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Agriculture and Natural Resources | California Institute for Water Resources

Effects of Application of Winery Wastewater on Soil, Grape Nutrition, and Juice and Wine Quality

Principal Investigators:

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Project Summary

Many wineries are interested in wastewater recovery and re-use. This study investigated the effects on grape and wine composition and quality when winery wastewater (WW) was used for irrigation. The entire life cycle of the grape/wine production was examined, starting with the water and soil samples, leaves and grapes at both veraison and harvest, analysis of the wine and a sensory comparison of the finished products. Vineyards in Napa (Site A) and Sonoma (Site B) counties were utilized for this project. All samples were analyzed for Na^+, Mg^{2+}, K^+, and Ca^{2+} metals by Inductively Coupled Plasma Mass Spectrometry (ICP-MS) and the grapes and wine samples were analyzed for total phenolics and tannins. Na^+ and K^+ concentrations were higher in the winery wastewater compared to the control water due to the presence of grape solids and detergents (Table 1 and 2). The winery WW from Site A and B had respectively a sodium adsorption rate (SAR) of 21.0 and 5.7 and an EC of 2.38 dS/m and 0.43 dS/m which categorized as moderate risk wastewaters per risk guidelines (Ayers and Westcot, 1994).

Site A soil samples showed no major accumulations of cations (Table 3). Site A only uses WW for supplemental irrigation so the soil (Clear Lake Clay series (fine, smectitic thermic xeric Endoaquert)) is not continuously exposed to high Na^+ conditions. Soil samples from the Site B winery WW treated vineyard contained significantly higher levels of K^+ and Na^+ in all soil layers compared to the control. Site B vineyards have been irrigated fully with winery WW for 21 years on Los Gatos-Josephine series (Fine-loamy, meixed, mesic typic Argixeroll) soil.

The leaf samples showed significant increases in Na^+ (Site A, 20%; Site B 43%) and Mg^{2+} (Site A, 30%; Site B, 12%) between the treatments at harvest but not close to limiting levels (Netzer et al., 2014) (Figures 1 and 2). Site A grapes and wines showed no significant differences between the treatments. There were, however, small but significant increases in both Na^+ and K^+ in the WW treated grapes from Site B compared to the control. However, the WW irrigated grapes had smaller berries which would have increased the concentration of cations. Site B wine cations followed the same trends. The grape samples did not show a consistent trend between the two vineyards and displayed no linear relationship with cation accumulations in the leaves.

Phenolic analyses showed minor but significant differences between treatments but not enough to have any sensory and thus quality impact on the final wines. This study demonstrated for the two commercial sites investigated that no negative impact were visible on grapevines irrigated with winery WW when the wastewater contained N < 50 mg/L and is not saline (EC < 4000 µS/cm or 4 dS/m). Although rootstock, grape variety and soil type can influence the impact of WW use, we determined that the quality (chemical composition) of the WW used in this study is one of the major factors for this positive outcome.

Table 1. Chemical properties and cation concentrations of Site A irrigation water (n=3).

Site A		Control		WW		
		Mean	(StDev)	Mean	(StDev)	Notes
pH	--	7.75	(0.06)	9.09	(0.02)	***
EC[ŧ]	(µS/cm)	436	(3)	2380	(30)	***
Nitrates	(mg/L)	0.12	(0.10)	11.95	(1.10)	***
Ammonia	(mg/L)	0.34	(0.29)	2.26	(0.55)	***
Na^+	(mg/L)	35.4	(0.7)	424.7	(9.2)	***
Mg^{2+}	(mg/L)	29.1	(0.6)	24.9	(0.3)	***
K^+	(mg/L)	2.4	(0.9)	129.6	(3.8)	***
Ca^{2+}	(mg/L)	24.8	(0.5)	20.9	(0.2)	***
SAR[†]	$(mmol/L)^{0.5}$	1.6		21.0		
PAR[‡]	$(mmol/L)^{0.5}$	0.1		3.8		

[ŧ]EC, electrical conductivity; [†]SAR, sodium adsorption ratio; [‡]PAR, potassium adsorption ratio
* = P-value < 0.05, ** = P-value <0.01, *** = P-value <0.001, N.S. = Not Significant

Table 2. Chemical properties and cation concentrations of Site B irrigation water (n=3).

Site B		Control		WW		
		Mean	(StDev)	Mean	(StDev)	Notes
pH	--	7.62	(0.03)	7.48	(0.01)	**
EC[ŧ]	(µS/cm)	427	(3)	428	(2)	N.S.
Nitrates	(mg/L)	2.03	(0.24)	2.53	(0.66)	N.S.
Ammonia	(mg/L)	ND		ND		
Na^+	(mg/L)	27.2	(0.2)	134.5	(2.7)	***
Mg^{2+}	(mg/L)	24.1	(0.2)	28.9	(0.6)	***
K^+	(mg/L)	0.768	(0.012)	109.0	(0.7)	***
Ca^{2+}	(mg/L)	28.1	(0.3)	36.1	(1.0)	***
SAR[†]	$(mmol/L)^{0.5}$	0.13		5.72		
PAR[‡]	$(mmol/L)^{0.5}$	0.02		2.73		

[ŧ]EC, electrical conductivity; [†]SAR, sodium adsorption ratio; [‡]PAR, potassium adsorption ratio
* = P-value < 0.05, ** = P-value <0.01, *** = P-value <0.001, N.S. = Not Significant
ND = not detectable

Table 3. Site A soil data by depth (n=5). GWC, pH, and EC were determined from saturated paste extractions, C and N were determined by total combustion, and cations were determined by ICP-MS.

	Depth (cm)	Control Mean (SD)	WW Mean (SD)	Significance (P)
GWC[ϕ] (%)	0 to 20	11.1 (0.8)	16.7 (2.1)	**
	20 to 40	14.3 (1.0)	19.0 (1.7)	**
	40 to 60	15.9 (0.9)	23.5 (3.0)	*
pH	0 to 20	6.36 (0.70)	6.42 (0.31)	N.S.
	20 to 40	6.37 (0.63)	6.64 (0.34)	N.S.
	40 to 60	6.64 (0.70)	6.74 (0.26)	N.S.
EC[ˠ] (µS/cm)	0 to 20	435 (195)	390 (138)	N.S.
	20 to 40	219 (79)	375 (97)	N.S.
	40 to 60	342 (227)	407 (160)	N.S.
C[ȿ] (%)	0 to 20	1.70 (0.10)	1.30 (0.72)	N.S.
	20 to 40	1.13 (0.21)	0.73 (0.38)	N.S.
	40 to 60	0.86 (0.21)	0.65 (0.23)	N.S.
N[ʃ] (%)	0 to 20	0.165 (0.007)	0.137 (0.050)	N.S.
	20 to 40	0.125 (0.020)	0.119 (0.035)	N.S.
	40 to 60	0.098 (0.016)	0.122 (0.014)	N.S.
Na^+ (mg/kg)	0 to 20	3.75 (0.74)	4.61 (2.16)	N.S.
	20 to 40	3.28 (0.83)	3.70 (1.49)	N.S.
	40 to 60	3.08 (0.99)	3.39 (0.88)	N.S.
Mg^{2+} (mg/kg)	0 to 20	4.29 (0.46)	3.38 (0.66)	N.S.
	20 to 40	3.49 (0.47)	4.30 (1.17)	N.S.
	40 to 60	3.40 (1.57)	5.69 (2.38)	N.S.
K^+ (mg/kg)	0 to 20	1.54 (0.78)	0.78 (0.20)	N.S.
	20 to 40	0.84 (0.30)	0.51 (0.24)	*
	40 to 60	1.12 (0.60)	0.44 (0.18)	N.S.
Ca^{2+} (mg/kg)	0 to 20	7.08 (4.05)	3.68 (0.95)	N.S.
	20 to 40	3.59 (0.64)	3.56 (1.66)	N.S.
	40 to 60	2.61 (1.95)	2.79 (1.23)	N.S.

[ϕ]GWC, gravimetric water content; [ˠ]EC, electrical conductivity; [ȿ]C, carbon; [ʃ]N, nitrogen* = P-value < 0.05, ** = P-value <0.01, *** = P-value <0.001, N.S. = Not Significant

Table 4. Site B soil data by depth (n=5). GWC, pH, and EC were determined from saturated paste extractions, C and N were determined by total combustion, and cations were determined by ICP-MS.

	Depth (cm)	Control Mean (SD)	Treatment Mean (SD)	Significance (P)
GWC	0 to 20	17.4 (0.4)	12.0 (0.6)	***
(%)	20 to 40	17.1 (0.5)	21.7 (1.7)	**
	40 to 60	17.0 (0.3)	18.8 (0.7)	**
pH	0 to 20	5.96 (0.92)	6.61 (0.22)	N.S.
	20 to 40	6.36 (0.36)	6.46 (0.02)	N.S.
	40 to 60	5.12 (0.14)	6.29 (0.11)	***
EC	0 to 20	0.611 (0.217)	2.01 (0.15)	***
(dS/m)	20 to 40	0.411 (0.027)	2.06 (0.12)	***
	40 to 60	0.343 (0.010)	1.42 (0.10)	***
C	0 to 20	0.94 (0.24)	0.99 (0.80)	N.S.
(%)	20 to 40	0.83 (0.10)	0.58 (0.22)	N.S.
	40 to 60	0.87 (0.11)	0.71 (0.68)	N.S.
N	0 to 20	0.086 (0.013)	0.111 (0.057)	N.S.
(%)	20 to 40	0.079 (0.007)	0.083 (0.012)	N.S.
	40 to 60	0.081 (0.009)	0.090 (0.038)	N.S.
Na^+	0 to 20	5.59 (0.97)	10.7 (2.3)	**
	20 to 40	5.15 (1.00)	11.5 (3.4)	*
	40 to 60	3.91 (0.39)	23.8 (4.4)	***
Mg^{2+}	0 to 20	1.33 (0.37)	1.57 (0.33)	N.S.
	20 to 40	0.91 (0.17)	0.69 (0.18)	N.S.
	40 to 60	0.66 (0.06)	1.05 (0.18)	*
K^+	0 to 20	3.19 (1.09)	9.06 (1.99)	**
	20 to 40	1.24 (0.36)	4.44 (1.22)	**
	40 to 60	0.86 (0.08)	8.05 (1.52)	***
Ca^{2+}	0 to 20	3.71 (1.02)	3.56 (0.75)	N.S.
	20 to 40	2.29 (0.43)	1.44 (0.39)	*
	40 to 60	1.85 (0.23)	2.41 (0.38)	*

[ϕ]GWC, gravimetric water content; [ŧ]EC, electrical conductivity; [ș]C, carbon; [ʃ]N, nitrogen* = P-value < 0.05, ** = P-value <0.01, *** = P-value <0.001, N.S. = Not Significant

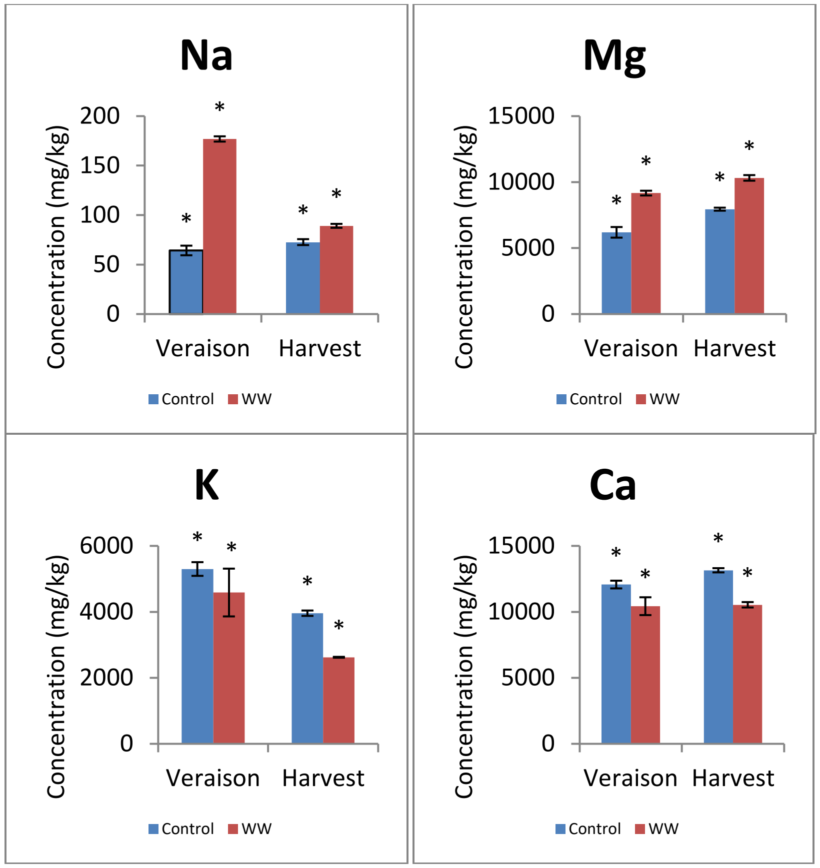

Figure 1. Cation concentrations in dried leaf material from Site A as determined by ICP-MS. Data plotted are means and the error bars show StDev (n=5). * Denotes significance ($P<0.05$)

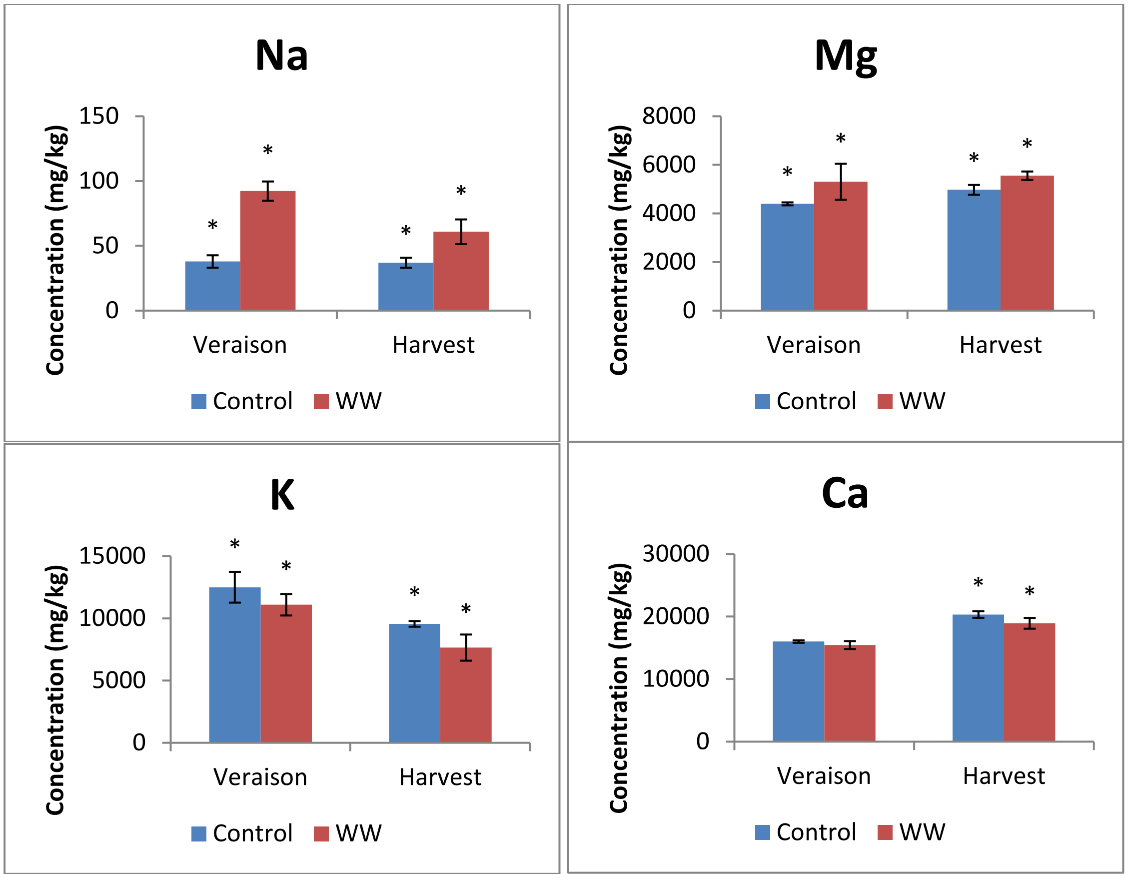

Figure 2. Cation concentrations in dried leaf material from Site B as measured by ICP-MS. Data plotted are means and the error bars show StDev (n=5). * Denotes significance (P<0.05)

Ayers, R. S. W. and D. W. Westcot. *Water quality for agriculture.* Rome: Food and Agriculture Organization 29 rev. 1, 1994.

Netzer, Y., M. Shenker, & A. Schwartz. "Effects of irrigation using treated wastewater on table grape vineyards: dynamics of sodium accumulation in soil and plant." *irrig Sci 32*, 2014: 283-294.

Research Program

Evaluate effects of simulated winery wastewater on: 1) grapevine development, yield, and nutrition; 2) juice and wine chemistry, and wine sensory characteristics, 3) soil properties.

A. **If needed, note and justify any revisions made to the original objectives and/or timetable.** After Leaf Roll Virus has moved into our original vines, which could severely affect the outcome of the study, we started collaborating with commercial wineries already using winery wastewater (WW) for irrigation to complete the study.

B. **Note any other challenges/circumstances encountered and steps taken to resolve them.** As stated above Leaf Roll Virus affected the vines under investigation, and this necessitated that we use vines in another vineyard that has been receiving some form of winery WW irrigation to complete this study. We secured a study site at a vineyard in Napa (2013) and another study site in Sonoma (2014) that uses respectively Na^+- and K^+-enriched winery WW for irrigation. The 2013 study site at Alpha Omega Winery (Rutherford, CA) consisted of Sauvignon blanc control (irrigation with well water) and winery WW irrigated blocks. The winery WW irrigation is Na-enriched due to the specifications of the Lyve winery wastewater system that they use.

The challenges here were that the winery WW site received minimal irrigation and that the WW was Na^+-enriched. For this reason, a K^+-enriched winery wastewater irrigation site were looked for in 2014 where the vines were fully irrigated. The 2014 study site consists of Cabernet Sauvignon vines from two adjacent sites. The control block, Furlong Vineyards (Geyserville, CA), uses standard irrigation water sources while the winery WW block, Francis Ford Coppola Vineyards (Geyserville, CA), uses K^+-enriched winery WW for irrigation.

The challenge here was that because the Furlong Vineyard was fully WW irrigated there was no control available within the same vineyard and we had to use an adjacent vineyard for the control. This vineyard, however was younger then the treatment vineyard with a different rootstock. The advantage of this site was that it has been WW irrigated for over 20 years and the potential to investigate build-up of salts in the soils. There were no major soil differences due to the fact that the vineyards were adjacent to each other.

PROJECT OUTCOMES:

The California wine industry is facing key issues such as limited water availability due to increasing demands from urban users and climate change, and the disposal of winery wastewater (WW). Applying wastewater to vineyards has potential economic, legal, and marketing advantages of reducing water input, retaining wastes, and recycling on the winery's own property. Although the recycling of winery WW on agricultural fields is occurring, the full implications of both current (Na^+ and K^+ rich water) and emerging (K^+ rich) practices on soil fertility, soil physical and chemical properties, and grapevine nutrition and juice characteristics, and resulting wine is not known.

In addition, because the impact of winery WW irrigation on vines are not known most wineries will use WW for irrigation of landscaping and frost and heat protection of their vines but not actually for irrigation purposes. We are addressing these issues by analyzing effects of both Na^+ and K^+ enriched winery WW on grapevine and grape development, nutrition and chemistry as well as evaluating the chemical composition and sensory characteristics of the resulting wines.

ANR funding has enabled us to collect and analyze samples from control and winery WW treated vineyards and make wines from these grapes. The resulting wines when appropriate have been analyzed by formal sensory analysis as well as evaluated at two different workshops. This study has enabled us to inform the grape and wine industry that winery WW irrigations with the composition that we evaluated will not result in any adverse effects on the quality of the grapes or the resulting wines.

This project strengthened our partnership with especially Francis Ford Coppola winery and they are interested in continuing our collaboration with future studies. This study created a lot of interest with wineries interested in using winery WW for irrigation or those using it already in a limited way. This study demonstrates that there is the potential for winery wastewater application to have no negative grapevine impact.

Then wastewater recycling within a vineyard/winery operation is a sustainable option that demonstrates commitment to lowering on- and off-site environmental impact, reducing water usage and wastewater flow to water treatment plants. This study is the first step in developing a list of recommendations for grape growers regarding the use of winery wastewater for grapevine irrigation. Further study is needed to investigate the use of diverse WW compositions on grapevines planted in different soils types. The preliminary data obtained here, will form the basis of new proposals to this regard.

Information Transfer/Outreach Program

Presentations at workshops:

- ROOTSTOCK seminar series in Napa (November 2014)
- Wine Flavor 101: Current Issues in Sustainable Winemaking 2015 Presentation handout: Effects of Winery Wastewater on Soil, Grape Nutrition, and Juice and Wine Quality (April 2015)
- Presentations at future Grape Days in Napa, Sonoma and Fresno Counties (March – August 2016)

Presentations at conferences:

- "Effects of winery wastewater on soil, grape nutrition, and wine quality" presented at the 66th American Society of Enology and Viticulture (ASEV) conference in Portland, OR (June 2015)

Papers/articles:

- Short Communication Titled "Effects of Winery Wastewater on Soil, Grape Nutrition, and Juice and Wine Quality" in Agricultural Water Management (In progress, March 2016)

Notable Achievements

LAY SUMMARY OF ACCOMPLISHMENTS:
The California wine industry is presently facing key issues such as limited water availability due to increasing demands from urban users and climate change, and the disposal of winery wastewater. These issues underscore the need to utilize other water sources for irrigation in agricultural systems, such as treated wastewater from wine production. Applying wastewater to

vineyards has the potential economic, legal, and marketing advantages of reducing water input, retaining wastes, and recycling on the winery's own property. Although the recycling and use of wastewater on agricultural fields is occurring, the full implications on soil fertility, soil physical and chemical properties, and grapevine nutrition and juice characteristics, and resulting wine is not known. In addition, because the impact of wastewater irrigation on vines are not known most wineries will use winery wastewater for irrigation of landscaping and frost and heat protection of their vines but not actually for irrigation purposes. This study addressed these issues by analyzing effects of both sodium and potassium enriched winery wastewater on grapevine and grape development, nutrition and chemistry as well as evaluating the chemical composition and sensory characteristics of the resulting wines.

This study demonstrated for the two commercial sites investigated that no negative impact were visible in grapevines irrigated with winery wastewater although it contained elevated levels of sodium and potassium when the wastewater contained less than 50 mg/L nitrogen and is not saline (EC < 4000 µS/cm). Recycling within a vineyard/winery operation is a sustainable option that demonstrates commitment to lowering on- and off-site environmental impact; reducing water usage and wastewater flow to water treatment plants.

Winery wastewater irrigated Cabernet Sauvignon grapes at harvest.

Taking soil samples in winery wastewater irrigated Cabernet Sauvignon vineyard.