# Toward the Improved Use of Remote Sensing and Process Modeling in California's Premium Wine Industry

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## INTRODUCTION

Winegrape quality is influenced by such factors as ratio of fruit to vine leaf area, amount of sunlight directly intercepted by grape clusters, and water stress levels. Vineyard canopy density (leaf area index, LAI) is thus a key variable of interest. California premium winegrowers are making increasing use of optical remote sensing as an additional tool for monitoring canopy density and managing vineyards [1]. In particular, high spatial resolution (2m) vegetation index imagery has been shown to be useful for subdividing individual fields ("blocks") for harvest based upon end-of-season vigor, as inferred by canopy density [2]. Block segmentation can result in more uniformly mature wine "lots" and, in some cases, ultimately in improved wine quality.

In partnership with the wine and commercial remote sensing industries, NASA/Earth Science Enterprise investigators continue to examine relationships among vine stress, canopy development, and resulting wine quality by combining remote sensing with an agro-ecosystem process model adapted from BIOME-BGC [3]. The model, which predicts fluxes of water and carbon, uses remotely sensed LAI to modulate photosynthesis and transpiration across the landscape. The modeling framework potentially enables improved specification of irrigation and nutritional requirements for greater block uniformity. Landscape analysis represents a departure from much of the vineyard remote sensing application to-date, which has tended to emphasize relative canopy differences within a particular block. As an initial step in this direction, we seek to determine the robustness of remote sensing for retrieving LAI across different blocks (ie, regionally) in the face of such potential confusion factors as trellis system, sun/view angle, topography, grape variety, soil type/brightness, and atmosphere.

## METHODS

The LAI-2000 Plant Canopy Analyzer (LI-COR Inc., Lincoln, NE, USA) was used to make indirect measurements of LAI ($LAI_i$) at 28 sites in California's Napa Valley (~38°26'N, 122°24'W), and at 22 sites in the nearby Carneros District (~38°14'N, 122°22'W). The sites were selected to represent the main trellis systems (split, vertical, sprawl) and variation in other factors mentioned above. At each site, a measurement of ambient light was made by holding the instrument at arm's length above the canopy. Two measurements were then made below canopy, one at row center and one at the midpoint between rows, then averaged and compared with ambient to derive $LAI_i$. The measurement period was 2-3 September 1999. All observations were made under diffuse light conditions, either with the sun below the horizon or during fog. GPS readings were taken at each site.

Direct LAI ($LAI_d$) measurements were made on 31-Aug-99 and 01-Sep-99 to calibrate the instrument readings. For this, three sites were chosen in the Napa Valley location, each on a different trellis system and with widely different row/vine spacing. LAI-2000 measurements were made under cloudcover at four nearby vines per site by the above method. All leaves were removed from each vine and weighed. A leaf subsample was then weighed and its area measured with an optical leaf area meter. Total vine leaf area (LAI_vine) in $m^2$ was calculated based on the corresponding weight ratio. $LAI_d$ was then calculated as:

$$LAI_d = (N\_vines * LAI\_vine)/10{,}000\ m^2\ ha^{-1},$$

where N_vines was the number of vines $ha^{-1}$ (arbitrarily chosen area) based upon measured row/vine spacing. Mean $LAI_d$ was compared with the mean $LAI_i$ at each of the three calibration sites.

Two meter multispectral images were collected above the Napa and Carneros sites with an airborne ADAR-5500 digital camera system (Positive Systems Inc., Whitefish, MT, USA) on 1-Aug-99. Although preceding ground measurements by about one month, vineyard canopy is fully expanded by mid-July and hence little change in LAI was expected during the intervening period. The Carneros imagery was collected ~12:15 local time and the Napa imagery at ~13:00, both with north heading flightline. Image pre-processing included vignette correction, band co-registration, and ground registration. Each pixel was then converted to normalized difference vegetation index (NDVI). Mean NDVI of a 3x3 pixel window centered on each indirect LAI sample site was calculated.

## RESULTS, FUTURE WORK

$LAI_i$ tended to underestimate $LAI_d$ at all three calibration sites. Underestimation in vineyards was also reported by [4], who suggest this is due to violation of the LAI-2000 assumption of random foliage distribution by row structure. Nonetheless, the relationship between $LAI_i$ and $LAI_d$ was highly linear with y-intercept near zero: $LAI_d = -0.05 + 1.43*LAI_i$ (Fig 1). This equation was used to adjust $LAI_i$ at all 50 sites. Adjusted $LAI_i$ was then compared to remotely sensed NDVI. The relationship was linear as might be expected given that LAI did not exceed a value of 3 (Figure 2), with $r^2$ of 0.61. The results provide a general indication that the simple NDVI is sensitive to vineyard LAI, and that remote sensing can potentially be used to map vineyard LAI regionally.

Future work will be performed to strengthen the remotely sensed LAI relationship. For instance, use of high spatial resolution satellite imagery will be evaluated to reduce complications related to differences in acquisition time (solar angle) and view geometry. Use of more complex vegetation indices such as SAVI or ARVI [5, 6] may lessen confusion due to soil and atmosphere. Finally, radiative transfer models [7, 8] may be useful in evaluating the influence of such critical factors as trellis type and row/vine spacing on vineyard canopy reflectance.

## REFERENCES

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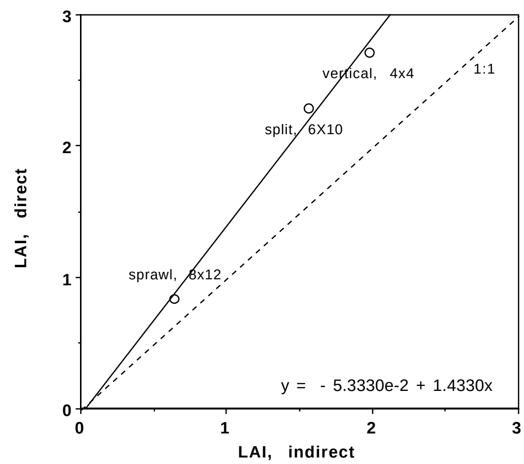


Fig 1. Indirect measurements of leaf area index with the LAI2000 plant canopy analyzer, vs. direct measurements by destructive harvest. Trellis type and row/vine spacing (ft) as noted. 1:1 line shown for reference.

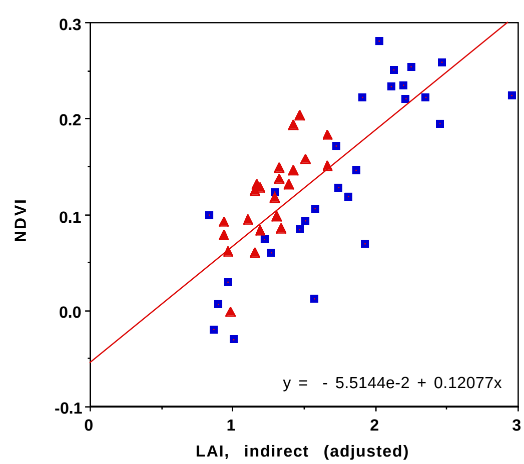


Fig 2. Indirect LAI measurements, adjusted by equation of Fig. 1, vs. airborne NDVI measurements at 50 vineyard sites in the Napa Valley (squares) and Carneros Region (triangles). Sites are fully expanded canopy, and represent variation in trellis system, planting density, age, variety, soil brightness and topography. NDVI values near zero are associated with sites of low planting density (*i.e.*, relatively high percentage exposed soil).