Survey of soil properties at some sites receiving winery wastewater in Marlborough

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Executive Summary

There has been a rapid expansion in the viticulture industry in New Zealand over the last decade. An inevitable consequence of this increase in production has been the generation of increasing amounts of a range of waste products. One such waste is winery wastewater, recognised as containing a number of components (i.e. salts, nutrients, organic load) that have the potential to negatively affect soil, plant and aquatic health if not disposed of in an appropriate manner.

One issue which has recently been highlighted as a result of land based application of winery wastewater is the potential for soils to accumulate sodium (Na) and potassium (K) to concentrations which may adversely alter soil physical properties such as aggregate stability and hydraulic conductivity.

There are currently 39 wineries in Marlborough that are applying winery wastewater to land, however only a small proportion regularly take soil samples to assess what effect application is having on soil properties. The objective of this study was to find out what effect land application of winery wastewater has had on soil properties in particular K and Na concentrations in soils.

Soils were sampled from 27 sites used by wineries to dispose of wastewater to land. Soils were analysed for pH, exchangeable cations (i.e. K, Na, Ca, Mg), electrical conductivity and Olsen P.

Results showed there was a wide range in values for soils that received winery wastewater, reflecting the inherent variability of soils at the different sites and the wide variability in the loading of winery wastewater to soils.

Significantly ($P < 0.05$) higher values were found for soil pH, exchangeable K, exchangeable Na, base saturation percentage and electrical conductivity in soils sampled from sites receiving winery wastewater compared to the control sites for the 0 – 7.5cm soil depth. These findings largely reflect the recognition that winery wastewater is known to contain a range of components including Na and K salts derived from cleaning products used in wineries along with grape lees and juice that are known to contain significant amounts of K. There were no significant differences found for the rest of the parameters measured.

A commonly used measure of the potential for Na and K to cause soil physical deterioration, i.e. clay dispersion and structural instability, is the Exchangeable Sodium Percentage and Exchangeable Potassium Percentage. Values for both measures were significantly higher on soils receiving winery wastewater. However, compared to threshold values developed in Australia and elsewhere, values are largely considered low for Na although there is a lack of reliable information of K thresholds in soils.

To address the lack of relevant information for K thresholds in soils, research is currently being undertaken by AgResearch on behalf of the Marlborough District Council. This research along with our own investigations will enable guidelines on wastewater quality to be developed. These guidelines will feed into our resource management plans and help improve how we manage winery wastewater discharges to land and protect soil health.

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1. Introduction

There has been a rapid expansion in the viticulture industry in New Zealand over the last decade, with the number of grapes being crushed increasing from 80,000 m^3 in 2000 to 285,000 m^3 in 2009 (New Zealand Wine Growers 2009). An inevitable consequence of this increase in production has been the generation of increasing amounts of a range of both solid and liquid wastes that are an integral part of the wine making process. One waste stream which has recently been receiving attention, particularly around how to manage its disposal and potential environmental effects is winery wastewater. Winery wastewater is a significant waste in the wine making process. For example, it has been estimated that for every 750 mL bottle of wine produced in New Zealand, approximately 7.5 L of wastewater is generated (Gabzdylova et al., 2009). This equates to approximately 380,000 m^3 of winery wastewater being produced annually.

The volume and composition of winery wastewater generated is highly variable. It is known to fluctuate depending on things such as the stage of the wine production cycle i.e. pre-vintage, vintage or post vintage, type of wine being produced, volume of grapes being crushed and, importantly, winery practices. For example, production practices which may affect winery wastewater volume and composition include wash down protocols (i.e. floor washing frequency), method of tank disinfection (i.e. steam or chemical), filtering method (i.e. diatomaceous earth or mechanical methods) and type and amount of disinfectant used (Kumar and Christen, 2009).

Because of the variation in management practices, winery wastewater can be composed of a range of components, some of which are at high concentrations that require it to be managed extremely carefully when being disposed of to avoid it having any negative effects on the environment (Moss et al. 2011). Table 1 summarises some of the contaminants in winery wastewater and some of the potential environmental effects it can pose to soil, plant and aquatic ecosystems.

While disposal of winery wastewater through municipal wastewater treatment plants is one option, this often isn't practical where wineries are located in the rural zone. In Marlborough, land application is generally the most common practice and is advocated through the Council resource management plans as the preferred method of disposal. However, because land application is the preferred option, it is imperative Council has an idea of the effects land application of winery wastewater has on our environment.

One issue which has been highlighted recently by work in Australia has been salt accumulation in soils receiving winery wastewater. In particular sodium (Na) and potassium (K) accumulation which are recognised as having the potential to affect soil physical properties (Laurenson and Houlbrooke, 2011; Laurenson et al., 2011). This is because these cations (positive ions) have large hydrated ion sizes and have an affinity for clay minerals in soil. This can result in swelling of clay particles and dispersion in some soil types (Levy and Freigenbaum, 1996) leading to deterioration of aggregate stability. This can lead to reduced infiltration of wastewater irrigation due to the loss of soil structural stability (Rengasamy, 2002).

Table 1 Types of contaminants in winery wastewater, origins and likely environmental effects (reprinted from Kumar and Christen, 2009)

Contaminant Class	Examples	Sources	Effects
Organics	Phenols, tannins, catechins, proteins, fructose, glucose, glycerol, ethanol, flavourings, citric acid, ethyl carbamate	Loss of juice, wine and lees, residues in cleaning waters and filters, solids reaching drains	Organism deaths, ecological function disruption, Odours generated by anaerobic decomposition, solubilisation of sorbed nutrients and heavy metals. Soil clogging
Nutrients	Nitrogen, Phosphorous, Potassium	Loss of juice, wine and lees, washings and ion exchange	Algal blooms, excess nitrate in water, high SAR
Salinity	Sodium chloride, Potassium chloride	Juice and wine, cleaning agents	Affects water taste, toxic to plants and animals
Sodicity	Sodium, potassium	Washing water	Degrades soil structure, toxicity to plants
Heavy metals	Al, Cd, Cr, Co, Cu, Ni, Pb, Zn, Hg	Al, Cu, piping and tanks, Pb soldering, brass fittings	Toxic to plants and animals
pH effects	Organic, sulphuric and phosphoric acids, sodium, magnesium and potassium hydroxides	Loss of juice, wine and lees, cleaning agents, wine stabilisation	Toxicity to macro and micro organisms, effect on solubility of heavy metals
Disinfectants	Sodium chloride, Sodium hypochlorite,	Sterilization of tanks, bottles, transfer lines	Formation of carcinogens (e.g. THM)
Soil Cloggers	Microbial cells and grape residues, flocculating/coagulating agents, bentonite, diatomaceous earth	loss of lees and marc, floor cleaning, filtering, wastewater sludge	Reduction in porosity, light transmission, odour generation

A review of some soil data supplied to Council from four sites that have received winery wastewater over the last decade or so indicates there has been an accumulation of particularly K (Figure 1) and lesser extent Na in these soils. What was notable at these sites is while soils are readily accumulating K, the accumulation is occurring over a relatively short interval e.g. more than doubling in as little as 5 years at site 4. Because the majority of wineries which disposed wastewater to land do not collect and analyse soil samples, we don't know if these K concentrations are typical.

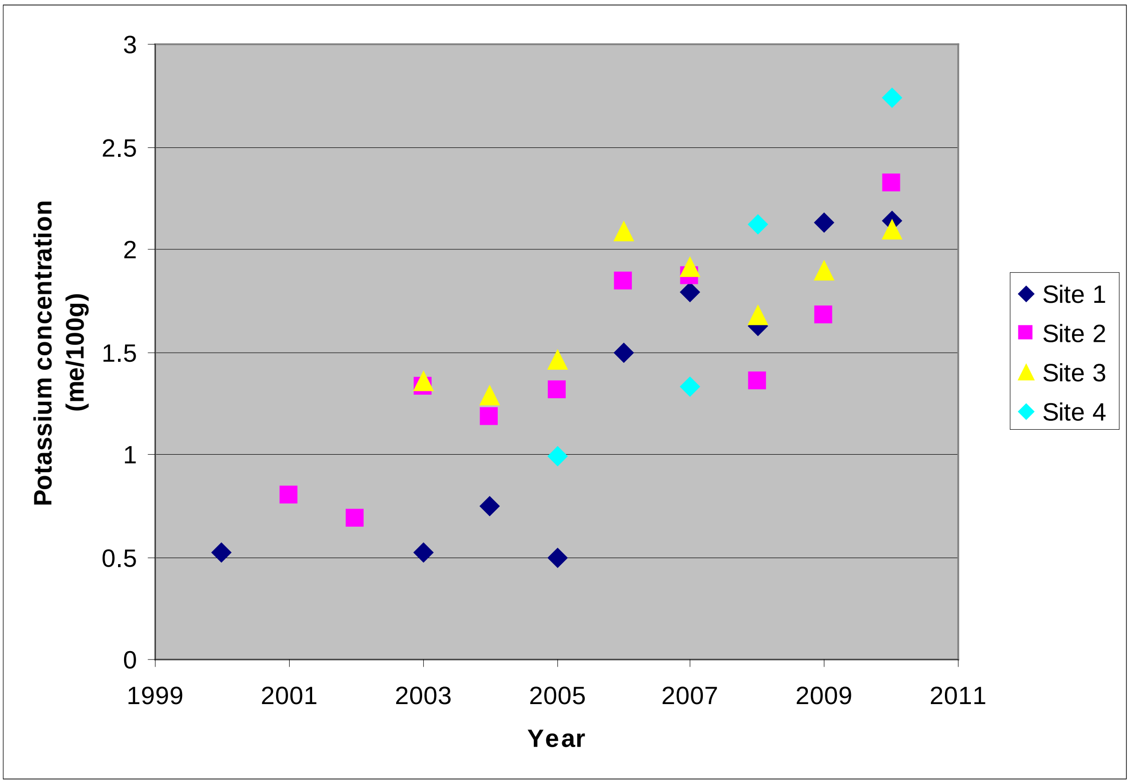

Figure 1 Soil K concentrations at four sites receiving winery wastewater

While there are currently 39 wineries in Marlborough that are disposing of their winery wastewater to land, only a small proportion regularly take soil samples to assess what effect wastewater application is having on soil properties. The objective of this study is therefore to find out what effect land application of winery wastewater has had on soil properties, in particular K and Na accumulation at a range of different sites.

2. Materials and Methods

2.1. Sites

Soils were sampled from 27 different sites - a site being an area of land used by a winery to dispose of winery wastewater to land. Some wineries had more than one area that was being used to dispose of winery wastewater, hence these sites were sampled separately, as were sites where more than one soil type was recognised across the disposal area. Soils were also sampled from an area deemed not to have been subject to winery wastewater disposal (i.e. control site). This was often a headland site or failing that within the middle of an inter-row.

2.2. Soil Sampling

Composite soil samples were collected which consisted of approximately 20 individual cores that were combined to form a single sample. Depending on whether there were excessive stones at a site, soils were sampled at two depths, 0 – 7.5cm and 0 – 15cm.

2.3. Soil Analyses

Soil pH was measured in water using glass electrodes and a 2:1 water to soil ratio. Olsen P (plant available phosphorous) was determined by extracting soils for 30 min with 0.5 M $NaHCO_3$ at pH 8.5 (Olsen, 1954) and measuring the phosphate concentration by the molybdenum blue method. Exchangeable calcium (Ca), magnesium (Mg), Na and K were determined by extraction in 1 M neutral ammonium acetate and concentrations measured by Inductively Coupled Optical Emission Spectrometry. Electrical conductivity (EC) was measured in a 1:5 soil:water extract. The Cation Exchange Capacity (CEC) is a quantitative measure of the ability of soil hold onto exchangeable cations. It was calculated as the sum of the Ca, Mg, Na and K and extractable acidity. Base saturation percentage (BS%) was calculated as the sum of the exchangeable cations of Ca, Mg, K, and Na, expressed as a percentage of the total number of sites available for cation exchange (CEC).

2.4. Statistical Analysis

Mean, minimum and maximums for individual soil properties and statistical comparisons between control sites and sites receiving winery wastewater were made using STATISTICA.

3. Results and discussion

3.1. Sites

Wineries are applying wastewater to a range of different landcovers. In the main sites are under exotic pasture or feed crops, which in some cases are being grazed by livestock (Figure 2, 3). However several sites are applying wastewater to areas planted in native and exotic shrubs or trees (Figure 4) and at a few sites, wastewater is being applied within the vineyards in the inter-rows (Figure 5).

As well as a variety of disposal sites, winery wastewater is being applied to land in a number of different ways including travelling irrigators, K-lines and fixed irrigator (Figure 2, 3, 4). This will affect the rates at which wastewater is applied to land and potentially over what area.

Figure 2 Travelling irrigator in pasture

Figure 3 K-line in grazed pasture

Figure 4 Fixed irrigator under trees

Figure 5 K-line in vineyard inter-row

3.2. Soil chemical results

A summary of chemical properties for soils sampled from control sites and sites that have received winery wastewater is given in Table 2.

Table 2 Soil chemical parameters from control sites and sites receiving winery wastewater

Soil parameter	**Control** 0 – 7.5cm		**Winery wastewater** 0 – 7.5cm		**Winery wastewater** 0 – 15cm	
	range	mean	range	mean	range	mean
pH	5.3 – 7.0	6.1	5.3 – 7.2	6.5	5.4 – 6.9	6.4
Olsen P (mg/L)	3 – 31	16	10 - 46	21	5 - 34	16
K (me/100g)	0.3 – 2.5	0.9	0.4 - 4.5	2.2	0.3 - 4.2	1.9
Ca (me/100g)	2.4 – 13.9	8.7	4.4 – 25.6	9.4	4.1 – 16.0	8.3
Mg (me/100g)	1.0 – 2.7	2.0	0.9 – 3.7	1.9	0.9 – 5.4	2.1
Na (me/100g)	0.05 – 0.32	0.12	0.12– 1.97	0.48	0.06 – 1.72	0.41
BS %	38 – 91	68	45 – 100	77	48 – 100	74
CEC (me/100g)	12 – 25	17	10 – 31	18	11 – 29	17
EC (mS/cm)	0.02 – 0.16	0.05	0.02 – 1.15	0.14	0.02 – 0.55	0.09

There was a wide range in values for individual soil properties which reflects in part the inherent variability of soils at the different sites. For example, soils ranged from stony recent soils derived from alluvium to older clay soils derived from loess. However, also important was the wide variability in the loading of winery wastewater to soils at the different sites. This is a factor of things like the size of the winery, length of time winery wastewater has been applied at the site, rate of loading and also the production practices which affect winery wastewater composition as discussed earlier.

Significantly ($P < 0.05$) higher values were found for soil pH, exchangeable K, exchangeable Na, base saturation percentage and electrical conductivity in soils sampled from sites receiving winery wastewater compared to the control sites for the 0 – 7.5cm soil depth (Table 2). There were no significant differences found for the rest of the parameters measured.

3.2.1. Soil pH

Soils receiving winery wastewater had pH values ranging from slightly acidic (pH 5.3) to slightly alkaline (pH 7.2). This may reflect the variability in pH of the winery wastewater, which is permitted to be between pH 4.5 – 8 prior to being disposed of to land. Despite the range in winery wastewater, soil pH was on average about 0.5 of a pH unit higher on sites receiving winery wastewater than the control sites (Table 2). A soil pH value of between 5.5 to 7.0 is considered to be about ideal in terms of maximising nutrient availability to plants in soils (McLaren and Cameron, 1990), so the majority of sites are within this optimal range.

3.2.2. Base Saturation

The BS% is a measure of the proportion of the soils exchange complex occupied by Ca, Na, Mg and Na ions. On average values were higher in soils receiving winery wastewater compared to control sites, which largely reflected the elevated concentrations of K and Na in winery wastewater (Table 2). For example, Laurenson and Houlbrooke (2011) showed the average composition of cations in winery wastewater for some wineries in Marlborough was 120.2 mg/L for Na, 179.1 mg/L for K, 3.6 mg/L for Mg and 21.4 mg/L for Ca. There was however an exception at one site which had a BS% value of 100%. The soil at this site had recently received an application of gypsum (which contains up to 23% Ca) and as a result the exchange complex was dominated (83%) by Ca ions.

3.2.3. Electrical Conductivity

Soil electrical conductivity is a measure of the concentrations of salts (i.e. cations and anions such as chloride, bicarbonates) in soils and provides an indication of soil salinity. Soils with elevated salinity are known to affect plant growth either directly by the toxicity of ions such as Na or by reducing water availability to plants through reducing osmotic potential. Because of the elevated concentration of ions in winery wastewater from cleaning products, grape juice etc, on average EC values were higher in these soils compared to the control soils (Table 2). However, although EC was elevated, values were still orders of magnitude lower than what would be classified as a saline soil which is >4 mS/cm (Rowell, 1994).

3.2.4. Exchangeable Na and K

The application of winery wastewater resulted in an accumulation of Na in soils (Table 2). On average concentrations were more than three times those of control sites for both the 0 – 7.5cm and 0 – 15cm sample depth. Several studies have found increasing Na in soils over time as a result of receiving winery wastewater (Kumar and Kookana, 2006). The main source of sodium in winery wastewater is cleaning and sterilization products used in the winery i.e. caustic soda (sodium hydroxide) and sodium hypochlorite respectively (Kumar and Christen, 2009).

As with Na, the application of winery wastewater resulted in an accumulation of K in soils (Table 2). On average concentrations were about double those of the control sites for both the 0 – 7.5cm and 0 - 15cm soil sampling depth. Several other studies have found an accumulation of K in soils that have received winery wastewater. Quayle et al. (2010) found that while a surface soil at a site receiving winery wastewater for three years had Na and Mg concentrations that approximately halved, Ca remained relatively unchanged but K concentrations doubled. Kumar and Kookana, (2006), also found significantly higher concentrations of available K in soils from a range of different sites that had been receiving winery wastewater compared to non-irrigated control plots. The K in the wastewater comes from several sources although the main ones are the grape lees, spent grape juice and also potassium hydroxide cleaners (Kumar and Christen, 2009).

A commonly used measure of the potential for Na and K to cause soil physical deterioration i.e. clay dispersion and structural instability is the Exchangeable Sodium Percentage (ESP) and Exchangeable Potassium Percentage (EPP). The ESP quantifies the exchangeable Na cation in relation to the CEC of soil (Equation 1).

$$ESP\ \% = [Na^+] \,/\, (CEC) \times 100 \qquad \text{(Equation 1)}$$

The EPP quantifies the exchangeable K cation in relation to the CEC of soil (Equation 2).

EPP % = [K+]/ (CEC) x 100 (Equation 2)

Soil ESP and EPP values for control sites and sites that have received winery wastewater are given in Table 3. On average ESP values were significantly higher at sites receiving wastewater than the control sites. Although, with the exception of two sites, values were still well below what would be considered as being sodic soils and subject to structural instability. In Australia for example, the critical ESP value above which soils are classified as sodic is 6 (Sumner, 1993; Isbell et al., 1997). However, it is recognised that the risk depends to a large extent on soil properties such as texture and the salinity of the soil solution. For example, in a study of the risk of soil dispersion in a Barossa chromosol soil with a ESP value of 8, Laurenson (2010) found that the risk ranged from low where EC values were >0.65 dS m^{-1} to high when EC is <0.2 dS m^{-1}.

Table 3 Soil ESP and EPP values for control sites and sites that have received winery wastewater

	Exchangeable Sodium Percentage		**Exchangeable Potassium Percentage**	
	Range	mean	Range	mean
Control	0.3 – 1.7	0.7	1.5 – 11.9	5.3
0 – 7.5cm	0.6 – 9.9	2.7	2.1 – 27.1	13.0
0 – 15 cm	0.4 – 8.2	2.3	20 – 24.9	11.6

Exchangeable potassium percentage values were also higher in soils receiving winery wastewater compared to the control soils (Table 3). In comparison to Na, the influence of K ions on soil structure is less widely documented and the EPP threshold at which effects on soil structure are evident is poorly defined. However, work that has been undertaken recently demonstrates that like for Na, dispersion depends to a large extent on the inherent soil properties such as texture and the salinity of the soil solution. For example, as in the study by Laurenson (2010), the Barossa soil with a EPP value of 11 had a medium risk of dispersion at a EC <0.2 dSm^{-1}, but low with an EC > 0.2 dSm^{-1}.

3.3. Future work

3.3.1. Seasonal variation

As discussed already, there is a large amount of variability in the volume and composition of winery wastewater. A significant amount of this variation is a result of the different practices that occur at different times of the year. For example, typically wastewater produced during vintage has a higher biological oxygen demand, total nutrients and in particular salt content than wastewater produced during non-vintage (Kumar and Christen, 2009).

Along with higher volumes of wastewater being produced during vintage, the greatest loadings of salts to soil will be around this period. Hence sampling and testing for soil K and Na straight after vintage may result in higher concentrations than for soils sampled in other parts of the year. For example, several studies have shown exchangeable K concentrations in soils vary depending on when in the year soils were sampled (Liebhardt and Teel, 1977; Lockman and Molloy, 1984). To determine if there is any significant temporal variation in exchangeable K concentrations in soils, samples are to be taken quarterly from four sites currently receiving winery wastewater.

3.3.2. Relationship between electrical conductivity and exchangeable Na and K in soils

A project designed to address the relationship between Na and K concentration in winery wastewater and soil structure is currently being undertaken by AgResearch. It will specifically investigate the physio-chemical processes leading to soil dispersion in some Marlborough soils currently used for disposal of winery wastewater. This research will enable guidelines to be set on wastewater quality suitable for application to land in order to protect soil health.

4. Conclusions

- There was a wide range in values in soils sampled from sites receiving winery wastewater. This reflected the inherent variability of soils at the different sites and the wide variability in the loading of winery wastewater to soils at the different sites.
- Sites receiving winery wastewater had higher soil pH, exchangeable K, exchangeable Na, base saturation percentage and electrical conductivity values than soils at control sites.
- These differences largely reflect the fact that Na and K based cleaning products are used in wineries, and grape lees and juice are known to contain significant amounts of K.
- ESP and EPP values were significantly higher on soils receiving winery wastewater although compared to threshold values that were indicators of soil structural instability were low.
- However there is a lack of reliable information for critical K thresholds in soils.
- A further project designed to address the relationship between Na and K concentrations in winery wastewater and soil structure is currently being undertaken by AgResearch. This research along with our own investigations will enable guidelines on wastewater quality to be developed. These guidelines will feed into our resource management plans and help improve how we manage winery wastewater discharges to land and protect soil health.

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