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Leaf color and vine size are related to yield in a phylloxera-infested vineyard

by

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S u m m a r y : The uneven spread of phylloxera infestation and associated vine symptoms in vineyards usually complicates yield estimates and vineyard replacement decisions. In a Cabernet Sauvignon vineyard with AXR#1 rootstock the current season's and following season's yields of 40 vine plots correlated ($r \geq 0.77$, $p \leq 0.05$) with early to midseason leaf and canopy spectra measured in the field, laboratory and remotely with aircraft-borne sensors.

K e y w o r d s : Phylloxera infestation, yield estimation, canopy spectra, chlorophyll, pruning weight.

Introduction

In California's Napa and Sonoma County vineyards, about 70 % of the vines were grafted to AXR#1 rootstock which tolerates phylloxera biotype A (Granett *et al.* 1987; DeBenedictis and Granett 1993). In the early 1980's biotype B emerged there. It so devastates AXR#1 that the vineyards had to be replanted with rootstocks resistant to biotypes A and B.

Timing of replanting is difficult because vineyards do not decline uniformly. A patchwork of uninfested vines and infested asymptomatic vines, vines with declining productivity and unproductive vines typifies most infested vineyards.

Because phylloxera-infested vines on susceptible rootstocks eventually become chlorotic with lower yields and leaf area (Davidson and Nougaret 1921), we reasoned that vine leaf area and leaf chlorophyll would correlate with yield. Chlorophyll shares the attributes ascribed to nitrogen as a "physiological indicator of cumulative stress": it responds to long-term stress and is easy to measure (Stutte and Stutte 1992). Our goal was to determine if the ranking of such an array of vines by stress indicators would correspond to their future ranking by yield and thereby improve the calculation of the economics and timing of replanting.

Materials and methods

T h e v i n e y a r d : In a Cabernet Sauvignon vineyard block near Oakville, California, the vines were grafted to AXR#1 rootstock. No factor other than differences in phylloxera infestation was detected that would account for differences in vine growth and yield after infestation. Our search for such factors included examination of soil pits dug near the study plots.

The vines were planted in 1981 on Clear Lake clay and Bale clay loam. The vineyard is nearly level, covers 12.2 acres, is drip irrigated and has its 3.65 m wide rows oriented NE to SW. Vines are 2.43 m apart in rows and are cordon-trained.

The same commercial practices for vines in and outside the plots were employed. Winter pruning left both canes and spurs with fewer buds retained on weaker vines. In 1993 vineyard workers removed shoots from all but the weakest vines and equalized mean shoot and cluster numbers among all plots; they did not remove shoots in the summer of 1994. Tilling removed under-vine and between-row vegetation.

P l o t s e l e c t i o n : We used 1992 infrared aerial photographs in conjunction with May 7, 1993, phylloxera sampling to select nine 40-vine plots. In the photographs plots 1, 2, and 3 exhibited reduced growth previously found to be symptomatic of phylloxera infestation (Wildman *et al.* 1983); the other six plots appeared to be healthy. By sampling about every 40th vine throughout the vineyard, we also identified plots without detectable phylloxera as well as asymptomatic, infested plots. Fig. 1 indicates the location and identifying number of each plot along with its mean phylloxera rating, described below, for July 1993 and 1994.

As shown in Fig. 1, 1993 phylloxera infestation was greatest in the south portion of the block and decreased from south to north except for a second heavy infestation in plot 6. Consequently, we had to select plots with the desired infestation and decline characteristics along this gradient, so we could not randomize "treatments" to eliminate effects due to undetected soil differences, drainage, or other factors that might have existed along the same gradient.

Fourteen vines per plot were sampled only to estimate leaf area. Because the sampling was destructive, we did not take other measurements of these vines. The remain-

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ing 26 vines per plot were sampled for yields, pruning weights, and field leaf spectral measurements. Only primary vines, defined in the next section, were sampled for laboratory leaf spectral measurements.

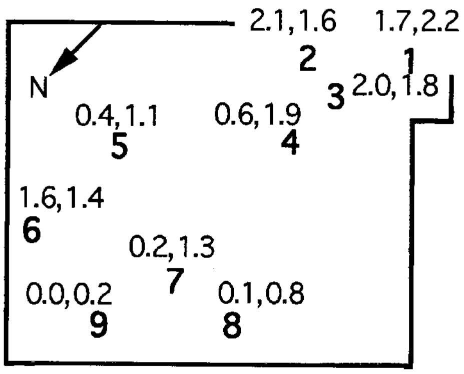

Fig. 1: Map of study plots. Bold numbers in larger font give plot number designation. Numbers above plot number are the plots' mean phylloxera rating by July 1993 (left), and mean phylloxera rating by July 1994 (right). For example, plot 4 has a phylloxera rating of 0.6 in 1993 and 1.9 in 1994.

Phylloxera sampling: We selected 8 vines ("primary vines", labeled "P") in the middle of two rows to develop phylloxera estimates for each plot. To avoid damaging the roots of the primary vines which might affect leaf reflectance and yields as well as other research objectives, we sampled 9 vines (labeled "S1" or "S2" in Fig. 1) along diagonals adjacent to the primary vines alternating between S1 and S2 each sampling date. Each primary vine was given the average phylloxera rating of the two neighboring sampled vines.

To sample we dug next to the trunk a cylindrical hole approximately 30 cm deep and 30 cm in diameter, excavated root pieces and examined them for phylloxera with a hand lens. We rated the vines on a 0 to 4 scale as follows: 0 = no phylloxera; 1 = just crawlers, or nodosities, or only 1-5 adults per 15 cm of root; 2 = 5 to 10 phylloxera per 15 cm of root; 3 = 10 to 25 feeding sites; 4 = roots densely covered with phylloxera. A vine was assigned the rating of the 15 cm piece with the highest infestation level. We used the averages of the June 10 and July 22 ratings as the estimated phylloxera level in 1993 and the higher of the May 25 or July 26 ratings for 1994 estimates.

Fruit yield and pruning weights: On September 27, 1993, we recorded the cluster number and weight of mature fruit for primary, S1 and S2 vines. On September 27, 1994, we took yield data from the 8 primary vines per plot. In 1993 we collected pruning weights after leaf fall from the primary, S1 and S2 vines.

Leaf area measurements: We estimated average plot leaf area by shoot sampling 14 vines per plot, seven on July 15 and 22 and seven on August 17, 18, and 19, 1993. The L vines were not used for yield, pruning weights or leaf measurements. We recorded the number of shoots and then removed two randomly selected shoots per vine.

Leaves with widths greater than 1.5 cm were placed in freezer bags or paper envelopes and stored in insulated, chilled boxes. We measured leaf area with a LI-COR LI 3100 area meter (LiCor, Inc., Lincoln, NE) and recorded main leaf and lateral leaf area. The leaf area per shoot times the number of shoots per vine yielded an estimate of the leaf area per vine. We used this value to estimate the total leaf area per plot.

Field chlorophyll measurements: The Minolta SPAD-502 chlorophyll meter (Minolta Corp., Ramsey, NJ) converts leaf transmittance of 940 and 650 nm light to SPAD units, which had the following relationship to grape leaf chlorophyll concentration:

Chlorophyll (mg/cm^2) = 0.001605·SPAD - 0.009951.

$R^2 = 0.914$ (Osborn and DeBenedictis 1993, unpubl.).

We averaged 6 SPAD readings per leaf. In 1993 measured leaves were two nodes above the second cluster on vigorous shoots. When shoots had 3 clusters the sampled leaf opposed a cluster. After establishing that the coefficient of variation among selected shoots was less than 10 %, we took one leaf from one vigorous shoot per vine and did not distinguish between shoots that grew from canes or spurs. We chose shoots on the southeast side. Chlorophyll meter readings were taken on May 18, June 9, July 15, August 19, September 3 and 16, and October 20 on primary vines. The September 3 readings included the phylloxera sampled S1 and S2 vines.

In 1994 we averaged the readings of 4 leaves per primary vine, 2 from each side. We took leaves opposite the second cluster on May 5, and the second leaf above the second cluster on May 25, June 29, and July 26.

Laboratory reflectance measurements: Leaves taken for SPAD readings were placed in a freezer bag before storing in a chilled cooler chest for transport to the laboratory where we measured its reflectance within 12 h. SPAD readings did not change during this period indicating stable chlorophyll concentrations. Over the visible and near-infrared region (here 400-2500 nm) a NIRSystems Model 6500 spectrophotometer (NIRSystems, Silver Spring, MD) measured reflectance at every 2 nm. Previous studies (Vogelmann *et al.* 1993, Carter and Miller 1994) found reflectance amplitude at the green peak (GP) at 550 nm and the red edge inflection point (REIP) in the 680-750 nm region to be sensitive to plant stress. We wanted to determine how closely these measurements correlated with in-field SPAD readings. Measurement dates in 1993 were the same as for the chlorophyll meter readings described above, except for the addition of a July 26 and the omission of the September 16 measurements.

Canopy reflectance measurements: Digital imagery was collected over the vineyard by an airborne CASI instrument (ITRES Research, Alberta, Canada) on July 28, 1993. CASI measured at-sensor-radiance (solar radiance reflected from the surface and atmosphere) at 787 and 680 nm. The spatial resolution of the data was about 1.8 m x 1.8 m. On August 1, 1994, the Electro-Optic Camera (NASA's Ames Research Center, Moffett Field, CA) measured at-sensor-radiance at 775 and 680 nm. The spatial resolution of the data was about 4.6 m x 4.6 m (Johnson *et al.* 1996.). From these data we computed the ratio of near infrared (775, 787 nm) to red (680 nm) reflectance, NIR:RED, which is related to canopy leaf area (TUCKER 1979; BAUER 1985).

Statistical analysis: We analyzed data using SYSTAT software (SYSTAT Inc. 1992, Version 5.2).

Results

Regressions of plot mean phylloxera ratings against plot mean yields were nearly the same with primary vines or sampled (S1 and S2) vines: less than 10 % difference for slope and 5 % difference for intercept and coefficient of determination (R^2). Regression of the mean plot yields versus mean plot phylloxera ratings for the combined primary and sampled vines produced an R^2 of 0.85, a result in accord with our findings during plot selection that phylloxera was the principal stress factor affecting yield (see Fig. 2 a). For the regression of these 1993 mid-season phylloxera ratings against 1994 yields (see Fig. 2 b) the R^2 was 0.92.

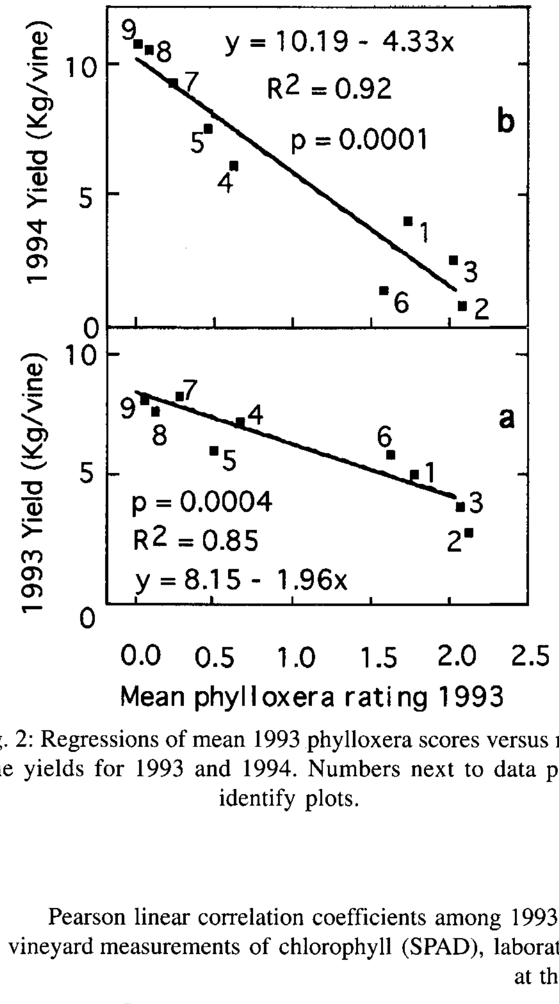

Fig. 2: Regressions of mean 1993 phylloxera scores versus mean vine yields for 1993 and 1994. Numbers next to data points identify plots.

To evaluate which early to mid-season field, laboratory, and remotely-sensed measurements correlate with the following season's yields as well as current season's we separated 1993 data into those collected between May 18 and September 3, and those collected later which would not help growers anticipate current season's yields. Correlations among late season, 1993 measurements and between them and 1993 and 1994 yields are in Tab. 1, which also contains correlations with leaf area, a destructive measure too time consuming to be of practical use, but which we measured along with pruning weights to provide ground-based validation of the airborne measurements. For 1993 mean plot NIR:RED and leaf area correlated with a coefficient of 0.82; NIR:RED and dormant pruning weights correlated with a coefficient of 0.84. Although summer shoot removal most likely reduced dormant pruning weights, the removal occurred before the NIR:RED measurements.

Early to midseason 1993 measurements of NIR:RED and SPAD correlate highly with 1993 and 1994 yields (see Tab. 2). As Tab. 1 indicates, GP and REIP closely correlate with SPAD and for brevity are omitted from Tab. 2 and the following results of regressing spectral measurements against yields.

Regressions of May - September 1993 SPAD against mean plot yields for 1993 and 1994 are significant ($p \leq 0.05$) (Fig. 3). The regressions of 1993 NIR:RED against mean plot yields of 1993 and 1994 are significant ($p \leq 0.001$). NIR:RED's close correlation with each of the May–September SPAD values suggests a May–September NIR:RED series regressed against yields would closely match Fig. 3. The regression of 1994 NIR:RED versus 1994 yield is significant ($p \leq 0.001$).

Regressions of May 25, June 29, and July 26, 1994, SPAD versus 1994 yield (not shown) do not significantly differ from those of 1993 SPAD versus 1994 yields. In short, plotting the following season yields against current season SPAD readings, gives nearly the same regressions as obtained with SPAD readings taken 12-16 months later.

Table 1

Pearson linear correlation coefficients among 1993 and 1994 mean plot yields, vine leaf area and late season, 1993 vineyard measurements of chlorophyll (SPAD), laboratory reflectance measurements (REIP) and the reflectance amplitude at the green peak (GP)

	Yield 1993	Yield 1994	SPAD Sep 16	SPAD Oct 20	REIP Sep 16	REIP Oct 20	GP Sep 16	GP Oct 20	Pruning Weight
SPAD Sep 16	0.89	0.89							
SPAD Oct 20	0.95	0.97	0.89						
REIP Sep 16	0.91	0.89	0.99	0.90					
REIP Oct 20	0.92	0.98	0.84	0.97	0.83				
GP Sep 16	-0.91	-0.84	-0.98	-0.90	-0.97	-0.81			
GP Oct 20	-0.95	-0.91	-0.89	-0.97	-0.90	-0.92	0.93		
Pruning wt.	0.73	0.77	0.87	0.81	0.86	0.74	-0.86	-0.85	
Leaf Area	0.76	0.57	0.56	0.65	0.59	0.66	-0.65	-0.77	0.81

Table 2

Pearson linear correlation coefficients among 1993 and 1994 mean plot yields, phylloxera infestation and May 18 to September 3, 1993 vineyard measurements. NIR:RED = Near infrared to red reflectance; SPAD: see Tab. 1

	Yield 1993	Yield 1994	Phyll-oxera	NIR: RED	SPAD May 18	SPAD Jun 9	SPAD Jul 15	SPAD Aug 19
Phylloxera	-0.94	-0.96						
NIR:RED	0.93	0.90	-0.98					
SPAD May 18	0.83	0.85	-0.92	0.94				
SPAD Jun 9	0.92	0.80	-0.87	0.92	0.85			
SPAD Jul 15	0.85	0.85	-0.94	0.96	0.93	0.88		
SPAD Aug 19	0.83	0.77	-0.89	0.94	0.94	0.87	0.96	
SPAD Sep 3	0.96	0.92	-0.95	0.96	0.91	0.96	0.92	0.90

Table 3

Pearson linear correlation coefficients among 1994 mean plot yields, phylloxera infestation and 1994 vineyard measurements. NIR:RED, SPAD: see Tabs. 1 and 2

	Yield	Phyll-oxera	NIR: RED	SPAD May 5	SPAD May 25	SPAD Jun 29
Phylloxera	-0.70					
NIR:RED	0.92	-0.80				
SPAD May 5	0.95	-0.72	0.89			
SPAD May 25	0.95	-0.79	0.94	0.86		
SPAD Jun 29	0.96	-0.67	0.91	0.85	0.97	
SPAD Jul 26	0.99	-0.78	0.93	0.94	0.96	0.96

In Fig. 3 slopes within regression line sets – 1993 SPAD versus 1993 yields and 1993 SPAD versus 1994 yields – do not significantly differ. However, 3 of the 5 pairs of lines that regress the same SPAD values against different years' yields have different slopes ($p \leq 0.05$).

Tab. 3 contains correlations among 1994 yields, phylloxera ratings, NIR:RED, and May–July SPAD readings.

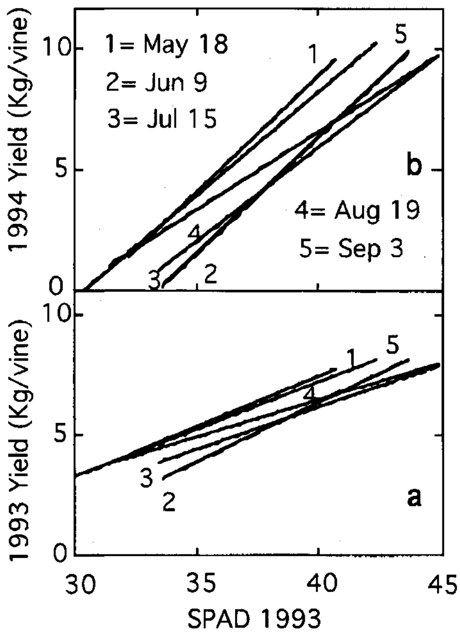

Fig. 3: Regressions of mean SPAD values in 1993 versus mean vine yields for 1993 and 1994. Numbers on regression lines indicate sampling dates.

Discussion

The significant regressions between yield and several preharvest, quantifiable measurements offer growers the possibility of anticipating by 5-16 months yield differences among vineyard plots and calculating the economic consequences of these anticipated differences. These will be rank differences among plots rather than absolute differences, because the regression coefficients (slopes) may vary from year to year as Figs. 2 and 3 show; however, slopes of the 1993 regression lines would have been greater (with smaller differences between 1993 and 1994 regressions), if vineyard crews had not excessively shoot-thinned healthier vines in early July 1993. By reducing cluster numbers of healthier vines to equal the cluster numbers of the weaker vines, shoot thinning reduced yield of healthier plots. This accounts for the anomaly of greater yield in plots 5, 7, 8, and 9 in 1994 than in 1993, even though Fig. 1 shows phylloxera ratings for these plots increasing in 1994. In addition, excessive shoot thinning unintentionally established the minimal difference between low and high yielding plots: about a 2.5 fold difference evident in Figs. 2 a and 3 a. That is, vinegrowers finding a range of phylloxera ratings and NIR:RED or SPAD readings similar to those in the vineyard we studied are unlikely to find their highest yielding plot producing less than 2.5 times their lowest yielding plot.

Of the methods we used, aircraft mounted sensors to record NIR:RED and the chlorophyll meter are the most practical for quantifying differences within vineyards. An airborne service can scan quickly several thousand acres, process the data and supply growers with NIR:RED in the form of digitized images. Moreover, data from two flights can be processed to produce images that reveal changes that occurred between flights (JOHNSON *et al.* 1996.) However, the use of NIR:RED may not be as appropriate for vineyards with green understory vegetation at the time of overflights. Also, overflight costs will place remote sensing out of the reach of growers who cannot share the costs or distribute them over many acres.

The chlorophyll meter is an affordable alternative for growers without access to a remote sensing provider and for growers whose vineyard or financial conditions rule out airborne mapping. Whereas a remote sensor with adequate resolution can measure each vine in a vineyard, growers with chlorophyll meters will probably choose to measure a sample of vines, because each leaf will require at least one minute to select, measure, record the SPAD value, and move to the next vine.

The chlorophyll meter offers advantages over other ground-based methods of assessing vines: 1) whereas the chlorophyll meter is a grower-affordable field instrument, a NIRS spectrophotometer is an expensive laboratory instrument, 2) SPAD readings are largely independent of meter operator and can be compared to readings taken months or a year later, data qualities that are difficult to obtain with subjective vine scoring, 3) taking chlorophyll readings is noninvasive, in contrast to labor-intensive phylloxera sampling which may open sites for invasion by pathogens.

Conclusion

Early symptoms of phylloxera infestation include reductions in chlorophyll and vine size that correlate with reductions of current and following season yields. Leaf and canopy spectral properties can delineate stressed areas in a vineyard and can rank these areas by yield 5 to 16 months before harvest. Vineyard managers may use this information to plan vineyard replanting.

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References

Bauer, M. E.; 1985: Spectral inputs to crop identification and condition assessment. Proc. Inst. Electric. Electron. Engin. **73**, 1071-1085.

Carter, G. A.; Miller, R. L.; 1994: Early Detection of Plant Stress by Digital Imaging within Narrow Stress-Sensitive Wavebands. Remote Sensing Environ. **50**, 295-302.

Davidson, W. M.; Nougaret, R. L.; 1921: The Grape Phylloxera in California. Bureau of Entomol., USDA Bull. (903) 1-128.

DeBenedictis, J. A.; Granett, J.; 1993: Laboratory evaluation of grape roots as hosts of California grape phylloxera biotypes. Amer. J. Enol. Viticult. **44**, 285-291.

Granett, J.; Goheen, A. C.; Lider, L. A.; Whilt, J. J.; 1987: Evaluation of grape rootstocks for resistance to type A and type B grape phylloxera. Amer. J. Enol. Viticult. **38**, 298-300.

Johnson, L.; Lobitz, B.; Armstrong, R.; Baldy, R.; Weber, E.; DeBenedictis, J.; Bosch, D.; 1996: Airborne imaging aids vineyard canopy evaluation. Calif. Agricult. **50** (4), 14-18.

Osborn, B.; DeBenedictis, J. A.; 1993: Unpublished data.

Stutte, G. W.; Stutte, C. A.; 1992: Use of near-infrared video for localizing nitrogen stress in peach orchards. HortTechnology **2**, 224-227.

Tucker, C. J.; 1979: Red and photographic infrared linear combinations for monitoring vegetation. Remote Sensing Environ. **8**, 127-150.

Vogelmann, J. E.; Rock, B. N.; Moss, D. M.; 1993: Red edge spectral measurements from sugar maple leaves. Intern. J. Remote Sensing **14** (8), 1563-1575.

Wildman, W. E.; Nagaoka, R. T.; Lider, L. A.; 1983: Monitoring spread of grape phylloxera by color infrared photography and ground investigation. Amer. J. Enol. Viticult. **34**, 83-94.

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