Agricultural Water Management 180 (2017) 178–189

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

Impact of winery wastewater irrigation on soil, grape and wine composition

David R. Hirzel[a], Kerri Steenwerth[b], Sanjai J. Parikh[c], Anita Oberholster[a,*]

[a] Department of Viticulture and Enology, One Shields Ave., University of California Davis, Davis, CA 95616, USA
[b] USDA/ARS Crops Pathology and Genetics Research Unit, c/o Department of Viticulture and Enology, RMI North, Rm 1151, 595 Hilgard Ln., Davis, CA 95616, USA
[c] Department of Land, Air and Water Resources, One Shields Ave., University of California Davis, Davis, CA 95616, USA

ARTICLE INFO

Article history:
Received 10 June 2016
Received in revised form 19 October 2016
Accepted 22 October 2016
Available online 18 November 2016

Keywords:
Sodium
Salinity
Irrigation
Winery
Vineyard
Wastewater

ABSTRACT

This study investigated the effects of WW irrigation on grape and wine chemical composition and sensory attributes in vineyards in Napa and Sonoma Counties. The life cycle of the grape/wine production was examined, including irrigation water and soil samples, leaves and grapes at both veraison and harvest, analysis of the wine and a sensory comparison of the finished products. Samples were analyzed for Na^+, Mg^{2+}, K^+, and Ca^{2+} cations by inductively coupled plasma mass spectrometry (ICP-MS), and the phenolic composition of the grapes and wine samples were analyzed by reverse phase high performance liquid chromatography (RP-HPLC). Na^+ and K^+ concentrations were higher in the winery wastewater compared to the control water due to the presence of grape solids and detergents. The WW irrigated soil samples showed accumulations of Na^+ and K^+ cations while the leaf samples from vines receiving WW contained more Na^+ and Mg^{2+} and less K^+ and Ca^{2+} than the control water treatments. These values were not, however, close to values that would limit growth. The grape samples did not show a consistent trend between the two vineyards and displayed no linear relationship with accumulation of cations in the leaves. Phenolic analyses showed minor although significant differences between treatments, but sensory analysis did not reveal any perceived impact on the wines.

Published by Elsevier B.V.

1. Introduction

As the domestic demand for clean water increases and drought conditions become more frequent (IPCC, 2013), many wineries are interested in wastewater recovery and re-use. In 2014, California produced 835 million gallons of wine (Bureau., Alcohol and Tobacco Tax and Trade, 2015). Using an industry assumption that every gallon of wine produced will generate seven gallons of wastewater (Oakley, 2009), California potentially generated over 5 billion gallons of wastewater in 2014. Wastewater recycling within a vineyard/winery operation represents a sustainable approach that demonstrates commitment to lowering off-site environmental impact.

Winery wastewater (WW) is generated from grape processing and from cleaning operations within the winery. The WW volume and composition will vary greatly based on time of year, the size of the winery, and type of wine produced (Buelow et al., 2015b). The wastewater contains wine and cleaning chemicals (e.g., NaOH and KOH) and, during harvest, will contain high quantities of grape juice and solids. These waste streams are usually high in organic content, sugars, organic acids, and higher molecular weight compounds (Arienzo et al., 2009; Buelow et al., 2015b), leading to an increase in the biological oxygen demand (BOD). Grape juice is the main source of the high K^+ levels in WW (Boulton, 1980) and, during harvest, the increased volumes of grape juice in the WW can raise the K^+ concentration to over 1000 mg/L (Arienzo et al., 2009). Most of the Na^+ in WW comes from cleansers used for sanitation, making the Na^+ concentration dependent on the amount of sanitation operations rather than the tonnage of grapes being processed (Laurenson and Houlbrooke, 2011). WW is typically treated with aeration ponds to remove undesired organic waste compounds before discharging it to the environment or disposal system (Mosse et al., 2011). The WW pH is neutralized and aerated to meet the BOD of the bacteria that breakdown the heavier organics and convert ammonia into nitrates (Mahajan et al., 2009). Most treatment systems do not remove cations from the WW making reuse for irrigation problematic.

* Corresponding author.
E-mail address: aoberholster@ucdavis.edu (A. Oberholster).

http://dx.doi.org/10.1016/j.agwat.2016.10.019
0378-3774/Published by Elsevier B.V.

Irrigating with WW rich with Na+ and K+ can negatively impact soil structure as Na^+ and K^+ are relatively large monovalent cations that can displace divalent Ca^{2+} and Mg^{2+} cations from the soil matrix. In part, this leads to swelling and dispersion of the clay layers and weakening of the soil's structural stability (Rengasamy and Marchuk, 2011). Prolonged application of WW can lead to build up of Na^+ and K^+ in soils, especially near the surface due to WW evaporation (Mosse et al., 2013). After hydraulic conductivity has been reduced due to soil swelling and dispersion, it is difficult to reverse the process (Buelow et al., 2015a; Levy and Torrento, 1995).

Vines irrigated with high levels of Na^+ have been shown to suffer negative effects. The vines can be affected by reduced osmotic pressure around the roots and increased toxicity in the plant tissues. Swelling and dispersion of clay in the soil matrix reduce the infiltration rates of water and oxygen (Rengasamy and Olsson, 1991), leading to anoxic conditions that can effect root growth. For grape vines, a Na^+ concentration of 800 to 1000 mg/kg in the petioles is considered toxic (Netzer et al., 2014). The toxicity symptoms appear as leaf chlorosis (burns on the leaf margin) followed by premature defoliation (Prior et al., 1992; Paranychianakis and Angelakis, 2008).

Berry size and quantity, fruit acidity, and quality of the juice can be affected by the application of reclaimed WW. Paranychianakis et al. (2004) reported that Sultana vines irrigated with WW (mean 240 mg/L Na^+) produced fewer berries that were smaller sized and that the juice had higher pH and titratable acidity (TA) and lower total soluble solids (TSS) than the control vines. Stevens et al. (2011) and Stevens and Partington (2013) found that irrigation of Colombard vines with saline WW (3.5 dS/m and 170 mg/L Na^+) for five seasons reduced the berry size and crop yield. The resulting juice had higher pH but lower TA and K^+. In contrast, Netzer et al. (2014) did a six year study using treated wastewater (1.8 dS/m and 135 mg/L Na^+) on Superior Seedless table grapes and found that, while the vines accumulated Na^+, the crop yields were unaffected by the water quality treatments. Syrah grapes irrigated with high Na^+ WW (920 mg/L Na^+) showed an increase in total phenolics at harvest in comparison to grapes irrigated with the control well water (Mosse et al., 2013). Conversely, Merlot grapes irrigated with high nitrogen (N) WW (50 mg/L) showed a decrease in anthocyanins (Hilbert et al., 2003). These studies did not demonstrate a consistent effect of WW on yield and other grape contributes, which may be a consequence of different varietals studied and site conditions.

The purpose of the current study was to examine WW recycling in an industrial setting and compare it against conventional irrigation practices. The study examined the life cycle of grape and wine production. The irrigation water and soil, leaves and grapes at veraison and harvest and the resulting wines were sampled for compositional analysis. A sensory comparison of the finished products was also conducted. The analyses focused on concentrations of the mobile cations Na^+, Mg^{2+}, K^+, and Ca^{2+} and any changes to the phenolic profiles of the grapes and wines.

2. Materials and methods

2.1. Vineyard specifications

Two major wine producing regions from Northern California were selected for this study. Site A is located in Napa Valley American Viticultural Area (AVA), CA. The soil profile is the Clear Lake series (fine, smectitic, thermic xeric Endoaquert) (NRCS, 2011), a vertisol typical of basin floors and alluvial fans derived from sedimentary rocks. The soil horizons are categorized as sandy loam from 0 to 45 cm and slow draining smectite dominated clays below 45 cm. The water table without irrigation is between 1.2 to 3 m deep. Site A is planted with *Vitis vinifera* cv. Sauvignon blanc (SB) (UCD clone 1) on rootstock 1103P. The control block (well water) has 8 rows of 180 vines and the WW irrigated block has 20 rows of 80 vines, both planted on 3.1 by 1.2 m spacing. Two rows and four vines along the edges of the blocks were excluded from sampling to avoid edge effects. The vines are 21 years old and the treatment block has been irrigated with WW for 3 years. The WW at Site A is Na^+-enriched due to use of NaOH to neutralize the pH of the waste stream. After treatment with a bioreactor (Lyve™ WW treatment systems, Napa, CA), the WW is stored in a pond until it is needed for frost and fire protection and limited drip irrigation for the vineyards (Table 1).

Table 1
Irrigation and precipitation conditions during WW study.

Year	Precipitation (mm)		Irrigation (L/vine)	
	Annual	Seasonal[a]	Annual	Seasonal[a]
Site A 2013	206.2	43.2	143.9	101.4
Site B 2014	879.0	58.4	683.4	273.4

[a] Precipitation and/or irrigation from 1 April to 31 Oct.

Site B is located in Alexander Valley AVA, CA and consists of *Vitis vinifera* cv. Cabernet Sauvignon (CS) vines from two adjacent sites. Soils are Los Gatos-Josephine series (fine-loamy, mixed, mesic typic Argixeroll) (NRCS, 2011), a mollisol typical of hill tops and slopes. The soil horizons are loam and gravelly loam (mixed mineralogy) weathered from sedimentary rock near the surface and clay loam starting around 38 cm depth. These are well drained and shallow soils with the bedrock at around 80 cm depth. The control block is irrigated with well water while the WW block uses K^+-enriched WW for irrigation. The control block is composed of seven year old CS vines, clone FPS 7 on Swarzmann rootstock (2.5 by 1.8 m spacing) and the WW block is composed of 21 year old CS vines, clone FPS 8 on Teleki 5c rootstock (2.5 by 1.5 m spacing). These were the closest blocks available with the same soils. Both the control and WW blocks were 20 rows of 60 vines. Two rows and four vines along the edges of the blocks were excluded from sampling to avoid edge effects. The WW at Site B is K^+-enriched due to the K^+-based cleansers used for winery sanitation in addition to the K^+ present in grape must. The treatment system uses two aeration ponds cascading to a large storage pond where the WW has 60 to 90 day retention time and an in-line filtration system before discharging to drip irrigators (Table 1). Site B has been using WW for irrigation for 21 years. Due to rainfall and winery logistics, the harvest of the WW block at Site B was delayed for 3 weeks longer than planned. The irrigation volumes and precipitation contributions for Site A and B for the relevant season and year are provided in Table 1.

The experimental design for this study was intended to provide a survey of the irrigation impacts of WW on vineyard soils, vines, grapes and resulting wines. Leaf and grape samples were taken to be representative of vines harvested for winemaking. Leaf and grapes samples were composited and then divided into quintuplicate biological samples to determine the variability within the treatments.

2.2. Sampling and analysis

Irrigation and wastewater samples were collected in triplicate at harvest from both the control and the treatment irrigation sources using acid-washed plastic bottles and transported immediately to UC Davis in Styrofoam coolers with cold packs. The samples were analyzed for pH, EC, ammonia, and nitrates using methods outlined in Buelow et al. (2015b). Samples were stored at 4 °C until cation