SPECTRAL RESPONSE OF WATER STRESS IN QUERCUS SPP.

IMPLICATIONS TOWARD EARLY DETECTION OF OAK WILT DISEASE

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www.utsa.edu/LRSG/local_research/local.htm
Introduction

- Oak wilt disease basics. What is it and where is it?
- Can imaging spectrometry detect subtle changes in leaf-level water/wilt stress?
- An oak wilt inoculation experiment. Preliminary results and discussion.
- Future directions for this research.
What is Oak Wilt disease?

- Disease agent is the fungus *Ceratocystis fagacearum*
- Tree’s response to infection is to secrete gums and tyloses that block water-conducting xylem tissue
- Red oak family is most susceptible
- Oak wilt ranges from central Texas to the upper midwest
- First described in the 1930’s
- Has killed millions of trees
National distribution of oak wilt
Imaging Spectrometry

Acquisition of many contiguous spectral bands across the visible and infrared portions of the EM spectrum

Hyperspectral Imaging satellite and air-borne

Many surface materials have characteristic and diagnostic spectral features

Field Spectrometry data collection

The Goal:
Classification, identification, and spatial quantification of surface materials
Characteristic Spectra

A Typical Vegetation Reflectance Spectra

- *Leaf structure*
- *Leaf water content*
- *Leaf chemistry*

Wavelength:
- Visible: 350 - 570 nm
- Near infrared: 700 - 1300 nm
- Middle infrared: 1300 - 2500 nm

Reflectance:
- 0.0 to 0.6
Inoculation experiment

- Specimens: Forty *Quercus virginiana* (Live Oak), ~5 years old
- Environmental conditions: Full sun exposure, potted in 10 liter containers, watered with drip irrigation (~1.5 liters/day), mulched
- Source of inoculum: Texas A&M University plant pathology dept.
- Inoculation technique: excision of a 0.5 x 3.0 cm strip of tissue into xylem; insertion of an inoculum–soaked piece of sponge into wound; taped
- Water stress treatment: a 6 day cessation of irrigation
- Data collection: pre- and post-stress biophysical and spectral parameters
## Inoculation experiment

**Experimental design:**

<table>
<thead>
<tr>
<th>Drought Stress</th>
<th>Oak Wilt Stress</th>
<th>No inoculation</th>
<th>Inoculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal water</td>
<td>Treatment 1</td>
<td>Treatment 1</td>
<td>Treatment 2</td>
</tr>
<tr>
<td></td>
<td>n=10</td>
<td>n=10</td>
<td>n=10</td>
</tr>
<tr>
<td>Water withdrawal</td>
<td>Treatment 3</td>
<td>Treatment 3</td>
<td>Treatment 4</td>
</tr>
<tr>
<td></td>
<td>n=10</td>
<td>n=10</td>
<td>n=10</td>
</tr>
</tbody>
</table>
Inoculation experiment timeline

- **Tree purchase**
  - May 26 – Jul 25

- **Acclimation period**
  - Jul 26 – Aug 2

- **Drought stress**
  - Jul 26 – Aug 2

- **Waiting for infection??**
  - Jul 26 – Aug 2

- **Water resumption**
  - Oct 13

- **Baseline spectra collected**
  - 5/26
  - 6/23
  - 7/16 - 21

- **Water stress spectra collected**
  - 8/02

- **Stress recovery spectra collected**
  - 8/18
  - 9/02

- **xylem water potential data collected**
  - 7/28
  - 8/03
  - 8/09
  - 8/18

- **leaf water content data collected**
  - 7/27
  - 8/02
  - 8/09
  - 9/02
Biophysical parameters tested

- Leaf water content (LWC)
  - \((Wt_{\text{fresh}} - Wt_{\text{dry}})/Wt_{\text{fresh}}\)

- Xylem water potential (XWP)
  - A measure of the free energy (pressure) of water in the xylem tissue (mPa)

- Spectral red edge parameters
  - \(\text{REP}_{\text{max}} = 1\text{st derivative value @ local maxima}\)
  - \(\text{REP}_{\lambda} = \text{wavelength @ 1}\text{st derivative local maxima}\)

- Spectral indices sensitive to water stress
## Spectral vegetation indices (SVI) used in this study

<table>
<thead>
<tr>
<th>SVI</th>
<th>Formula</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>NDVI(1)</strong></td>
<td>( \frac{(R_{750} - R_{660})}{(R_{750} + R_{660})} )</td>
<td>-</td>
</tr>
<tr>
<td><strong>DWSI(1)</strong></td>
<td>( \frac{R_{800}}{R_{1660}} )</td>
<td>Apan, et al., 2003</td>
</tr>
<tr>
<td><strong>NDWI(H)</strong></td>
<td>( \frac{(R_{1070} - R_{1200})}{(R_{1070} + R_{1200})} )</td>
<td>Ustin, et al., 2002</td>
</tr>
<tr>
<td><strong>MSI</strong></td>
<td>( \frac{R_{1600}}{R_{820}} )</td>
<td>Hunt &amp; Rock, 1989</td>
</tr>
</tbody>
</table>
Baseline parameters across treatments

- **Xylem water potential (XWP) - July 28**
  - $-0.28 \pm 0.13$ MPa (mean ± 1 σ).

- **Leaf water content (LWC) – July 27**
  - Fully turgid leaves
    - $53.9 \pm 2.4$ % (mean ± 1 σ).
  - Same leaves in their fresh state
    - $52.0 \pm 2.2$ % (mean ± 1 σ).
Baseline spectra
(40 trees – 10 leaf spectra per tree)
Post water withdrawal spectra across non-stressed and stressed treatments
Post water withdrawal standard deviation for treatments 1/2 v 3/4

These spectra are indicative of a mean leaf water loss of 11.63 ± 6.29% (by weight) from the non-stressed group to the stressed group.
Comparison of leaf vs. tree level variance pre and post stress
## Statistical Analysis

<table>
<thead>
<tr>
<th>Analysis of spectral components (SVI’s, REP)</th>
<th>Analysis of whole spectra</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Why?</strong></td>
<td><strong>Why?</strong></td>
</tr>
<tr>
<td>Can specific SVI’s and REP parameters discriminate water stress with statistical significance?</td>
<td>What individual bands or band regions significantly discriminate water stress?</td>
</tr>
<tr>
<td><strong>How?</strong></td>
<td><strong>How?</strong></td>
</tr>
<tr>
<td>Analysis of variance (ANOVA)</td>
<td>Pearson’s $R^2$ correlation</td>
</tr>
<tr>
<td><strong>What?</strong></td>
<td><strong>What?</strong></td>
</tr>
<tr>
<td>Variance across treatment means</td>
<td>Correlation of $\Delta LWC$ and $\Delta REF$ across treatments (for all $\lambda$)</td>
</tr>
</tbody>
</table>
Details of derivative spectra

**Red edge position**

- Treatment 1
- Treatment 2
- Treatment 3
- Treatment 4

**Leading edge of second water absorption feature**

- Treatment 1
- Treatment 2
- Treatment 3
- Treatment 4

**Chlorophyll absorption region**

- Treatment 1
- Treatment 2
- Treatment 3
- Treatment 4
ANOVA Results

Baseline

Post Stress

$\text{REP}_{\text{max}}$ (P = 0.521)

$\text{REP}_{\text{max}}$ (P = 0.001)

Post stress XWP: P = 0.0002 (Kruskal-Wallis non-parametric)

Post stress LWC: P < 0.0001 (Kruskal-Wallis non-parametric)
ANOVA Results

**NDVI**

\[ (P = 0.004) \]

Not stressed

**MSI**

\[ (P < 0.0001) \]

Not stressed

**DWSI**

\[ (P < 0.0001) \]

Not stressed

**NDWI**

\[ (P < 0.0001) \]

Not stressed
$R^2$ correlation results

$\Delta R^2_{\text{REF}} (\text{REF}_{\text{stressed}} - \text{REF}_{\text{mean non-stressed}})$ regressed against $\Delta LWC$
Are current hyperspectral classification algorithms capable of spectrally separating the stressed and non-stressed treatments?
36 tree spectra

background spectra

Resampling to 10 nm

Build image map (Excel spreadsheet)

Convert to ENVI standard file

Spectral Angle Mapper classification

Discriminate Analysis Feature Extraction

Reclassify
Application of the Spectral Angle Mapper (SAM) algorithm to classification of the synthetic image map

Image map of 36 mean tree spectra w/ background spectra of limestone and juniper

OVERALL CLASS PERFORMANCE
(349 / 350 ) = 99.7%
Kappa Statistic = 99.5%. Kappa Variance = 0.000025.

SAM classification of 213 bands

OVERALL CLASS PERFORMANCE
(304 / 350 ) = 86.7%
Kappa Statistic = 76.9%. Kappa Variance = 0.001054.

SAM classification after DAFE
Conclusions

- All biophysical and spectral parameters tested were statistically significant for a mean leaf water loss of 11.63%.
- Other regions of the derivative spectra hold promise for detection of subtle water stress changes.
- Peak $R^2$ correlations (0.75+) for leaf water content occurred in the 1300 – 1900 nm region of the spectra.
- Spectral angle mapper classification method (post feature extraction) successfully separated stressed trees from non-stressed.
Future Directions

- Which spectral bands, in particular, are statistically significant for water stress detection?
- What is the lowest % leaf water loss significantly detectable with spectra?
- How will the oak wilt spectral response differ from normal water stress?
- Will leaf-level spectra scale up to canopy level?

Will current image analysis algorithms discriminate vegetation stress responses at the canopy level?
Questions?
Effects of water loss