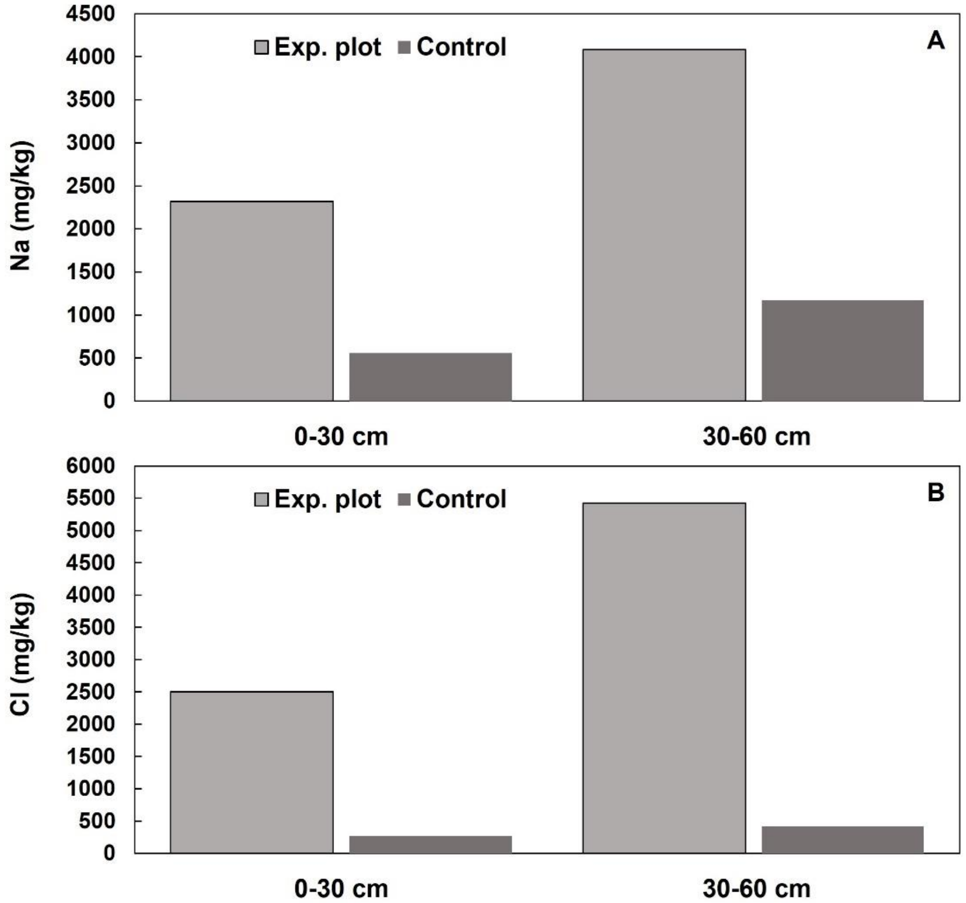

Figure 6.4. Variation in (A) Na and (B) Cl in the grapevine roots sampled from 0-30 cm and 30-60 cm soil depth layers at Spruitdrift.

The in-field fractional use (augmentation) of winery wastewater with raw water for vineyard irrigation promoted the accumulation of N, P and K in the roots of the experiment grapevines at Lutzville measured in May 2021 (Fig. 6.5).

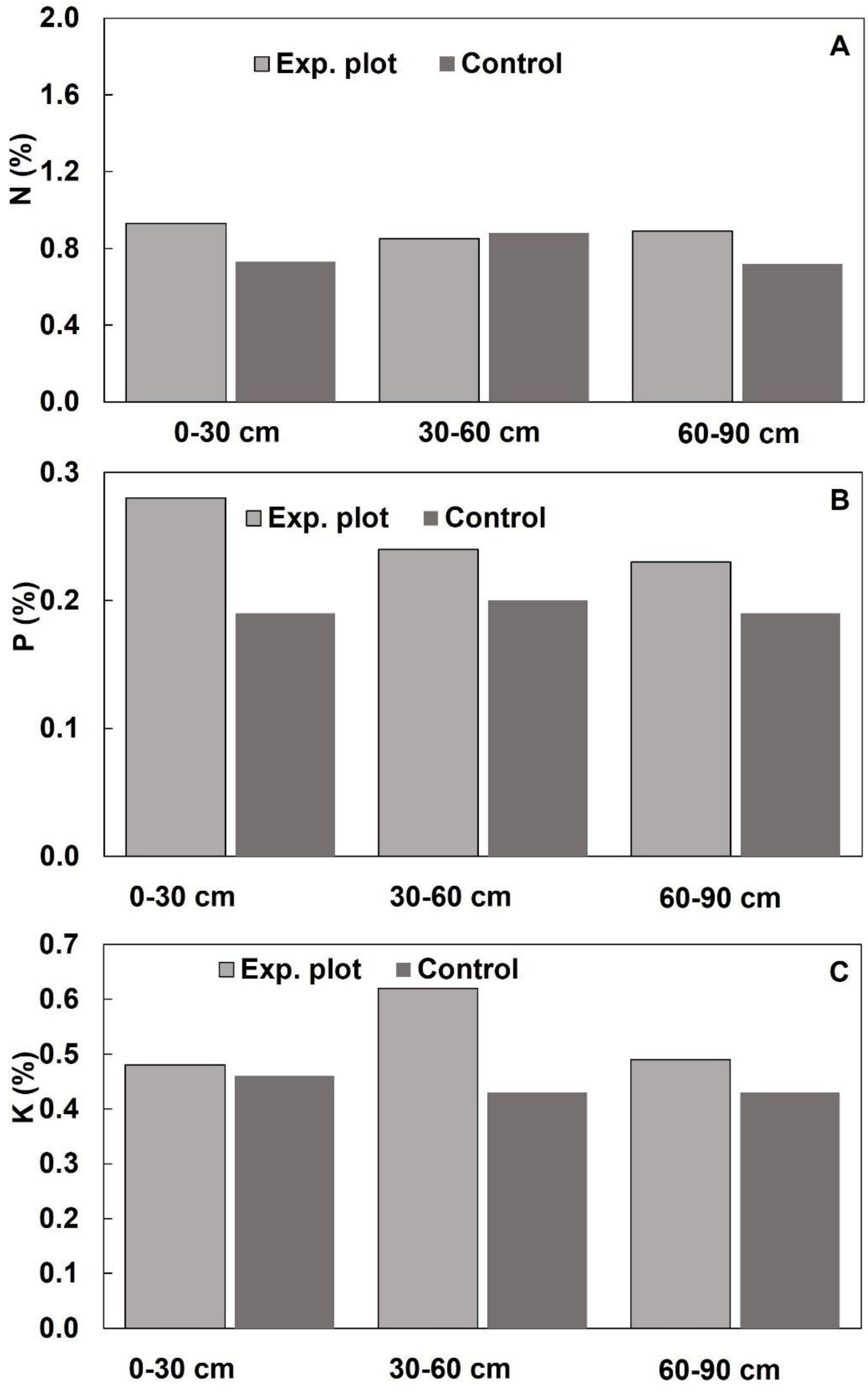

Figure 6.5. Variation in (A) N, (B) P and (C) K in the grapevine roots sampled from 0-30 cm, 30-60 cm and 60-90 cm soil depth layers at Lutzville.

In contrast to the Spruitdrift plot, there were no detrimental effects of the in-field fractional use (augmentation) of winery wastewater with raw water for irrigation on Na and Cl accumulation in the grapevine roots at Lutzville (Fig. 6.6).

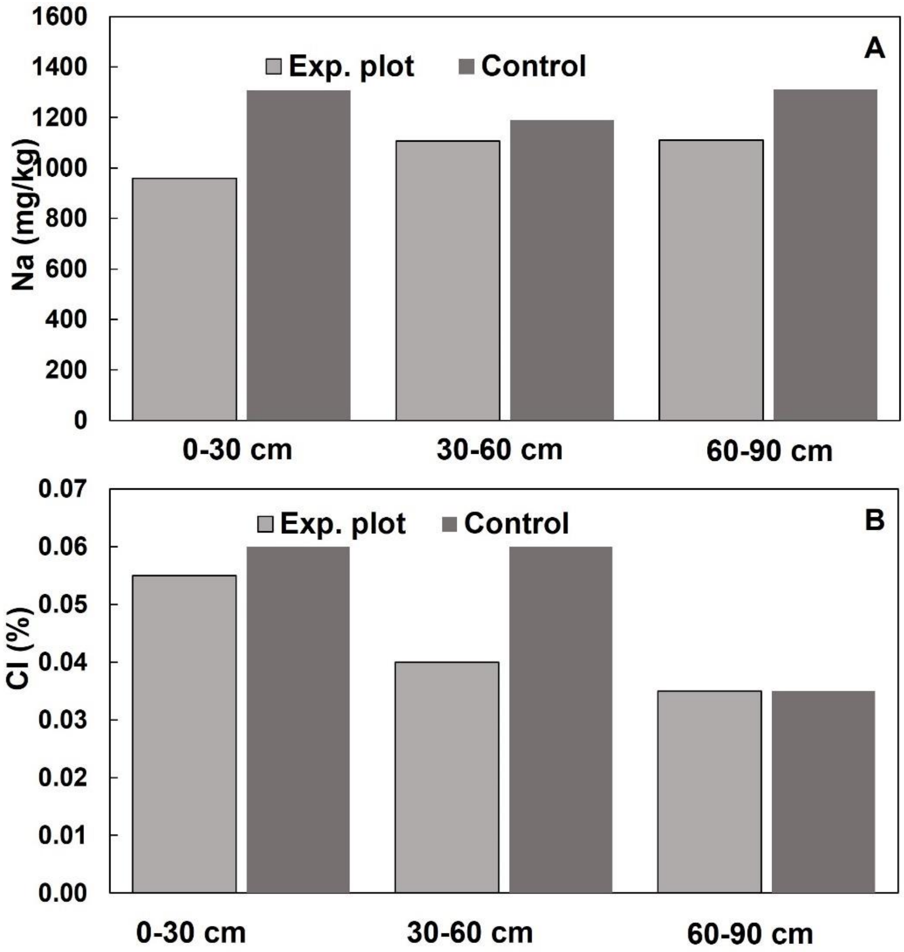

Figure 6.6. Variation in (A) Na and (B) Cl in the grapevine roots sampled from 0-30 cm, 30-60 cm and 60-90 cm soil depth layers at Lutzville.

6.3.2. Permanent wood

At pruning in July 2019, visual observation revealed that salts had precipitated on the grapevine trunks where diluted winery wastewater was applied for two seasons (Fig. 6.7).

Figure 6.7. Example of salt deposits on the lower section of grapevine trunks in the experiment plot at Spruitdrift in September 2019.

The Na, Mn and Fe in permanent wood sampled from grapevines in the shallow sand experiment plot at Spruitdrift in July 2019 was substantially higher compared to the control (Table 6.1). This indicated that the grapevine stored these elements in the permanent above-ground structure. Although grapevines in the experiment plot were irrigated with raw water from September 2019, the damage was still visible at the end of November 2019 (Fig. 6.8). Interestingly, high levels of Na in the 60-90 cm soil layer in the control, *i.e.* below the root zone, did not seem to have a negative effect on visual grapevine performance. After two years of irrigation with raw water, the levels of Na, Mn and Fe measured in the permanent wood in July 2021 at the Spruitdrift experiment plot (Table 6.2) were substantially lower compared to levels in July 2019. There were no general trends in the element contents of the permanent wood of grapevines growing in the experiment plot and control sections at Lutzville (Table 6.3).

Table 6.1. N, P, K, Ca, Mg, Na, Mn and Fe element contents in the permanent wood of grapevines growing in the experiment plot and control at Spruitdrift in July 2019.

	N	P	K	Ca	Mg	Na	Mn	Fe
			(%)				(mg/kg)	
Exp. plot	0.95	0.11	0.52	1.62	0.54	1400	207	2773
Control	0.70	0.09	0.53	1.45	0.31	700	99	813

Figure 6.8. Grapevine vegetative growth at the end of November 2019 (A) in the experiment plot where the in-field fractional use (augmentation) of winery wastewater with raw water was used for vineyard irrigation and (B) in the control where raw water was applied.

Table 6.2. N, P, K, Ca, Mg, Na, Mn and Fe element contents in the permanent wood of grapevines growing in the experiment plot and control at Spruitdrift in July 2021.

	N	P	K	Ca	Mg	Na	Mn	Fe
			(%)				(mg/kg)	
Exp. plot	0.59	0.11	0.42	0.48	0.17	805	47	384
Control	0.50	0.09	0.42	0.65	0.23	686	70	562

Table 6.3. N, P, K, Ca, Mg, Na, Mn and Fe element contents in the permanent wood of grapevines growing in the experiment plot and control at Lutzville in July 2021.

	N	P	K	Ca	Mg	Na	Mn	Fe
			(%)				(mg/kg)	
Exp. plot	0.56	0.08	0.37	0.63	0.13	182	37	357
Control	0.66	0.07	0.31	0.81	0.15	209	43	244

6.4. CONCLUSIONS

The accumulation of elements in the permanent structure of the grapevine at the Spruitdrift shallow sand experiment plot, particularly Na and Cl, could explain the poor response of the grapevines to the in-field fractional use (augmentation) of winery wastewater with raw water for vineyard irrigation. Under the prevailing conditions, the wastewater irrigation was terminated. Results showed that the levels of Na and Cl could decline in the permanent parts if the grapevines were irrigated with raw water. On the deep sand experiment plot at Lutzville, no detrimental effects of the in-field fractional use (augmentation) of winery wastewater with raw water for vineyard irrigation was observed. Soil analyses of samples collected from the Spruitdrift experiment plot after the winter of 2019 showed a substantial accumulation of salts and this particular soil/climate combination should be considered unsuitable for the long-term application of winery wastewater.

CHAPTER 7: RECOMMENDATIONS AND PROPOSED FUTURE RESEARCH WORK

7.1. RECOMMENDATIONS

Results indicated that winery wastewater can be a beneficial sources 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.

7.2. 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.

- 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.

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APPENDIX A
CAPACITY BUILDING

K Hoogendijk

Miss Karla Hoogendijk registered at the Stellenbosch University in 2017 to obtain a MSc. Agric (Soil Science) degree. Miss Hoogendijk investigated the long term effects of irrigation with treated wastewater on the soil chemical and physical status in commercial vineyards in the Coastal region; and the effect of irrigation with in-field fractional use of winery wastewater with raw water on selected soils and grapevines under different climates. Therefore, the title of her thesis was “Soil and grapevine responses to irrigation with treated municipal and winery wastewaters”. Her supervisor and co-supervisor was Dr Eduard Hoffman of Soil Science, Stellenbosch University and Dr Philip Myburgh of ARC, respectively.

The work of Miss Hoogendijk formed part of the general aim of the project to assess the fitness for use of augmented winery wastewater for irrigation of different soil types with varying rainfall quantities and leaching levels on vineyard performance in terms of yield and wine quality. Her work can be linked to the specific aim to determine the appropriate level of in-field augmentation of winery wastewater with raw water with specific reference to pH, EC, SAR/PAR and COD. The work can also be linked to the specific aim 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 augmented winery wastewater.

The work of Miss Hoogendijk can be linked to Deliverables 2 (First Annual Progress and Capacity Building Report), 3 (First Interim Report on Post-harvest Field and Laboratory Work), 4 (Second Annual Progress and Capacity Building Report), 5 (Second Interim Report on Post-harvest Field and Laboratory Work) and 11 (Final Report).

Miss Hoogendijk submitted her thesis to Stellenbosch University in December 2018 and she gave her thesis presentation on Monday 4 February 2019. She graduated in April 2019. The summary of her work, as given in the thesis, is provided below.

Abstract as given in published thesis of Miss Hoogendijk

In recent years, water scarcity and the ongoing drought have had serious implications for the agricultural industry in the Western Cape. The present study investigated the sustainability of two different types of wastewater for use as alternative irrigation water for grapevine production. The first objective was to assess the long-term effects of treated municipal wastewater irrigation on soils and grapevines in commercial vineyards in the Coastal region.

The second objective was to investigate the use of in-field fractionally applied winery wastewater with raw water for grapevine irrigation under different climatic conditions. To assess the impact of treated municipal wastewater irrigation on soil and grapevines, a long-term trial was conducted in commercial vineyards in the Coastal region of the Western Cape. Cabernet Sauvignon and Sauvignon Blanc grapevines were irrigated using treated municipal wastewater from the Potsdam wastewater treatment works for 11 years. Grapevines were either rainfed (RF), irrigated with treated municipal wastewater *via* a single dripper line (SLD) or received twice the volume of wastewater *via* a double dripper line (DLD). Irrigation using treated municipal wastewater increased soil pH and electrical conductivity (EC_e). Furthermore, an accumulation of chloride (Cl^-) was observed in the topsoil, probably due to the chlorine-disinfection process that is carried out as part of the treatment process at the wastewater treatment works. Appreciable amounts of sodium (Na^+) and potassium (K^+) also accumulated in the topsoil due to wastewater irrigation. However, this did not result in enhanced uptake by grapevines. The near-saturation hydraulic conductivity (K_{ns}) at the surface of the soil decreased as the EC_e in the topsoil increased, with the lowest K_{ns} recorded for the DLD treatments. The irrigation reduced water constraints throughout the growing season compared to RF conditions, particularly in the case of Cabernet Sauvignon. Consequently, the SLD and DLD grapevines produced stronger vegetative growth and higher yields compared to RF. The present study indicated that, with proper management, grapevines can be irrigated successfully using treated municipal wastewater.

Previous research has indicated that soil type and winter rainfall have a pronounced effect on salt accumulation where winery wastewater is used for irrigation. The present study investigated the short-term effects of irrigation using in-field fractionally applied winery wastewater with raw water on different soil types under different climates. Suitable experiment sites were identified in the Coastal, Breede River and Lower Olifants River wine production regions, due to their vast difference in climate. Within each region, two plots of differing soil textures were selected. One season of irrigation using fractionally applied winery wastewater with raw water did not have a pronounced effect on soil EC_e or soil organic carbon content (SOC). Variable amounts of plant nutrients were supplied to grapevines *via* the irrigation water. High K^+ concentrations in the wastewater resulted in an accumulation in the soil and a subsequent increase in extractable potassium percentage (EPP´). Under the prevailing conditions, irrigation using in-field fractionally applied winery wastewater did not have adverse effects on grapevine vegetative growth, yield or grape juice characteristics. However, further research is needed to assess the sustainability of this particular practice over the long-term.

L Mabongo

Mr Luvuyo Mabongo started off in the Soil and Water Science Division of ARC Infruitec-Nietvoorbij as an ARC intern for a year. Mr Mabongo did very well as a student intern within the division and was identified as having the potential to do further studies in soil and plant related sciences. Mr Mabongo was also keen to continue with post-graduate studies. Mr Mabongo was awarded a WRC/DST linked Water RDI Roadmap Bursary funding for 2019 and 2020 to work on the project.

Mr Mabongo registered at the North West University for a Master of Science in Crop Science. His supervisor is Professor Gestring from North West University. Dr Dimpho Elephant, a soil scientist who recently joined Professor Gestring's department, is a co-supervisor. Dr Carolyn Howell is also be a co-supervisor. The preliminary title of his thesis is "Effect of winery wastewater irrigation on selected soil chemical parameters and enzyme activities in three simulated irrigation seasons". The main focus of his work is to investigate the effect of winery wastewater irrigation on soil chemical parameters in four different selected soils, namely $pH_{(KCl)}$, $EC_{(e)}$, phosphorus (P), K, Ca, Mg, Na and soil organic carbon (SOC). Mr Mabongo has also investigated the effect of winery wastewater irrigation on β-glucosidase activity and phosphatase activity in four different selected soils. Four different soils from the greater project in the grape growing regions in the Western Cape Province were included in the study.

Determining effects of irrigation with winery wastewater on soils and crops in field experiments requires elaborate infrastructure (Myburgh *et al.*, 2014). Furthermore, field experiments are normally carried out with one specific soil type. Since different soils respond differently to winery wastewater irrigation (Mulidzi, 2001), it is essential to determine the effects of winery wastewater on soils that differ pedogenically. However, it would be too expensive to erect the required infrastructure for a range of soils under the same set of environmental conditions. Consequently, pot experiments seem to be an alternative to study effects of wastewater on soil responses because a range of soils can be included which can be irrigated with the same wastewater. Given that winery wastewater can be stored in tanks, pot experiments can continue throughout the year if the pots are sheltered from rain. This reduces the duration of experiments compared to field trials. If pot experiments are carried out correctly, drainage and leaching of elements can be avoided. Taking the above-mentioned into consideration, this study was a pot experiment to determine the effects of winery wastewater irrigation on soil chemical and microbiological responses of different soils, and formed part of the above-mentioned project on the use of winery wastewater for vineyard.

The pot experiment was carried out under a rain shelter at ARC Infruitec-Nietvoorbij. Pots of the four soils were irrigated with either wastewater or de-ionised water (control). In total, there were therefore eight treatments. Municipal water for the control treatments was used. For the wastewater treatments, undiluted winery wastewater was applied at 60% depletion. The COD in the undiluted wastewater and municipal water was measured using a spectrophotometer (Aqualitic COD-reactor®, Dortmund) with appropriate test kits (COD, CSB, 0-15000 mg/L). The eight treatments were replicated three times and applied over three simulated irrigation seasons. Each season consisted of six irrigations, which was estimated as the number of irrigations a vineyard would require during the harvest period, *i.e.* when the highest volumes of wastewater are produced. A total of 18 irrigations were applied over the three simulated irrigation seasons. Following each simulated season, *i.e.* after 6, 12, and 18 irrigations, the soil chemical and microbial status was determined.

The work of Mr Mabongo formed part of the general aim of the project to assess the fitness for use of augmented winery wastewater for irrigation of different soil types with varying rainfall quantities and leaching levels on vineyard performance in terms of yield and wine quality. His work could be linked to the specific aim to determine the appropriate level of in-field augmentation of winery wastewater with raw water with specific reference to pH, EC, SAR/PAR and COD. The work can also be linked to the specific aim 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 augmented winery wastewater. The work of Mr Mabongo can be linked to Deliverables 6 (Third Annual Progress and Capacity Building Report), 7 (Third Interim Report on Post-harvest Field and Laboratory Work), 8 (Fourth Annual Progress and Capacity Building Report and 11 (Final Report). Mr Mabongo will submit an Annual report in February 2020 on his work in Deliverable 13 according to the amended contract.

Mr Mabongo also assisted the project team with the field work of the greater project. When Mr Gert Malan left the employment of ARC on 31 May 2019, Mr Mabongo assisted the project team with the neutron probe measurements at all the sites. Assisting the project team he gained valuable practical experience in the field of irrigation. This built capacity within the Soil and Water Science division at ARC Infruitec-Nietvoorbij. Mr Mabongo was also incorporated into the professional environment within the division as all of the other ARC employees.

Mr Mabongo has completed all his experimental work and has almost finished writing his thesis. It will be submitted for examination soon.

T Sikhau

Ms Takalani Sikhau registered at Cape Peninsula University of Technology to do a Master of Agriculture. Her supervisor was Professor Lewu from Cape Peninsula University of Technology. Drs. Reckson Mulidzi and Carolyn Howell were co-supervisors. The preliminary title of her thesis was “Soil chemical and microbiological responses to irrigation with diluted winery wastewater in a Shiraz vineyard in the coastal region of South Africa”. The objectives of her study was to investigate the response of selected grapevine, soil nutrient and soil enzyme activities in a vineyard with different combinations of catch/interception and winter cover crops irrigated with diluted winery wastewater. The enzymes Ms Sikhau focussed on were β-glucosidase, phosphatase and urease activities. She analysed the soil for the enzymes in the soil microbiology lab at the Soil and Water Science division of ARC Infruitec-Nietvoorbij. Her work will be form part of the general aim of the project to assess the fitness for use of augmented winery wastewater for irrigation of different soil types with varying rainfall quantities and leaching levels on vineyard performance in terms of yield and wine quality. Her work can be linked to the specific aim to determine the appropriate level of in-field augmentation of winery wastewater with raw water with specific reference to pH, EC, SAR/PAR and COD. The work can also be linked to the specific aim 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 augmented winery wastewater. The work of Ms Sikhau can be linked to Deliverables 9 (Fourth Interim Report on Post-harvest Field and Laboratory Work) and 11 (Final Report).

Ms Sikau has submitted her thesis for examination and is currently waiting for feedback. She has also started to prepare scientific articles on her work.

APPENDIX B
KNOWLEDGE DISSEMINATION

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 Science 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.

A presentation was made at the 2020 Virtual SASEV Conference In November entitled "Quality and nutrient load of treated municipal wastewater with particular reference to grapevines – A case study" by C Howell, K Hoogendijk and P Myburgh.

PUBLICATIONS

The information was also disseminated through the following publications:
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.

At the Winetech Soil and Water Science 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.

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.

DATA AVAILABILITY

The raw, unprocessed data are available five years on compact disk from ARC Infruitec-Nietvoorbij. Any publication emanating from the research can be made available on request.

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APPENDIX C

TEMPERATURE

Appendix C.1. Comparison between long term mean (LTM) and the 2017/18, 2018/19, 2019/20 and 2020/21 seasons' maximum and minimum temperature measured by ARC-ISCW near Stellenbosch.

Month	T_x (°C)					T_n (°C)				
	LTM	2017/18	2018/19	2019/20	2020/21	*LTM*	2017/18	2018/19	2019/20	2020/21
September	*20.69*	21.88	19.16	24.29	20.16	*8.62*	8.90	6.66	10.20	7.18
October	*24.18*	23.40	26.83	24.17	24.36	*11.41*	9.38	13.37	9.86	9.73
November	*26.46*	26.17	28.10	26.42	25.67	*13.31*	12.87	13.31	12.62	13.75
December	*28.93*	29.90	28.72	27.62	28.01	*15.72*	16.37	14.51	14.96	14.70
January	*30.93*	31.50	30.04	30.06	30.93	*17.31*	17.44	15.22	16.70	16.87
February	*31.22*	31.88	32.00	31.65	30.43	*17.06*	16.43	17.29	17.21	16.24
March	*29.34*	27.79	28.22	29.52	27.45	*15.04*	14.83	14.93	14.28	14.71
April	*25.87*	25.69	25.26	25.81	28.37	*12.07*	12.19	11.70	11.20	11.53
May	*21.45*	21.79	22.96	23.86	21.63	*8.77*	9.45	8.55	7.40	7.77
June	*18.58*	18.17	19.76	19.69	20.44	*6.27*	7.33	5.49	6.79	6.96
July	*18.35*	20.38	17.30	19.97	17.29	*5.77*	5.79	6.97	3.85	4.34
August	*18.58*	16.92	19.38	17.09	17.84	*6.87*	4.95	5.63	5.19	4.97

Appendix C.2. Comparison between long term mean (LTM) and the 2017/18, 2018/19, 2019/20 and 2020/21 seasons' maximum and minimum temperature measured by ARC-ISCW near Robertson.

Month	T_x (°C)					T_n (°C)				
	LTM	2017/18	2018/19	2019/20	2020/21	*LTM*	2017/18	2018/19	2019/20	2020/21
September	*22.24*	23.73	20.77	26.92	22.75	*7.64*	8.29	6.81	8.65	7.00
October	*24.89*	24.83	29.44	26.57	25.88	*10.54*	8.45	10.86	10.33	10.13
November	*27.02*	26.17	28.84	28.94	27.36	*12.58*	11.70	11.21	12.50	11.99
December	*29.00*	29.08	31.24	29.78	30.41	*14.78*	14.22	14.45	13.29	13.79
January	*30.83*	30.76	31.33	30.43	32.47	*16.33*	16.11	14.61	16.29	15.60
February	*30.76*	31.48	31.98	32.24	32.45	*16.22*	15.37	16.45	15.70	14.66
March	*28.88*	27.40	29.17	30.33	29.43	*13.94*	13.07	15.06	13.44	13.30
April	*25.62*	26.13	26.14	27.82	28.14	*10.57*	10.71	10.36	8.65	10.92
May	*22.85*	23.56	24.52	26.94	23.67	*8.15*	8.47	7.33	6.71	7.56
June	*19.34*	19.89	21.79	22.15	22.04	*5.49*	5.81	4.75	6.27	6.89
July	*19.04*	21.03	20.69	21.59	18.80	*4.41*	4.99	5.99	3.94	3.14
August	*20.00*	18.51	22.52	18.87	19.73	*5.58*	4.35	4.71	4.76	6.45

Appendix C.3. Comparison between long term mean (LTM) and the 2017/18, 2018/19, 2019/20 and 2020/21 seasons' maximum and minimum temperature measured by ARC-ISCW near Lutzville.

Month	T_x (°C)					T_n (°C)				
	LTM	2017/18	2018/19	2019/20	2020/21	*LTM*	2017/18	2018/19	2019/20	2020/21
September	*23.60*	25.36	22.33	28.02	24.13	*8.21*	8.53	7.83	10.51	7.70
October	*25.91*	25.93	30.67	26.84	25.83	*10.29*	9.64	13.57	10.40	10.13
November	*27.56*	27.48	27.69	27.58	26.70	*11.81*	11.79	11.95	12.10	12.13
December	*28.62*	29.80	27.18	27.80	27.66	*13.89*	13.64	13.89	13.39	13.66
January	*29.97*	29.88	28.68	28.30	29.89	*15.14*	15.66	14.37	15.26	15.09
February	*30.28*	31.05	30.49	31.51	29.87	*14.91*	14.76	15.92	16.17	13.51
March	*29.34*	27.82	27.45	29.08	29.27	*13.44*	12.84	14.34	14.26	13.63
April	*27.76*	27.21	26.66	28.03	30.92	*11.98*	11.84	11.14	12.14	12.62
May	*24.15*	25.27	25.95	27.10	24.70	*10.10*	11.07	10.12	8.92	9.85
June	*20.61*	22.03	23.71	23.36	23.11	*7.92*	9.38	7.60	7.58	9.66
July	*21.00*	23.99	20.75	23.96	20.45	*7.14*	8.92	7.88	7.46	5.17
August	*21.39*	20.05	23.14	22.06	21.00	*7.14*	5.54	6.13	6.62	6.80

Appendix C.4. Comparison between long term mean (LTM) and the 2017/18, 2018/19, 2019/20 and 2020/21 seasons' maximum and minimum temperature measured by ARC-ISCW near Vredendal.

Month	T_x (°C)					T_n (°C)				
	LTM	2017/18	2018/19	2019/20	2020/21	*LTM*	2017/18	2018/19	2019/20	2020/21
September	*23.77*	25.36	21.49	28.19	24.04	*7.72*	7.77	6.52	9.54	6.47
October	*26.27*	26.13	30.26	27.42	26.46	*9.93*	9.39	13.22	9.81	9.40
November	*27.96*	28.22	27.86	28.68	27.13	*11.88*	11.51	11.25	11.75	11.63
December	*29.25*	30.69	27.43	28.58	28.83	*13.54*	13.73	13.43	13.32	13.25
January	*31.14*	30.29	29.33	29.47	31.37	*14.93*	15.49	13.67	14.84	14.73
February	*31.18*	31.22	31.32	32.75	31.26	*14.65*	14.71	15.28	15.94	13.13
March	*30.33*	27.62	27.86	29.84	29.98	*13.11*	12.49	13.70	13.65	12.86
April	*28.51*	26.70	26.60	28.04	31.41	*11.06*	11.52	11.13	11.46	11.86
May	*24.51*	24.19	25.70	26.97	24.50	*8.91*	10.03	9.05	7.53	8.35
June	*20.84*	20.94	22.94	22.96	22.51	*6.76*	8.33	5.81	6.79	8.30
July	*21.31*	22.81	20.17	23.39	19.67	*5.88*	7.20	6.21	5.94	3.74
August	*21.33*	19.11	22.78	20.23	20.78	*6.22*	4.73	4.89	4.79	5.46

APPENDIX D

RELATIVE HUMIDITY

Appendix D.1. Comparison between long term mean (LTM) and the 2017/18, 2018/19, 2019/20 and 2020/21 seasons' maximum and minimum relative humidity measured by ARC-ISCW near Stellenbosch.

Month	RH$_x$ (%)					RH$_n$ (%)				
	LTM	2017/18	2018/19	2019/20	2020/21	*LTM*	2017/18	2018/19	2019/20	2020/21
September	*91.15*	88.97	94.87	87.43	92.35	*48.69*	39.93	47.44	36.61	42.38
October	*86.45*	86.09	80.10	89.81	87.96	*43.67*	34.13	32.15	32.25	35.12
November	*84.01*	80.81	77.93	84.25	79.75	*39.49*	32.25	26.03	34.13	35.58
December	*81.78*	73.05	87.12	78.24	82.62	*37.48*	27.15	31.43	31.64	35.38
January	*81.29*	80.28	80.67	81.22	78.92	*36.55*	32.07	27.38	35.08	31.12
February	*82.50*	80.71	80.74	77.98	79.04	*37.33*	24.50	30.22	30.86	28.75
March	*84.06*	80.96	87.30	83.34	84.66	*37.04*	32.48	40.65	31.92	39.07
April	*86.49*	87.29	86.85	84.60	87.90	*41.81*	35.17	38.61	33.14	31.12
May	*92.94*	92.97	91.31	93.43	94.61	*51.91*	46.85	40.93	36.55	45.21
June	*93.94*	95.06	94.72	94.77	93.72	*56.56*	53.72	42.84	51.12	46.34
July	*93.30*	93.40	95.60	95.41	94.58	*51.90*	41.32	58.01	40.90	45.37
August	*92.30*	93.97	94.25	93.04	93.04	*50.73*	48.90	45.47	49.11	45.85

Appendix D.2. Comparison between long term mean (LTM) and the 2017/18, 2018/19, 2019/20 and 2020/21 seasons' maximum and minimum relative humidity measured by ARC-ISCW near Robertson.

Month	RH$_x$ (%)					RH$_n$ (%)				
	LTM	2017/18	2018/19	2019/20	2020/21	*LTM*	2017/18	2018/19	2019/20	2020/21
September	*90.30*	88.73	89.20	87.85	91.66	*42.20*	32.49	39.08	29.03	35.44
October	*90.11*	85.45	87.79	88.86	90.77	*45.70*	29.39	26.22	25.87	33.46
November	*87.71*	88.71	87.94	86.58	88.71	*40.81*	32.98	25.61	27.99	32.54
December	*87.81*	83.82	87.85	83.63	88.41	*42.91*	30.91	26.00	27.75	30.55
January	*87.63*	85.63	86.72	88.57	87.16	*40.34*	35.03	26.63	39.85	30.28
February	*87.92*	86.48	89.47	90.01	87.26	*38.64*	28.29	33.35	33.20	26.92
March	*89.75*	90.49	92.34	90.88	91.61	*39.97*	37.76	39.31	34.52	34.24
April	*91.53*	90.19	93.59	90.96	92.09	*41.58*	34.06	38.72	30.48	37.41
May	*91.90*	89.33	94.24	93.80	94.31	*45.89*	36.15	36.24	29.94	39.74
June	*92.20*	92.51	93.65	92.87	92.33	*46.36*	40.56	34.98	39.62	40.30
July	*92.30*	92.18	90.27	94.15	93.23	*46.57*	38.35	39.00	35.23	41.83
August	*90.90*	91.85	91.09	91.73	93.91	*44.16*	39.67	29.89	39.92	41.26

Appendix D.3. Comparison between long term mean (LTM) and the 2017/18, 2018/19, 2019/20 and 2020/21 seasons' maximum and minimum relative humidity measured by ARC-ISCW near Lutzville.

Month	RH$_x$ (%)					RH$_n$ (%)				
	LTM	2017/18	2018/19	2019/20	2020/21	*LTM*	2017/18	2018/19	2019/20	2020/21
September	*92.67*	90.31	93.33	84.47	94.26	*34.27*	31.25	38.43	28.37	32.37
October	*90.13*	85.07	76.83	91.18	90.53	*32.82*	29.26	25.27	28.84	35.75
November	*89.77*	88.89	86.81	89.64	88.55	*31.88*	32.17	30.24	31.85	36.70
December	*89.67*	86.69	91.00	88.11	91.80	*34.63*	30.46	40.40	35.11	38.45
January	*89.63*	89.30	89.57	91.60	90.17	*34.93*	36.79	37.19	43.53	37.41
February	*89.87*	87.44	89.84	88.91	90.84	*34.17*	31.70	38.72	36.01	35.67
March	*90.16*	91.93	92.42	91.69	91.48	*33.30*	37.29	45.59	38.24	37.15
April	*87.28*	92.57	91.49	89.59	87.50	*32.32*	36.53	36.24	32.47	31.13
May	*90.90*	89.37	91.35	90.68	92.84	*39.51*	37.34	35.22	29.70	40.15
June	*90.98*	89.19	87.89	92.00	90.64	*43.84*	44.06	33.46	36.75	42.88
July	*90.37*	83.30	94.67	89.24	91.48	*40.81*	33.65	47.24	30.09	39.55
August	*92.89*	94.78	93.58	95.62	94.11	*39.92*	38.14	34.41	35.12	38.88

Appendix D.4. Comparison between long term mean (LTM) and the 2017/18, 2018/19, 2019/20 and 2020/21 seasons' maximum and minimum relative humidity measured by ARC-ISCW near Vredendal.

Month	RH$_x$ (%)					RH$_n$ (%)				
	LTM	2017/18	2018/19	2019/20	2020/21	*LTM*	2017/18	2018/19	2019/20	2020/21
September	*92.67*	85.24	91.23	80.85	90.77	*34.27*	27.36	36.78	24.13	28.37
October	*90.13*	80.71	72.63	86.99	86.65	*32.82*	25.17	22.47	23.29	29.25
November	*89.77*	83.08	81.24	84.94	83.72	*31.88*	26.08	25.35	25.23	31.22
December	*89.67*	80.14	86.99	82.33	87.49	*34.63*	24.79	34.81	27.86	30.05
January	*89.63*	84.63	86.05	87.00	84.74	*34.93*	31.17	30.34	34.38	29.15
February	*89.87*	82.34	85.59	84.24	85.15	*34.17*	26.78	31.53	27.76	26.83
March	*90.16*	87.38	88.74	86.47	87.65	*33.30*	32.69	38.82	30.71	30.55
April	*87.28*	88.57	86.90	85.93	82.63	*32.32*	33.05	31.07	27.91	24.36
May	*90.90*	86.34	88.37	86.72	89.43	*39.51*	35.27	31.00	25.21	35.47
June	*90.98*	88.04	87.84	88.74	88.50	*43.84*	42.98	31.25	32.44	39.40
July	*90.37*	83.18	92.33	86.63	90.51	*40.81*	32.28	44.02	28.06	37.76
August	*92.89*	92.53	90.05	90.68	90.56	*39.92*	36.26	30.48	34.59	34.19

APPENDIX E
WIND SPEED

Appendix E.1. Comparison between long term mean (LTM) and the 2017/18, 2018/19, 2019/20 and 2020/21 seasons' wind speed measured by ARC-ISCW near Stellenbosch.

Month	U_2 (m/s)				
	LTM	2017/18	2018/19	2019/20	2020/21
September	*2.15*	1.70	0.91	1.36	1.26
October	*2.63*	1.58	1.92	2.99	1.59
November	*2.88*	2.35	2.04	1.89	1.84
December	*3.15*	2.76	1.47	1.22	1.97
January	*3.29*	2.56	2.18	2.32	2.20
February	*3.18*	2.36	2.10	2.20	2.05
March	*2.85*	2.12	1.70	1.65	1.46
April	*2.33*	1.54	1.51	1.22	1.23
May	*1.81*	0.88	1.17	0.69	0.64
June	*1.75*	0.93	0.94	0.61	0.73
July	*1.83*	0.68	0.98	0.66	0.66
August	*1.97*	1.01	0.93	0.98	0.97

Appendix E.2. Comparison between long term mean (LTM) and the 2017/18, 2018/19, 2019/20 and 2020/21 seasons' wind speed measured by ARC-ISCW near Robertson.

Month	U_2 (m/s)				
	LTM	2017/18	2018/19	2019/20	2020/21
September	*2.01*	1.77	2.14	1.66	1.93
October	*2.07*	2.15	1.62	2.11	1.45
November	*1.91*	1.70	1.63	1.92	1.82
December	*1.80*	1.64	2.03	2.18	1.61
January	*1.75*	1.62	1.87	1.44	1.59
February	*1.67*	1.53	1.37	1.46	1.42
March	*1.52*	1.28	1.23	1.16	1.46
April	*1.37*	1.47	1.17	1.34	0.88
May	*1.53*	1.79	1.19	1.06	1.20
June	*1.64*	2.13	1.86	1.38	1.57
July	*1.57*	1.19	2.76	1.36	1.67
August	*1.96*	1.80	2.14	2.11	1.36

Appendix E.3. Comparison between long term mean (LTM) and the 2017/18, 2018/19, 2019/20 and 2020/21 seasons' wind speed measured by ARC-ISCW near Lutzville.

Month	**U_2 (m/s)**				
	LTM	**2017/18**	**2018/19**	**2019/20**	**2020/21**
September	*2.16*	2.47	2.39	2.70	2.38
October	*2.44*	3.04	3.45	2.83	2.78
November	*2.71*	3.02	3.21	2.93	3.28
December	*2.66*	3.14	2.82	3.16	2.90
January	*2.69*	3.14	3.07	2.85	3.21
February	*2.45*	2.90	2.80	3.08	3.00
March	*2.15*	2.45	2.33	2.58	2.31
April	*1.93*	2.10	2.15	2.09	2.05
May	*1.73*	1.83	1.77	1.74	1.72
June	*1.76*	1.91	1.93	1.99	1.99
July	*1.75*	2.35	1.97	2.38	1.91
August	*1.95*	2.13	2.04	2.16	2.20

Appendix E.4. Comparison between long term mean (LTM) and the 2017/18, 2018/19, 2019/20 and 2020/21 seasons' wind speed measured by ARC-ISCW near Vredendal.

Month	**U_2 (m/s)**				
	LTM	**2017/18**	**2018/19**	**2019/20**	**2020/21**
September	*2.49*	2.36	2.09	2.27	1.86
October	*3.05*	3.07	3.19	2.76	2.24
November	*3.47*	3.38	3.26	3.05	2.96
December	*3.48*	3.45	3.11	3.35	3.04
January	*3.42*	3.59	3.38	3.19	3.13
February	*3.15*	3.27	2.90	2.80	3.04
March	*2.73*	2.71	2.61	2.34	2.15
April	*2.26*	2.07	2.16	1.64	1.63
May	*1.85*	1.56	1.46	1.42	1.26
June	*1.84*	1.57	1.54	1.44	1.27
July	*1.74*	2.35	1.55	1.63	1.20
August	*2.07*	1.92	1.49	1.66	1.57