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Effect of chemical oxygen demand on the ability of some cover crops to prevent mineral accumulation in a sandy vineyard soil irrigated with augmented winery wastewater

by

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DECLARATION

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ABSTRACT

During the past years government regulations concerning winery effluent became stricter to protect the environment. Wineries are continually improving wastewater management and finding appropriate ways to reduce cellar effluent. Due to water scarcity in South Africa, it could be a huge advantage if winery effluent could be used as irrigation water for vineyards. If the industry can re-use the untreated wastewater, it will not only save a huge amount of irrigation water, but it will also be able to get rid of the vast amount of cellar effluent.

Grape production plays a major role in agriculture worldwide. The world production of grapes worldwide in 2013 was 751 MgL. South Africa is the 9th biggest wine producer in the world with 10 X 10HL of wine.

In the earlier years of wine production in South Africa, the small volumes of winery wastewater did not have a negative impact on the environment but with the increased volumes over the last years, the possibility of contamination of the soil and the environment has increased. Government decided to regulate the irrigation of cellar effluent with the National Water Act of 1998 as approved by the Department of Water Affairs (DWAF).

There are different ways to get rid of cellar effluent. One successful way is by constructed wetlands where plants are used to break down minerals which could be detrimental to the environment. This is a successful way to get rid of cellar effluent but could take up to six weeks before the mineral contents can be broken down by the plants. Another way is to use bio-reactors to break down the contents of the cellar effluent, but this is expensive.

Wastewater consists of important nutrients needed for plant growth such as macro-nutrients like N, P, K and micro-nutrients like Fe, Zn, Mn and Cu and a substantial amount of organic matter. If cellar water, just like domestic wastewater is used for irrigation the farmer can save water when he uses less fertiliser, because of the high nutrient content in the cellar effluent.

If cover crops such as oats (*Avena sativa* L. cv. Pallinup) in winter and pearl millet (*Pennisetum glaucum* (L.) R. Br.) in summer can be used to remove excess cations, as well as unwanted chemicals such as toxic metals from the soil, it may result in effluent water with a higher chemical oxygen demand (COD) level than the current legal limitations that can be used to irrigate the vineyard. The aim of this project was, therefore, to determine the ability of oat and pearl millet cover crop to remove excess minerals from the soil irrigated with augmented water at different COD levels, without a negative effect on growth and yield of the vineyard or wine quality. Field trials were carried out in a Cabernet Sauvignon/99 Richter vineyard established on a sandy soil at the Goudini Cellar near Rawsonville.

The oat and pearl millet cover crops were irrigated at different COD levels to evaluate their potential to extract minerals with high concentrations which can be detrimental to the vineyard. Ten treatments were replicated three times in a randomised block design: two with raw water and eight using augmented water. The augmented water treatments were mixed with clean water in tanks to achieve COD levels ranging from 100 mg/L to 3000 mg/L. The effect of the different COD levels of the cellar effluent on the cover crops and the soil were determined.

The winery effluent did not have a negative effect on the growth of oat (*A. sativa*) and pearl millet (*P. glaucum*). The oat and pearl millet showed high potential to accumulate N and K. The pearl millet removed higher concentrations of P, Ca and Mg in the soil than the oats. Sodium was not successfully removed by oat and pearl millet in 2011 and 2012. High levels of sodium in the soil can give salinity problems. It is advised that cellars use KOH based cleaning agents instead of NaOH in the cellars.

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GLOSSARY

%	percentage
AA	Varian Spectr AA flame spectrophotometer
As	arsenic
ARC	Agricultural Research Council
B	boron
BOD	biological oxygen demand
°C	grade Celsius
Ca	calcium
Cd	cadmium
CEC	cation exchange capacity
COD	chemical oxygen demand
CO_2	carbon dioxide
Cr	chromium
Cu	copper
DWAF	Department of Water Affairs
EC	electrical conductivity
Fe	iron
ha	hectare
Hg	mercury
HL	hectoliter
K	potassium
kg/ha	kilogram per hectare
KOH	potassium hydroxide
LSD	least significant difference
L	litre
m^3	cubic meter

Mg	magnesium
mg/L	milligram per litre
MgL	megaliters
ml	millilitre
mm	millimetre
Mn	manganese
mS/m	milli Siemens per metre
Mql	thousands of quintals
N	nitrogen
Na	sodium
NaOH	sodium hydroxide
NS	not significant
O_2	oxygen
p	value
P	phosphorus
Pb	lead
pH	alkali or acid range from 1 to 14
ppm	parts per million
SAR	sodium adsorption ratio
SO_4	sulphate
t	tonne
t/ha	tonnes per hectare
Zn	zinc

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CHAPTER 1
GENERAL INTRODUCTON

1.1. Introduction

South Africa is a country with limited water supply. The long term average rainfall in South Africa is 450 mm per year in comparison to 860 mm in the rest of the world. Sixty five percent of the surface area receives less than the 450 mm needed for dry land agriculture. The dry west of South Africa (21% of the total surface area) receives less than 200 mm per annum (Bhaktawar *et al.,* 2012). Considering the climate of South Africa, the ever increasing population and the demand on the industrial and agricultural water need, it is evident that drastic measures are needed to meet future demands.

Grape production plays a major role in agriculture worldwide. The production of grapes worldwide in 2013 was 751 MqL (OIV, 2013). South Africa is the 9th biggest wine producer in the world with 10 X 10 HL of wine (OIV, 2013).

Wine cellars in South Africa and the rest of the world are getting rid of cellar effluent by means of constructed wetlands (Mulidzi, 2005). In these wetlands, plants such as cattails (*Scirpus* spp), bulrush (*Typha spp*) and reeds (*Phragmites* spp) which have the ability to accumulate toxic elements from cellar effluent (Mulidzi, 2008) are planted. Cellar effluent may also be processed by bioreactors to break up toxic elements in the effluent before it is safely distributed to the environment, but this can be costly.

It was stated by Van Schoor (2005) that in South Africa, 95% of the wineries were irrigated with wastewater through sprinkler systems in the earlier years. If a cellar wants to irrigate his cellar effluent, it must be done according to requirements of the National Water Act of 1998 and approved by the Department of Water Affairs (DWAF) (Van Schoor, 2005).

All winery wastewater contain organic material. The amount of organic material present is most usefully expressed in terms of the amount of oxygen required to oxidise (break down) the organic material in a given volume of the wastewater (Mulidzi *et al*., 2009). This requirement is known as the chemical oxygen demand (COD), and is expressed in mg of oxygen per litre of water (mg 0_2/L). Government regulations indicate that COD levels in winery wastewater may not exceed 5000 mg/L (Van Schoor, 2005). The accuracy of this value has, however, not been determined. Should research show that 5000 mg/L is conservative, a new limit could be proposed. Adoption of a higher limit would result in enormous cost savings to the wine grape industry through reduced wastewater processing costs.

1.2. The use of cover crops, pearl millet (*P. glaucum*) and oats (*A. sativa*) to accumulate minerals from irrigated cellar effluent

The effect of winery wastewater irrigated on pearl millet (Fig. 1.1) was tested in a glasshouse study by Mosse *et al*. (2010). The results showed that the cellar effluent did not have a negative effect on pearl millet, but it also showed the necessity to give extra irrigations with clean water. In our study pearl millet and oats were given clean water when there was no cellar water available to irrigate.

Figure 1.1. Pearl millet in the vineyard at Rawsonville

According to Han *et al*. (2013), *A. sativa* (Fig. 1.2) has the potential to absorb and accumulate minerals from the soil. It was decided to use pearl millet as a summer crop and oats as a winter crop as suggested by Agricol, which is a seed company.

Figure 1.2. Oats in the vineyard at Rawsonville

1.3. Motivation for this study

If it can be demonstrated that wineries can re-use their wastewater without a detrimental effect to the vineyard and the nearby environment, irrigation water will be saved and the disposal of winery wastewater will become easier and cheaper. Therefore the objective of this study was to evaluate the potential of oats, *A. sativa* L. cv. Pallinup, and pearl millet, *P. glaucum* (L.) R. Br. to remove macro- and micro-nutrients from the irrigated cellar effluent in the soil at different COD concentrations from 100 mg/L to 3000 mg/L and to decide what is the highest COD level that is safe to use for irrigation.

If cellar effluent could be successfully irrigated in vineyards, it will solve the problem to get rid of cellar effluent effectively. It will prevent the storage of cellar effluent in a catchment area for weeks before being distributed to the environment. If cellar effluent could be used for irrigation without having a detrimental effect on the vineyards or the soil, more cellar effluent could be removed in this manner than all the other techniques put together. All cellars have vineyards available to which the winery wastewater could be distributed. Many plants have been indicated by researchers of their ability to accumulate toxic minerals (phytoremediation) in different field locations (Mulidzi, 2008; Raskin, 1997).

1.4. The scope of the thesis

The oats and pearl millet cover crops were irrigated at different COD levels to evaluate their potential to extract minerals with high concentrations which can be detrimental to the vineyard. Ten treatments were replicated three times in a randomised block design: two treatments with raw water and eight treatments using augmented water. The augmented water was mixed with clean water in tanks to achieve COD levels ranging from 100 mg/L to 3000 mg/L. The effects of different COD levels of the cellar effluent on the cover crops and the soil were determined and how effective could the cover crops accumulate the minerals from the soil especially K and Na.

1.5. Structure of the thesis

The thesis consists of a general introduction (Chapter 1) and a literature study (Chapter 2). Chapter 3 evaluates the potential of the cover crop, *A. sativa* L. cv. Pallinup (oats) to remove macro- and micro-elements from the vineyard soil irrigated with cellar effluent from 2010 to 2012. Chapter 4 reports the potential of the cover crop, *P. glaucum* (L.) R. Br. (Pearl millet) to remove macro- and micro-nutrients from the soil from 2011 to 2012. Chapter 5 evaluated the combination of oats and pearl millet to remove macro- and micro-nutrients from the soil with a special emphasis on the effect in the soil. Chapter 6 is a concluding summary of the whole study.

1.6. References

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CHAPTER 2
GENERAL LITERATURE STUDY

2.1. Introduction

Most parts of South Africa can be described as semi-arid with approximately 65% of the country receiving less than 450 mm rain (Bhaktawar *et al.,* 2012). In regions with summer rainfall, the amount of evapotranspiration will be high, causing a decrease in the run-off and accessible water for agriculture and human consumption (Binns *et al.*, 2001). In 2010 the total yearly water usage in South Africa was 22,400 million m^3, of which 50% was used for irrigation (Agholor, 2013). South Africa's population is increasing by approximately 1.7 % each year, lower than most other African countries but higher than Western Europe and North America (Binns *et al*., 2001).

South Africa is a country with a limited water supply. South Africa is the 29th country out of 193 countries with a drought record, and it was estimated in 2005 that there is 1110 m^3 water for every individual yearly (Muller *et al*., 2009). With the higher demand on South Africa's water reserves in future by both the population and industry there is a need to find new ways to conserve water and re-use wastewater in agriculture.

2.2. Cellar effluent generated by the wine industry in South Africa

In South Africa there was 103 093 hectares under wine production in 2013 with 3323 grape producers (Table 2.1) and 564 wine cellars. The wine production of South Africa was 1, 156,9 million litres of wine in 2013 (SAWIS, 2014). According to Lagoudi *et al*. (2004), two to fourteen litres of cellar effluent could be produced to make one litre of wine. This means that between 2, 313.8 million and 16, 196.6 million litres cellar effluent is generated annually by the wine cellars. If the wine industry can use the cellar effluent for irrigation, a huge amount of water can be saved and made available for personal use, industries and agriculture that would also contribute towards economic viability of wine production in the country.

Table 2.1. Number of wineries in South Africa with production category in 2013

TONS	NUMBER OF PRODUCERS
100	1 249
100 – 500	1 216
500 – 1000	429
1000 – 5000	416
5000 – 10 000	13
Total wineries	3 323

Source: SAWIS (2011)

If cellar effluent could be used for irrigation of crops, it has the potential to save rainwater but more importantly create an opportunity to get rid of huge amounts of cellar effluent in a

responsible way (Laurenson *et al.*, 2011). In 2013, 123 624 ha land was used to produce 1,095 million litres of grape juice for the production of 79.1% wine, 3.6% brandy, 12.2% distilling wine and 5.1% grape juice concentrate (SAWIS, 2014).

New strategies need to be researched that will help ensure a sufficient supply of water for future generations. If winery effluent could be safely used for irrigation, it would rid the cellars of their wastewater, whilst helping to reduce water usage in the agricultural sector.

2.3. Composition of cellar effluent

The most significant components of grapes which have a negative effect on the environment is the wastewater solids present in cellar effluent such as berry skins, seeds, bunch stems, lees, used filter material and sediment (Van Schoor, 2005). Solid waste produces bad smells, could pollute the environment and suppress the growth of plants (Conradie *et al*., 2014). Wastewater can increase the salt concentrations of natural water habitats such as dams, rivers, soil water or wetlands. During the harvest period (approximately 6 to 20 weeks), the grapes are crushed and fermentation takes place. During the post-harvest period other ingredients such as bentonite and filtration substances generate more cellar waste. These materials are gathered and worked into the vineyard soil as a compost layer.

During the wine-making process of white wine the grape juice is removed from the grapes before fermentation which gives the marc a high sugar and N concentration. When red wine is made the grape skins is left in the wine during fermentation which results in a low sugar and tannin content (Laurenson & Holbrouke, 2012). Winery wastewater has high amounts of Na and K because of the cleaning products used, grape deposits and waste from the winemaking process. When vines are irrigated with winery wastewater the amount of K applied is more than that which the grapevine consumes (Laurenson *et al.*, 2011).

Na, K, Ca, Mg and Fe had the highest concentrations in the cellar effluent (Sheridan *et al.*, 2011), (See Table 2.2). The K levels of the cellar effluent increase substantially during the harvest peak and return to normal after harvest. Potassium is an important element in grapes and contributes significantly to the grapevine metabolism. The Na levels remained the same throughout the year because the same water source and cleaning agents were used. An excessive uptake of Na^+ could reduce the uptake of Ca^+ and Mg^+ which may cause a deficit in vineyards (Laurenson *et al.,* 2011). They also indicated that a high Na^+ concentration in white wine could decrease the pH and have a negative effect on wine quality with higher amounts of phenolic substances in white wines. The COD was high from the start of the harvest until the middle of the harvest but at a lower level from the middle of the harvest to the end of the harvest (Sheridan, *et al.*, 2011). An example of the composition of winery wastewater is shown

in Table 2.2. (Sheridan *et al.*, 2011). Cr, B and As elements were not present in the effluent of the cellar. Zn, Cu, Mn and Pb were present in negligible amounts in the winery wastewater.

Table 2.2. The composition of cellar effluent at a cellar as determined by an initial investigation at the beginning of the harvest season

Component	Concentration[1] (mg/L)	Standard deviation (mg/L)
Zn	0.71	0.00497
Mg	12.3	0.0123
Ca	59.3	0.5337
Na	54.5	0.109
K	82.9	0.1658
Cu	0.03	0.00612
Fe	21.35	0.06405
Mn	0.29	0.00203
Cr	Not detected	Not detected
Pb	0.11	0.02541
B	Not detected	Not detected
As	Not detected	Not detected

Source: Sheridan *et al*. (2011)

[1] Metals in solution was measured by atomic absorption (AA) using a Varian Spect AA flame spectrophotometer.

The biochemical oxygen demand (BOD) is the amount of oxygen that bacteria takes from water when the organic matter is oxidised and it is expressed as mg/L or parts per million (ppm). The test is done at a specified temperature (usually at 20°C) and the time that it takes is normally 5 days (thus BOD_5). The COD is the measurement of the oxygen which corresponds with the organic substance matter of a sample that was oxidised by a strong oxidant (Attiogbe, *et al.*, 2007). The BOD is used to measure the level of the organic pollution in wastewater, but it is a difficult measurement taking five days and therefore it is better to use the COD method in the laboratory in about one hour.

Legislation specify that recycled water must be in a pH range of 5.5 - 7.5 and the COD should not be more than 75 mg/L when more than 2000 m^3/ha/day is irrigated and not more than 5 000 mg/L when less than 50 m^3/ha/day is being irrigated (South African Water Act, no. 36, 1998) before it may be released into the natural habitat (Malandra *et al.*, 2003). It was found that winery wastewater normally has a pH of between 3 and 4, and a COD level of 800 - 12

800 mg/L. However, on the harvest load and processing activities the COD levels can increase to 25 000 mg/L (Malandra *et al.*, 2003).

Accessibility of N to vines fluctuate very much as it is influenced by soil temperature, pH and exposure to air and water (Laurenson *et al.,* 2011). Grapevines are perennial and require substantially lower amounts of P than annual crops. Therefore, P deficits are rare. The high levels of K in the winery wastewater can result in poor wine quality. This is caused by the production of insoluble potassium bitartrate and a reduction in the accessible tartaric acid component (Laurenson *et al*., 2011). If soils have a high Na content, it may result in more Na being absorbed by the grapevine and less Ca and Mg being available for the vineyard, which may lead to Ca and Mg deficiencies.

2.4. Irrigation with cellar effluent

Government passed regulations stipulating the way in which a cellar may distribute cellar waste. This law prescribed the legal limits for COD, pH, electrical conductivity (EC), sodium adsorption ratio (SAR) and *Eschericia coli* in the cellar effluent with different maximum irrigation volumes (Table 2.3).

Table 2.3. Legislated limits for COD, pH, EC, SAR and *E. Coli* restriction for irrigation with wastewater in South Africa

Parameter	Maximum irrigation volume allowed (m^3/ha/day)		
	< 50	**< 500**	**< 2000**
COD (mg/L)	5000	400	75
pH	6-9	6-9	5.5-9.5
EC (mS/m)	200	200	70-150
SAR	< 5	< 5	Other criteria apply
E. coli	> 100 000 by 100ml in any amount of m^3/ha/day		

Source: Adapted from Van Schoor (2005)

Untreated cellar effluent may not be discarded in the natural water environment and must therefore be treated or used for irrigation (Van Schoor, 2001). If any person on any day uses more than 10 m^3 of water for any fruit and vegetable production, wine cellars, fisheries or household irrigation, he or she must register as a water user and is allowed to use 500 m^3 of water each day (for crop production, including pastures). The following guidelines must be adhered to: If the COD is higher than 400 mg/L but lower than 5000 mg/L, a registered water user may irrigate on any day without a licence. These irrigations may only be applied above the 100 year flood-line, or further than 100 meter from a water resource or borehole that is

used for normal drinking water or used by cattle, whichever distance is the furthest, when no contamination of soil water or shallow water should be expected. Records must be kept on a weekly basis of the amount and quality of the water used (van Schoor, 2005).

With the use of wastewater for the irrigation of field crops in dry regions, both nutrients and toxic chemical substances could be applied in high concentrations to the soil-plant systems. This could impact negatively on the production and quality of the crops and the soil (Rusan *et al*., 2007). Therefore, when irrigating with wastewater, the soil and crop nutrient content should be monitored and soil fertility boundaries should be kept in mind.

2.5. Management of cellar effluent

The South African wine industry, in collaboration with the Agrochemical Industry, Universities, Wine and Spirit Board and ARC-Infruitec-Nietvoorbij compiled a set of standard guidelines in 1998 to which the wine industry must abide which was called the Integrated Production of Wine (IPW). The IPW guidelines include guidelines for the disposal of solid waste and sludge from wastewater dams in accordance with national legislation (Tromp *et al*., 2005).

The South African government has also provided legislation to conserve the natural reserves and protecting the environment. Acts were pursued in parliament to manage the water of South Africa, namely the Constitution of the Republic of South Africa (Act 108 of 1996), the Environment Conservation Act (Act 73 of 1989), the National Environmental Management (Act 107 of 1998) and the National Water Act (Act 36 of 1998) (Hayward *et al*., 2000). A cellar may not operate unless an environment impact study according to Article 21 of the Environment Conservation Act (Act No 73 of 1998) has been done of the cellar's operations (Van Schoor, 2001).

According to a study done by Mosse *et al* (2011) in Australia, when a sodium based cleaning agent such as sodium hydroxide (NaOH) is used in the cellars, there is a high possibility that the Na cations will build up in the soil when cellar effluent is irrigated in vineyards. On the other hand, according to Mosse *et al*. (2011) calcium and magnesium may reduce the amount of sodium uptake by the vineyard and decrease the sodium adsorption ratio (SAR). High amounts of Na accumulated in grape vines will suppress Ca^{2+} and Mg^{2+} uptake with a negative impact on wine growth. Na in grapes has the potential to decrease the wine pH and lead to higher amounts of unwanted phenolic compounds in white wine varieties (Laurenson *et al*., 2011). Mosse *et al*., (2011) recommended the potassium hydroxide (KOH) should rather be used instead of NaOH. KOH is not very much more expensive than NaOH in South Africa. If KOH is being used rather than NaOH sodium cannot be deposited in the soil.

High levels of organic wastewater material in wastewater can block the soil pores which can prevent water reaching the plant roots. Cellar effluent with a high organic matter and a high salinity may have a negative effect on soil if large quantities is exposed to land (Mosse *et al.*, 2011). Van Schoor (2005) indicated that treated cellar effluent up to 2000 m^3/ha/day may be irrigated under the following conditions:

- Faecal coliforms may not be more than 1000 per 100 ml.
- COD must not be more than 75 mg/L.
- pH range must be between 5.5 and 9.5.
- Ammonia (ionised and un-ionised), as nitrogen, may not be more than 3 mg/L
- Nitrate/nitrite (nitrogen) may not be more than 15 mg/L.
- Chlorine, (free chlorine) may not be more than 0.25 mg/L.
- Particles in suspension must not be more than 25 mg/L.
- Ortho-phosphate may not be more than 10 mg/L.
- Fluoride may not be more than I mg/L.
- Soaps, oils and greases may not be more than 2.5 mg/L.

The EC of the water that is used in the winery may not escalate by more than 70 mS/m. This means that if the water that is pumped from a borehole is 20 mS/m, the EC of the water leaving the winery may not be more than 90 mS/m. Irrespective of the EC of the water entering the winery, the wastewater's EC may not be more than 150 mS/m.

2.6. The accumulation of standard and heavy metals by cover crops (Phytoremediation)

The term phytoremediation ("phyto" meaning plant and the Latin suffix "remedium" meaning to lean or restore) actually refers to the removal of contaminating ingredients from the soil by plants and retaining it (Cunningham *et al*., 1997). Phytoremediation is a process where a plant extracts specific chemical elements with its roots from its surroundings (Raskin *et al*., 1997). These ingredients can be metals from cellar effluent, mining industries or petroleum products. Phytoextraction occurs when plants take up metals from the soil and move them through the plant system to the shoots. The contaminated shoots can then be removed and discarded in a responsible way. If the environment has a high percentage of toxification, it is impossible for plants to remove all chemicals by a phytoremeditive method. When this situation occurs, other methods could be used additionally to solve the problem.

2.7. The performance of oats (*A. sativa* L. cv Pallinup), as a cover crop to take up minerals

Oats have the ability to produce dry material over the long term under different climatic conditions. *Avena sativa* L. v. Overberg ('Overberg' oats) gave an average of 4.87 t/ha in a trial over a period of 10 years on a Nietvoorbij farm near Stellenbosch (Fourie *et al.*, 2006a). The average production of *Avena strigosa* L. v Saia (Saia oats) was 2.92 t/ha from the 1993/94 to the 2002/03 seasons on a sandy soil at Nietvoorbij research farm near Lutzville (Fourie *et al.*, 2005). The production of two oats species 'Overberg' and 'Saia' oats at the Nietvoorbíj Research farm near Robertson research farm was on an average of 6.52 t/ha (1991), 761 t/ha (1992) and 6.48 t/ha (1991), 7.29 t/ha (1992), respectively (Fourie *et al.*, 2006b). The species should preferably be sown during the beginning of April at a seeding density of 100 kg/ha (Fourie, 2000). Weekly irrigation of 18 mm up to 10 weeks after seeding followed by fortnightly irrigations of 18 mm until the end of August promoted and facilitated maximum growth (Fourie *et al.*, 2006b).

The nutrient content of oats for seven and fifteen weeks after emergence is shown in Table 2.4. The N and K levels of seven weeks after emergence was 4.66% and 3.84% and fifteen weeks after emergence was 3.15% and 2.56% respectively (Bezuidenhout, 2012). According to Bezuidenhout this indicated that the oats has the potential to extract significant amounts of N and K from the soil. The Na content of 1005 mg/kg was high after seven weeks after emergence but it decreased to 241.2 mg/kg after fifteen weeks. This is an indication that oats have the potential to extract higher amounts of Na from the soil during the first seven weeks than later during their growth period.

Table 2.4. Nutrient content of oats, 7 and 15 weeks after emergence

Treatment	Ca	Mg	N	P	K	Na	S	Zn	Cu	Fe	Al
	(%)					(mg/kg)					
Seven weeks after emergence											
Oats	0.36	0.25	4.66	0.47	3.84	1005.0	0.19	46	20.6	224	131
Fifteen weeks after emergence											
Oats	0.74	0.40	3.15	0.27	2.56	241.2	1.10	20	3.2	78	34

Adapted from Bezuidenhout, 2012

2.8. The performance of pearl millet, *P. glaucum* as a cover crop to take up minerals

P. glaucum can adapt to a variety of soil and climatic conditions because it can survive without water for a long time (Al-Suhaibani, 2011). Pearl millet can be grown in low quality soils with minimum irrigation or rain (500 mm per annum) but it prefers sandy or light loam soils (Cook, 2005). The species will grow in clay soils with good infiltration but saturated soils impact negatively on their growth. A pH range of 5.5 - 7.0 is preferred but it will grow in soils with a pH as high as 8.3 and as low as 4.5. Fertiliser rates of 20 to 30 kg/ha P and 40 to 50 kg/ha K before sowing will increase performance. In some cases where a high amount of fibre is removed from the field, a follow-up application of 20 to 30 kg/ha P and up to 100 kg/ha K may also improve growth and levels of performance. A good production level can be maintained if 50 kg/ha N is given after every harvest. The mineral content of Mn, P and K was 190 mg/100g, 339 mg/100g and 418mg/100g, respectively (Table 2.5) which indicated that pearl millet has a good potential to extract minerals from the soil.

Table 2.5. Mineral composition of pearl millet

Mineral	(mg/100g)
Calcium	37
Copper	9.8
Iron	114
Manganese	190
Magnesium	0.8
Phosphorus	339
Potassium	418
Sodium	15
Zinc	2.0
Chloride	43

Source: Obilana (2011)

Treated effluent from waste stabilization ponds were used to irrigate pearl millet (Khan *et al.,* 2012). The average mineral of the effluent was 17.2 mg/L N, 3.92 mg/L P, 6.87 mg/L K, and 590.88 mg/L organic matter respectively. The average N, P and K amounts applied by irrigation amounted to 16.36 kg/ha N, 2.90 kg/ha P and 5.54 kg/ha K. The plant height, number of leaves per plant and leaf area increased with treated wastewater, but the thickness of the stem did not change. The treated effluent therefore improved the growth and development of the plant. Irrigation with treated effluent can increase the concentration of micro-organisms in the soil such as bacteria, fungi and actinomycetes and increase nutrient accessibility in plants.

Khan *et al.* (2010) also indicated that the entire nitrogen and carbon content of the soil will escalate with the increased microbial action in the soil.

2.9. Summary

Governments in most of the countries realize that industries and agriculture should increase their water use efficiency as it is becoming an increasingly scarce commodity. Every country must do its utmost to save water and recycle where possible. Laws have been put in place to improve water management. South Africa has strict laws in the Agricultural sector on the management of water resources. In the wine industry the Integrated Production of Wine (IPW) was established in 1998 supplying guidelines for the management of cellar effluent. All the cellars in South Africa are being checked on a regular basis to see that they handle their wastewater according to these guidelines (Tromp *et al.*, 2005). Cellar wastewater has also been distributed successfully to the envìronment by effluent ponds where plants are used to take up minerals to prevent soil degradation. Plants that can be used in the ponds are cattails (*Scirpus* spp.), bulrush (*Typha*, spp) and reeds (*Phragmites*, spp.) (Mulidzi, 2005).

The wineries must try to reduce water pollution with the following procedures:

1. Do not use products containing Na. This will have a positive effect on the SAR. NaOH is used to dissolve the potassium bitartrate which deposits in the tanks and apparatus during the fermentation process. Potassium hydroxide (KOH) can be used instead of sodium hydroxide (NaOH) (Van Schoor, 2005).

2. Reduce COD of the effluent. This can easily be done by capturing solids that are bigger than 0.5 - 1.0 mm with mesh frames. Capturing of solids should be done after solids have been deposited in tanks. The quicker the solids can be removed from the wastewater, the lower the COD in the wastewater will be. If phosphoric acid is used instead of citric acid after the initial washing with KOH the COD will also be reduced.

3. Reduce the use of salts (K, Ca, Na and Mg) in the cellar. With this strategy it will be possible to reduce the EC to the legal levels for advantageous crop irrigation. To use ozone instead of disinfectants and cleaning products, it could reduce EC and COD of wastewater effectively.

4. Wineries must make use of data sheets from chemical suppliers to make sure that only approved products is used with no negative impact on the environment. When wastewater cannot be treated effectively because of technical restrictions or low budgets, sewage water must not be used with winery wastewater for irrigating purposes. This will help to stop spreading of bacteria, viruses and parasites like the tapeworm. Spreading of faecal coliforms and *E coli* will also be reduced.

2.10. Motivation for this study

All cellars must get rid of their cellar effluent water in a responsible way all over the world. In South Africa, the cellars are governed by strict laws how to get rid of their cellar effluent. Constructed wetlands is a successful way cellars can use to break down the toxic elements in the cellar effluent but this can be time consuming and the cellar must also get rid of a vast amount of cellar effluent. Big machines, like bio-reactors are also used to break down cellar effluent but this can be very expensive. All cellars have vineyards. If the vineyards could be irrigated with the cellar effluent and the cover crops can accumulate toxic elements from the soil and this method does not have a negative impact on the vineyard, huge amounts of effluent can be distributed in a responsible way. Another advantage with irrigation with cellar effluent, is that the farmer may reduce his fertiliser additions because the cellar effluent contains high amounts of N, P and K. It is very important to make sure that other substances in the cellar effluent, like *E. coli* are within the legal limits to ensure that fruit is safe for human consumption.

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CHAPTER 3
THE POTENTIAL OF *AVENA SATIVA* (OATS) TO REMOVE MACRO- AND MICRO-ELEMENTS FROM VINEYARD SOIL IRRIGATED WITH CELLAR EFFLUENT

Abstract

Government regulations concerning the use and disposal of winery effluent are becoming increasingly strict, the aim being to protect the environment. In response, wineries are continually trying to improve wastewater management and finding better ways to eliminate or reduce waste. Due to water scarcity, it would be hugely beneficial to viticulture if winery effluent could be used to irrigate vineyards. Oats has the potential to accumulate minerals from the soil.

Oats were irrigated with cellar effluent irrigations from 100 mg/L to 3 000 mg/L COD concentrations (eight treatments) in 2010, 2011 and 2012 in a vineyard at the Goudini Cellar near Rawsonville. High amounts of N, P and K were removed from the soil. The farmer may cut back on his fertiliser use when he irrigates with cellar effluent because of the high amounts of N, P and K in the cellar effluent. Sodium was not removed successfully from the soil by oats during the trial. Cellars are advised to use K-based cleaning agents because high amounts of Na can cause sodicity problems in the soil.

3.1. Introduction

A potential problem with winery wastewater is that, in addition to organic material (chemical oxygen demand), such wastes also contain high concentrations of mineral elements, like the cations sodium (Na) and potassium (K). These Na^+ and K^+ are constituents of the cleaning products of grape marc and grape sediment (Laurenson & Houlbrooke, 2011). Excess Na and K in the soil contribute to salinity problems causing clay bulging and scattering, preventing irrigated water reaching the lower levels of the soil (Laurenson & Houlbrooke, 2011). Furthermore, excess K tends to increase wine pH and has negative effects on especially red wine colour because the fermentation process in red wines is longer than in white wines (Mpelasoka *et al.,* 2003).

A likely solution to high soil cation concentrations is to use a cover crop, such as oats, to extract the excess cations from the soil. A potential drawback is that the cover crop will itself require water, in addition to that needed by the grapevines. Normally a winter growing cover crop is sprayed in September (bud break) to prevent competition with the vineyard for water. Controlling a cereal cover crop (oats are widely used in vineyards) chemically at bud break, rather than at the end of November, can bring about a water saving of between 43 and 47 mm

per ha per annum (J.C. Fourie, personal communication). This implies that the cost, in terms of water needed by the winter growing cover crop can be kept within limits.

3.2 Materials and methods

This study forms part of a larger ARC project titled 'The impact of wastewater irrigation by wineries on soils, crop growth and product quality' (Myburgh, 2010).

3.2.1. Experiment layout

The trial was carried out in a Cabernet Sauvignon/Richter 99 vineyard established on a sandy soil (coarse sand: 16.3 %, medium sand: 36.1 %, fine sand: 43.3 %, silt: 1.2 %, clay: 3.1 %) at the Goudini Cellar (Fig. 3.1) near Rawsonville (33°40'06.98" S, 19°15'48.06" E). The vineyard was planted near the Goudini Cellar in 2001. Grapevines were spaced 1.2 m in the row, and 2.4 m between rows. The vineyard was divided into 104 m^2 plots, each containing 10 experimental vines, five in each of two adjacent rows. Nine treatments (eight using COD-augmented water, and one using raw water) were applied (Table 3.1), each replicated randomly, in three blocks (Table 3.2). Experimental grapevines in each plot were separated from those in the next plot by four buffer vines, with one buffer row between rows containing experimental vines. The COD-augmented water was prepared on-site in 15 000 L tanks (Fig. 3.2) before irrigation with cellar effluent was done in the vineyard.

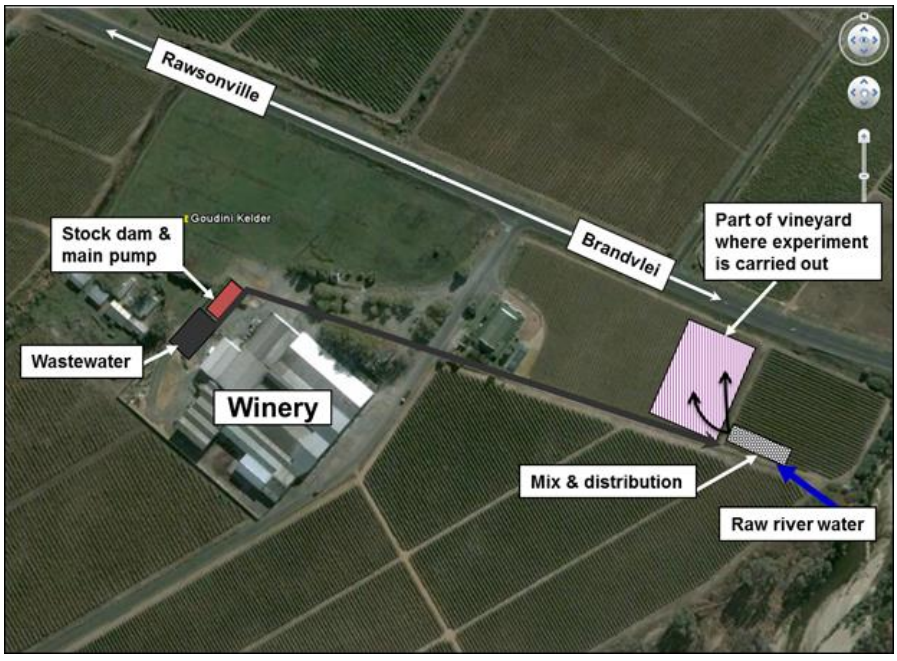

Figure 3.1. Layout of the infrastructure and vineyard where the winery wastewater project was carried out at the Goudini winery near Rawsonville

Table 3.1. Irrigation water treatments to determine the effect of irrigation with augmented winery wastewater on grapevine yield and wine quality

Treatment Number	Treatment description		
	Irrigation water	COD level (mg/L)	Irrigation / cultivation strategy
T1	Raw water	N/a	50% PAW[(1)] depletion+ cover crop
T2	Augmented water	100	50% PAW depletion + cover crop
T3	Augmented water	250	50% PAW depletion + cover crop
T4	Augmented water	500	50% PAW depletion + cover crop
T5	Augmented water	1000	50% PAW depletion + cover crop
T6	Augmented water	1500	50% PAW depletion + cover crop
T7	Augmented water	2000	50% PAW depletion + cover crop
T8	Augmented water	2500	50% PAW depletion + cover crop
T9	Augmented water	3000	50% PAW depletion + cover crop
T10	Control	N/a	50% PAW depletion + no cover crop

(1) PAW = plant available water.

Table 3.2. Experiment layout and irrigation water treatments to determine the effects of augmented winery wastewater on grapevine yield and wine quality (R = replication, T = treatment, COD = target chemical oxygen demand)

R1T10 Control (no cover crop)	**R1T4** COD = 500 mg/L	**R2T1** Raw water	**R2T2** COD = 100 mg/L	**R3T8** COD = 2500 mg/L
R1T8 COD = 2500 mg/L	**R1T5** COD = 1000 mg/L	**R2T6** COD = 1500 mg/L	**R2T3** COD = 250 mg/L	**R3T9** COD = 3000 mg/L
R1T9 COD = 3000 mg/L	**R1T3** COD = 250 mg/L	**R2T10 Control** (no cover crop)	**R3T1** Raw water	**R3T5** COD = 1000 mg/L
R1T6 COD = 1500 mg/L	**R1T7** COD = 2000 mg/L	**R2T9** COD = 3000 mg/L	**R3T7** COD = 2000 mg/L	**R3T4** COD = 500 mg/L
R1T2 COD = 100 mg/L	**R2T5** COD = 1000 mg/L	**R2T4** COD = 500 mg/L	**R3T3** COD = 250 mg/L	**R3T2** COD = 100 mg/L
R1T1 Raw water	**R2T8** COD = 2500 mg/L	**R2T7** COD = 2000 mg/L	**R3T6** COD = 1500 mg/L	**R3T10** Control (no cover crop)

Figure 3.2. Wastewater mix and distribution plant in the experimental vineyard at the Goudini Winery at Rawsonville

3.2.2. Irrigations applied

In 2010, 2011 and 2012 three, six and five irrigations with cellar effluent were respectively applied in the vineyard (Table 3.3). Oat crops were irrigated with clean river water from the Holsloot river during the rest of the year after the irrigation with the cellar effluent stopped.

Table 3.3. Irrigations of cellar wastewater given to the vineyard at the Goudini cellar near Rawsonville in 2010, 2011 and 2012

2010		2011		2012	
25 March	57 mm	9 February	64 mm	6 March	70 mm
12 April	51 mm	23 February	64 mm	16 March	43 mm *
3 May	52 mm	9 March	64 mm	2 April	43 mm *
		23 March	64 mm	16 April	43 mm *
		6 April	64 mm	2 May	21 mm *
		3 April	64 mm		
Total = 160 mm		Total = 384 mm		Total = 220 mm	

* There was not enough cellar wastewater generated by the cellar to irrigate up to the 70 mm target.

3.2.3. Water quality

All treatments were irrigated with clean river water (raw) from bud break until the first effluent was produced in the winery. The cellar effluent was pumped from the cellar to a dam next to the cellar where it was pumped to a sedimentation dam (Fig.3.3). The overflow from the sedimentation dam was collected in the stock dam. Water samples were taken from the stock dam to determine the COD levels. The COD of the winery wastewater was determined with a CBS/COD-reactor from Aqualitic® (Germany) as well as an AL 250 COD Vario spectrophotometer (Anonymous, 2009). The COD level of the sample was then used to determine the amount of cellar effluent water necessary to achieve the various COD concentrations for the 8 tanks (T2 to T9) (Fig.3.2) at the vineyard trial. Each tank was marked at the level to which it needed to be filled with cellar effluent to obtain the specified COD concentration. After the correct amount of cellar effluent was added from the stock dam, the tanks were filled up with clean river water. The contents of the tanks were then ready for irrigations in the various plots.

Figure 3.3. The sedimentation dam in front and the stock dam at the back

Approximately one hour after each irrigation commenced, a water sample was taken from each treatment tank. Each sample was analysed to determine pH, EC and COD as well as the cations (Na, K, Ca, Mg, B, Mn, Cu and Zn) and anions (Cl, CO_3 SO_4, P, NH_4N and NO_3-N). The SAR was calculated from the Na, Ca and Mg concentrations. Concentrations of heavy metals (Cd, Cr, Pb, Hg and As) were also determined in 2010 (data not shown). The

concentrations of measurements was not repeated during 2011 and 2012 because the results of the concentrations was negligible; and due to high costs, the analyses were not repeated in the subsequent years.

3.2.4. Fertilisers applications

During seedbed preparation and directly after the seeds were sown, 14 kg/ha N was given (mid-April 2010). Another 14 kg/ha N was applied at the four to six leaf stages of the cover crop in mid-June to promote the vegetative growth of the oats. To maximise cover crop growth 9.5 kg/ha P was applied at the end of March 2010 during seedbed preparation. This fertilizer program was based on the guidelines of Fourie (2011) and was repeated in 2011 and 2012.

3.2.5. Establishment of oats

The *A. sativa* L.cv Pallinup (oats), cover crop was planted at 100 kg/ha in mid-April of 2010, 2011 and 2012. The above-ground growth of the oats were harvested from an area of 0.5 m^2 in each plot at the end of July 2010. The fresh mass were determined, where after the samples were oven dried at 105°C for 48 hours to determine the dry mass.

The oat samples were analysed for the following elements: N, P, K, Ca, Mg, Na, Mn, Fe, Cu, Zn and B. The samples were also analysed for Cd, Cr, Pb, Hg and As. The macro and micro-element and heavy metal content were determined using the method described by Isaac & Johnson (1998) and by means of an ICP-OES spectrometer. The N content was determined using the methods described by Horneck & Miller (1998) by means of a nitrogen analyser.

After sampling, the remaining cover crop was slashed and removed from the plots. The cover crop was allowed to re-grow until the end of September 2010 when the sampling, slashing and residue removal actions were repeated. The remaining stubble was controlled chemically in October with 2.16 kg/ha glyphosate applied full surface. At the end of October 2010, however the remaining oats fibre was incorporated into the soil with a disk-harrow to prepare a seedbed for the summer growing cover crop.

In 2011 and 2012 all these actions were repeated, except that the oats was only harvested once, at the end of September. The chemical analyses of the heavy metals such as Cd, Pb, Cr, As and Hg were not done in 2011 and 2012 since the effluent water did not contain significant amounts of these elements, with some even being absent in the results of 2010.

3.3. Results and discussion

3.3.1. Oat crop growth

The irrigation of the cellar effluent did not affect the growth of the oats negatively and even stimulated the growth of oats in the 2012 season with higher growth mass than the 2011 season (Table 3.4). In an irrigation trial that was done with treated wastewater irrigation in the Loess area of China, the growth production of the irrigated cover crops were higher and no negative effect on the growth of wheat was observed (Wang *et al.*, 2007). In the 2010 season, the highest yield of oats was 5.75 t/ha in Rawsonville which is comparable to the 7.07 ton/ha obtained in the Robertson area by Fourie (2006). In the 2011 season, at Rawsonville the highest yield was 6.26 t/ha which compares well against the oats yield of 7.07 t/ha in the Robertson area. In the 2012 season, the highest yield of 7.72 t/ha compared well against the 7.07 t/ha in the Robertson area. The cellar effluent did not decrease the growth production of oats; the production was in fact more in 2012 which could be because of macro element uptake of N, P and K by oats. Although the 2012 trial did not receive enough effluent irrigation like the 2011 trial, it could be concluded that the increased yield recorded in the 2012 is as a result of the residual accumulations of effluent minerals from the previous years.

Table 3.4. The dry matter production (DMP) of oats harvested at Goudini Cellar near Rawsonville in 2010 to 2012

Treatment no. & target COD (mg/L)	DMP (t/ha)				
	2010 season			2011 season	2012 season
	First harvest	Second harvest	Total	One Harvest	One harvest
T1 – Raw	4.08	1.35	5.43	2.75 b[(2)]	8.27
T2 – 100	3.30	2.45	5.75	4.01 ab	4.76
T3 – 250	3.24	1.98	5.22	4.68 ab	7.08
T4 – 500	4.04	1.71	5.75	6.26 a	7.72
T5 – 1000	3.44	1.97	5.41	4.42 ab	6.78
T6 – 1500	3.62	1.92	5.54	5.64 a	7.21
T7 – 2000	2.56	2.62	5.18	5.36 a	7.26
T8 – 2500	2.70	2.03	4.73	4.46 ab	6.05
T9 – 3000	3.35	2.02	5.37	4.45 ab	4.84
LSD (p≤0.05)	NS[(1)]	NS	NS	2.32	NS

[(1)] NS = Not significant.
[(2)] Values followed by the same letter within a column do not differ significantly (*p≤0.05*).

3.3.2. Oat crop chemical composition

The chemical composition of the oats is shown in Tables 3.5 to 3.10. The macro- nutrient content of N in the treatments did not differ significantly ($p \leq 0.05$) in any of the three years except for N during the first harvest of 2010 and the first harvest of 2011 (Table 3.5). The highest amount of N (2.65%) was observed in the T3 (250 mg/L) treatment in the first harvest of 2010. In the first harvest of 2010 there was a higher chemical N content in the T2, T3, T6, T7 and T9 treatments (Table 3.5). The highest amount of N in the oats of the 2011 season was in the T8 treatment. According to Rusan *et al*. (2007), the concentration of N in a trial was 1.08% after wastewater application for 2 years. The concentration of N in the oats of all the treatments in the first harvest of 2010 was almost more than double of the 1.08 % concentration in the trial of Rusan *et al*. (2007) where barley was irrigated for 2 years. This means that the oats took up higher amounts of N from the cellar effluent than the barley in the trial that was reported by Rusan *et al*. (2007).

The P concentration in 2010, 2011 and 2012 (Table 3.5) was slightly higher than the concentration of 0.19% P in the barley at the trial of Rusan, *et al*. (2007). The P concentration in the oats did not differ significantly between the treatments and over the 3 years. The K concentration in the first harvest was higher than the second harvest of 2010 (Table 3.6). The oats had a slightly higher Ca concentration in the first harvest than the second harvest of 2010 (Table 3.6) and there were no significant difference from 2010 to 2012 in the harvests. The single harvests of oats in 2011 and 2012 had about the same Ca concentrations.

The concentration of Mg remained similar over the 2010, 2011 and 2012 seasons (Table 3.6) except for 2010 with about double the concentration of the other years. The average Na content in the second harvest of 2010 and the single harvest of 2011 was higher than the first harvest of 2010 (Table 3.6). The Na content in 2012 was exceptionally high and cannot be used in the results. The concentration of the Mn in the T4 (500 mg/L COD) level was exceptionally high with 128 mg/kg in the second harvest of 2010 (Table 3.7). The cumulative Fe content of oat in the T4 (500 mg/L COD) treatment was unusually high with 556 mg/kg (Table 3.7). The highest chemical Fe content in 2011 and 2012 was 129 mg/kg in the T2 (100 mg/L COD level) and 400 mg/kg; T9 (2000 mg/L). The chemical content for Cu (Table 3.8) was about the same for all the treatments (T1 to T9) in the first and second harvest of 2010 and the single harvests of 2011 and 2012 but there was a slightly lower Cu content in the single harvests of oats in 2011 and 2012 than the concentration in the first and second harvest of 2010. The Zn content in the oats of 2011 and 2012 was lower in all the COD concentrations compared to the first and second harvest of 2010 (Table 3.8).

In general, there was no significant ($p < 0.05$) difference in the accumulation of a group of elements in the tissue of oat tested across the whole treatments. However, it is interesting to note the significant drop in Zn accumulation between 2010 (average: 32 mg/kg) and the two subsequent years with an average of 5 mg/kg. This observation showed a reversed scenario where the result indicated an initial leap in B accumulation between 2010 and 2011 and later dipped in 2012. However, the 2012 B content in oat tissue is considerably higher than 2010. The result on the Zn may be explained by quality of wastewater which was not tested for boron in the subsequent years after 2010. Consequently, the increase in the B content may be due to accumulation of the element in the effluent over the three years of the trials.

There was a decrease in the element content of N, K and Ca from the first harvest to the second harvest of oats in 2010. Mg had no trends in the 2010, 2011 and 2012 seasons. High amounts of Na content was observed for all treatments irrespective of the COD concentration of the effluent water used for irrigation. In the treatments between the COD levels, there was not a significant correlation according to the element content of the macro-elements. No significant difference of the element content was found between treatments as far as the micro-nutrients are concerned. The heavy metals namely Cd, Pb, As and Hg was either absent or present in insignificant amounts in 2010 (data not shown).

Table 3.5. Chemical analyses, macro-nutrients, N, P and K of oats at Goudini Cellar near Rawsonville in 2010, 2011 and 2012

Treatment no.& target COD (mg/L)	N (%)		N (%)	N (%)	P (%)		P (%)	P (%)	K (%)		K (%)	K (%)
	2010		2011	2012	2010		2011	2012	2010		2011	2012
	First harvest	Second harvest	One harvest	One harvest	First harvest	Second harvest	One harvest	One harvest	First harvest	Second harvest	One harvest	One harvest
T1 - Raw	1.83 bc[(1)]	1.21	1.34 bc	1.57	0.40	0.31	0.40	0.31	2.65	1.06	1.25	1.64 c [(1)]
T2 - 100	2.16 bc	1.26	1.26 bc	1.65	0.40	0.34	0.40	0.34	2.64	1.59	1.56	1.73 c
T3 - 250	2.65 a	1.21	1.33 bc	1.19	0.43	0.35	0.43	0.35	2.91	1.71	1.14	1.91 abc
T4 - 500	1.77 c	1.28	1.41 bc	1.66	0.42	0.31	0.42	0.31	2.83	1.59	1.34	1.91 bc
T5 - 1000	1.74 c	1.14	1.27 bc	1.30	0.37	0.30	0.37	0.30	2.31	1.55	1.38	1.64 c
T6 - 1500	2.15 bc	1.73	1.23 c	1.36	0.37	0.32	0.37	0.32	2.64	1.73	1.27	2.13 abc
T7 - 2000	2.04 bc	1.30	1.61 ab	1.84	0.43	0.34	0.43	0.34	3.11	1.58	1.73	2.51 ab
T8 - 2500	1.84 bc	1.41	1.91 a	1.53	0.42	0.47	0.42	0.47	2.71	1.78	1.80	2.00 abc
T9 - 3000	2.25 ab	1.38	1.61 ab	1.87	0.44	0.40	0.44	0.40	3.08	1.68	1.73	2.54 a
LSD (p≤0.05)	0.47	NS [(2)]	0.37	NS	NS	NS	NS	NS	NS [(2)]	NS	NS	0.63

[(1)] Values followed by the same letter within a column do not differ significantly (p≤0.05).
[(2)] NS = Not significant.

Table 3.6. Chemical analyses, macro-nutrients, Ca, Mg and micro-nutrient Na of oats at Goudini Cellar near Rawsonville in 2010, 2011 and 2012

Treatment no.& target COD (mg/L)	Ca (%)		Ca (%)	Ca (%)	Mg (%)		Mg (%)	Mg (%)	Na (mg/kg)		Na (mg/kg)	Na (mg/kg)
	2010		2011	2012	2010		2011	2012	2010		2011	2012
	First harvest	Second harvest	One harvest	One harvest	First harvest	Second harvest	One harvest	One harvest	First harvest	Second harvest	One harvest	One harvest
T1 - Raw	0.32	0.14	0.18	0.17	0.18	0.15	0.22	0.18	172	321	373	2286 abc[(1)]
T2 - 100	0.34	0.16	0.17	0.24	0.19	0.15	0.21	0.20	213	332	461	2662 ab
T3 - 250	0.37	0.21	0.16	0.15	0.20	0.19	0.22	0.13	247	549	467	982 e
T4 - 500	0.32	0.16	0.17	0.14	0.20	0.13	0.22	0.14	256	239	438	1582 cde
T5 - 1000	0.30	0.18	0.15	0.15	0.16	0.14	0.22	0.13	118	296	492	2080 bcd
T6 - 1500	0.29	0.20	0.14	0.14	0.16	0.18	0.21	0.13	200	334	404	1386 cde
T7 - 2000	0.31	0.15	0.16	0.17	0.18	0.14	0.22	0.17	158	203	366	2058 bcd
T8 - 2500	0.32	0.16	0.15	0.15	0.16	0.14	0.23	0.14	174	168	375	1270 de
T9 - 3000	0.29	0.17	0.14	0.16	0.17	0.15	0.22	0.17	145	308	358	3199 a
LSD (p≤0.05)	NS [(2)]	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	914

[(1)] Values followed by the same letter within a column do not differ significantly (p≤0.05).
[(2)] NS = Not significant.

Table 3.7. Chemical analyses, micro-nutrients Mn and Fe of oats at Goudini Cellar near Rawsonville in 2011, 2011 and 2012

Treatment no.& target COD (mg/L)	Mn (mg/kg)		Mn (mg/kg)	Mn (mg/kg)	Fe (mg/kg)		Fe (mg/kg)	Fe (mg/kg)
	2010		2011	2012	2010		2011	2012
	First harvest	Second harvest	One harvest	One harvest	First harvest	Second harvest	One harvest	One harvest
T1 - Raw	11	31	12 bc [1]	2.67	69	330	81 de	491
T2 - 100	18	18	6 d	18.00	71	195	129 ab	378
T3 - 250	25	22	15 abc	9.33	80	168	113 bc	125
T4 - 500	17	128	12 bc	9.67	72	484	148 a	122
T5 - 1000	23	48	18 a	15.33	71	202	103 cd	148
T6 - 1500	18	40	13 abc	8.67	73	242	92 cde	131
T7 - 2000	17	25	11 cd	14.67	71	207	103 cd	394
T8 - 2500	19	22	17 ab	9.67	70	171	90 de	159
T9 - 3000	16	22	11 cd	9.33	70	149	75 e	400
LSD p≤0.05)	NS [2]	NS	5.63	NS	NS	NS	22.3	NS

[1] Values followed by the same letter within a column do not differ significantly (p≤0.05).

[2] NS = Not significant.

Table 3.8. Chemical analyses, micro-nutrients, Cu, Zn and B of oats at Goudini Cellar near Rawsonville in 2010, 2011 and 2012

Treatment no.& target COD (mg/L)	Cu (mg/kg)		Cu (mg/kg)	Cu (mg/kg)	Zn (mg/kg)		Zn (mg/kg)	Zn (mg/kg)	B (mg/kg)		B (mg/kg)	B (mg/kg)
	2010		2011	2012	2010		2011	2012	2010		2011	2012
	First harvest	Second harvest	One harvest	One harvest	First harvest	Second Harvest	One harvest	One harvest	First harvest	Second harvest	One harvest	One harvest
T1 - Raw	5	5	4	4	25	39	3	7	5	10	29	17
T2 - 100	4	4	3	4	26	36	4	5	5	8	24	21
T3 - 250	5	5	4	3	32	42	4	6	5	6	28	15
T4 - 500	5	5	3	3	28	34	3	5	6	5	30	19
T5 - 1000	5	5	4	3	26	39	4	6	5	6	34	22
T6 - 1500	5	5	3	3	27	36	4	7	5	5	28	16
T7 - 2000	5	5	4	4	33	39	4	5	6	6	33	22
T8 - 2500	5	5	4	3	32	56	4	6	6	5	40	21
T9 - 3000	5	5	4	5	34	57	4	6	5	7	33	24
LSD p≤0.05)	NS [(1)]	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[(1)] NS = Not significant.

3.3.3. Amounts of elements removed by the oats

The amounts of N removed by the oats in the 2010, 2011 and the 2012 seasons is shown in Table 3.9. Higher amounts of N were taken up in the first harvest than the second harvest. This could be because the vineyard accumulated N from the soil before the second harvest during September. According to Khan *et a*l. (2012), the total amount of N in the soil is also increased by high cellar effluent concentration in the soil. This trend was observed for P as well (Table 3.9).

The amount of P removed by the oats was higher in the first harvest than in the second harvest of 2010 (Table 3.9). The amounts of P in 2010 and the harvest of oats in 2011 and 2012 seasons were relatively the same. Higher amounts of K was extracted with averages of 73.6 kg/ha and 73.29 kg/ha in the first and second harvest of 2010 (Table 3.9). Arienzo *et al*. (2009) declared that wheat (*Triticum aestivu*m) with a yield of 2 t/ha, could take up 149 kg/ha K. Therefore, oats showed a similar potential uptake reported in wheat.

Mohammed and Ayadi (2004) also observed a high uptake of K with secondary treated wastewater irrigated on corn (*Zea mays*) for two seasons and vetch (*Vicia sativa*) for one season. The totals in the 2011 and 2012 season had lower values and there was no trend with increased COD concentrations. Slightly higher amounts of Ca were taken up in the totals of the 2010 season than in the totals of the 2011 and 2012 seasons (Table 3.10). The Mg content was slightly higher in the 2011 and 2012 seasons than the 2010 season. This could be because more cellar effluent was irrigated in the 2011 and 2012 seasons than the 2010 season with a higher Mg availability (Table 3.10).

Oats took up slightly higher amounts of Na in the totals of the 2010 season than in the totals of the 2011 and 2012 seasons due to two seasons of harvest in 2010 (Table 3.10). The element Na had a significant difference in the second harvest with the highest amount in T3 (COD – 250 mg/L) in 2010 with 2.43 kg/ha. Oats extracted more Na in the 2012 season than in 2010 and 2011, with the average value of 9.79 kg/ha compared to an average of 0.50 kg/ha (first harvest, 2011), 1.29 kg/ha (second harvest, 2011) and 1.45 kg/ha (2011), respectively (Table 3.10).

Table 3.9. The amount of macro-elements, N, P and K removed by oats at Goudini Cellar near Rawsonville in 2010, 2011 and 2012

Treatment no.& target COD (mg/L)	N (kg/ha)		N (kg/ha)	N (kg/ha)	P (kg/ha)		P (kg/ha)	P (kg/ha)	K (kg/ha)		K (kg/ha)	K (kg/ha)
	2010		2011	2012	2010		2011	2012	2010		2011	2012
	First harvest	Second harvest	One harvest	One harvest	First harvest	Second harvest	One harvest	One harvest	First harvest	Second harvest	One harvest	One harvest
T1 - Raw	60.17	15.03 b[1]	30.07	105	12.9	3.9	12.9	3.9	86.8	32.7 c	27.93	108.67
T2 - 100	58.49	24.73 ab	42.70	62	10.7	6.7	10.7	6.7	71.8	84.9 ab	52.57	64.83
T3 - 250	69.09	19.13 ab	44.60	67	10.9	5.5	10.9	5.5	75.7	75.7 ab	38.10	105.27
T4 - 500	57.66	17.53 ab	74.30	101	13.3	4.3	13.3	4.3	94.6	54.1 bc	71.23	114.80
T5 - 1000	50.62	18.00 ab	24.97	68	9.5	4.7	9.5	4.7	63.0	58.7 bc	26.57	88.53
T6 - 1500	62.54	26.63 a	54.23	79	10.8	4.9	10.8	4.9	78.0	68.2 bc	55.57	123.03
T7 - 2000	41.70	27.17 a	71.07	105	8.9	7.1	8.9	7.1	64.1	89.9 ab	80.50	141.87
T8 - 2500	39.71	22.90 ab	67.33	76	9.2	7.6	9.2	7.6	59.1	108.7 a	64.43	96.70
T9 - 3000	61.46	22.23 ab	57.07	66	12.0	6.5	12.0	6.5	69.7	86.7 ab	59.07	91.77
LSD p≤0.05)	NS [2]	10.64	NS	NS	NS	NS	NS	NS	NS	38.40	NS	NS

[1] Values followed by the same letter within a column do not differ significantly (p≤0.05).

[2] NS = Not significant.

Table 3.10. Amounts of macro-elements, Ca, Mg and micro-element, Na removed by oats at Goudini Cellar near Rawsonville in 2010, 2011 and 2012

Treatment no.& target COD (mg/L)	Ca (kg/ha)		Ca (kg/ha)	Ca (kg/ha)	Mg (kg/ha)		Mg (kg/ha)	Mg (kg/ha)	Na (kg/ha)		Na (kg/ha)	Na (kg/ha)
	2010		2011	2012	2010		2011	2012	2010		2011	2012
	First harvest	Second harvest	One harvest	One harvest	First harvest	Second harvest	One harvest	One harvest	First harvest	Second harvest	One harvest	One harvest
T1 - Raw	10.3	4.3	3.87	11.40	6.0	4.6	4.90	11.67	0.55	0.99 bc[1]	0.83	15.12
T2 - 100	9.0	8.5	5.37	8.77	5.1	8.0	6.87	7.47	0.54	1.19 bc	1.52	9.50
T3 - 250	9.7	9.3	5.20	8.53	5.2	8.4	7.17	7.40	0.63	2.43 a	1.54	5.60
T4 - 500	10.7	10.7	9.03	8.30	6.6	4.4	10.97	8.47	0.90	0.81 c	2.35	9.44
T5 - 1000	8.3	8.3	2.97	7.77	4.6	5.3	4.27	6.97	0.30	1.12 bc	0.93	11.17
T6 - 1500	8.7	8.7	6.33	8.27	4.8	7.1	9.43	7.53	0.60	1.32 bc	1.79	6.00
T7 - 2000	6.3	6.3	7.00	9.57	3.7	7.9	9.63	9.57	0.31	1.15 bc	1.56	12.04
T8 - 2500	7.0	7.0	5.33	6.83	3.5	8.5	8.07	7.07	0.32	1.03 bc	1.29	6.32
T9 - 3000	8.0	8.0	5.03	5.63	4.7	7.8	7.67	5.53	0.39	1.59 b	1.26	12.40
LSD p≤0.05)	NS [2]	NS	NS	NS	NS	NS	NS	NS	NS	0.67	NS	NS

[1] Values followed by the same letter within a column do not differ significantly (p≤0.05).
[2] NS = Not significant.

Oats extracted higher amounts of Mn and Fe in the totals of the 2010 season than in the 2011 and 2012 seasons because of the two harvests (Table 3.11). Oats extracted more Cu and Zn in the 2010 season than in the 2012 seasons (Table 3.12). The oats also extracted more B in the total of the 2010 season than in the 2011 and 2012 seasons (Table 3.12).

3.4. Summary

The chemical analyses of the oats had about the same element content range for all the elements in all the 2010, 2011 and 2012 seasons. The element extraction of the oats for N, P and K in the first harvest were much higher than in the second harvest of the 2010 season. The reason could be that the vineyard accumulated more N and P in September which was not available for the oats when the vineyard needs more nutrition at the start of the growing season. This study indicated that more extraction of the elements is possible with two harvests of oats in the same season. Relatively high amounts of N and K were extracted in the 2012 season. This could indicate the importance of the planting date of oats as early as possible so that the growth period peak with high cellar activity but it must be remembered that the fluctuation of high concentrations in the cellar effluent could have an effect on the extraction of elements. This is why the pearl millet (Chapter 4) had better accumulation of elements because the growth period peaked with high cellar effluent activity and more cellar effluent were irrigated. Oats could not extract Na successfully from the soil and therefore cellars are advised to use K-based cleaning agents rather than Na-based cleaning agents.

Table 3.11. Amounts of micro-elements, Mn and Fe removed by oats at Goudini Cellar near Rawsonville in 2010, 2011 and 2012

Treatment no.& target COD (mg/L)	Mn (kg/ha)		Mn (kg/ha)	Mn (kg/ha)	Fe (kg/ha)		Fe (kg/ha)	Fe (kg/ha)
	2010		2011	2012	2010		2011	2012
	First harvest	Second Harvest	One harvest	One harvest	First harvest	Second harvest	One harvest	One harvest
T1 - Raw	0.03	0.10 b [1]	0.027	0.130	0.22	1.02 b	0.17 b	3.233
T2 - 100	0.04	0.09 b	0.020	0.274	0.18	1.04 b	0.43 b	1.252
T3 - 250	0.07	0.10 b	0.050	0.071	0.20	0.74 b	0.38 b	0.720
T4 - 500	0.06	0.43 a	0.063	0.084	0.23	1.65 a	0.77 a	0.743
T5 - 1000	0.06	0.18 b	0.033	0.249	0.19	0.76 b	0.20 b	0.747
T6 - 1500	0.05	0.16 b	0.060	0.062	0.21	0.95 b	0.41 b	0.753
T7 - 2000	0.03	0.14 b	0.047	0.177	0.15	1.18 ab	0.45 b	2.163
T8 - 2500	0.04	0.14 b	0.053	0.079	0.14	1.05 b	0.33 b	0.787
T9 - 3000	0.04	0.11 b	0.037	0.094	0.15	0.77 b	0.26 b	1.177
(LSD p≤0.05)	NS [2]	0.10	NS	NS	NS	0.52	0.28	NS

[1] Values followed by the same letter within a column do not differ significantly (p≤0.05).
[2] NS = Not significant.

Table 3.12. Amounts of micro-elements, Cu, Zn and B removed by the oats at Goudini Cellar near Rawsonville in 2010, 2011 and 2012

Treatment no.& target COD (mg/L)	Cu (kg/ha)		Cu (kg/ha)	Cu (kg/ha)	Zn (kg/ha)		Zn (kg/ha)	Zn (kg/ha)	B (kg/ha)		B (kg/ha)	B (kg/ha)
	2010		2011	2012	2010		2011	2012	2010		2011	2012
	First harvest	Second harvest	One harvest	One harvest	First harvest	Second harvest	One harvest	One harvest	First harvest	Second harvest	One harvest	One harvest
T1 - Raw	0.016	0.017	0.010	0.027	0.079	0.012 cd [1]	0.011	0.023	0.010	0.067a [1]	0.063	0.110
T2 - 100	0.011	0.023	0.013	0.013	0.068	0.193 bcd	0.011	0.023	0.020	0.027 b	0.087	0.077
T3 - 250	0.012	0.023	0.010	0.017	0.080	0.187 cd	0.012	0.027	0.013	0.033 b	0.093	0.090
T4 - 500	0.016	0.017	0.017	0.017	0.091	0.117 d	0.011	0.017	0.030	0.033 b	0.157	0.117
T5 - 1000	0.013	0.020	0.010	0.017	0.069	0.147 cd	0.011	0.023	0.013	0.033 b	0.063	0.113
T6 - 1500	0.014	0.020	0.013	0.020	0.079	0.143 cd	0.011	0.027	0.023	0.030 b	0.123	0.090
T7 - 2000	0.010	0.030	0.013	0.023	0.068	0.220 bc	0.008	0.030	0.027	0.033 b	0.140	0.130
T8 - 2500	0.011	0.030	0.017	0.013	0.070	0.340 a	0.009	0.037	0.023	0.023 b	0.133	0.103
T9 - 3000	0.013	0.027	0.013	0.017	0.090	0.293 ab	0.012	0.033	0.020	0.030 b	0.117	0.090
(LSD p≤0.05)	NS [2]	NS	NS	NS	NS	0.10	NS [2]	NS	NS	0.023	NS	NS

[1] Values followed by the same letter within a column do not differ significantly (p≤0.05).

[2] NS = Not significant.

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CHAPTER 4
THE POTENTIAL OF PEARL MILLET (*PENNISETUM GLAUCUM*), TO REMOVE MACRO- AND MICRO-ELEMENTS FROM A VINEYARD SOIL IRRIGATED WITH CELLAR EFFLUENT

Abstract

Pearl millet can grow in clay to sandy soils, but it is better adapted in light sandy to sandy-loam soils. Pearl millet does not endure water logging situations in soils. It can handle soil acidity and is fairly adaptable to salinity situations (Baligar & Fagaria, 2007). Treated wastewater is gaining acceptance in very dry and moderately dry regions of the world. Pearl millet was established in a vineyard at the Goudini Cellar at Rawsonville during December 2010 and January 2012. Cellar effluent irrigations from 100 mg/L to 3 000 mg/L COD concentrations (eight treatments) were applied in the vineyard from 2011 to 2012.

The cellar effluent did not have a negative impact on the growth of the pearl millet. Sufficient amounts of N, P and K were removed from the soil after cellar effluent irrigations in the trial. More N, P and K were removed from the soil in the second harvests than the first harvests in both the 2011 and 2012 seasons but higher amounts of N, P and K were removed in the 2011 season than in the 2012 season. The reason could be because more cellar effluent could be irrigated in 2011 than 2012 (Table 3.3). Pearl millet has the ability to remove sufficient amounts of macro- and micro-elements from the soil especially N, P and K. Sodium could not be removed successfully by pearl millet. Therefore it is advised that K-based cleaning agents like KOH should rather be used than NaOH cleaning agents.

4.1. Introduction

Treated wastewater was irrigated on table grapes in a six-year trial on table grapes *V. vinifera* cv. *Superior Seedless* (also called 'Sugraone)' in Southern Israel (Netzer *et al*., 2014). The outcome of the study was that the treated wastewater did not have a negative effect on the superior table grapes ('Sugraone') after six years except for Na^+ build up in the vines with or without fertilizer. However, this salinity problem can be corrected by irrigating clean water after several wastewater irrigations. The problem of Na^+ uptake by the vineyard can be prevented if cellars use KOH instead of NaOH cleaning agents. If grapes can be irrigated with industrial wastewater, it can be successfully irrigated with cellar effluent.

Pakistan is a country with limited water supply located in dry and semi-dry regions. A study was done to evaluate the growth and yield reaction of pearl millet irrigated with treated effluent from wastewater stabilising ponds. Treatment of waste water using waste stabilization ponds is used everywhere in the world especially in countries that does not have the ability to use

advanced technology to treat wastewater. Pearl millet can grow with a limited supply of irrigation water. In the study that was done in Pakistan to evaluate the growth and yield response in the species it was found that pearl millet can be irrigated successful, with effluent from waste stabilization ponds. The treated effluent increased the growth of pearl millet and the organic matter in the soil (Khan *et al*., 2012). This indicate that pearl millet has the potential to accumulate elements from the soil.

This study evaluates the ability of pearl millet to remove macro- and micro-elements especially Na and K, from the soil after cellar effluent irrigation with different COD concentrations to prevent accumulation in the soil and the uptake by the vineyard of these elements.

4.2. Materials and methods

4.2.1. Experiment layout

Refer to Chapter 3.2.1 for details of the experimental layout of the field trial.

4.2.2. Irrigations applied

Refer to Chapter 3.2.2 for details of the irrigations applied.

4.2.3. Fertilisers applied

Seed bed preparation was done with a disc harrow and 28 kg/ha N were applied after the crop was sown. Six weeks later, at the two to six leaf stage, another supplement of 28 kg/ha N was applied. In the 2012 season, when the pearl millet was established during the second week of January, 28 kg/ha N was applied. In February 2012, 28 kg/ha N was applied at the two to six leaf stage. The N given at the two to six leave stage was given as an extra supplement to enhance growth. To ensure sufficient growth of the pearl millet 30 kg/ha P was applied during middle November in 2011 and 2012 just before seed bed preparation was done with a disc harrow.

4.2.4. Establishment of pearl millet

Pearl millet, *P. glaucum*, hybrid babala, was established in a vineyard at Rawsonville in December 2010 and January 2012 to intercept mineral elements from the irrigated cellar effluent. It was decided that a summer crop like pearl millet should be established and that the growth rate must peak with the starting of the irrigation of the cellar effluent in the 2011 and 2012 seasons. In the second season of 2012 the pearl millet was sown later because the growth period of the pearl millet in the first season stopped before the peak period of the cellar effluent in March when accumulation of mineral elements by the pearl millet is expected.

Pearl millet was planted at a seeding density of 40 kg/ha during the last week of November 2010. Samples from of 0.5 m^2 plots were taken of the above-ground growth of the pearl millet in mid-January 2011 and oven dried at 105°C for 48 hours to determine the dry mass. Fresh samples were also taken of each plot to be analysed for N, P, K, Ca, Mg, Na, Mn, Fe, Cu, Zn and B. Concentrations of heavy metals (Cd, Pb. Cr, As and Hg) were also determined. N content was determined using the methods described by Horneck & Miller (1998) by means of a nitrogen analyser. The macro- and micro-elements as well as the heavy metals were determined using the method described by Isaac & Johnson (1998) and by means of an ICP-OES spectrometer.

After sampling, the cover crop remains were slashed and removed from the plots. The cover crop was allowed to re-grow until the end of February 2011 when the sampling, slashing and residue removal actions were repeated. During the second week of March 2011, a seedbed was prepared for the oats with a disc-harrow incorporating the cover crop fibre into the soil. The reason for this action was to allow the cover crop fibre to decompose in the soil providing a good seedbed for the oats.

In the 2012 season the pearl millet cover crop was established six weeks later during the second week of January 2012 at a seeding density of 40 kg/ha. This was done because the pearl millet reached the end of its growth stage (when the time for accumulating elements is good) in the first year of the establishment season before the peak period of available cellar effluent to irrigate. All the sampling, slashing and residue removal actions were performed in 2012 during the first week of March and on the last week of April. In the 2011 and 2012 seasons the pearl millet that were slashed were removed from the experimental plots to prevent that minerals are recycled in the soil when the disk plough action is done in October.

4.3. Results and discussion

4.3.1. Pearl millet crop growth

The irrigation with the cellar effluent did not have a negative impact on the growth of the pearl millet (Table 4.1). The average dry matter production was 2.1 t/ha in the second week of January (first harvest) and 8.33 t/ha in the fourth week of February (second harvest). The increase from an average of 2.01 t/ha in the first harvest to an average of 8.33 in the second harvest could be because of the accumulation of high amounts of N, P and K from the cellar effluent (Table 4.8 & 4.9). The normal production for pearl millet is between 2.0 and 5.0 ton/ha (Coelho *et al*, 2009). In the 2011 season the pearl millet had a good average total yield from the first and second season of 10.42 t/ha. This could be because of higher nutrient accumulation from the cellar effluent. According to Khan *et al*. (2012), the increased growth of

pearl millet was not only because of more accessible N, P and K but also because of huge amounts of organic matter which improved the soil structure to allow more available water and nutrients.

In the second season (2012) the cellar effluent did not have a negative impact on the growth of pearl millet. The average dry mass was 1.55 t/ha in the first week of March 2012 and 4.42 t/ha in the fourth week of April 2012. There was a decrease of the dry material of the total harvest of the pearl millet in the 2011 season compared to the 2012 season from 10.42 t/ha to 5.97 t/ha. Although the pearl millet was planted three weeks later in 2012 to have a better chance to take up minerals it is possible that the planting date of the first season was actually a better time for a high yield. This was also the conclusion made by Deshmukh *et al.* (2013) that the earliest date gave the highest, yield when Pearl millet was sown on three different dates in an experimental trial. These authors reasoned that the earlier sown crop was subjected to better climatic conditions which could have a positive effect on the growth yield.

4.3.2. Pearl millet chemical composition

The concentration content of N in the first harvests of pearl millet was much higher than in the second harvests in the 2011 and the 2012 seasons (Table 4.2). According to Ozores-Hampton (2012), the nitrogen concentration in pearl millet with clean water was 1% during the evaluation of cover crops. The N amount in pearl millet after irrigation with cellar effluent was higher than 1% which means the pearl millet accumulated N successfully. This trend was also observed in the concentration content of P in the 2011 season with the highest content of 0.95 % in the T6, 1500 mg/L. The concentration of P in the first and second harvest of 2012 was about the same (Table 4.2). The irrigated pearl millet with cellar effluent had higher amounts of P than the irrigated pearl millet with 0.2 – 0.4% P with clean water according to Ozores-Hampton (2012).

The concentration of K was much higher in the first harvest of both the 2011 and 2012 seasons. There were no correlation with the increase of the COD concentration of the cellar effluent and the K – content of the pearl millet (Table 4.3). The concentration of K was 2.0 – 4.0% in Pearl millet in a field experiment by Ozores-Hampton (2012). The concentration of K in pearl millet was much higher in the first harvest of 2011 than in the second harvest of 2011 and the first and second harvest of 2012 compared to the concentration (2.0 – 4.0%) stated by Ozores-Hampton (2012). The high amounts of K in the first harvest of 2011 is evidence of the potential of pearl millet to accumulate K nutrients.

This trend with higher first harvest concentrations than the second harvest was also the same for Ca (Table 4.3). The concentration of Ca in pearl millet was 0.30 % in a field experiment conducted by Mustafa *et al*. (2007). Magnesium had more or less the same concentration in

the first and second harvest of both the 2011 and 2012 seasons (Table 4.3). In a field experiment by Mustafa *et al*. (2007) the Na concentration was 114.2 mg/kg (average of five cultivars of pearl millet). In the trial at Goudini the Na concentrations of pearl millet was higher than the Na content in the trial by Mustafa *et al*. (2007) in the first and second harvest of the 2011 and 2012 seasons (Table 4.3).

Manganese and iron had a higher concentration in the first harvest than in the second harvest in 2011 and 2012 (Table 4.4). The concentration of Mn and Fe was 17.0 mg/kg and 41.5 mg/kg in a field experiment that was done by Mustafa *et al.* (2007). Copper had a much higher concentration content in the first harvest than in the second harvest in the 2011 and 2012 seasons (Table 4.5). The Cu concentration in pearl millet was 41.5 mg/kg in a field trial that was done by Mustafa *et a*l. (2007). Zinc did not show trends between the first and the second harvests of 2011 and 2012 (Table 4.5). The concentrations of Zn in the first season was a little bit higher than in the second season. The concentration of Zn in pearl millet was 47.4 mg/kg in a field trial by Mustafa *et al*. (2007). The Zn uptake in the Goudini trial was more or less the same. The concentration of B was much higher in the first harvest than in the second harvest of the 2011 season (Table 4.5). In the 2012 season, there were no significant difference in the accumulation of B. The concentration content in the first harvest of B in the 2011 season was very high compared to the amounts in the second harvest of 2011 or the first and second harvest of the 2012 season (Table 4.5).

Table 4.1. Dry matter production (DMP) of pearl millet harvested at Goudini Cellar near Rawsonville in 2011 and 2012

Treatment no. & target COD (mg/L)	DMP (t/ha)[1]					
	First harvest Jan 2011	Second harvest Febr 2011	Total	First harvest March 2012	Second harvest April 2012	Total
T1 – Raw	2.76	7.40	10.16	1.07	3.81	4.88
T2 – 100	1.76	7.63	9.39	2.01	3.70	5.71
T3 – 250	1.69	7.92	9.61	2.04	6.25	8.29
T4 – 500	2.63	8.06	10.69	1.13	5.14	6.27
T5 – 1000	1.47	8.61	10.08	1.20	3.55	4.75
T6 – 1500	2.53	7.27	9.80	2.03	4.07	6.10
T7 – 2000	1.70	10.17	11.88	1.53	4.96	6.49
T8 – 2500	1.85	8.98	10.84	1.94	3.62	5.56
T9 – 3000	2.50	8.90	11.29	1.03	4.64	5.67

[1]Data did not differ significantly at the 5% probability level.

Table 4.2. Chemical analyses of the macro-elements, N, P and K of pearl millet at Goudini Cellar near Rawsonville in 2011 and 2012

Treatment no.& target COD (mg/L)	N (kg/ha)		N (kg/ha)		P (kg/ha)		P (kg/ha)		K (kg/ha)		K (kg/ha)	
	2011		2012		2011		2012		2011		2012	
	First harvest	Second harvest	First harvest	Second harvest	First harvest	Second harvest	First harvest	Second harvest	First harvest	Second harvest	First harvest	Second harvest
T1 - Raw	2.94	1.36	2.63	1.27	0.70 bcd [1]	0.36	0.44 a	0.38	5.41	1.80	3.50	1.64
T2 - 100	2.98	0.76	2.63	1.63	0.60 d	0.36	0.39 abc	0.32	5.66	2.53	4.26	0.90
T3 - 250	3.16	0.86	2.27	1.84	0.74 bc	0.49	0.33 abcd	0.48	5.02	2.65	3.40	2.28
T4 - 500	3.16	0.99	3.31	1.44	0.61 d	0.32	0.32 abcde	0.29	5.29	2.17	3.29	2.08
T5 - 1000	3.46	1.16	3.40	1.26	0.61 d	0.44	0.19 e	0.29	5.25	3.12	3.56	1.67
T6 - 1500	3.16	1.00	2.66	1.54	0.95 a	0.42	0.25 de	0.28	5.15	2.72	2.78	2.03
T7 - 2000	3.11	1.16	2.82	1.68	0.61 d	0.37	0.27 cde	0.38	6.31	1.62	3.75	2.00
T8 - 2500	2.43	1.01	2.62	1.63	0.76 b	0.50	0.41 ab	0.38	5.60	3.66	3.68	2.16
T9 - 3000	2.93	0.85	3.49	1.77	0.70 bcd	0.41	0.28 bcde	0.31	5.25	2.92	3.49	1.72
LSD p≤0.05)	NS [2]	NS	NS	NS	0.10	NS	0.13	NS	NS	NS	NS	NS

[1] Values followed by the same letter within a column do not differ significantly (p≤0.05).

[2] NS = Not significant.

Table 4.3. Chemical analyses of the macro-elements, Ca, Mg and micro-element, Na of pearl millet at Goudini Cellar near Rawsonville in 2011 and 2012

Treatment no. & target COD (mg/L)	Ca (%)		Ca (%)		Mg (%)		Mg (%)		Na (mg/kg)		Na (mg/kg)	
	2011		2012		2011		2012		2011		2012	
	First Harvest	Second harvest	First harvest	Second Harvest	First harvest	Second Harvest	First harvest	Second harvest	First harvest	Second harvest	First harvest	Second harvest
T1 – Raw	0.63 bc [1]	0.38	0.74 a	0.40	0.44	0.34	0.49	0.40	217	212	212	212
T2 – 100	0.63 bc	0.38	0.57 bc	0.39	0.39	0.37	0.43	0.42	229	305	242	190
T3 – 250	0.74 b	0.41	0.72 a	0.36	0.41	0.38	0.39	0.38	221	267	167	203
T4 – 500	0.70 bc	0.34	0.69 ab	0.32	0.47	0.32	0.43	0.41	213	262	175	220
T5 – 1000	0.72 bc	0.50	0.82 a	0.41	0.44	0.42	0.50	0.45	215	290	184	220
T6 – 1500	0.93 a	0.43	0.54 cd	0.38	0.36	0.40	0.42	0.40	215	258	177	212
T7 – 2000	0.68 bc	035	0.36 e	0.34	0.40	0.31	0.32	0.40	224	217	205	191
T8 – 2500	0.62 c	0.51	0.41 de	0.44	0.36	0.46	0.40	0.52	216	328	212	243
T9 – 3000	0.65 bc	0.35	0.53 cd	0.44	0.35	0.35	0.40	0.44	221	385	202	200
LSD (P≤0.05)	0.11	NS[2]	0.15	NS	NS	NS	NS	NS	NS	NS	NS	NS

[1] Values followed by the same letter within a column do not differ significantly (p≤0.05).

[2] NS = Not significant.

Table 4.4. Chemical analyses of the micro-elements, Mn and Fe of pearl millet at Goudini Cellar near Rawsonville in 2011 and 2012

Treatment no. & target COD (mg/L)	Mn (mg/kg)		Mn (mg/kg)		Fe (mg/kg)		Fe (mg/kg)	
	2011		2012		2011		2012	
	First Harvest	Second harvest	First Harvest	Second harvest	First harvest	Second harvest	First harvest	Second harvest
T1 – Raw	46	25	29.33 ab [1]	13.33	125	128	198.00 a	123.67
T2 – 100	42	18	21.67 bc	9.33	135	179	183.00 ab	122.67
T3 – 250	54	17	16.00 cc	13.33	126	124	132.00 d	169.33
T4 – 500	57	18	27.67 ab	10.33	148	145	195.67 a	128.00
T5 – 1000	58	27	32.67 a	12.33	135	163	137.00 d	145.00
T6 – 1500	51	22	18.33 c	15.00	134	128	137.00 d	132.00
T7 – 2000	50	19	15.67 c	12.00	147	146	167.67 bc	212.33
T8 – 2500	55	23	18.67 c	17.67	125	143	143.67 d	185.33
T9 – 3000	44	17	19.33 c	11.00	136	129	147.67 cd	145.30
LSD (P≤0.05)	NS [2]	NS	7.71	NS	NS	NS	22.47	NS

[1] Values followed by the same letter within a column do not differ significantly (p≤0.05).

[2] NS = Not significant.

Table 4.5. Chemical analyses of the micro-elements, Cu, Zn and B of pearl millet at Goudini Cellar near Rawsonville in 2011 and 2012

Treatment no. & target COD (mg/L)	Cu (mg/kg)		Cu (mg/kg)		Zn (mg/kg)		Zn (mg/kg)		B (mg/kg)		B (mg/kg)	
	2011		2012		2011		2012		2011		2012	
	First harvest	Second harvest	First harvest	Second Harvest	First harvest	Second harvest	First harvest	Second harvest	First harvest	Second harvest	First harvest	Second harvest
T1 – Raw	13	7	10.67	4.67	40	40.00 c [1]	31.67	44.67	22	6	9.33	6.33
T2 – 100	12	6	10.00	4.67	44	29.67 d	35.33	31.33	23	4	6.67	5.33
T3 – 250	13	7	7.33	5.33	43	45.67 bcd	29.67	38.33	25	5	5.00	5.33
T4 – 500	13	5	10.00	4.67	43	32.67 cd	35.00	28.00	126	4	6.67	5.00
T5 – 1000	15	6	10.33	4.00	57	48.67 abcd	38.00	34.33	29	6	7.33	5.67
T6 – 1500	14	6	8.33	5.67	51	50.33 abc	29.67	35.67	28	6	5.33	6.33
T7 – 2000	15	6	8.67	5.33	48	53.33 ab	26.33	42.33	26	7	5.33	7.30
T8 – 2500	10	7	10.00	5.67	42	66.67 a	32.00	47.33	23	7	5.67	7.00
T9 – 3000	13	6	10.00	5.00	47	48.33 abcd	29.67	36.33	23	5	6.67	6.33
LSD (P≤0.05)	NS [2]	NS	NS	NS	NS	19.20	NS	NS	NS	NS	NS	NS

[1] Values followed by the same letter within a column do not differ significantly (p≤0.05).

[2] NS = Not significant.

4.3.3. Amounts of elements removed by pearl millet

Higher amounts of N were removed by pearl millet in the second harvest than in the first harvest in both the 2011 and 2012 seasons (Table 4.6). The pearl millet extracted substantially more N in the 2011 season than in the 2012 season. This could be because more cellar effluent were irrigated in the 2011 season than in the 2012 season (Table 3.2) with more nutrients available for pearl millet to accumulate. Total N uptake by Pearl millet was 78.24 kg/ha (6.36 tonnes/ha) in a trial that was done by Parihar *et al*. (2009) on a research farm of the Indian Agricultural Research Institute, New Delhi during the rainy and winter seasons from 2005 to 2007, with clean water and standard fertigation. Pearl millet took up more N of the cellar effluent in Goudini in most of the total N of 2011 and 2012. There was no correlation with the increase of the concentration of the COD of the cellar effluent and the N taken up by pearl millet.

Phosphorus has the same trend as N with more extraction in the 2011 season than in the 2012 season (Table 4.6). More P was also removed in the second harvest than in the first harvest in both the 2011 and 2012 seasons. Significantly higher amounts of the total of P was extracted by pearl millet in the 2011 season than the 2012 season. The pearl millet did not take up higher amounts of P as the COD concentrations increased. The P uptake of Pearl millet was 29.45 kg/ha with clean water and standard fertigation in a trial by Parihar *et al.* (2009). At the Goudini trial during the first harvest of 2011, pearl millet took up lower amounts than the 29.45 kg/ha reported by Parihar *et al*. (2009). The second harvest of pearl millet in 2012 took up lower amounts of P than the 29.45 kg/ha that was accumulated in a trial by Parihar *et al.* (2009).

The K uptake of pearl millet was higher in the second harvest than in the first harvest in 2011 and 2012 from T2 (100 mg/L) to T9 (3000 mg/L), (Table 4.7). The reason was because cellar effluent increased the K substance in the soil and gave pearl millet the opportunity for a higher accumulation of K. Pathak *et al.* (2011), also came to this conclusion when long-term sewage irrigation increased the K quantity in soils. The pearl millet removed more than double the total amounts of K in the 2011 season than in the 2012 season (Table 4.7). In a field trial that was done by Coelho *et al.* (2009), the K - uptake was also higher in the first season (2006) with 92.74 kg/ha than the second season (2007) with 70.60 kg/ha.

The pearl millet removed higher amounts of Ca and Mg in most of the treatments in the second harvest than in the first harvest, in both the 2011 and 2012 seasons (Table 4.7 and 4.8). Pacheco *et al.* (2012), also had the same results in a field trial when the amounts of Ca and Mg taken up by pearl millet increased with later harvest dates.

Table 4.6. Amounts of macro-elements, N and P removed by pearl millet harvested at the Goudini Cellar near Rawsonville in 2011 and 2012

Treatment no. & target COD (mg/L)	N (kg/ha)		N (kg/ha)	N (kg/ha)		N (kg/ha)	P (kg/ha)		P (kg/ha)	P (kg/ha)		P (kg/ha)
	2011		2011	2012		2012	2011		2011	2012		2012
	First harvest	Second harvest	Total	First Harvest	Second harvest	Total	First harvest	Second Harvest	Total	First harvest	Second harvest	Total
T1 – Raw	60.3	103.1 ab[(1)]	163.4	22.33	38.63 c	60.96 c	14.9 ab	21.5	36.4	3.80 bc	11.40	15.20
T2 – 100	40.3	48.8 d	92.10	42.13	47.53 bc	89.66 abc	8.3 b	21.8	30.1	6.33 a	9.63	15.96
T3 – 250	42.1	72.7 bcd	114.8	37.43	76.63 a	114.06 a	10.1 b	30.0	40.1	5.37 ab	20.97	26.34
T4 – 500	67.6	64.3 cd	131.9	31.63	39.37 c	71.00 bc	9.5 ab	21.5	31.0	2.90 c	8.17	11.60
T5 – 1000	38.2	98.4 ab	136.6	33.33	35.83 c	69.16 bc	7.2 b	31.2	38.4	1.93 c	8.17	8.17
T6 – 1500	67.1	75.3 bcd	142.6	42.93	48.77 bc	91.70 abc	19.4 a	24.3	43.7	4.13 abc	8.60	14.66
T7 – 2000	43.3	114.5 a	157.8	34.67	65.70 ab	100.37 ab	8.2 b	30.8	39.0	3.37 bc	14.33	17.70
T8 – 2500	36.6	87.4 abc	124.0	4370	46.17 c	89.87 abc	11.2 ab	36.4	47.6	6.27 a	10.90	17.17
T9 – 3000	59.6	75.5 bcd	135.1	27.80	45.57 c	73.37 bc	14.0 ab	29.3	43.3	2.47 c	7.90	10.37
LSD (P≤0.05)	NS [(2]	31.8	NS	NS	18.49	31.65	0.1	NS	NS	2.64	NS	NS

[(1)] Values followed by the same letter within a column do not differ significantly (p≤0.05).

[(2)] NS = Not significant.

Table 4.7. Amounts of macro-elements, K and Ca removed by pearl millet harvested at the Goudini Cellar near Rawsonville in 2011 and 2012

Treatment no. & target COD (mg/L)	K (kg/ha)		K (kg/ha)	K (kg/ha)		K (kg/ha)	Ca (kg/ha)		Ca (kg/ha)	Ca (kg/ha)		Ca (kg/ha)
	2011		2011	2012		2012	2011		2011	2012		2012
	First harvest	Second harvest	Total	First Harvest	Second harvest	Total	First harvest	Second Harvest	Total	First harvest	Second harvest	Total
T1 – Raw	116.3	104.9	221.2	29.84 c [1]	49.90 c	79.74 de	13.6 ab	22.6	36.2	6.30	1.97	18.57
T2 – 100	80.2	153.3	233.5	68.14 a	58.30 bc	126.44 ab	9.3 b	22.8	32.1	9.17	11.47	20.64
T3 – 250	67.1	158.2	225.3	57.84 ab	97.20 a	152.04 a	9.8 b	24.5	34.3	11.50	15.40	26.90
T4 – 500	14.3	139.4	253.7	30.06 c	57.10 bc	87.16 cde	15.0 ab	22.8	37.8	6.60	8.80	15.40
T5 – 1000	60.2	217.1	277.3	31.09 bc	47.43 c	78.52 de	8.2 b	34.3	42.5	7.60	11.43	19.03
T6 – 1500	99.6	157.8	257.4	44.81 abc	64.77 bc	109.58 bcd	18.9 a	24.8	43.7	8.67	11.93	20.60
T7 – 2000	74.9	141.1	216.0	45.78 abc	77.30 ab	123.08 ab	9.5 b	29.6	39.1	4.27	13.13	17.40
T8 – 2500	81.4	251.7	333.0	58.49 a	60.90 bc	119.39 abc	9.1 b	37.5	46.6	6.30	12.80	27.40
T9 – 3000	105.0	204.5	309.5	29.65 c	43.90 c	73.55 e	13.5 ab	24.7	38.2	4.30	11.07	15.37
LSD (P≤0.05)	NS [2]	NS	NS	24.45	27.34	35.36	0.1	NS	NS	NS	NS	NS

[1] Values followed by the same letter within a column do not differ significantly (p≤0.05).

[2] NS = Not significant

Table 4.8. Amounts of macro-element, Mg and micro-element, Na removed by pearl millet at Goudini Cellar near Rawsonville in 2011 and 2012

Treatment no. & target COD (mg/L)	Mg (kg/ha)		Mg (kg/ha)	Mg (kg/ha)		Mg (kg/ha)	Na (kg/ha)		Na (kg/ha)	Na (kg/ha)		Na (kg/ha)
	2011		2011	2012		2012	2011		2011	2012		2012
	First harvest	Second harvest	Total	First Harvest	Second harvest	Total	First harvest	Second Harvest	Total	First harvest	Second harvest	Total
T1 – Raw	9.4	19.8	29.2	4.17	12.23	16.40	0.47	1.23	1.70	0.18 c [1]	0.64	0.82
T2 – 100	5.5	22.5	28.0	6.90	12.40	19.30	0.34	1.86	2.20	0.38 a	0.57	0.95
T3 – 250	5.6	23.2	28.8	6.57	15.73	22.3	0.28	1.66	1.94	0.27 abc	0.87	1.14
T4 – 500	9.7	21.2	30.9	4.27	10.47	19.01	0.46	1.65	2.11	0.16 c	0.60	0.76
T5 – 1000	5.1	29.1	34.2	3.97	11.77	15.74	0.25	2.05	2.30	0.16 c	0.63	0.79
T6 – 1500	7.7	23.2	30.9	6.90	14.23	21.13	0.44	1.52	1.96	0.29 abc	0.69	0.98
T7 – 2000	5.6	26.4	32.0	4.00	15.37	19.37	0.31	1.87	2.18	0.25 bc	0.75	1.00
T8 – 2500	5.2	32.5	37.7	6.40	14.87	21.27	0.32	2.32	2.64	0.34 ab	0.72	1.06
T9 – 3000	7.2	24.9	32.1	3.40	11.33	14.73	0.42	2.67	3.09	0.17 c	0.51	0.68
LSD (P≤0.05)	NS [2]	NS	NS	NS	NS	NS	NS	NS	NS	0.13	NS	NS

[1] Values followed by the same letter within a column do not differ significantly (p≤0.05).

[2] NS = Not significant

Higher amounts of Na were removed by the pearl millet in the second harvest than in the first harvest (Table 4.10). In 2011 the pearl millet took up more than double the amounts of Na in the 2011 season than in the 2012 season. The reason for the highest accumulation of Na in 2011 could be because the dry matter production was the highest in 2011.

Manganese was taken up by the pearl millet in higher amounts in the second harvest than in the first harvest in the 2011 season (Table 4.11). In the 2012 season the pearl millet removed about the same amounts of Mn in the first and second harvest. The pearl millet removed higher amounts of Fe from the second harvest than the first harvest in the 2011 and 2012 seasons (Table 4.9). Higher amounts of Fe were taken up by the pearl millet in the 2011 season than in the 2012 season.

Higher amounts of Cu and Zn were removed by the pearl millet in the second harvest than in the first harvest in the 2011 season (Table 4.10). The amounts of Cu removed by pearl millet was the same in the totals of both the 2011 and 2012 seasons. Pearl millet took up higher total amounts of Zn in the 2011 season than in 2012. The amounts of B removed by pearl millet had no trends (Table 4.11).

Except for Na and B all the macro and micro-nutrients were removed by pearl millet with higher amounts in the second harvest than in the first harvest. Higher amounts of macro- and micro-elements were removed in the 2011 season than in the 2012 season and this suggests that the pearl millet removed the elements from the cellar effluent more successfully in the 2011 than in 2012. The pearl millet also had a better production rate in the 2011 season than in the 2012 season (Table 4.1).

The chemical analyses of the heavy metals such as Cd, Pb, Cr, As and Hg were not done in 2011 and 2012 since the effluent water did not contain significant amounts of those elements, with some even being absent in the results of 2010.

Table 4.9. Amounts of micro-elements, Mn and Fe removed by pearl millet at Goudini Cellar near Rawsonville in 2011 and 2012

Treatment no. & target COD (mg/L)	Mn (kg/ha)		Mn (kg/ha)	Mn (kg/ha)		Mn (kg/ha)	Fe (kg/ha)		Fe (kg/ha)	Fe (kg/ha)		Fe (kg/ha)
	2011		2011	2012		2012	2011		2011	2012		2012
	First harvest	Second harvest	Total	First Harvest	Second harvest	Total	First harvest	Second Harvest	Total	First harvest	Second harvest	Total
T1 – Raw	0.09	0.14	0.23	0.02	0.04	0.06	0.25	0.74	0.99	0.17	0.38	0.55
T2 – 100	0.06	0.11	0.17	0.04	0.03	0.07	0.20	1.12	1.32	0.29	0.35	0.64
T3 – 250	0.07	0.11	0.18	0.03	0.06	0.09	0.16	0.77	0.93	0.22	0.76	0.98
T4 – 500	0.13	0.11	0.24	0.03	0.03	0.06	0.2	0.99	1.31	0.18	0.35	0.53
T5 – 1000	0.07	0.18	0.25	0.03	0.04	0.07	0.15	1.12	1.27	0.13	0.41	0.54
T6 – 1500	0.10	0.13	0.23	0.03	0.05	0.08	0.27	0.74	1.01	0.22	0.42	0.64
T7 – 2000	0.07	0.16	0.23	0.02	0.04	0.06	0.21	1.23	1.44	0.20	0.83	1.03
T8 – 2500	0.08	0.17	0.25	0.03	0.05	0.08	0.19	1.00	1.19	0.22	0.54	0.76
T9 – 3000	0.09	0.12	0.21	0.02	0.03	0.05	0.28	0.89	1.17	0.12	0.37	0.49
LSD (P≤0.05)	NS[(1)]	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[(1)] NS = Not significant.

Table 4.10. Amounts of micro-elements, Cu and Zn removed by pearl millet at Goudini Cellar near Rawsonville in 2011 and 2012

Treatment no. & target COD (mg/L)	Cu (kg/ha)		Cu (kg/ha)	Cu (kg/ha)		Cu (kg/ha)	Zn (kg/ha)		Zn (kg/ha)	Zn (kg/ha)		Zn (kg/ha)
	2011		2011	2012		2012	2011		2011	2012		2012
	First harvest	Second harvest	Total	First harvest	Second harvest	Total	First harvest	Second Harvest	Total	First harvest	Second harvest	Total
T1 – Raw	0.03	0.04	0.07	0.01	0.01	0.02	0.08	0.24 c [1]	0.32 bc	0.03	0.13	0.16
T2 – 100	0.02	0.04	0.06	0.02	0.01	0.03	0.06	0.18 c	0.24 c	0.06	0.09	0.15
T3 – 250	0.02	0.04	0.06	0.01	0.03	0.04	0.06	0.28 bc	0.34 bc	0.05	0.16	0.21
T4 – 500	0.03	0.04	0.07	0.01	0.01	0.02	0.09	0.22 c	0.31 bc	0.03	0.08	0.11
T5 – 1000	0.02	0.04	0.06	0.01	0.01	0.02	0.07	0.33 abc	0.40 abc	0.04	0.10	0.14
T6 – 1500	0.03	0.04	0.07	0.01	0.02	0.03	0.11	0.29 bc	0.40 abc	0.05	0.11	0.16
T7 – 2000	0.02	0.05	0.07	0.01	0.02	0.03	0.07	0.45 ab	0.52 a	0.03	0.16	0.19
T8 – 2500	0.02	0.05	0.07	0.02	0.02	0.04	0.06	0.48 a	0.54 a	0.05	0.14	0.19
T9 – 3000	0.03	0.04	0.07	001	0.01	0.02	0.09	0.34 abc	0.43 ab	0.02	0.10	0.12
LSD (P≤0.05)	NS [2]	NS	NS	NS	NS	NS	NS	0.18	0.18	NS	NS	NS

[1] Values followed by the same letter within a column do not differ significantly (p≤0.05).

[2] NS = Not significant.

Table 4.11. Amounts of micro-element, B removed by pearl millet at Goudini Cellar near Rawsonville in 2011 and 2012

Treatment no. & target COD (mg/L)	B (kg/ha)		B (kg/ha)	B (kg/ha)		B (kg/ha)
	2011		2011	2012		2012
	First harvest	Second harvest	Total	First harvest	Second harvest	Total
T1 – Raw	0.04	0.04	0.08	0.01	0.02	0.03
T2 – 100	0.03	0.03	0.06	0.01	0.01	0.02
T3 – 250	0.03	0.03	0.06	0.01	0.02	0.03
T4 – 500	0.06	0.03	0.09	0.01	0.02	0.03
T5 – 1000	0.03	0.04	0.07	0.01	0.02	0.03
T6 – 1500	0.06	0.03	0.09	0.01	0.02	0.03
T7 – 2000	0.4	0.05	0.09	0.01	0.03	0.04
T8 – 2500	0.03	0.05	0.08	0.01	0.02	0.03
T9 – 3000	0.06	0.04	0.10	0.01	0.02	0.03
LSD (P≤0.05)	NS[(1)]	NS	NS	NS	NS	NS

[(1)] NS = Not significant.

4.4. Summary

Sufficient accumulation of N and K of the cover crop pearl millet took place in the 2011 and 2012 seasons (Tables 4.8 and 4.9). Most of the minerals that were taken up successfully did not necessarily show an increase in the correlation with an increase of the COD levels.

The removal of cellar effluent in a way that is safe to the environment will differ from cellar to cellar, according to different production levels, soil structures and climatic conditions. Cellars are advised not to use Na-based cleaning agents but rather K-based cleaning agents to prevent sodicity problems.

4.5. References

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CHAPTER 5
THE POTENTIAL OF *PENNISETUM GLAUCUM* (PEARL MILLET) AND *AVENA SATIVA* (OATS) TO REMOVE MACRO- AND MICRO- ELEMENTS FROM VINEYARD SOIL IRRIGATED WITH CELLAR EFFLUENT OVER A THREE YEAR PERIOD

Abstract

Oats (*A. sativa L.* cv Pallinup) and pearl millet (*P. glaucum*) were irrigated with cellar effluent from 100 mg/L to 3 000 mg/L COD concentrations in a vineyard at the Goudini Cellar near Rawsonville. The cellar effluent at the Goudini cellar did not have a negative effect on the growth of oats and pearl millet, the soil status as well as the wine quality. The soil status were examined for pH, EC, P, K, Ca, Mg, Na and organic C. Higher concentrations of P, K and Ca were present in the topsoil (0-300 mm) than the sub-soil (300-600 mm). No amounts of elements were found in high concentrations in the soil which could have a detrimental effect on the vineyard or the wines that were made from the vineyard. The potential of pearl millet and oats to accumulate macro- and micro-elements from the soil were evaluated. N and K were successfully removed in the 2011 and 2012 seasons, but P was only removed successfully in 2011. The farmer may use less N and K fertiliser if he irrigates with cellar effluent. Sodium was not removed successfully by pearl millet and oats in 2011 and 2012. Cellars are advised not to use Na-based cleaning agents like NaOH, but rather K-based cleaning agents like KOH.

5.1. Introduction.

Winery wastewater contains a higher concentration of salts than treated wastewater used by municipalities (Laurenson *et al.*, 2010). According to these authors the highest concentration of Na and K is present in winery wastewater compared to municipal waters which has more abundant Na, because of the use of cleaning agents like NaOH and KOH in the cellar. If winery wastewater is irrigated there is the potential for the Na and K to buildup in higher quantities in the soil which could have a negative effect on the growth of the vineyard.

The potential of *A. sativa* L. cv Pallinup (oats) and *P. glaucum* L.R.Br (pearl millet) to remove macro- and micro- elements from the soil was evaluated together with the use of fertilisers, like N and P. Cellar effluent contains the necessary N and P that is needed by crops and it also increase the nutrient content of the soil (Singh *et al.*, 2012). If cellar effluent is irrigated the farmer may reduce the amount of fertiliser used. One of the major problems in soils which can be caused by cellar effluent is salinity. Salinity can be the result when sodium combines and enlarge with clay particles scattering them and causing a negative effect in the absorbency of the soil (Toze, 2004). This usually happens in clay soils more easily than sandy soils. It

could also happen when SAR and PAR is more than 6 and 10 respectively (Laurenson & Houlbrooke, 2011). This problem can be solved by applying calcium in the form of gypsum, lime [$CaCO_3$] and calcium nitrate [$Ca(NO_3)_2$]. This trial documents the potential of pearl millet planted after oat in the removal of macro- and micro- elements in an effluent irrigated vineyard.

5.2. Materials and methods

5.2.1. Water quality of the cellar effluent

See Chapter 3.2.3.

5.2.2. Soil chemical status

Soil samples were taken from each of the nine treatment plots at 0-30 cm, 30-60 cm and 60-90 cm depth, in May 2010 (after irrigation with cellar effluent that started in March 2010) and in September 2010 (after the cover crop were harvested). The samples were analysed to determine pH, electrical conductivity (EC), P, K, Ca, Mg, Na and organic C.

All these soil sampling actions were repeated in 2011 and 2012 but samples were only taken from the vine row and the middle row of treatments 1, 3, 5, 7, and 9 to save costs. Repetitions were pooled to save costs and no statistical analyses could be done.

5.3. Results and discussion

5.3.1. Water quality of the cellar effluent

The water quality of the cellar effluent was determined to make sure that the correct COD levels was given and to determine the element content of the water. During the winemaking process from February until April there was the highest concentration of elements especially Na and K in the cellar effluent (Sheridan *et al*., 2011). It is a standard practice to remove most of the solid material like grape stems and pips from cellar effluent before it is removed from the cellar in a responsible way.

The actual COD levels that was given during the 2010 to the 2012 season (data not shown) was near the COD-levels that had to be given according to the project plan. The pH, EC, and SAR (data not shown) was in the range that was set by the legal limits for wastewater irrigation (Table 1.1 in Chapter 1). The pH values had a small decrease with the increase of the COD values (data not shown). The element content of N, P, K, Ca, Mg, Na, Fe, and B increased with the higher concentrations in the COD levels of the cellar effluent in every year as expected (Tables 5.1 and 5.2). The Mg and Na were exceptionally higher in the 2011 season than the 2012 season.

Table 5.1. Nitrogen, phosphorus, potassium and calsium in raw winery wastewater and augmented winery wastewater used for irrigation of Cabernet Sauvignon/99 R at Goudini Cellar near Rawsonville during the 2010, 2011 and 2012 seasons

Treatment no. & target COD (mg/L)	N (kg/ha)			P (kg/ha)			K (kg/ha)			Ca (kg/ha)		
	2010	2011	2012	2010	2011	2012	2010	2011	2012	2010	2011	2012
T1 – Raw	no	5.53	3.32	0.0	0.09	0.07	5	8	7	10	32	15
T2 – 100	data	3.61	1.47	0.0	0.07	0.23	11	14	11	9	31	15
T3 – 250		3.28	1.25	0.0	0.39	0.63	20	25	22	10	31	18
T4 – 500		2.62	2.02	0.2	1.18	1.37	37	44	36	11	33	20
T5 – 1000		3.01	2.22	0.7	3.18	2.95	79	79	65	14	35	25
T6 – 1500		4.39	3.09	1.2	5.35	4.43	111	113	87	16	39	29
T7 – 2000		4.76	4.26	1.7	8.46	5.24	141	149	104	18	40	33
T8 – 2500		4.69	6.31	2.7	10.37	6.82	170	173	135	20	41	37
T9 – 3000		5.43	6.40	3.4	13.46	8.03	206	215	158	22	43	41

Tables 5.1 - 5.4 were adapted from Myburgh (2010; 2011 & 2012).

Table 5.2. Magnesium, sodium, iron and boron in raw winery wastewater and augmented winery wastewater used for irrigation of Cabernet Sauvignon/99R at Goudini Cellar near Rawsonville during the 2010, 2011 and 2012 seasons

Treatment no. & target COD (mg/L)	Mg (kg/ha)			Na (kg/ha)			Fe (kg/ha)			B (kg/ha)		
	2010	2011	2012	2010	2011	2012	2010	2011	2012	2010	2011	2012
T1 – Raw	6.4	20.1	10	18	53	33	0.0	1.29	0.2	0.122	0.08	0.03
T2 – 100	5.9	19.6	10	18	54	37	0.1	2.12	0.3	0.064	0.10	0.03
T3 – 250	6.0	19.8	10	20	60	38	0.1	1.88	0.4	0.075	0.13	0.05
T4 – 500	6.3	20.2	11	23	73	42	0.3	1.95	0.6	0.096	0.18	0.10
T5 – 1000	6.5	20.7	11	31	81	50	0.5	1.17	0.9	0.159	0.29	0.17
T6 – 1500	6.8	21.6	12	37	97	55	0.7	2.24	1.3	0.197	0.39	0.24
T7 – 2000	7.1	22.2	12	43	105	62	0.9	1.95	1.5	0.236	0.49	0.32
T8 – 2500	7.7	22.1	13	50	110	69	1.1	2.64	2.1	0.313	0.58	0.41
T9 – 3000	7.7	22.9	14	57	122	74	1.3	3.29	2.6	0.386	0.71	0.44

5.3.2. Soil chemical status

The soil pH of the five treatments remained the same over the 2010 to the 2012 seasons in the 0 to 60 cm soil depths (Table 5.3), except for oats which had an increase from about 5 to 7 in treatments 3 and 5 in the 0 to 300 mm soil layers. This was the same as the results of Masto *et al.* (2009), where a sewage effluent in a sandy loam soil did not increase the pH after 20 years. The electrical conductivity remained relatively the same from May 2010 to September 2012 (Table 5.4). The P and K content in the soil were higher in the 0 to 300 mm than in the 300 mm to 600 mm soil depths (Table 5.16). Mohammed and Mazahreh (2003) had a trial with corn (*Zea mays*) for two seasons and vetch (*Vicia sativa*) for one season where the topsoil also had a higher amount of P and K than the subsoil. The highest P and K content were during October 2010 after the oat was planted (Tables 5.5 and 5.6). During September in 2011 and 2012 the P and K content reduced in the topsoil which shows that the Pearl millet was able to take up sufficient P and K in the topsoil.

Ca content (Table 5.7) and Mg content (Table 5.8) was about the same from May 2010 to September 2012. The Na content (Table 5.9) and organic C (Table 5.10) remained the same from May 2010 to September 2012. Wastewaters with a high organic material may cause soil compaction (Mosse *et al.*, 2011), but this did not happen at the Goudini trial. The reason might be because it was a sandy soil and the oats and the pearl millet as a cover crop prevented soil compaction.

According to the soil data there were no accumulation of elements in the soil over the 2010, 2011 and 2012 seasons. This also confirms that the oats, *A. sativa* and the pearl millet, *P. glaucum* took up sufficient minerals to prevent a detrimental effect on the vineyard. The cellar effluent did not have a negative impact on the organic content in the soil.

Table 5.3. The pH of the soil for the 0 to 600 mm layers during May 2010 until September 2012 at Goudini Cellar near Rawsonville

Treatments-COD levels (mg/L)	Soil layers	pH content of treatments for 0-600 mm soil layers.			
		May 2010	Oct 2010	Sept 2011	Sept 2012
		"Control"	Just oats	After oats and pearl millet	After oats and pearl millet
1 – Raw	0-300 mm	4.9	6.8	5.6	5.5
	300-600 mm	4.8	6.8	5.2	5.6
3 – 250	0-300 mm	5.4	7.2	5.5	5.3
	300-600 mm	5.1	7.2	5.5	5.3
5 – 1000	0-300 mm	5.4	7.1	5.0	5.1
	300-600 mm	4.7	7.1	4.8	5.3
7 – 2000	0-300 mm	5.3	5.6	5.3	5.2
	300-600 mm	5.4	4.9	4.7	4.7
9 – 3000	0-300 mm	5.7	5.4	5.7	6.5
	300-600 mm	5.2	5.0	5.6	6.5

(pH = KCL method)

Table 5.4. Electrical conductivity of the soil for the 0 to 600 mm layers taken during May 2010 until September 2012 at Goudini Cellar near Rawsonville

Treatments-COD levels (mg/L)	Soil layers	Electrical conductivity (dS/m) of treatments for 0-600 mm soil layers.			
		May 2010	Oct 2010	Sept 2011	Sept 2012
		"Control"	Just oats	After oats and pearl millet	After oats and pearl millet
1 – Raw	0-300 mm	0.11	0.07	0.04	0.11
	300-600 mm	0.10	0.06	0.05	0.07
3 – 250	0-300 mm	0.07	0.07	0.05	0.07
	300-600 mm	0.06	0.06	0.04	0.06
5 – 1000	0-300 mm	0.07	0.06	0.04	0.09
	300-600 mm	0.07	0.06	0.04	0.06
7 – 2000	0-300 mm	0.05	0.06	0.04	0.08
	300-600 mm	0.06	0.05	0.03	0.06
9 – 3000	0-300 mm	0.07	0.05	0.03	0.08
	300-600 mm	0.05	0.06	0.04	0.08

Table 5.5. The P content of the soil samples for the 0 cm to 600 mm depths taken during May 2010 until September 2012 at Goudini Cella near Rawsonville

Treatments-COD levels (mg/L)	Soil layers	Average P content (mg/kg) of treatments for 0-600 mm soil layers			
		May 2010	Oct 2010	Sept 2011	Sept 2012
		"Control"	Just oats	After oats and pearl millet	After oats and pearl millet
1 – Raw	0-300 mm	212	323	227	262
	300-600 mm	65	226	98	87
3 – 250	0-300 mm	219	440	230	200
	300-600 mm	120	298	109	61
5 – 1000	0-300 mm	218	261	196	229
	300-600 mm	105	162	140	61
7 – 2000	0-300 mm	210	425	230	228
	300-600 mm	130	142	111	65
9 – 3000	0-300 mm	235	302	248	243
	300-600 mm	102	169	169	138

Table 5.6. The K content of the soil samples for the 0 cm to 600 mm depths taken during May 2010 until September 2012 at Goudini Cellar near Rawsonville

Treatments-COD levels (mg/L)	Soil layers	Average K content (cmol/kg) of treatments for 0-600 mm soil layers			
		May 2010	Oct 2010	Sept 2011	Sept 2012
		"Control"	Just oats	After oats and pearl millet	After oats and pearl millet
1 – Raw	0-300 mm	0.15	0.19	0.14	0.15
	300-600 mm	0.12	0.17	0.12	0.06
3 – 250	0-300 mm	0.15	0.18	0.15	0.14
	300-600 mm	0.12	0.15	0.13	0.12
5 – 1000	0-300 mm	0.23	0.24	0.18	0.13
	300-600 mm	0.12	0.19	0.13	0.12
7 – 2000	0-300 mm	0.26	0.29	0.28	0.18
	300-600 mm	0.14	0.11	0.18	0.09
9 – 3000	0-300 mm	0.30	0.19	0.27	0.20
	300-600 mm	0.11	0.14	0.24	0.08

Table 5.7. The Ca content of the soil samples for the 0 cm to 600 mm layers taken during May 2010 until September 2012 at Goudini Cellar near Rawsonville

Treatments-COD levels (mg/L)	Soil layers	Average Ca content (cmol/kg) of treatments for 0-600 mm soil layers			
		May 2010	Oct 2010	Sept 2011	Sept 2012
		"Control"	Just oats	After oats and pearl millet	After oats and pearl millet
1 – Raw	0-300 mm	1.66	2.01	2.49	3.07
	300-600 mm	1.11	1.36	1.58	1.97
3 – 250	0-300 mm	2.17	2.95	2.45	2.56
	300-600 mm	1.54	1.67	2.12	1.65
5 – 1000	0-300 mm	2.19	2.18	1.95	2.43
	300-600 mm	1.18	1.52	1.59	1.65
7 – 2000	0-300 mm	2.35	2.93	2.38	2.50
	300-600 mm	2.48	1.28	1.32	1.39
9 – 3000	0-300 mm	2.76	2.00	2.62	2.87
	300-600 mm	1.70	1.29	2.42	2.62

Table 5.8. The Mg content of the soil samples for the 0 cm to 600 mm depths taken during May 2010 until September 2012 at Goudini Cellar near Rawsonville

Treatments-COD levels (mg/L)	Soil layers	Average Mg content (cmol/kg) of treatments for 0-600 mm soil layers			
		May 2010	Oct 2010	Sep 2011	Sep 2012
		"Control"	Just oats	After oats and pearl millet	After oats and pearl millet
1 – Raw	0-300 mm	0.71	0.87	1.13	1.15
	300-600 mm	0.52	0.61	0.85	0.92
3 – 250	0-300 mm	0.85	1.19	0.98	0.90
	300-600 mm	0.56	0.83	0.81	0.66
5 – 1000	0-300 mm	0.91	0.94	0.75	0.83
	300-600 mm	0.49	0.77	0.67	0.66
7 – 2000	0-300 mm	0.99	1.17	1.07	1.03
	300-600 mm	1.11	0.78	0.63	0.66
9 – 3000	0-300 mm	1.02	0.86	1.03	1.08
	300-600 mm	0.71	0.67	1.06	1.15

Table 5.9. The Na content of the soil for the 0 cm to 600 mm layers taken during May 2010 until September 2012 at Goudini Cellar near Rawsonville

Treatments-COD levels (mg/L)	Soil layers	Average Na content (cmol/kg) of treatments for 0-600 mm soil layers			
		May 2010	Oct 2010	Sep 2011	Sep 2012
		"Control"	Just oats	After oats and pearl millet	After oats and pearl millet
1 – Raw	0-300 mm	0.07	0.07	0.09	0.09
	300-600 mm	0.07	0.07	0.09	0.09
3 – 250	0-300 mm	0.08	0.07	0.09	0.09
	300-600 mm	0.06	0.07	0.09	0.09
5 – 1000	0-300 mm	0.08	0.08	0.10	0.10
	300-600 mm	0.07	0.08	0.11	0.09
7 – 2000	0-300 mm	0.10	0.08	0.08	0.10
	300-600 mm	0.08	0.08	0.10	0.09
9 – 3000	0-300 mm	0.09	0.09	0.07	0.10
	300-600 mm	0.07	0.08	0.11	0.12

Table 5.10. The organic C of the soil for the 0 cm to 600 mm layers taken during May 2010 until September 2012 at Goudini Cellar near Rawsonville

Treatments-COD levels (mg/L)	Soil Layers	Organic C (%) content of treatments for 0-600 mm soil layers			
		May 2010	Oct 2010	Sep 2011	Sep 2012
		"Control"	Just oats	After oats and pearl millet	After oats and pearl millet
1 – Raw	0-300 mm	0.80	0.87	1.06	0.98
	300-600 mm	0.55	0.96	0.77	0.68
3 – 250	0-300 mm	1.83	0.73	0.95	0.75
	300-600 mm	0.53	0.91	0.56	0.53
5 – 1000	0-300 mm	0.82	0.78	0.96	0.72
	300-600 mm	0.60	0.80	0.67	0.53
7 – 2000	0-300 mm	0.96	0.90	0.92	0.82
	300-600 mm	0.94	0.97	0.87	0.68
9 – 3000	0-300 mm	0.74	0.81	0.37	1.02
	300-600 mm	0.61	0.88	0.92	0.73

5.4. Potential of oats and pearl millet to remove elements from irrigated cellar effluent

The balance of N after cellar effluent irrigations were applied and removed by pearl millet and oats show that the pearl millet and oats removed more N than applied by the cellar effluent and fertiliser in the 2011 and 2012 seasons (Table 5.11 and 5.12) except T5 (1000 mg/L COD) with 23.84 kg/ha in the 2011 season. In 2010 there was no data for the N content of the cellar effluent applied before the oats were established. Although more N was removed by the pearl millet the vineyard did not show any N deficiencies. Myburgh (2010-2012) found no negative effect on the growth or the yield of the grapevine at the Goudini trial.

In 2011 more P was removed from the soil by oats and pearl millet than were applied by cellar effluent (Table 5.13). In the 2012 season pearl millet and oats only removed more P in the T1, T3 and T7 treatments (Table 5.14). The minimum requirement of P for vineyards is 20 mg/kg (Raath & Conradie, 2000). The P content in the soil (Table 5.5) showed that there was enough P available for the vineyard from May 2010 until September 2012. Higher P amounts were available in the 0-300 mm than in the 300-600 mm soil depths (Table 5.5). According to Mohammad and Mazahreh (2003), the build-up of salts in the topsoil could be because of dispersion in the topsoil.

More K was removed from the soil by the pearl millet and oats than were applied by the cellar effluent in 2011 and 2012 (Table 5.15). According to Conradie (2013, personal communication), the K content in the soil required for a vineyard is 4% cation exchange capacity (CEC). The K content from May 2012 until September was higher than the 4% (CEC) required, except for the treatments 1, 7 and 9 of the 300 mm to the 600 mm which was 2.3%, 3.5% and 1% CEC.

The balance of Ca after cellar effluent irrigations were applied and removed by pearl millet and oats were slightly more than was available in the soil for the 2011 and 2012 seasons (Table 5.16 and 5.17), except for treatments T7, T8 and T9 in the 2012 season where a slight excess remained in the soil (Table 5.18). The Ca requirements for soil is 1 to 1.5 cmol/kg according to Conradie (personal communication). The Ca content in the soil was above the limits required for a vineyard soil (Table 5.7) from May 2010 until May 2012 (all amounts ≥ 1.5 cmol/kg).

Table 5.11. The balance of N after cellar effluent irrigations and fertiliser were applied, and the amounts removed by pearl millet and oats at Goudini near Rawsonville in 2011

Treatment no. & target COD (mg/L)	2011						
	N (kg/ha)	N (kg/ha)	N (kg/ha)	N (kg/ha)	N (kg/ha)	N (kg/ha)	N (kg/ha)
	Applied via cellar effluent	Applied by fertiliser	Total cellar effluent + fertiliser (A)	Removed by pearl millet	Removed by oats	Total removed by pearl millet and oats (B)	Balance (A) - (B)
T1 – Raw	5.53	84	89.53	163.4	30.07	193.5	-103.97
T2 – 100	3.61	84	87.61	92.1	42.7	134.8	-47.19
T3 – 250	3.28	84	87.28	114.8	44.6	159.4	-72.09
T4 – 500	2.62	84	86.62	131.9	74.3	206.2	-119.61
T5 – 1000	3.01	84	87.01	36.2	24.97	63.2	23.84
T6 – 1500	4.39	84	88.39	142.6	54.23	196.8	-108.44
T7 – 2000	4.76	84	88.76	157.8	71.07	228.8	-140.08
T8 – 2500	4.69	84	88.69	124.0	67.33	191.4	-102.67
T9 – 3000	5.43	84	89.43	136.1	57.07	192.2	-102.74

Table 5.12. The balance of N after cellar effluent irrigations and fertiliser were applied, and the amounts removed by pearl millet and oats at Goudini Cellar near Rawsonville in 2012

Treatment no. & target COD (mg/L)	2012						
	N (kg/ha)	N (kg/ha)	N (kg/ha)	N (kg/ha)	N (kg/ha)	N (kg/ha)	N (kg/ha)
	Applied via cellar effluent	Applied by fertiliser	Total cellar effluent + fertiliser (A)	Removed by pearl millet	Removed by oats	Total removed by pearl millet and oats (B)	Balance (A) - (B)
T1 – Raw	3.32	84	87.32	60.96	105	166.0	-76.64
T2 – 100	1.47	84	85.47	89.65	62	151.7	-66.19
T3 – 250	1.25	84	85.25	114.06	67	181.1	-95.81
T4 – 500	2.02	84	85.02	71.00	101	172.0	-85.98
T5 – 1000	2.22	84	86.22	69.16	68	137.2	-50.94
T6 – 1500	3.09	84	87.09	91.70	79	170.7	-83.61
T7 – 2000	4.25	84	88.26	100.37	105	205.4	-177.11
T8 – 2500	6.31	84	90.31	89.87	76	165.9	-75.56
T9 – 3000	6.4	84	90.40	73.37	66	139.4	-48.97

Table 5.13. The balance of P after cellar effluent irrigations and fertiliser were applied, and the amounts removed by pearl millet and oats at Goudini Cellar near Rawsonville in 2011

Treatment no. & target COD (mg/L)	2011						
	P (kg/ha)	P (kg/ha)	P (kg/ha)	P (kg/ha)	P (kg/ha)	P (kg/ha)	P (kg/ha)
	Applied via cellar effluent	Applied by fertiliser	Total cellar effluent + fertiliser (A)	Removed by pearl millet	Removed by oats	Total removed by pearl millet and oats (B)	Balance (A) - (B)
T1 – Raw	0.09	30	9.59	36.4	7.2	43.6	- 13.51
T2 – 100	0.07	30	9.57	30.1	9.3	39.4	- 9.33
T3 – 250	0.39	30	9.89	40.1	10.9	61.0	- 20.61
T4 – 500	1.18	30	10.68	31.0	17.2	48.2	- 17.02
T5 – 1000	3.18	30	12.68	38.4	6.2	44.6	- 11.42
T6 – 1500	5.35	30	14.85	43.7	14.0	57.7	- 22.35
T7 – 2000	8.46	30	17.96	39.0	17.2	45.2	- 17.74
T8 – 2500	10.37	30	19.87	47.6	14.4	62.0	- 21.63
T9 – 3000	13.46	30	22.96	43.3	13.2	56.5	- 13.04

Table 5.14. The balance of P after cellar effluent irrigations and fertiliser were applied, and the amounts removed by pearl millet and oats at Goudin Cellar near Rawsonville in 2012

Treatment no. & target COD (mg/L)	2012						
	P (kg/ha)	P (kg/ha)	P (kg/ha)	P (kg/ha)	P (kg/ha)	P (kg/ha)	P (kg/ha)
	Applied via cellar effluent	Applied by fertiliser	Total cellar effluent + fertiliser (A)	Removed by pearl millet	Removed by oats	Total removed by pearl millet and oats (B)	Balance (A) - (B)
T1 – Raw	0.07	30	30.07	15.2	19.1	34.3	- 4.2
T2 – 100	0.23	30	30.25	15.96	10.67	26.63	3.6
T3 – 250	0.63	30	30.63	28.34	14.23	42.57	- 11.94
T4 – 500	1.37	30	31.37	11.6	17.53	29.13	2.24
T5 – 1000	2.95	30	32.95	8.17	15.00	23.17	9.78
T6 – 1500	4.43	30	34.43	14.66	16.53	31.19	3.24
T7 – 2000	5.24	30	35.24	17.7	18.13	35.83	- 0.59
T8 – 2500	6.82	30	36.82	17.17	13.13	30.3	6.52
T9 – 3000	8.03	30	38.03	10.37	13.83	24.2	13.83

Table 5.15. The balance of K after cellar effluent irrigations were applied, and the amounts removed by pearl millet and oats at Goudini Cellar near Rawsonville in 2011 and 2012

Treatment no. & target COD (mg/L)	2011				2012			
	K (kg/ha)	K (kg/ha)	K (kg/ha)	K (kg/ha)	K (kg/ha)	K (kg/ha)	K (kg/ha)	K (kg/ha)
	Applied via cellar effluent (A)	Removed by pearl millet (B)	Removed by oats (C)	Balance A - (B+C)	Applied via cellar effluent (A)	Removed by pearl millet (B)	Removed by oats (C)	Balance A - (B+C)
T1 – Raw	8	221.2	27.9	-241.13	6.6	79.74	108.67	-181.81
T2 – 100	14	233.5	52.6	-272.07	11.0	126.44	64.83	-180.27
T3 – 250	25	225.3	38.1	-238.40	21.6	152.04	105.27	-235.71
T4 – 500	44	253.7	71.2	-280.93	35.9	87.16	114.8	-166.06
T5 – 1000	79	277.3	26.6	-224.87	65.1	78.52	88.53	-101.95
T6 – 1500	113	257.4	55.6	-199.97	87.3	109.58	123.0	-145.31
T7 – 2000	149	216.0	80.5	-147.50	104	123.08	141.87	-160.95
T8 – 2500	173	333.1	64.4	-224.53	134.5	119.39	96.7	-81.59
T9 – 3000	215	309.5	59.1	-153.57	157.7	73.55	91.77	-7.62

Table 5.16. The balance of Ca after cellar effluent irrigations were applied and the amounts removed by pearl millet and oats at Goudini Cellar near Rawsonville in 2011

Treatment no. & target COD (mg/L)	2011			
	Ca(kg/ha)	Ca (kg/ha)	Ca (kg/ha)	Ca (kg/ha)
	Applied via cellar effluent (A)	Removed by pearl millet (B)	Removed by oats (C)	Balance A - (B+C)
T1 – Raw	31.7	36.2	3.87	-8.37
T2 – 100	30.7	32.1	5.37	-6.77
T3 – 250	30.8	34.3	5.2	-8.70
T4 – 500	32.9	37.8	9.03	-13.93
T5 – 1000	34.9	42.5	2.97	-10.57
T6 – 1500	38.5	43.7	6.33	-11.53
T7 – 2000	39.9	39.1	7.0	-6.20
T8 – 2500	40.8	46.6	5.33	-11.13
T9 – 3000	43.1	38.2	5.03	-0.13

Table 5.17. The balance of Ca after cellar effluent irrigations were applied and the amounts removed by pearl millet and oats at Rawsonville in 2012

Treatment no. & target COD (mg/L)	2012			
	Ca (kg/ha)	Ca (kg/ha)	Ca (kg/ha)	Ca (kg/ha)
	Applied via cellar effluent (A)	Removed by pearl millet (B)	Removed by oats (C)	Balance A - (B+C)
T1 – Raw	14.9	18.57	11.4	-15.07
T2 – 100	15.4	20.64	8.77	-14.01
T3 – 250	17.5	26.9	8.53	-17.99
T4 – 500	20.1	15.4	8.3	-3.60
T5 – 1000	25.0	19.03	7.77	-1.80
T6 – 1500	28.6	20.6	8.27	-0.27
T7 – 2000	32.5	17.4	9.57	5.33
T8 – 2500	36.5	27.1	6.83	2.57
T9 – 3000	40.7	15.37	5.63	18.70

The balance of Mg after cellar effluent irrigations were applied, and removed by pearl millet and oats, were slightly more than was available in the 2011 and the 2012 seasons (Table 5.18 and 5.19). The requirements for the Mg content in the soil for a vineyard is 0.3 cmol/kg (Conradie, personal communication). The Mg content in the soil (Table 5.8) was more than the required level for all the treatments from May 2010 to September 2012.

The balance of Na after cellar irrigations were applied, and removed by pearl millet and oats was in excess in 2011 and 2012 (Table 5.20 and 5.21). The requirements for a sodium content which is safe for the vineyard is an electrical conductivity (ECe) of <0.25 dS/m (Richards, 1954). The ECe in the soil from May 2010 until September 2012 was < 0.25 dS/m which indicate that the Na content remained low within a safe limit (Table 5.9).

Higher amounts of P, K, Ca and Mg were found in most of the topsoil (0 – 300 mm) than in the subsoil (300 mm – 600 mm). This was also the same conclusion made by Mohammed and Mazahreh (2003) due to effect of evaporation and the lack of washing of the salts to the lower depths in the soil.

Table 5.18. The balance of Mg after cellar effluent irrigations were applied and removed by pearl millet and oats at Goudini Cellar near Rawsonville in 2011

Treatment no. & target COD (mg/L)	2011			
	Mg (kg/ha)	Mg (kg/ha)	Mg (kg/ha)	Mg (kg/ha)
	Applied via cellar effluent (A)	Removed by pearl millet (B)	Removed by oats (C)	Balance A - (B+C)
T1 – Raw	20.1	29.2	4.90	-14.00
T2 – 100	19.6	28.0	6.87	-15.27
T3 – 250	19.8	28.8	7.17	-16.17
T4 – 500	20.2	30.9	10.97	-21.67
T5 – 1000	20.7	34.2	4.27	-17.77
T6 – 1500	21.6	30.9	9.43	-18.73
T7 – 2000	22.2	32.0	9.63	-19.43
T8 – 2500	22.1	37.7	8.07	-23.97
T9 – 3000	22.9	32.1	7.67	-16.87

Table 5.19. The balance of Mg after cellar effluent irrigations were applied and removed by pearl millet and oats at Goudini Cellar near Rawsonville in 2012

Treatment no. & target COD (mg/L)	2012			
	Mg (kg/ha)	Mg (kg/ha)	Mg (kg/ha)	Mg (kg/ha)
	Applied via cellar effluent (A)	Removed by pearl millet (B)	Removed by oats (C)	Balance A - (B+C)
T1 – Raw	9.7	16.4	11.67	-18.37
T2 – 100	9.9	19.3	7.47	-16.87
T3 – 250	10.4	22.3	7.40	-19.30
T4 – 500	10.6	19.01	8.47	-16.88
T5 – 1000	11.3	15.74	6.97	-11.41
T6 – 1500	12.2	21.13	7.53	-16.46
T7 – 2000	12.4	19.37	9.57	-16.54
T8 – 2500	12.8	21.27	7.07	-15.54
T9 – 3000	13.7	14.73	5.35	-6.56

Table 5.20. The balance of Na after cellar effluent irrigations were applied and removed by pearl millet and oats at Goudini Cellar near Rawsonville in 2011

Treatment no. & target COD (mg/L)	2011			
	Na (kg/ha)	Na (kg/ha)	Na (kg/ha)	Na (kg/ha)
	Applied via cellar effluent (A)	Removed by pearl millet (B)	Removed by oats (C)	Balance A - (B+C)
T1 – Raw	20.1	1.70	4.90	13.50
T2 – 100	19.6	2.20	6.87	10.53
T3 – 250	19.3	1.94	7.17	10.19
T4 – 500	20.2	2.11	10.97	7.02
T5 – 1000	20.7	2.30	4.27	14.13
T6 – 1500	21.6	1.96	9.43	10.21
T7 – 2000	22.2	2.18	9.63	11.81
T8 – 2500	22.1	2.64	8.07	10.71
T9 – 3000	22.9	3.09	7.67	10.76

Table 5.21. The balance of Na after cellar effluent irrigations were applied and removed by pearl millet and oats at Goudini Cellar near Rawsonville in 2012

Treatment no. & target COD (mg/L)	2012			
	Na (kg/ha)	Na (kg/ha)	Na (kg/ha)	Na (kg/ha)
	Applied via cellar effluent (A)	Removed by pearl millet (B)	Removed by oats (C)	Balance A - (B+C)
T1 – Raw	32.80	0.82	15.12	16.86
T2 – 100	36.50	0.96	9.50	26.04
T3 – 250	37.50	1.14	5.60	30.76
T4 – 500	42.40	0.76	9.44	32.20
T5 – 1000	49.50	0.79	11.17	37.54
T6 – 1500	54.90	0.98	8.00	45.92
T7 – 2000	61.50	1.00	12.04	48.46
T8 – 2500	69.10	1.06	6.32	61.72
T9 – 3000	74.00	0.68	12.40	60.92

5.5. Summary

The wastewater did not have a negative impact on the growth of the cover crops. The oats, *A. sativa* L. cv. Pallinup and pearl millet, *P. glaucum* have the potential to accumulate N, P, K, Ca and Mg but not Na. Pearl millet took up higher amounts of elements because the wastewater irrigations were given while the pearl millet was in its active growth stage and it was during the harvest time when there is more wastewater and the concentrations of the elements in the wastewater is high. The oats took up high amounts of N and P although it was three months after the harvest when the cellar activities peaked and there were high volumes of wastewater. The pearl millet and the oats showed good potential as a combination of a summer and winter growing cover crop to trap and accumulate elements. If cellar wastewater is used for irrigation, then the fertilisers like nitrogen and phosphate may be reduced, because there are high amounts of these elements present in the cellar water available for the vineyard and cover crops (Grewal & Maheshwari, 2013). To prevent high concentration of Na in the soil, it is advisable to replace NaOH cleaning agent with KOH as cleaning agents in the cellars.

5.6. References

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CHAPTER 6
CONLUDING SUMMARY

The irrigation of the cellar effluent did not have a negative impact on the growth of the oats and the pearl millet. Sufficient amounts of N, P, K, Mg and Ca were removed from the soil by oats and pearl millet. Oats and Pearl millet showed the potential to remove exceptionally high amounts of N and K in the 2011 and 2012 seasons.

Sodium was not removed successfully by oats and pearl millet. It is advised that cellars do not use cleaning agents which has Na as an ingredient to prevent the accumulation of Na in soil. Cleaning agents with KOH may rather be used. This was also the conclusion made by Sheridan *et al*. (2011) about the seasonal characterisation of winery effluent in South Africa. Potassium hydroxide is only a little more expensive in South Africa. However, there could also be situations where the K content in the cellar effluent is too high. In these situations cleaning agents with Na like NaOH can be used as practiced in a wine cellar in Australia (Arienzo *et al*., 2009).

It is possible that too much N, P and K may be removed by the pearl millet and oats from the soil which may cause deficiencies in the vineyard. In this situation the cover crops can be slashed earlier in the season to decrease the amounts of elements removed. It is important to remove the cover crop fibre out of the vineyard preventing the accumulation of excessive undesirable elements in the soil.

According to the present study, cellar effluent with a maximum COD level of 2500 to 3000 mg/L may be used in a vineyard with a sandy soil.

Although cover crops like pearl millet showed the potential to take up elements to prevent a high accumulation in the soil that could have a negative impact on the vineyard, this study was done only over two years and there is a need to test this study over the long term and also with different soils. Other plants may also be investigated for their potential to extract cellar effluent for example Indian mustard (*Brassica juncea*), maize (*Zea mays*), barley (*Hordeum vulgare*), sunflower (*Helianthus annuus*) and ryegrass (*Lolium perenne*) (Ping *et al.*, 2009).

Vetiver grass (*Vetiveria zizanoides*) may also be used successfully as a cover crop to remove toxic elements. Vetiver grass performed the best against bahia grass (*Paspalum notatum*) and St Augustinegrass (*Stenotaphrum secundatum*) and bana grass (*Pennisetum glaucum_P. purpureum*) in a field experiment that was done by Xia & Ke (2003). Vetiver grass is a permanent cover crop and therefore the aboveground growth can be removed twice a year with a weed slasher. Vetiver grass also has the advantage that because it is a permanent

cover crop, only one crop is used throughout the year. It is only necessary to remove the above ground growth through the year and apply fertiliser when needed.

6.1. References

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