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Review of guidelines for the management of winery wastewater and grape marc

Prepared for Marlborough District Council

June 2012

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1. Executive Summary

Where winery wastes are applied to land there is an imperative need to prevent adverse effects of such practice on aquatic environments and soil/plant health. Through a review of literature and current guidelines from other wine producing areas overseas, including Australia, South Africa and the United States of America, we have identified and discussed the environmental issues associated with land application of both grape marc and winery wastewater. We have identified soil parameters, which should be monitored in order to prevent or minimise the contamination of surface and ground waters where waste is applied to land. Nutrients, high BOD and salts are of primary concern. The concentrations of heavy metals and other contaminants are however, generally low and pose limited environmental risk.

Precise estimates of quantity and quality of wastewater supply in the wine industry are not well established. Therefore, we recommend a record of the amount of wastewater and solids that are produced be kept. Sampling of wastewater and grape marc composition during vintage period is also recommended in order to determine appropriate loading rates to land. Prior to land application we recommend the soil depth, infiltration rate and maximum water storage be determined and irrigation management units (IMUs) identified. A decision tool has been developed to guide appropriate application of winery wastewater to each IMU. This is based on the minimum conditions that should be adhered to, to avoid direct losses of land-applied wastewater. The quantity of waste applied to land, information on area covered, date of application and location of application should also be recorded

The risk of soil dispersion in Marlborough soils is expected to be low due to the low clay content of soils and the regular rainfall that displaces and leaches monovalent cations (namely Na^+ and K^+) down the soil profile. Currently 39 wineries apply winery wastewater to land in the Marlborough District, however, few take regular soil samples to monitor any effect wastewater application may be having on soil properties. We therefore recommend that soil testing be carried out routinely (i.e. every 1 to 2 years) to identify imbalances in soil fertility and/or the build-up of undesirable salts.

Grape marc contains a large amount of N, P and K, however, the availability of these nutrients is generally low. Nutrient loading should be determined based on plant requirements, however, as a precautionary approach, we recommend a default limit of 150 kg N/ha/yr due to the uncertainties with soil N mineralisation rates. When grape marc is stored, it should be fully contained on a concrete pad or impermeable surface.

We strongly recommend that a nutrient budget be developed for areas receiving grape marc and/or winery wastewater. Finally, we advise a precautionary approach to

managing the risks associated with grape marc as we recognise there are gaps in scientific knowledge.

2. Introduction

Marlborough is the largest grape producing region of New Zealand where a significant volume of winery wastewater is generated (New Zealand Winegrowers 2009). Rapid expansion of the viticulture industry in Marlborough has lead to an increase in wine production from 80,000 m^3 in 2000 to 285,000 m^3 in 2009 (New Zealand Winegrowers 2009). Increased production has been coupled with the generation of significantly larger volumes of winery wastewater and grape marc, an unavoidable component of the wine production process (Laurenson *et al.* 2012). In New Zealand, approximately 7.5 L of winery wastewater is produced per 750 mL bottle of wine (Gabzdylova *et al.* 2009) which equates to approximately 380,000 m^3 of winery wastewater and approximately 73,000 tons of grape marc annually (assuming 16% of original fruit is left as marc). The wine industry and regional authorities are increasingly focusing on land application of winery wastes as the most cost effective and environmentally sound means of disposal. This form of disposal does however raise concern over potential impacts on soil and crop health, and off-site environmental pollution associated with nutrient leaching and run-off.

The Resource Management Act (1991) aims to promote the sustainable management of natural and physical resources and provides the basis upon which regional policy statements, policies and plans, and district plans are prepared. The Resource Management Act (1991) does not explicitly address the management of waste yet does require that adverse effects associated with their disposal are avoided, mitigated or remedied. Essentially, wineries are obliged to dispose of wastewater and grape marc in a sustainable manner that does not contaminate drinking water sources or result in off-site pollution.

Precise estimates of quantity and quality of wastewater supply in the wine industry, their potential value as an irrigation source or soil amendment and the expected adverse effect associated with their uncontrolled use/disposal are not well established.

3. Winery wastewater Characterisation

The volume of winery wastewater produced over the year will be governed by the quantity of grapes that are crushed (GWRDC 2011). In Marlborough peak wastewater generation will occur in March and April during vintage and will consist primarily of water that has been used to clean tanks, transfer lines and equipment. Typically in Marlborough, irrigation is required from October to March when soil water deficit is greatest. Therefore, where winery wastewater is applied to land, storage is often needed so that irrigation can coincide with crop water utilisation requirements.

Chemical composition of winery wastewater is an important determinant of suitability when irrigated to land and may require up-grade of treatment facilities in order to produce water fit for the crop or soil type (South Australian EPA 2004). This may not always be feasible for small scale operators and therefore disposal of wastewater to municipal wastewater treatment plants or collective facilities handling wastewater from a number of wineries can be a suitable alternative (Kumar and Christen 2009).

Winery wastewater may contain constituents of environmental and soil/plant toxicological concern including heavy metals, nitrogen (N) and phosphorus (P) and high biological oxygen demand (BOD) (Mosse *et al.* 2011). Nutrient concentrations of winery wastewater are reasonably high yet can increase 3 to 4-fold during vintage (Laurenson *et al.* 2012). The concentrations of easily biodegradable organic compounds such as sugar and ethanol are also high. These organic compounds are typically quantified through measure of BOD. The total salt content of winery wastewater, including the concentration of specific salt ions, is also high due mainly to chemical cleaning products and grape lees. Winery wastewater tends to have elevated concentrations of both K^+ and Na^+ monovalent cations. These monovalent cations accumulate in soils due to evapo-concentration of the soil solution. The cation composition, in particular K^+ and Na^+ in final wastewater varies depending on winery size, treatment process and season (Arienzo *et al.* 2009). Typical chemical composition values of winery wastewater are shown in Table 1.

Table 1. Selected chemical concentrations of winery wastewaters

Parameter	Concentration
pH	4 – 8.0
Electrical conductivity (EC) (dS/m)	1.3 – 3.5
Total Nitrogen (TN) (mg/L)	1.9 – 70
Total Phosphorus (TP) (mg/L)	5.3-17
Biological oxygen demand (BOD) (mg/L)	1000-8000
Sodium (Na) (mg/L)	50 – 340
Potassium (K) (mg/L)	3 - 410
Sodium adsorption ratio (SAR)	6.5 – 15
Potassium adsorption ratio (PAR)	2.1 – 3.2
Cation ratio of structural stability (CROSS)	2.5-13.3

Sources: ANZECC & ARMCANZ (2000), Kumar and Christen (2009), Laurenson *et al.* (2012), Arienzo *et al.* (2009)

In South Australia, the management of winery wastewater is legislated under the South Australian EPA Guidelines for Wineries and Distilleries (South Australian EPA 2004). Where winery wastewater is irrigated at rates greater than 100 mm per annum, routine soil testing is required to demonstrate no adverse changes to soil properties, particularly hydraulic properties (South Australian EPA 2004). Emphasis in the these guidelines is placed on producing and managing winery wastewater of a given quality that is fit for the intended purpose rather than general classifications often ascribed to municipal wastewater. Subsequently, the concentration of constituents, including salts, in winery wastewater varies greatly between locations (ANZECC & ARMCANZ 2000; Kumar and Christen 2009).

4. Grape marc characterisation

Grape marc comprises approximately 8% seeds, 10% stems, 25% skins, 57% pulp and when applied to land is able to return a considerable amount of nutrients and organic matter (OM) to soils. Typical composition of grape marc is shown in Table 2, however, it will vary depending on the wine variety produced. For instance in the production of white wines, juice is pressed out of grapes before fermentation and therefore the marc has high sugar and N concentration. In the case of red wine however, grapes remain in the wine during fermentation and therefore the resulting marc is typically low in sugar and tannins, that remain in the wine.

Grape marc decomposes slowly due to the large proportion of seeds that are high in lignin (Fernández *et al.* 2008). Therefore, microbial breakdown of these carbon compounds is slow requiring a stockpiling period of around 6-12 months. However, stored grape marc can result in significant emissions of ammonia (NH_3), nitrous oxide (N_2O) and methane (CH_4) due to the N and carbon (C) content that promote volatilisation, denitrification and methanogenesis.

A large proportion of N in composted grape marc is in organic form and must be first mineralised to either nitrate (NO_3^-) or ammonium (NH_4^+) before it is available to plants. The predominant factor influencing net immobilisation over net mineralisation is the C:N ratio. While both processes can occur simultaneously, immobilisation is generally favoured in soils with a C:N ratio of approximately 30:1 or greater. When the C:N ratio declines below approximately 20:1, there is a shift towards net mineralisation and N is released. In seven composted grape marc samples investigated by Patti *et al.* (2004), C:N ratio ranged between 15-21 to 1, with 85% of samples above 19. These values are similar to those reported by Agnew *et al.* (2005) where C:N values were in the range of 20-23 and suggest a proportion of N will be plant available. This plant available form of N is also at risk of being leached or lost via gaseous emissions. In addition to C, the rate of N transformation will also depend on temperature, dry matter content, and the pH of the grape marc.

Similar to N, P in grape marc must also undergo a process of transformation from an organic to inorganic form before being plant available. Generally P in manures and composts will be comparatively more available than N, however the transformation to plant available form will be dependent primarily on the composition of the grape marc itself. As noted by Patti *et al.* (2004) the vast majority of P in grape marc is however, not plant available and may reflect the high pH and/or calcium (Ca) concentration in a particular marc material.

The final grape marc, both fermented and unfermented, contain a variety of chemical components including cellulose, tartaric acid, unfermentable sugars, tannins, phenolic substances and alcohol. The moisture content of white and red wine marc varies also depending on the degree of pressing. White wines for instance are gently pressed and therefore have higher moisture content than red wines that are pressed hard and therefore produce a dry marc.

Table 2. Selected chemical concentrations of winery wastewaters. Adapted from Patti *et al.* (2004), Starnes Saunders *et al.* (1982).

Parameter	Fresh[#]	Composted
Dry matter content (%)	49	42-53
pH		
EC (dS/m)		
Total nitrogen (%)	1.2-1.88	1.5-2.2
Total phosphorus (mg/L)	2500	1700-3100
Total potassium (mg/L)	24000	23000-31000
Total sodium (mg/L)	550	370-740
Total calcium (mg/L)	5400	5200-9800
Total magnesium (mg/L)	2200	1600-2500
Total sulphur (mg/kg)	1400	1300-2000
C:N Ratio	21	15-21
Trace elements (mg/kg)		
Copper	83	49-95
Zinc	62	23-34
Manganese	130	38-86
Molybdenum	<10	<10
Iron	6400	3000-5100
Boron	25	23-53
Other metals (mg/kg)		
Asenic	2.4	<0.02-1.5
Cadmium	<0.5	<0.5
Lead	<10.0	<10.0
Mercury	0.079	0.055-0.096
Selenium	0.14	0.031-0.089
Aluminium	11000	4000-9100
Chromium	16	7-15
Nickel	6	<5

[#] based on a single sample of grape marc that was 3 months old with exception of total N where n= 8.

5. Suitable management of winery wastewater and grape marc

For a land treatment system to be sustainable it must be efficient in both the retention of waste constituents in the soil and the subsequent plant uptake or attenuation of nutrients and contaminants applied. Environmental Protection Agency Guidelines from South Australia (South Australian EPA 2004) require wineries to maintain and submit a record of solid and liquid wastes produced each year. Included in this is the quantity of waste produced, how it is managed, and, if managed on-site, details of the date that it is applied to land, the area covered and location of the application.

5.1 Hydraulic loading

The transport pathway of solutes and suspended solids in drainage water is dictated by soil hydrology. A soil's drainage capacity is usually determined by factors such as soil texture, pore continuity and proximity to water tables. Water movement through the soil is measured as hydraulic conductivity, usually in units of mm hr^{-1} or m s^{-1}. In general, the finer a soil texture, the less continuity of pores. Hence a sandy soil will have greater drainage capacity than fine-grained silt or clay soil (Hillel 1980). However, many exceptions occur. Soil texture is one factor governing unsaturated flow, whereas saturated flow is largely governed by soil density, macroporosity and soil structure.

For a land treatment system to be sustainable it must be efficient in both the retention of winery wastewater constituents in the soil and the subsequent plant uptake of nutrients applied. The longer the wastewater resides in the soil's active root zone, the greater the opportunity for the soil to physically filter out constituents whilst attenuating potential contaminants and nutrients. In order to prevent loss of nutrients in surface runoff and deep drainage the depth of winery wastewater irrigation should be less than the soil water deficit at the time of application.

This will require basic knowledge of soils to which winery wastewater is applied. For sites that contain more than one soil type, hydraulic loadings should be adjusted according for each soil. Alternatively, a blanket application rate could be set based on the most limiting soil type. Identification of unique irrigation management units (IMU) is encouraged in South Australian Guidelines for Wineries and Distilleries (South Australian EPA 2004). These IMUs should reflect dominant soil types at an irrigated site and are defined by the following soil parameters: texture, structure, chemistry, water holding capacity, depth of topsoil, effective rooting depth, depth to impeded clay layers or layers highly permeable to water. The AgResearch Soil Risk Framework for effluent management (Houlbrooke and Monaghan 2010) adopts IMUs based on drainage class that includes:

A Artificial drainage or coarse soil structure

B Impeded drainage or low infiltration rate

C Sloping land (>7^{o} slope)

D Well drained flat land (<7^{o} slope)

E Other well drained but very stoney flat land (<7^{o} slope)

Guidelines for winery wastewater application land in South Africa, Australia, New Zealand and the United States all stipulate that no contamination of ground or surface water should occur during irrigation. With regard to hydraulic loading this requires consideration of both depth and rate of application for each IMU. As far as we are aware however, there is limited advice specific to winery wastewater where a depth and rate criteria are described based on soil type.

Depth of winery wastewater irrigation refers to the daily amount of winery wastewater applied. Deferred irrigation, should be based on the application criteria described by:

$$\boldsymbol{E}_i + \boldsymbol{\theta}_i\boldsymbol{Z}_R \leq \boldsymbol{\theta}_{FC}\boldsymbol{Z}_R \qquad \text{eq. 1}$$

$$\boldsymbol{E}_i \leq \boldsymbol{Z}_R\ (\boldsymbol{\theta}_{FC} - \boldsymbol{\theta}_i) \qquad \text{eq. 2}$$

Where $\boldsymbol{E}_i$ is the depth of winery wastewater applied (mm) on day *i*, $\boldsymbol{Z}_{R,}$ is the effective rooting depth (mm), θ_{FC} is the soil water content (SWC) at field capacity ($m^3\ m^{-3}$), and θ_i is the SWC on day *i* ($m^3\ m^{-3}$) (Houlbrooke *et al.* 2004b). Both these equations effectively state that the existing soil moisture deficit in the root zone plus the depth of winery wastewater applied should be less than maximum soil water storage (field capacity). An estimate of the maximum soil water storage volumes for a range of soils are shown below in Table 3. Soil moisture and water budget calculations will enable the correct depth of wastewater to be applied yet will require equipment such as aquaflex tapes or tensiometers to measure soil moisture content.

Table 3. Estimated maximum soil water storage volumes. Adapted from DairyNZ Ltd. (2011)

Soil class	Volumetric soil water content (%)
Clay loam	17 - 21
Silt loam (no stones or gravel)	12 - 17
Silt loam (< 30 % stones by volume)[#]	8 - 10
Sandy loam	7 - 13
Sand	5 - 7

[#]for soil with ≥30% stones, scale the given values for silt loam (no stones or gravel) relative to the volume of stones

The application rate (intensity) of winery wastewater application has a strong influence on nutrient treatment efficiency when applying to soils that; exhibit a high degree of preferential flow, have a drainage limitation or that are located on sloping land. Water may flow laterally across the soil surface as overland flow, particularly when the rate of hydraulic loading exceeds the infiltration rate of the soil. Different soils have different infiltration rates and abilities to absorb and drain water. In order to reduce the risk of surface water contamination as a result of overland flow, winery wastewater application rates should be matched to the soil's ability to absorb or infiltrate it. Low rate applicators apply wastewater at instantaneous rates < 10 mm/hr (and often < 5 mm/hr) and therefore reduce the risk of exceeding a soil's infiltration capacity, thus preventing ponding and surface runoff. Furthermore, the slower application rates increase the likelihood of retaining the applied nutrients in the root zone, as the low application rate decreases the likelihood of preferential flow and allow a greater volume of applied wastewater to move through smaller soil pores via matrix flow. This enables greater attenuation of nutrients and contaminants in the soil-plant system (McLeod *et al.* 1998; Monaghan *et al.* 2010).

5.2 Nutrient loading

Winery wastewater contains a considerable amount of N (approximately 35 mg/L; range 1.9-70 mg/L; Table 1), particularly during vintage. The concentration of P is also high at around 15 mg/L (range 5.3-17 mg/L; Table 1). Therefore, when winery wastewater and grape marc are applied to land; there is potential that N and P are lost to surface or ground water which is an issue of environmental concern. Ideally, wineries that irrigate more than 100 mm of wastewater per year should monitor ground water if it is less than 15 metres below the surface, and, surface water bodies if they are located within 50 metres of the irrigation disposal site.

Generally N is leached in the form of NO_3^- and is a function of N input (from any source), the NO_3^- concentration in solution and also the flow of water from the soil profile as deep drainage or surface water run-off. The accumulation of NO_3^- in soils will be closely associated with the amount that is applied in wastewater or grape marc and the amount of N taken up by plants and immobilised or mineralised within the soil organic C pools.

Soil processes responsible for the attenuation and amelioration of waste constituents occur mostly within the active plant rooting zone. Hydraulic loading depths that allow longer contact time between soil and waste constituents in the root zone will maximise nutrient assimilation and subsequent renovation (Olson *et al.* 2009). Management practices that minimise NO_3^- leaching under winery wastewater application should consider the vulnerability of a particular soil to leaching (i.e. drainage class), the type and rate of wastewater applied, annual precipitation, time of application and the N use of the cover crop (Skerman 2000). Within New Zealand's low intensity pasture based systems, permissible loading of N is restricted to 150-200 kg N ha^{-1} and many studies suggest this is an appropriate limit to ensure minimal NO_3^- leaching loss (Cameron *et al.* 1996). South African guidelines for winery wastewater allow up to 2000 m^3 to be applied on any given day when the N loading is less than 18 mg/L, this equates to a loading of

36 kg (no area specified). However, hydraulic loading in combination with the total N load will ultimately influence the fate of N.

In some soil profiles, soil cracking, root and worm channels and large macropores may encourage preferential, or by-pass flow, that minimises the interaction between soil and wastewater/marc thereby limiting plant uptake. If the application depth of winery wastewater exceeds the water holding capacity of the soil or the antecedent soil moisture content is high, a large proportion will preferentially flow through macropores (Houlbrooke *et al.* 2004a). There is a greater tendency for overland flow when soil hydraulic conductivity and infiltration rate are low or when wastewater is applied to saturated soils. However, generally the loss of N via surface run-off (i.e. incorporated with overland flow) is small relative to losses in drainage (McDowell *et al.* 2008).

By increasing application frequency, the applied depth and nutrient loading rate in a single event can be reduced, thereby extending the retention time of winery wastewater in the active rooting zone and improving plant nutrient use efficiency by better matching demand. This was illustrated by Bond *et al.* (1995) where no adverse effect on groundwater quality occurred at sites where wastewater was applied to match plant water use, yet when applied at twice the irrigation demand large amounts of N were leached.

Higher N content and solid to liquid ratio of winery grape marc typically limits the hydraulic loading rate (application depths) and therefore preferential flow of NO_3^- is generally low (McDowell *et al.* 2008). However, it is recommended that marc is applied to match the agronomic N requirement of the crop. As discussed previously, a considerable amount of N will be retained in organic form that is not at risk of being leached or lost as gaseous emissions. The exact quantity of plant available-N (i.e. mineral-N) will however depend on mineralisation/immobilisation rates in the soil that may vary considerably depending on a number of site specific biological conditions. For pasture we recommend a limit of 150 kg N/ha which is a conservative approach to N management. This can be revised with further knowledge of site-specific conditions including assessment of soil characteristics, mineralisation rates, climate, and the agronomic N needs of the crops. Poor timing of N and excess loading relative to crop demand can be a major pathway for N loss particularly via surface flow (Beckwith *et al.* 1998).

Where winery wastewater and grape marc are applied to soils, P is lost via leaching or overland flow as either water soluble P or bound to soil particles. Overland flow is generally the predominant pathway for P transfer to streams and rivers, however, leaching may occur in soils with low or saturated P sorption capacity and high macroporosity that enables preferential flow under saturated conditions. Redding (2001) reported evidence of P leaching in two Australian soils, one a coarse textured sandy soil and the other a light-medium clay soil. Leaching in the sandy soil reflects the poor P retention and rapid draining characteristics while in the clay, soil leaching was attributed to irrigation management that encouraged preferential flow.

Phosphorus is relatively immobile in soils compared to N, and application of grape marc is unlikely to result in P leaching from the soil profile due to the low concentration. Principal mechanisms by which P is retained in soils receiving winery wastewater and grape marc include soil adsorption/fixation, biological immobilisation or precipitation with Ca compounds. The ability of the soil to retain P depends on the amount of oxide (iron, aluminium, manganese), clay and organic matter and soil pH (i.e. increasing with higher pH). A small fraction will remain in soil solution as water soluble P and is readily available to plants or subject to loss (Sharpley *et al.* 2001). The P retention mechanisms in most New Zealand soils are believed to result in a low risk of P leaching (White and Sharpley 1996). McDowell and Sharpley (2002) however, reported a close association between the available P concentration in surface soils and subsequent loss in overland flow.

The primary benefit of a land-based waste treatment system is the nutritional benefit to plants and the consequent nutrient removal with growth. Irrigation of winery wastewater will normally increase production and crop nutrient and protein content due primarily to the NPK content. This will also be similar for grape marc, however additional benefits of improved water holding capacity and greater soil biological recycling will also contribute to improved plant growth.

5.3 Soil chemistry and plant growth

Plant response to applied wastewater is strongly influenced by a number of factors including application method, rate and time, antecedent soil fertility and the climate conditions (Laurenson *et al.* 2012). Furthermore, nutrient uptake will vary depending on crop type and the volume and nutrient content of the dry matter it produces. Critical to the system management is knowledge of how much nutrient is directly available to the crop and how much will be removed by the crop. The supply of large quantities of selective nutrients, particularly N and K, with winery wastewater irrigation could affect the nutrient balances and the botanical composition of the crop (Campbell *et al.* 1980; Laurenson *et al.* 2012). There have been claims that excessive nutrient loading through farm dairy effluent (FDE) irrigation, which is also high in K, has led to nutrient-related metabolic disorders in grazing animals (Bolan *et al.* 2004). In the case of grape marc that has been co-composted, the chemical, nutrient and volume of the final product should be determined prior to application to land.

Efficient nutrient management, in particular N, should be based on meeting the actual N demand of the plant. Increased potential for offsite loss of N may contribute to environmental issues in aquatic systems. South Australian Guidelines for wineries and distilleries (South Australian EPA 2004) require nutrient loading to be incorporated into nutrient budgeting analysis of the whole farm. A whole farm nutrient budget accounts for the total input and output of nutrients to the farm plus those nutrients transferred within the farm. Inputs to the farm include those in wastes, fertilisers, purchased feed stuffs, biological fixation (in legume based systems) and rainfall. Nutrient outputs include those removed in crop, animals or produce removed from the farm (i.e. sold) or nutrients lost through leaching, gaseous loss and run-off. A nutrient budget for application of winery wastes to land may only need to be specific to the components of the waste management system (i.e. non grazed system) such as the concentration of the waste itself, quantity applied and the amount of nutrients removed by the crop. Nutrient loss during storage will be via gaseous emissions and leaching therefore if storage is required, leachate should be contained by using a sealed pad and bunding (where necessary) and air flow maintained.

Plant availability of N in soils irrigated with winery wastewater also varies in relation to changes in soil temperature, pH, aeration and water content (White *et al.* 2007). Grape marc has high solid-to-liquid ratio, and the concentration of plant available-N is low, therefore availability will be driven by soil biological processes following application. In a wastewater investigated by Neilsen *et al.* (1989), less than 30% of N was plant available at the time of application (i.e. 70% is organic-N, which is not plant available) and this proved problematic in matching N demand with supply during the growing season.

Micronutrients were found in trace amounts in seven grape marc materials investigated by Patti *et al.* (2004) with exception of iron that naturally occurs in soils at high concentrations. Although essential to plant growth, when found in high concentration they can have a toxic effect on plant growth. In general, grape marc can be an important source of micronutrients, however their concentration is not typically at levels that may pose a risk to plant growth.

South Australian guidelines (South Australian EPA 2004) recommend testing of soils irrigated with winery wastewater (where application rate exceeds 100 mm per year) on an annual basis and compare against a control site where no winery waste has been applied. Ideally soil sampling should be carried out for each IMU.

5.4 Salinity and high sodium and potassium concentration

Increased soil salinity as a result of irrigation, can have a detrimental effect on plant growth and may cause an adverse decline in soil aggregation. Winery wastewater contains high salt concentrations (Table 1) and therefore has considerably greater salt loading relative to irrigating with river, ground or mains supply (i.e. town) water. Salt accumulation may affect plant health and specific ions, sodium (Na^+) and potassium ions (K^+) may affect soil structure.

Soil dispersion is closely associated with the abundance of either Na^+ or K^+ on the soil exchange complex relative to calcium ions (Ca^{2+}) and magnesium (Mg^{2+}). The effect of exchangeable Na^+ on soil structure has been widely publicised. In efforts to mitigate sodic conditions in soils, there has been a recent trend towards using potassium hydroxide (KOH) in replace of sodium hydroxide (NaOH) for cleaning and sterilisation purposes; this however raises the K^+ concentration in the final waste stream. Although guidelines for the application of wastewater to soil provide recommended sodium adsorption ratio (SAR) threshold values for the prevention of sodic conditions in irrigated soils, limited attention is given to the individual and combined effects of K^+ on soil dispersion (ANZECC & ARMCANZ 2000).

The SAR and potassium adsorption ratio (PAR) are widely used indices to describe the risk of soil dispersion (Laurenson *et al.* 2011). These equations describe the molar ratio relationship between Na^+ or K^+ and di-valent cations, Mg^{2+} and Ca^{2+} (where concentrations of cations are expressed as $mmol_c/L$). In wastewaters containing high concentrations of both Na^+ and K^+, as in the case of winery wastewater, the 'cations ratio of structural stability' (CROSS) equation (Rengasamy and Marchuk 2011) is a more appropriate evaluation of waters containing all basic cations including Ca^{2+}, Mg^{2+}, K^+ and Na^+. This approach has recently been used to assess potential impact of winery wastewater irrigation on soil structure (Jayawardane *et al.* 2011).

$$CROSS\ (mmol/L)^{0.5} = \frac{[Na^+] + 0.56[K^+]}{\sqrt{\{[Ca^{2+}] + 0.6[Mg^{2+}]\}/2}} \quad (4)$$

Soil dispersion of two Marlborough soils; a Wairau silt loam (Recent soil), and a Paynter silt loam (Gley soil), in response to winery wastewater CROSS was investigated by Laurenson and Houlbrooke (2012). This was done with the intention of developing guidelines for winery wastewater irrigation in Marlborough. Overall soil dispersion was extremely low relative to reported values in Australian soils. This was believed to reflect the high silt content of the Marlborough soils. A precautionary approach was taken when recommending an upper limit for CROSS in winery wastewater. This recommendation is shown graphically in Figure 1 for varying electrical conductivity (EC) values of winery wastewater. At an EC of 1.5 dS m^{-1} for instance, CROSS of winery wastewater should be less than 20.

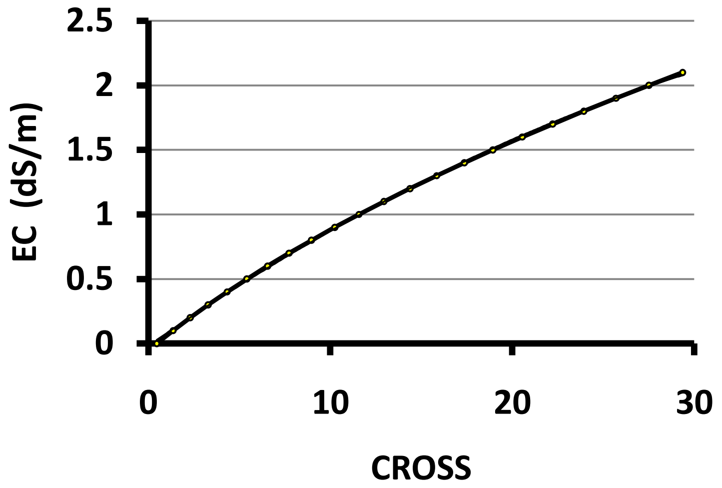

Figure 1. Recommend CROSS and electrical conductivity (EC) for winery wastewater applied to land in the Marlborough Region.

Guidelines from South Africa recommend winery wastewater should have an SAR (equivalent to CROSS when only Na^+ is concerned) less than 5 when EC is 2 dS/m (van Schoor 2005). This is a conservative measure that is likely to be too stringent for Marlborough where soils are more freely draining and have lower clay content.

In Marlborough, both Pallic and Recent soils are used for grape growing with a smaller region of Organic soils on the river escarpments of the lower Awatere Valley. Recent soils drain freely and monovalent cations will percolate more readily with annual rainfall and irrigation cycles due primarily to their low soil bulk density and clay content. Accumulation of Na^+ and K^+ associated with winery wastewater irrigation will likely be less pronounced than in the heavier Pallic soils, that have slower drainage.

Based on a recent report by Gray (2012) however , there appears to be limited evidence that exchangeable sodium percentage (ESP) or exchangeable potassium percentage (EPP) are at a concerning level despite the large variation in soil drainage properties across the sites sampled. Therefore we suggest that if the CROSS of winery wastewater, with an EC of 1.5 dS/m, is kept below 20, no adverse soil structural changes will develop. We suggest this recommendation should be revised for winery wastewater with lower EC.

5.5 Contaminants

Heavy metal concentrations in grape marc, investigated by Patti *et al.* (2004), were generally low (Table 2) and were not dissimilar to background concentrations found in soils. Patti *et al.* (2004) speculate that heavy metals found in grape marc have in fact originated from the soil in the vineyard and were in all cases concentrations were lower than commercially sold composts from municipal green waste collection. Flocculating or coagulating agents used to treat waste may have eco-toxicological effects on soil. Those generally used in the wine making process however pose limited risk to soil biology. As reported by Smith (1996), contaminants in solid wastes are retained in surface soils with very limited downward movement through the soil profile and therefore are unlikely to affect groundwater quality.

5.6 Winery waste pH

Winery wastewater may contain high concentrations of bicarbonate from cleaning products and when applied to land can cause soil pH to increase (Suarez *et al.* 2006). At pH > 8, the formation of carbonate precipitates will occur in soils irrigated with winery wastewaters that have high bicarbonate content (Eshel *et al.* 2007). Divalent cations, Mg^{2+} and Ca^{2+}, in solution and on exchange sites can act as conjugate cations in this precipitation, however Na^{+} and K^{+} do not precipitate to the same extent (Stumm and Morgan 1996; Suarez *et al.* 2006). This removal of divalent cations from the soil solution raises the CROSS of the soil solution and the resulting exchangeable sodium ESP or EPP. This subsequently increases the potential for clay dispersion (Suarez *et al.* 2008).

Even wastewaters with acidic to neutral pH have been reported to increase soil pH following irrigation (Sparling *et al.* 2001). Irrigation of winery wastewater (pH 4.4 to 5.0) to a Red gum plantation in Berri, South Australia, resulted in a 1.5 to 2.0 unit increase in soil pH (approximately 7.7 to 9.3) over the course of five years (Environment Australia 2001). Changes in pH of woodlot, pasture and vineyard soils irrigated with winery wastewater have also been reported by Kumar and Christen (2009). These researchers report a 1 to 2 unit increase in soil $pH_{(1:5)}$ at most sites, however changes were less apparent in soils with initially high pH. The availability of nutrients for plant uptake is highly dependent on soil pH and alkaline soil conditions can limit the supply of nutrients (Bolan and Hedley 2003). Despite a high bicarbonate concentration, Bueno *et al.* (2009) report a slight reduction in pH following the application of wine vinasse (pH 5.8 post-application) onto a Mediterranean soil. The reduction was attributed to greater microbial transformation of organic sugars and an EC (9.2 dS m^{-1}) significantly greater than many wastewaters used in New Zealand.

Increased soil pH has been shown to raise the cation exchange capacity in variably charged soils (Bolan *et al.* 2003; Bolan *et al.* 1999). Greater CEC reported by Laurenson (2011), was associated with a subsequent increase in exchangeable K^{+} under winery wastewater. In the presence of Na^{+}, Bolan *et al.* (1996) reported a 2.5-fold increase in dispersed clay (% of soil) when soil pH was increased from 6.0 to 7.0. When Ca^{2+} was the dominant cation in solution however, flocculation of clays was maintained and an improvement in soil hydraulic conductivity was evident. We recommend that testing of winery wastewater pH and soil pH be included in annual soil testing protocol.

5.7 Biological oxygen demand (BOD)

The BOD of wastes is a measure of the oxygen consumption during the breakdown of organic matter. When discharged directly to surface waters, the BOD has a significant impact on aquatic eco-systems by limiting available oxygen. The high BOD in grape marc and wastewater may temporarily reduce soil oxygen, particularly when combined with high soil moisture content under large application depths (Clemens and Huschka 2001). However the ability of soils to assimilate wastewater and marc is rapid and anaerobic conditions are not persistent, particularly if applied at rates suitable to the nutrient demand and, in the case of winery wastewater, when there is a suitable soil moisture deficit (Houlbrooke *et al.* 2006). Studies have investigated the effect of distillery, winery, dairy factory and pulp mill waste application to land where BOD concentrations range between 3000- 8000 mg L^{-1}, with no adverse effect on soil quality (Ghani *et al.* 2005; Kumar and Christen 2009; Kumar and Kookana 2006; Sarathchandra *et al.* 2006). Immobilisation of N and subsequent poor grass growth has however been reported, due to a high C: N ratio and subsequent immobilisation of N (Sarathchandra *et al.* 2006). The Code of Practice for Winery Waste Management (New Zealand Winegrowers 2010) recommends a BOD loading no greater than 120 kg BOD/ha/day, that we feel is suitable for Marlborough soils.

5.8 Odour

Odour is not associated with any direct personal health effects yet may be a point of annoyance amongst surrounding land owners. The frequency, intensity, duration and offensiveness of the odour are the key factors causing nuisance. Generally odour can be avoided by preventing anaerobic conditions in the winery wastewater during storage and while being applied to land, maintaining adequate separation distance to neighbouring properties, and irrigating downwind at opportune times (i.e. late at night).

5.9 Decision support tool for applying winery wastewater to land

We recommend that winery wastewater management is matched with soil and landscape features in order to prevent direct losses of waste contaminants. A decision tool has been constructed by Houlbrooke and Monaghan (2010) to guide appropriate effluent management practice considering the effects-based assessment of different soil and landscape features (Table 4 and 5). It should be noted that these criteria are considered the minimum conditions that should be adhered to, to avoid direct losses of land-applied wastewater. The adoption of this best management practice would decrease the management risk associated with these soil and landscape features. It is possible for risks to be adequately managed given a judicious approach to the stated minimum criteria.

Table 4. Minimum criteria for a land-applied effluent management system to achieve (Houlbrooke and Monaghan 2010).

	Soil type				
Category	**A**	**B**	**C**	**D**	**E**
Soil and landscape feature	Artificial drainage or coarse soil structure	Impeded drainage or low infiltration rate	Sloping land (>7°) or land with hump & hollow drainage	Well drained flat land (<7°)	Other well drained but very stony[X] flat land (<7°)
Application depth (mm)	< SWD*	< SWD	< SWD	< 50% of PAW#	≤ 10 mm
Instantaneous application rate (mm/hr)	N/A**	N/A**	< soil infiltration rate	N/A	N/A
Average application rate (mm/hr)	< soil infiltration rate	< soil infiltration rate	< soil infiltration rate	< soil infiltration rate	< soil infiltration rate
Storage requirement	Apply only when SWD exists	Apply only when SWD exists	Apply only when SWD exists	24 hours drainage post saturation	24 hours drainage post saturation
Maximum N load	150 kg N/ha/yr	150 kg N/ha/yr	150 kg N/ha/yr	150 kg N/ha/yr	150 kg N/ha/yr

* SWD = soil water deficit, # PAW = Plant available water in the top 300 mm of soil,

X Very stony= soils with > 35% stone content in the top 200 mm of soil

** N/A = Not an essential criteria, however level of risk and management is lowered if using low application rates

Table 5. Recommended maximum application depths for different soil and landscape features using either a high or low application rate irrigation system (assumes suitable soil moisture contents and water holding capacity). Depths listed relate to the mean delivery depth across an irrigator's wetted footprint (Houlbrooke and Monaghan 2010).

Category	**A**	**B**	**C**	**D**	**E**
Maximum average depth#	Artificial drainage or coarse soil structure	Impeded drainage or low infiltration rate	Sloping land (>7°) or hump & hollow drained land	Well drained flat land (<7°)	Other well drained but very stony flat land (<7°)
Max depth: High rate tool	**10 mm**	**10 mm**	**10 mm***	**25 mm# (10 mm at field capacity)**	**10 mm**
Max depth: Low rate tool	**25 mm**	**25 mm**	**10 mm**	**25 mm**	**10 mm**

* *This method only applicable where instantaneous application rate < infiltration rate*

#*25 mm is the suggested maximum application depth when a suitable SWD exists (≥ 15 mm). Field capacity should not be exceeded by more than 10 mm using a high rate irrigator.*

6. Solid Waste

Grape marc can be used beneficially as a soil conditioner and is usually applied directly or rotted down post harvest and applied in spring of the same year. Stabilisation of the

C:N ratio in grape marc is achieved by stockpiling up to 12 months, however, this is often not feasible for small wineries. Storage of grape marc can lead to issues around odour and dust or may encourage breeding of insects and pests. Acidic leachate that is high in N can also contaminate soils and surface soils. For these reasons long term storage of grape marc is not desirable. Where storage is necessary, marc and leachate should be retained on a concrete pad or impermeable surface. Facilities composting on-site- must have a suitable monitoring program to assess effects of the composting process on the environment. When grape marc was applied to vineyard soils, Agnew *et al.* (2005) reported increased water retention, improved soil biological function, increased plant N and K content and greater vine yield. Juice brix and pH were however, not affected by grape marc composting and there was no greater incidence of frost damage in composted vines.

Grape marc can also be used as a stock feed, a component of composting for reuse in vineyards or sold for manufacturing of vitamins. In Australia, grape marc is further processed to produce alcohol; however, this is not common in New Zealand and has recently declined in Australia also.

6.1 Issues to consider when applying Grape marc to land

In order to prevent prolonged anaerobic soil conditions grape marc should be spread thinly and uniformly over the largest area possible. This will also help to minimise odour and leaching issues. The moisture content and chemical content should be determined and applied at an N loading rate < 150 kg N/ha with adequate resting periods between applications. It is recommended that the daily BOD loading be less than 120 kg BOD/ha.

The use of the effluent framework does not seem directly applicable to winery grape marc because the higher dry matter content and concentrated nutrient content means that volumes applied are considerably lower and therefore a greater proportion will remain on the soil surface post application as opposed to residing in the root zone or passing straight through it. However, aspects of Table 4 and 5 do relate to grape marc products such as the timing in relation to soil moisture.

6.2 Decision support tool for applying grape marc to land

Given the difference in management required between winery wastewater and grape marc, Houlbrooke *et al.* (2011) have developed a preliminary soil and landscape risk framework for solid dairy effluents that we feel will be suitable for the land application of grape marc . Table 6 recommends that grape marc be applied to land at loading rates < 3 t DM/ha. When being applied to a grazed pastoral landscape we recommend a maximum N loading of 150 kg N/ha. However when applied to cut and carry or cropping systems, crop and site dependant factors need to take account of crop N requirement and deep soil mineral N status. We recommend that grape marc should not be applied to soils wetter than field capacity or if rain is forecast. This will avoid runoff within a minimum of 48 hours (and recommended 10 day) period following application. We also recommend that soil temperature is above 4^{o} C when grape marc is applied so that plant growth activity is not limited.

Table 6. Minimum management criteria for a system where grape marc is applied to land (Houlbrooke *et al.* 2011).

	Soil type			
Category	**A**	**B**	**C**	**D**
Soil and landscape feature	Artificial drainage or coarse soil structure	Impeded drainage or low infiltration rate	Sloping land (>7°) or land with hump & hollow drainage	Well drained flat land (<7°)
Application volume - slurry	< 50m3/ha	< 50m3/ha	< 50m3/ha	< 50m3/ha
Application volume - solids	<3 t DM/ha	<3 t DM/ha	<3 t DM/ha	<3 t DM/ha
Soil moisture at application - solids	Avoid saturation: field capacity or drier	Avoid saturation: field capacity or drier	Avoid saturation: field capacity or drier	Avoid saturation: field capacity or drier
Maximum N load - pasture	150 kg N/ha/yr	150 kg N/ha/yr	150 kg N/ha/yr	150 kg N/ha/yr
Maximum N load - crop	Crop and site dependant	Crop and site dependant	Crop and site dependant	Crop and site dependant
Tactical timing if not incorporated	> 10 days until runoff event (min 48 hrs)	> 10 days until runoff event (min 48 hrs)	> 10 days until runoff event (min 48 hrs)	> 10 days until runoff event (min 48 hrs)
Optimum time of year	Late spring	Late spring	Late spring	Late spring
Minimum soil temperature	4 ºC	4 ºC	4 ºC	4 ºC

If grape marc is used as an animal feed, it is recommended that chemical residue testing is carried out before it is fed to stock. Alternatively, check the spray diaries from the vineyard where it originated and check for contaminants such as hydraulic oil. It is recommended a feed pad be used when feeding out to animals.

7. Conclusions

Poor management of winery wastewater can potentially lead to contamination of surface and ground waters and adversely affect soil and plant health. High nutrient loads, high BOD and salts are of primary concern. Winery wastewater should be applied when there is suitable soil water deficit and should be applied at an N loading rate < 150 kg N/ha and daily BOD loading less than 120 kg BOD/ha. The concentrations of heavy metals and other contaminants are generally low and pose limited risk.

A decision tool has been developed to guide appropriate application of winery wastewater. This is based on the minimum conditions that should be adhered to, to avoid direct losses of land-applied wastewater. Overall the risk of soil dispersion in Marlborough soils is relatively low due to their low clay content and the regular rainfall that displaces monovalent cations down the soil profile. As a precautionary approach we recommend an upper limit for CROSS in winery wastewater of 20 when EC is 1.5 dS m^{-1}.

Grape marc can be used beneficially as a soil conditioner and has shown to improve a number of soil qualities such as water holding capacity, soil carbon and biological function. Grape marc contains a large amount of N, P and K. The availability of these nutrients however is generally low due to the slow decomposition of grape marc constituents. Loading of nutrients should meet plant requirements, this is likely to be a conservative approach to N management due to the high organic –N content that must first be converted to a mineral-N form. However, given the uncertainties of soil mineralisation rates and other factors, that will vary between sites and soil conditions, this will help limit excess nutrient application and subsequent losses to surface and/or ground waters. To prevent prolonged anaerobic soil conditions grape marc should be spread thinly and uniformly over the largest area possible. It is recommended that the daily BOD loading be less than 120 kg BOD/ha. We recommend that grape marc be applied to land at loading rates < 3 t DM/ha/yr.

Storage of grape marc is not desirable, however when necessary, grape marc and leachate should be retained on a concrete pad or impermeable surface to minimise impacts from acidic leachate and high N content that can contaminate soil and water bodies.

8. Recommendations

- A record of the amount of wastewater and solids that are produced should be maintained. Waste flow volume must be synchronised with concentration information in order to calculate pollutant loading.
- Sampling of wastewater and grape marc composition is recommended, and should reflect the quality during vintage period.
- If wastes are land applied, information on area covered, date of application and location of application should also be recorded.

- Soil depth, infiltration rate and maximum water storage should be determined for each irrigation management unit prior to winery wastewater and grape marc application.
- Winery wastewater and grape marc should not be applied when soils are wet or at application rates that exceed the recommendations in this report.
- If an accumulation of soil ESP and/or EPP is detected in soil testing, hydraulic conductivity should be measured routinely (approx. every 2 years) to assess changes in soil structure due to high Na^+ and/or K^+ loading.
- Nutrient loading should be incorporated into nutrient budgeting analysis of the waste system. Loading rates of winery wastewater plus fertiliser and other N products should not exceed 150 kg N/ha/yr, while grape marc should be applied at an N loading rate that matches plant requirements (150 kg N/ha will be a suitable default, inclusive of fertiliser and other products that contain N).
- Where irrigated crops are fed to animals, K concentration in dry matter should be monitored to prevent metabolic disorders. Loading rates based on K should also be considered in the case of winery wastewaters that are high in K concentration. This will be particularly important where crop is destined for dairy cattle.
- Stockpiled grape marc should be fully contained on a concrete pad or impermeable surface and have adequate air flow.

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