REMOTE SENSING OF GRAPE K DEFICIENCY SYMPTOMS USING LEAF LEVEL HYPERSPECTRAL REFLECTANCE

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ABSTRACT

Potassium (K) is an important nutrient for grape because it sustains charge neutrality during organic acid transport, is a major ion involved in osmoregulation and stomatal function and contributes to pH status in grapes and wines. We assessed the utility of a number of vegetation indexes for detection of K deficiency symptoms in a commercial vineyard of Vitis vinifera cv Pinot Noir. A hyperspectral field spectroradiometer for the 350-2500 nm spectral region was used to measure light reflectance at the leaf level. This data allowed us to screen a broad range of spectral indexes to detect absorption features affected by potassium deficiency symptoms. We found there were few indexes directly influenced by K deficiency symptoms. Absorption features in the visible region, centered at approximately 495 nm and within the chlorophyll b absorption feature at 625 nm were sensitive, and particularly after transformation to derivative spectra. Concentrations of K in leaves with visible symptoms ranging from 0% to more than 60% color change on leaf surfaces were not statistically significantly different ($P \leq 0.05$). These results suggest that observed symptoms might have been the result of heat stress and resulting. Our results indicate that non-invasive monitoring using hyperspectral reflectance may be used for spatially constraining K deficiency for use in site-specific K applications with future investigations.

INTRODUCTION

Potassium (K) is an essential nutrient for plant growth, and is needed in relatively large amounts by many crops. In grapes, K deficiency results in reduced vine growth, premature leaf drop, and yield loss (Christensen et al., 1978). The importance of K nutrition under these conditions also relates to restricted photosynthetic sugar production for ripening, and altered pH of fruit and wines. High K levels diminish wine quality because of the known positive correlation that exists between K concentrations in grape berries and must pH (Boulton, 1980; Ruhl, 1989). Higher pHs (excess K) are generally associated with poor color development, lack of acidity in flavor and diminished wine longevity (Boulton, 2001). Excessive K uptake by grapes can further lead to a decrease in yeast-assimilable nitrogen and ammonia in fruit (Wehmeier, 2002) – both undesirable from the wine-making perspective. Finally, excess K in the must can precipitate as bi-potassium tartrate during cold stabilization. The above issues can often require that the winery purchase acid for pH adjustment to avoid losing an important wine sensory component (astringency).

Concentrations of K in the leaf petiole, the primary measurement used to monitor K nutrition of grape, can range from less than 1% to over 5% (Ruhl, 1989; Robinson, 1990). It also varies with phenological stage of development (Wolpert et al. 2005). Thus, the use of petiole concentrations are of somewhat questionable value, are labor intensive and were developed primarily for a table grape. *V. vinifera* cv Thompson Seedless. When grape growers use petiole analysis, generally numerous samples are taken throughout a field, and then pooled to provide an integrated report on K concentration within the block. This negates the possibility of having spatially constrained measures of K status.

In order to have a more effective means of detecting potassium deficiency in grape leaves and canopies for site specific or precision viticulture, a spectral reflectance index for a ground-level and airborne remote sensing would be useful. The use of hyperspectral reflectance indexes to estimate K concentrations in leaves has not been a subject of thorough investigation and very few studies exist (Ponzoni and Goncalves, 1999; Dury and Turner, 2001). During the summer of 2006, a July heat wave was followed by the onset of K deficiency symptoms in many California North Coast vineyards. During this period we evaluated spectral reflectance patterns in leaves to search for a useful index for K deficiency.

MATERIAL AND METHODS

Study area and vineyard

The vineyard was located in the Carneros Region in the Napa Valley, California within the coordinate boundaries of 38.247ºN, 122.366ºW (SW) and 38.247ºN, 122.361ºW (NE). The vineyard block selected for this study (3.63 ha) was planted in 1991 on an east-facing hillside of 2% to 17% slope. The vineyard was composed of a uniform planting of approximately 2,525 vines per hectare with 1.5 m x 2.4 m (vine x row) spacing. The vines consisted of a single cultivar (*Vitis vinifera* L., cv Pinot Noir clone UC2A) grafted onto the rootstock *V. riparia* x *V. rupestris* cv 3309C). The training system was a unilateral cordon with approximately 16 buds per meter on a three wire vertical shoot positioned trellis system. Shoot positioning wires were at 1.4 m and 2.0 m heights. Irrigation was drip, tillage occurred twice a year in spring and pest and weed control were uniform throughout. One hundred and fifty vines selected within a regular grid pattern of 8.5 m x 24 m spacing were monitored for two months to examine both water stressed and unstressed vines based on periodic measures of predawn water potential (Ψ_{PD}) and leaf water potential (Ψ_{leaf}). Ψ_{PD} ranged from –0.08 to –6.2 MPa and Ψ_{leaf} from –0.8 to –1.3 Mpa, depending on whether they were at the toe or top of the slope, respectively.

Potassium Deficiency Symptoms

During late July 2006 a heat wave occurred of 6 days duration in which temperatures exceeded a maximum of 32°C and minimum temperatures exceeded 22°C. In early September, leaf reflectance measurements were acquired for twenty-five (13 stressed and 12 unstressed) of the 150 vines were selected for more detailed analysis. The leaves were selected from the fruiting zone and were mature and fully expanded. Forty sample leaves were retrieved and visually separated into seven groups of increasing coloration symptomatic of potassium deficiency (0, 5-10, 10-20, 20-30, 30-50, 50-60, and greater than 60 percent color change on the surface), with varying numbers of leaves per group. The visual symptoms indicative of K deficiency included yellowing (but no leaves with any signs of necrosis), reddening and ‘black leaf (Christensen et al. 1978).

Potassium concentration in leaves

Extractable potassium content in leaves was determined on a dry weight basis (%). Leaves were crushed and ground in a Wiley Mill to pass a 20 mesh sieve. The samples were extracted in 2.0% acetic acid solution and analyzed using an atomic absorption spectrometer.

Spectral reflectance measurements

The leaves were kept in plastic bags with a moist filter paper in the dark of an ice chest to insure stomata were closed and water loss minimized. The leaves within each group were arranged in an overlapping cluster to hide the background black non-reflective plastic (Figure

1, left). The background cloth was move through the spectrometer field of view (FOV) for collecting 4 to 8 spectra measurements per leaf cluster. Each measurement was the mean of 3 spectral collections. The leaf reflectance was measured with an ASD Field Pro full range spectrometer (Analytic Spectral Devices, Boulder, CO) under full sun conditions at UC Davis on 11 September 2006 at one hour past solar noon (between 2:00 and 2:45 pm, PDT). The optical cable was affixed nadir on a tripod extending arm with a FOV of approximately 9 cm, under an 18 degree foreoptic on the tip of the optical cable. Before and after collecting leaf spectra, a series of Spectralon calibration panels, 0.99, 0.50, and 0.10 reflectance, (Labsphere, Inc, North Sutton, NH) were measured for post-calibration. The measurements were made rapidly to minimize water loss (Figure 1, right).

Figure 1: Leaves with 10-20% K deficiency symptoms (left), ASD field spectrometer (right).

The mean spectra of the multiple measurements were generated, post-processed, and analyzed with script written in Interactive Display Language (IDL, ITT Visual Information Solutions, Boulder, CO). After calibrating the mean spectra to manufacturer data from National Institute of Standards and Testing (NIST) calibration of the 0.50 and 0.10 reflectance panels, the one nm band-width spectra were smoothed with a 9-band weighted kernel to reduce noise. The spectral regions affected by atmospheric water were eliminated. The spectra were then used to generate 46 common canopy and leaf pigment and water spectral indexes and transform spectral derivative. The variability within the spectral indexes and their relationship to leaf coloration classes were evaluated using least squares fitting multiple regression techniques and analysis of variance within S-Plus software (Insightful Corp., Seattle, WA).

RESULTS

Potassium concentrations in leaves were not statistically significantly different although there was a trend towards lower K concentration in leaves with the highest percentage of visible leaf K deficiency symptoms. The leaf concentrations of K were 0.65 ± 0.07% for 0% visible symptoms (mean ± SE, n = 6), 0.56 ± 0.07% for 5 to 10% visible symptoms, 0.51± 0.07% for 10 ti 20% visible symptoms, 0.60 ± 0.04% for 20 to 30% visible symptoms, 0.59± 0.03% for 30 to 50% visible symptoms and 0.47 ± 0.04% for greater than 60% visible K deficiency symptoms. Similar results were obtained for petiole concentrations of K; however, petiole concentrations were extremely variable with coefficients of variation greater than 40%, ranged between approximately 0.4% up to approximately 4% content and are not included in this report.

The leaf spectral indexes, band derivatives and absorption depths were similar and there was no significant distinction between the groups that strictly followed deficiency symptom levels (Figure 2a & b). Visually sorting the leaves into coloration classes may decrease our ability to statistically spectrally separate the symptoms within and among the groups. In Figure 2a, the small amount of visually detectable color variation is most prominent in the green (555 nm), near-infrared (750 to 1200 nm), though the Normalized Difference Vegetation Index (NDVI = (NIR-Red)/(NIR+Red)) showed little variation at from 0.83 to 0.87. This narrow range of values was typical for all the pigments and water indexes evaluated. To sharpen spectral contrast, the reflectance values were transformed to their derivative spectra (Ben-dor and Banin, 1995) (Figure 2b). This process calculates the slope of a line tangent at each band by the derivative of a fitted polynomial to the portion of irregular spectral curve. The positive or negative value of the derivative increases with increasing change in the spectra in Figure 2a.

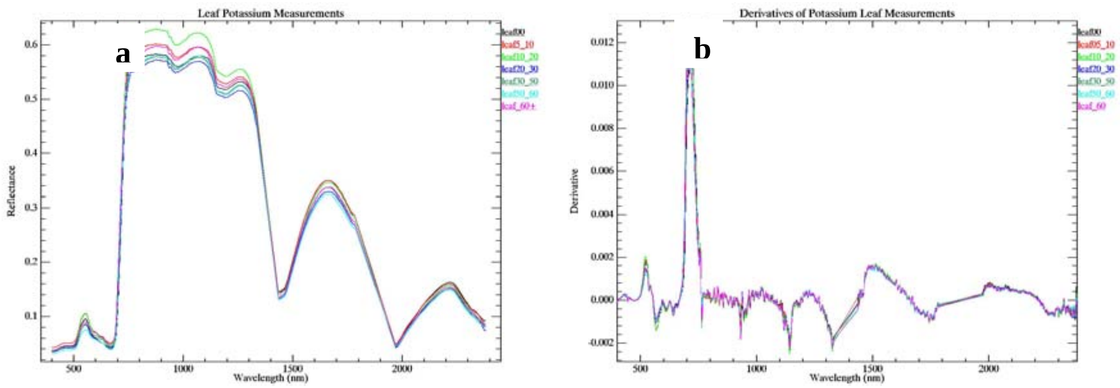

Figure 2: Mean spectra for leaves with K deficiency symptoms (a) and their derivatives (b). The ratios of the derivate values near blue, green, and red reflectance emphasize the change in absorption depths in the visible bands shown in Figure 3a and 3b respectively.

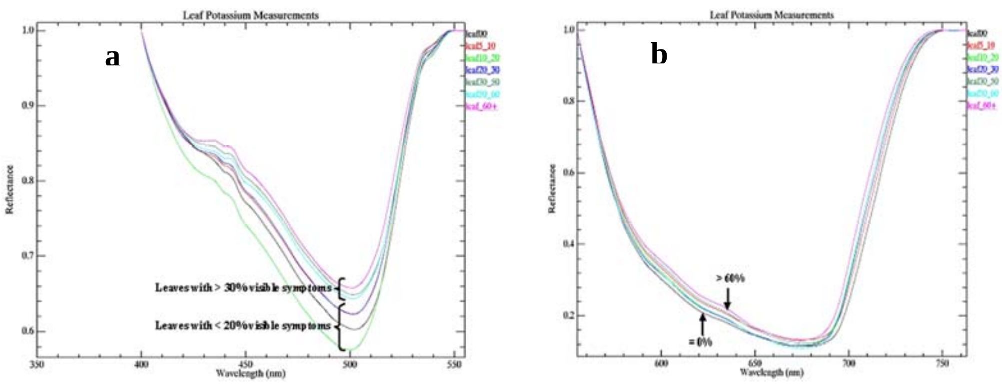

Figure 3: Band depths of the blue and red absorption features centered near 495 nm (a) and 625 nm (b) related to K deficiency symptoms.

The ratio of maxim to minimum derivative values between the green and red and between the blue and red were sensitive enough to track the seven classes within the clusters, though the variability of the spectral measurements within the classes reduced the significance. While color change from green to yellow, red and black in the leaves is distinct in localized areas, the proportion of green and red in the leaf is reduced by the mixture of spectra in the broad view of the leaf clusters. Band-depth analysis using continuum removal (Kokaly and Clark, 1999) appears to separate the cluster into two classes, less than and greater than the 30 % class in our visual estimate, seen Figure 3a. Statistically, the high variability within the measurements for the leaf classes decreased the significance for this separation.

DISCUSSION:

We have shown that features within the visible region are promising for the detection of K deficiency symptoms in grape leaves (*V. vinifera* cv Pinot Noir UC2A) through separating coloration classes by derivatives and continuum removal analysis of the leaf reflectance. Substantial increase in spectral indicators, though not statistically significant, tracked the increasing symptoms using derivatives of blue, green and red regions with respect to the order of leaves selected to represent K deficiency classes (0% symptoms visible, 5-10%, 10-20%, 20-30%, 30-50%, 50-60%, and greater 60 percent color change from green to yellow, red and black on the adaxial leaf surface). This visual assessment of K deficiency symptoms, though separated into discrete classes, did not statistical support the accuracy of the spectral measurement. The variability of the spectral measurements within classes does indicate the range of symptomatic coloration within each class. Common remote sensing analysis of band-depth measurements through continuum removal technique did support spectrally separating classes into two ranges, >30% visual symptoms and <30% visual symptoms.

It is possible that reflectance of the leaves may indicate that K deficiency coloration were symptomatic of the alteration in K partitioning due to heat stress rather than actual deficiency in K. It is not known how such partitioning might occur. However it is known that K deficiency due to rapid shoot growth in spring that generally exceeds the ability of root absorption to provide sufficient K can lead to temporary K deficiency in grape (spring fever) that is associated with yellowing of leaves caused by production of compounds such as putracene (Adams et al. 1990). Spectral features centered near 625 nm are the major reflectance bands for light absorption by chlorophyll a and b and other pigments. This indicates diminished chlorophyll concentration and increase in "red" pigments as a symptom of K deficiency, not the actual K content. Each of these hypotheses requires further examination under controlled conditions for K nutrition. Our results indicate that a relationship may exist between plant K nutrition levels and light reflectance features, and through continued investigations of canopy reflectance will improve future attempts to spatially constrain inadequate K nutrition.

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