Differences in Grape Phylloxera-related Grapevine Root Damage in Organically and Conventionally Managed Vineyards in California

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Abstract. Secondary infection of roots by fungal pathogens is a primary cause of vine damage in phylloxera-infested grapevines (*Vitis vinifera* L.). In summer and fall surveys in 1997 and 1998, grapevine root samples were taken from organically (OMVs) and conventionally managed vineyards (CMVs), all of which were phylloxera-infested. In both years, root samples from OMVs showed significantly less root necrosis caused by fungal pathogens than did samples from CMVs, averaging 9% in OMVs vs. 31% in CMVs. Phylloxera populations per 100 g of root did not differ significantly between OMVs and CMVs, although there was a trend toward higher populations in OMVs. Soil parameters, percent organic matter, total nitrogen, nitrate, and percent sand/silt/clay also did not differ significantly between the two regimes. Cultures of necrotic root tissue showed significantly higher levels of the beneficial fungus *Trichoderma* in OMVs in 1997 but not in 1998, and there were significantly higher levels of the pathogens *Fusarium oxysporum* and *Cylindrocarpon* sp. in CMVs in 1998 but not in 1997. Implications for further research and for viticulture are discussed.

Grape phylloxera, *Daktulosphaira vitifoliae* (Fitch) (Hemiptera: Phylloxeridae), is one of the most important pests of grape because it kills vines, and once in a susceptible vineyard cannot be controlled. Use of resistant rootstocks with parentage of North American *Vitis* prevents vineyard losses caused by phylloxera. Phylloxera remains a viticultural problem because the rootstock technology is not used universally, and because some of the more virulent phylloxera strains are selecting for certain rootstocks, especially those with partial *V. vinifera* parentage (Granett et al., 1996; Kocsis et al., 1999; Walker et al., 1998). Where phylloxera damage occurs, vine losses are high. No other generally applicable control tactics are consistently effective (e.g., Weber et al., 1996).

Alternative management tactics for grape phylloxera and phylloxera-related damage would be useful for preventing or slowing losses and for delaying the need to replace declining vineyards with vines grafted to resistant rootstocks. Cultural methods for controlling phylloxera damage would be less subject to natural selection for biotypes and would spread replanting costs over time. They could further provide a model for controlling other vine root pests and diseases.

Soilborne pathogens enter root wounds caused by phylloxera feeding and cause a substantial portion of the damage associated with phylloxera activity (Granett et al., 1998; Omer et al., 1995). A number of plant pathogens have been implicated in the damage, including *Fusarium* and *Pythium* species. Soils suppressive to these or other plant pathogens have been described for other plants and the suppression may be related to soil organic matter dynamics (Drinkwater et al., 1995; Hu et al., 1997a; Schneider and Huber, 1982; van Bruggen, 1995; Volland and Epstein, 1994). Nonquantitative reports from researchers in eastern Europe have described the recovery of phylloxera-infested vineyards with use of cover crops and compost amendments (Riabchun, 1971).

In California, vineyards may be certified as "organic" by following strict management rules, which include use of cover crops and organic matter amendments and not using certain types of chemicals. Such methods may bear a resemblance to reported characteristics attributed to pathogen-suppressive soils. We therefore hypothesize that organically managed

vineyards may result in reduced phylloxera numbers and phylloxera-related damage.

The purpose of this work was to determine whether differences in phylloxera populations or phylloxera-related damage could be attributed to organic or conventional management regimes.

Materials and Methods

Two types of long-term vineyard management regimes were compared, organic and conventional. Organically managed vineyards (OMV) chosen for study were certified by the California Certified Organic Farmers program (Santa Cruz) and were characterized by the use of cover crops and composts and no synthetic fertilizers or pesticides. Vineyards that had been organically certified for at least 5 years and were infested with phylloxera were selected for this study. The time threshold of 5 years of organic management was chosen based on experiences of organic farmers, consultants, and researchers indicating that the full effects of management by organic methods take 3 to 5 years to develop.

In Spring 1997, a total of four OMVs that fit these criteria were found in three California wine-growing counties: Napa, Sonoma, and Mendocino. No vineyards could be found in the northern San Joaquin Valley that fulfilled the criteria for OMV. Conventionally managed vineyards (CMV) infested with phylloxera were selected in the above three counties plus San Joaquin County to best duplicate the soil and climatic conditions of the chosen OMVs. All of the CMVs were managed with use of synthetic fertilizers, chemical pest and weed control, and, with the exception of one vineyard in 1998 (CV), no cover crops. CMVs were rejected from the study if insecticides were used to control phylloxera directly.

All vines were on AXR#1 rootstock except for the San Joaquin County vineyards, which were own-rooted (Table 1). Vineyards on sandy soils were rejected because phylloxera tend not to colonize effectively or to cause vine damage in these soils (Nougaret and Lapham, 1921).

Two sampling cycles, early summer (15 June–15 July) and early fall (1 Sept.–1 Oct.), were carried out in each of 2 years, 1997 and 1998. In 1997, one OMV, sampled in summer (VE), was lost to the study because it was replanted with resistant rootstock; we chose another vineyard (KW) to replace it. The CMV roster was reduced from eight to five vineyards in the Fall 1997 sampling for feasibility reasons. In 1998, two CMVs (EL and SF) from the 1997 sampling roster were rejected because of insecticide treatments for phylloxera begun in Spring 1998. A third CMV (CH) was lost because of vineyard replanting. These three were replaced in the 1998 sampling roster by CV, GC, and PO vineyards (Table 1). In the 1998 summer sampling, one new (i.e., not sampled in 1997) OMV (ZD) was substituted for the FE in order to add to the total number of OMVs sampled in the 2-year period. However, despite accounts that ZD had been infested with phylloxera in 1994, it was

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Table 1. Phylloxera populations and root necrosis in organic vs. conventional northern California vineyards. All vineyards were on AXR no. 1 rootstock unless otherwise noted.

Season	Vineyard	County	Comment	Necrosis (%)	Phylloxera ²
<i>Organic</i>					
Summer 1997	FL	Napa		9.2	78
	FE	Mendocino		10.5	163
	JR	Sonoma		11.8	442
	VE	Napa		<u>10.1</u>	<u>6008</u>
	Mean			10.4	1673
Fall 1997	FL	Napa		9.0	456
	FE	Mendocino		9.7	5
	JR	Sonoma		19.1	637
	KW	Sonoma		<u>13.7</u>	<u>85</u>
	Mean			12.9	296
Summer 1998	FL	Napa		4.6	143
	JR	Sonoma		5.3	89
	KW	Sonoma	Flooded winter/spring 1998 ^y	---	---
	Mean			5.0	116
Fall 1998	FL	Napa		6.8	6561
	JR	Sonoma		8.4	329
	KW	Sonoma	Flooded winter/spring 1998 ^y	---	---
	ZD	Napa	Control (uninfested) ^y	[2.5]	[0]
	FE	Mendocino		<u>7.5</u>	<u>444</u>
Mean (n = 134)				9.0 a	1132 a
SE				2.2	631
<i>Conventional</i>					
Summer 1997	VP	San Joaquin	Own rooted–Chenin blanc	22.0	115
	SF	Sonoma		14.9	550
	HH	Napa		20.5	105
	CH	Sonoma		56.3	1620
	EL	Napa		7.1	182
	WW	San Joaquin	Own rooted–Zinfandel	21.9	99
	HW	Sonoma		19.5	294
	VA	San Joaquin	Own rooted–Zinfandel	<u>28.5</u>	<u>62</u>
Mean				23.9	378
Fall 1997	VP	San Joaquin		29.8	266
	SF	Sonoma		40.3	401
	HH	Napa		36.3	687
	CH	Sonoma		24.7	78
	EL	Napa		<u>23.7</u>	<u>460</u>
	Mean			31.0	379
Summer 1998	VP	San Joaquin		56.1	370
	HH	Napa		31.9	434
	GC	Napa		6.0	173
	CV	Napa	Control (uninfested) ^y	[1.4]	[0]
	PO	Napa	Flooded winter/spring 1998 ^y	---	---
Mean				31.3	326
Fall 1998	VP	San Joaquin		44.0	30
	HH	Napa		38.2	357
	GC	Napa		12.5	179
	CV	Napa		<u>40.9</u>	<u>691</u>
Mean				33.9	314
Mean (n = 170)				30.1 b	305 a
SE				4.6	167

²No./100 g root dry weight.

^yControl (uninfested) samples not included in averages.

found to have neither phylloxera nor signs of phylloxera in 1998 and was replaced by FE again in the fall sampling. Data for 1998 for two additional vineyards (KW and PO) had to be rejected after sampling had terminated, because flooding in Winter and Spring 1998 had apparently killed all phylloxera. No phylloxera were found in these vineyards during either 1998 sampling.

Cover crops most often used in OMVs were winter barley (*Hordeum vulgare* L.), rye (*Secale cereale* L.), oats (*Avena sativa* L.), lana vetch (*Vicia villosa* Roth), common vetch (*Vicia sativa* L.), and purple vetch (*Vicia benghalensis* L.), burr, sub-, and berseem clo-

vers (*Trifolium* sp.), bell bean (*Vicia fava* L.), and mustards (*Brassica* sp.). The most common resident weed species, found in both OMVs and CMVs, were winter annual weedy grasses such as wild oat (*Avena fatua* L.), riggut brome (*Bromus rigidus* Roth), and wild barley (*Hordeum leporinum* Link), plus other non-grass species such as cheeseweed (*Malva parviflora* L.), various mustards (*Brassica* sp.), and common fiddleneck (*Amsinckia intermedia* Fischer & Meyer). Winter covers and weeds were disked under in spring in all vineyards with the exception of one OMV in 1998 (FE), which was converted to permanent cover, eliminating spring disking.

In 1998 only, resident vegetation and cover crop aboveground biomass samples were taken in March, before disking or mowing, by harvesting three samples of 1-m² area adjacent to where roots were sampled in each vineyard. Samples were dried at 60 °C for 24 h, weighed, and used to calculate spring biomass inputs per hectare.

Three soil samples were collected from 0- to 0.2-m-depth root at collection sites, combined, dried at 60 °C for 24 h, and analyzed by the Univ. of California Division of Agricultural and Natural Resources laboratory. Percent organic matter (OM%), total Kjeldal nitrogen (TKN), ammonium nitrogen (NH₄N), nitrate nitrogen (NO₃N), and percent sand, silt, and clay were determined for each sample.

Individual grapevine root samples, averaging 30 g dry weight, were taken by digging a hole ≈0.6 m long × 0.3 m wide × 0.2 m deep within 0.5 m of the base of each of 10 vines in each vineyard and collecting exposed roots. Individual vines were sampled only once. In 1998, control samples were collected from vines not infested with phylloxera for comparison of percent necrosis of infested vs. uninfested roots. In the case of CMVs, a noninfested part of one vineyard was used for control samples. None of the OMVs had phylloxera-free vines; therefore, a noninfested vineyard from outside the sampling roster was used for OMV control samples. Root samples were cooled to <10 °C upon excision and counts of phylloxera made within 24 h.

All samples showed signs of phylloxera infestation, either as phylloxera colonies, or as tuberosities (galls induced by phylloxera feeding on mature roots) or as nodosities (galls induced by phylloxera feeding on immature feeder roots). Phylloxera populations were counted and classed as eggs, 1st, 2nd, 3rd, 4th instars, or adults (Omer et al., 1997). Phylloxera populations on each root sample were recorded as numbers of total phylloxera of all stages per 100 g of root dry weight. After phylloxera counts were made, roots were washed of adhering soil and cross-sectioned at 4-cm intervals, and the percentage of the circumference showing necrosis of the phloem and phloem parenchyma tissues was recorded for each cross-section (Granett et al. 1998).

Root samples were assayed for presence of fungal species as described in Omer et al. (1995). Tissue sections (2 × 2 mm) from necrotic feeding sites of grape phylloxera were surface-sterilized in 70% ethanol for 30 s, and 0.5% sodium hypochlorite for 3 min, then rinsed twice in sterile distilled water and blotted dry with sterilized absorbent paper. Sections of necrotic root tissues were placed onto acidified potato dextrose agar (APDA) (Tsao, 1970), five necrotic sections per petri dish, and incubated at 24 °C for 6 d. One petri dish was used per root sample for each sampled site. Fungi isolated from these samples were identified based on colony and spore characteristics (Omer et al., 1995).

Data from phylloxera counts and root necrosis surveys were analyzed using analysis of variance (ANOVA) (PROC GLM, SAS Institute, 1989). Management and season were

Table 2. Analysis of variance for phylloxera populations and root necrosis in organically (OMV) vs. conventionally (CMV) managed vineyards, 1997 and 1998.

Year	Source of variation	df	Phylloxera populations		Root necrosis	
			F	P	F	P
1997	Management ^a	1	2.14	0.172	19.53	0.001
	Season ^b	1	2.75	0.099	3.86	0.051
	Site (management) ^c	11	5.63	0.0001	2.47	0.006
	Management*Season	1	0.08	0.773	0.83	0.357
1998	Management	1	0.03	0.873	6.95	0.034
	Season	1	1.83	0.178	1.49	0.224
	Site (management)	7	1.90	0.074	12.70	0.0001
	Management*Season	1	5.15	0.025	0.13	0.357

^aOrganic (OMV) vs. conventional (CMV).^bSummer and fall.^cSites nested within management.

Table 3. Soil analysis of organically (OMV) and conventionally (CMV) managed vineyards in 1997 and 1998.

Year	Variable	OMV	CMV	P value
1997	% OM	2.52 a ^z	2.06 a	0.06
	% Total N	0.15 a	0.12 a	0.08
	NO ₃ -N (ppm)	12.4 a	14.9 a	0.94
	% Sand	36 a	41.5 a	0.19
	% Silt	47 a	41 a	0.30
	% Clay	14.5 a	17.5 a	0.94
1998	% OM	2.72 a	2.20 a	0.17
	% Total N	0.14 a	0.12 a	0.11
	NO ₃ -N (ppm)	15.0 a	15.1 a	0.97
	Biomass ^y (Mkg-ha ⁻¹)	4.2 a	1.9 b	0.01

^zMean separation within columns and years by *t* test at $P \leq 0.05$.^ySpring 1998 biomass inputs from cover crops in OMVs and resident weeds in CMVs.

considered fixed effects; site nested within management was considered random effect. For testing significance, we used the “H” option to specify the appropriate error term. Type III sums of squares were used. Soil analysis data were analyzed with *t* tests at $P \leq 0.05$. Root necrosis percentage data were transformed to arcsin square roots before the ANOVA. A regression analysis was used to test the relationship between phylloxera populations (independent variable) and root necrosis (dependent variable).

Results

In both 1997 and 1998, percent root necrosis was significantly lower in OMVs, averaging 9% in OMVs and 30% in CMVs over the 2 years (Table 1). Percent root necrosis in both OMVs and CMVs was significantly higher in infested roots than in their respective noninfested controls. There was no significant difference in percent necrosis between OMV and CMV noninfested controls, which averaged $2.5\% \pm 1.3$ and $1.4\% \pm 0.59$ (mean $\pm$ SE) necrosis, respectively. Root necrosis was not significantly affected by season (Table 2).

Phylloxera populations were not affected by management type or season. Root necrosis was not related to phylloxera populations in OMVs; however, in CMVs root necrosis tended to increase as a function of phylloxera populations; this trend was significant in 1997 ($r^2 = 0.58$, $P = 0.0016$) but not in 1998.

Soil analyses indicated no significant difference between OMVs and CMVs in percent total OM or nitrogen (%N-total), or concentration of nitrate nitrogen (NO₃-N), and percent sand, silt, and clay did not differ significantly in either 1997 or 1998 (Table 3). When the 2 years of percent OM data were pooled, the difference between OMVs and CMVs was significant at $P = 0.015$ (OM% = 2.67 ± 0.16 SE for OMVs, 2.18 ± 0.11 for CMVs). Over all vineyards and both years there was a weak ($r^2 = 0.069$) but significant ($P < 0.001$) inverse correlation between root necrosis and soil OM%. Spring 1998 biomass inputs from cover crops in OMVs were significantly higher (4.3 ± 0.5 Mkg-ha⁻¹) than those from resident weeds in CMVs (1.9 ± 0.4 Mkg-ha⁻¹).

The incidence of beneficial fungus of the genus *Trichoderma* was significantly higher in OMVs in 1997 ($X^2 = 5.32$, df = 1, $P < 0.05$),

but not in 1998. *Fusarium oxysporum* and *Pythium ultimum* were the most common secondary pathogens in both vineyard types. In 1998, *Fusarium* and *Cylindrocarpus* pathogens were significantly higher in CMV soils (Table 4).

Discussion

Prior to this research, we hypothesized that organic management of vineyards would reduce both phylloxera populations on grapevine roots and phylloxera-related grapevine damage. Our data refute the hypothesis relative to phylloxera populations. Populations in the OMVs and CMVs sampled in this study were statistically indistinguishable when both years' data are considered.

The portion of the hypothesis relative to vine damage was evaluated as percentage of the sampled root circumferences showing necrosis. Granett et al. (1998) and Omer et al. (1999) have suggested that this is a reasonable measurement of phylloxera-related damage in vineyards. Our results showed that by this measure vine damage was lower in the OMVs than in the CMVs. Therefore, the portion of the hypothesis relative to vine damage is supported.

Our data do not explain the mechanisms by which OMVs resist vine damage. The 0.5% difference in OM% between OMVs and CMVs may be significant, considering that the range of OM% in soils is rarely outside 0.5% to 5% (Cox and Atkins, 1979). One possibility is that the higher organic matter supports higher microbial activity, which reduces infections by root pathogens (Hu et al., 1997a). The beneficial fungi *Trichoderma* sp. were not consistently more abundant in the OMVs, nor was the prevalence of particular pathogen infections substantially and consistently different between the two management regimes. Microbial differences between the two situations may be found in the future. The microbial community in the soil is complex and may intercept plant pathogens before they cause infection. Looking in feeding wounds, as we did, may be the least likely place to find beneficial microbes. A better understanding of soil community and community dynamics is needed.

Simple measurement of percent organic matter in the soil does not adequately reflect differences in microbial dynamics between OMVs and CMVs. Soil OM% subsumes three major pools of organic matter: “upstream” fresh plant material, “midstream” microbial biomass, and “downstream” highly stable humic substances (Paul, 1984). To understand

Table 4. Proportions of fungal isolations from phylloxera feeding sites on grapevine roots from organically (OMV) vs. conventionally (CMV) managed vineyards.

Year	Management	<i>Fusarium oxysporum</i>	<i>Fusarium roseum</i>	<i>Pythium ultimum</i>	<i>Cephalosporium</i> sp.	<i>Trichoderma</i> sp.	<i>Rhizoctonia</i> sp.	<i>Macrophomema</i> sp.	<i>Verticillium</i> sp.	<i>Cylindrocarpus</i>
1997	OMV	0.28 ^z	0.13	0.25	0.04	0.10 [*]	0.09	0.06	0	0
	CMV	0.35	0.10	0.25	0.12	0.02	0.1	0.02	0	0
1998	OMV	0.03 [*]	0	0.05	0	0.06	0.05	0	0.03	0.06 [*]
	CMV	0.23	0	0.06	0.05	0.11	0	0	0.05	0.22

^zTwenty-eight percent of cultures of necrotic tissue from phylloxera feeding sites were *F. oxysporum*.^{*}Significantly different from CMV at $P \leq 0.05$.

microbial dynamics, we must be able to measure an upstream microbial energy pool such as coarse organic debris (COD) (Hu et al., 1997b), and a correlate of microbial biomass such as potentially mineralizable nitrogen (Drinkwater et al., 1996). Coarse organic debris and microbial biomass have been related to suppression of soil pathogens (Boehm et al., 1997; Hu et al., 1997b). Use of these and other measures in models of organic matter dynamics, such as that of Verberne et al. (1990), may be useful for evaluating how farm management options will influence soil microbial dynamics, including pathogenesis.

A possible alternative cause of the suppression of plant pathogens in the OMVs might be soil conditions that induce plant resistance to pathogens, or "systemic acquired resistance" (SAR) (Sticher et al., 1997). Compost, which is commonly applied to OMVs, elicits SAR in another system (Zhang et al., 1998). Conversely, glyphosate (Roundup™, *N*-phosphonomethylglycine) a commonly used herbicide in CMVs (all CMVs in this study used glyphosate) inhibits the SAR response (Liu et al., 1997) and increases root pathogenesis (Descalzo et al., 1998) in other systems.

Although phylloxera are easily controlled by using strongly resistant rootstocks, phylloxera problems are prevalent worldwide. The reason for the continued problems with phylloxera is that there are negative incentives for using strongly resistant rootstocks in many situations, even though the risk of devastation by phylloxera is high. Current recommendations to farmers who have phylloxera problems are to remove the vineyards when they are no longer productive and replant with strongly resistant rootstocks. Supplementary control tactics for phylloxera are needed, especially control tactics that could be used to ameliorate damage in order to delay replanting of vineyards under attack. An understanding of the mechanisms by which damage in OMVs is reduced could provide the basis for formulating such control tactics.

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