APPLICATION OF REMOTE SENSING BY UNMANNED AERIAL VEHICLES TO MAP VARIABILITY IN ONTARIO RIESLING AND CABERNET FRANC VINEYARDS

Andrew G. Reynolds¹, Ralph Brown², Marilyne Jollineau³, Adam Shemrock⁴, Mehdi Shabanian⁵, Baozhong Meng⁵, Elena Kotsaki¹, Hyun-Suk Lee¹

¹Cool Climate Oenology and Viticulture Institute, Brock University, St. Catharines, ON; ²School of Engineering, University of Guelph, Guelph, ON; ³Dept. of Geography, Brock University; ⁴Air-Tech Solutions, Inverary, ON; ⁵Dept. of Molecular & Cellular Biology, University of Guelph, Guelph, ON

Acknowledgements: Funding provided by OMAFRA’s New Directions Program. Participating growers: Glenlake Vineyards, Pondview Estate Winery, Chateau des Charmes, William George, Ed Hughes, Thomas Kocsis, Cave Spring Estate Winery
Unmanned Aerial Vehicles (UAVs; drones)

• Attempts have been made with limited success to identify unique zones by remote sensing (RS) and to associate these with vine water status, soil moisture, vine vigor, yield, and berry composition.

• The data that is collected must be converted to variables, e.g., normalized difference vegetative index (NDVI) or other vegetation indices.

• Validation of data acquired by RS is still necessary to determine whether ostensibly-unique zones are relevant from a standpoint of physiology, productivity, and berry composition. One particular challenge involved masking of cover crop vegetation indices from all images to assess the vine canopy-specific VIs.

• RS has been used to directly predict grape composition variables particularly color and phenols. Others have investigated remotely sensed VIs, vine water status, and grape composition.

• Overall, RS has been proven as a useful tool for monitoring vineyard vegetative growth, and for making inferences about grape composition from multispectral measurements.
Thermal Sensors to Detect Water Stress

Jones et al. 2009
Thermal Sensors and Reflectance to Detect Water Stress

Zarco-Tejada et al. 2013a
NDVI Values to Estimate Vigor Zones

Primicerio et al. 2012
Estimation of Chlorophyll Content

Zarco-Tejada et al. 2013b
Objectives of Our Ongoing Studies

• Objectives were to assess the usefulness of unmanned aerial vehicles (UAVs; drones) for determining unique zones based on NDVI and thermal data, and to ascertain whether relationships might be observed between these and variables such as leaf ψ, soil moisture, stomatal conductance, winter hardiness (LT_{50}), vine size, yield components, berry composition, and grapevine leafroll virus (GVLR) status
Normalized Difference Vegetation Index (NDVI) = \frac{\text{NIR} - \text{Red}}{\text{NIR} + \text{Red}}

-1 \leq \text{NDVI} \leq +1

Source: earthobservatory.nasa.gov/Experiments/ICE/panama
• Buis [Lakeshore (Riesling); Four Mile Creek (Cabernet franc)]
• Pondview (Four Mile Creek)
• Chateau des Charmes (St. Davids Bench)
• George (Lincoln Lakeshore)
• Hughes (Riesling; Lincoln Lakeshore south)
• Kocsis (Cabernet franc; Lincoln Lakeshore south)
• Cave Spring Cellars (Beamsville Bench)
MATERIALS & METHODS

• Six each of Cabernet franc and Riesling vineyards (1-2 ha in area) in six different Niagara sub-appellations were chosen.

• Soil types varied substantially in these sub-appellations from well-drained coarse-textured Tavistock and Vineland series, to moderately-well drained Chinguacousy, and poorly-drained Jeddo and Beverly/Toledo soils.
MATERIALS & METHODS contd.

- Vineyards were GPS-delineated to determine shape using a Trimble Handheld GPS, equipped with TerraSync software. Sentinel vines (80-100) were identified in a ≈ 8m x 8m grid within each vineyard and geolocated by GPS.
- Vineyard soil moisture (SM) was measured by time domain reflectometry (TDR).
- Vine water status was measured using midday leaf \( \psi \) by pressure bomb; leaf transpiration (\( g_s \)) by a hand-held porometer.
- Greenseeker data were collected at fruit set, lag phase, & veraison to correspond to leaf \( \psi \), \( g_s \), & SM measurements.
- Flights took place once over each vineyard in early August (pre-veraison).
- Yield per vine and cluster number were determined. A 100-berry sample per vine was taken at harvest.
- Brix, titratable acidity, pH, free/bound terpenes (Riesling), & color/anthocyanins/phenols (Cabernet franc) were measured.
- Buds were assessed for winter hardiness (LT50) by differential thermal analysis in January-March.
Statistical Analysis & Mapping

**Statistics**
- Basic Statistics
- Linear correlation
- Regressions
- **Principal Component Analysis**
- Multilinear regression
- $k$-means clustering analysis

**Mapping & spatial analysis**
- Geo-location
- Inverse Distance Weighting Interpolation (IDW)
- Moran’s $i$ spatial autocorrelation Index
Results-PCA
George Riesling & Cabernet franc

Variables (axes F1 and F2: 29.76%)

Variables (axes F1 and F2: 40.78%)
Results-PCA
Pondview Riesling & Cabernet franc

Variables (axes F1 and F2: 31.80%)

Variables (axes F1 and F2: 31.68%)

Variables (axes F1 and F2: 13.61%)

Variables (axes F1 and F2: 12.36%)

F1 (18.19%)

F1 (19.32%)
## Summary of PCA Relationships with UAV Data

### DIRECT CORRELATIONS

<table>
<thead>
<tr>
<th>Variable</th>
<th>Riesling</th>
<th>Cabernet franc</th>
</tr>
</thead>
<tbody>
<tr>
<td>Greenseeker</td>
<td>●●●●●</td>
<td>●●●●</td>
</tr>
<tr>
<td>Vine size</td>
<td>●●●●●</td>
<td>●●●●</td>
</tr>
<tr>
<td>Soil moisture</td>
<td>●●●</td>
<td>●●●</td>
</tr>
<tr>
<td>Leaf $\psi$ (e.g. higher NDVI = higher water status)</td>
<td>●●</td>
<td>●</td>
</tr>
<tr>
<td>Transpiration</td>
<td>●●●●●</td>
<td>●●</td>
</tr>
<tr>
<td>Yield</td>
<td>●●●</td>
<td>●●</td>
</tr>
<tr>
<td>Clusters</td>
<td>●●</td>
<td>●</td>
</tr>
<tr>
<td>Berry wt.</td>
<td>●●●●●</td>
<td>●●</td>
</tr>
<tr>
<td>TA</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>LT50 1,2,3 (e.g. higher NDVI = less winter hardy)</td>
<td>●●</td>
<td>●●●</td>
</tr>
</tbody>
</table>

### INVERSE CORRELATIONS

<table>
<thead>
<tr>
<th>Variable</th>
<th>Riesling</th>
<th>Cabernet franc</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brix</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>pH</td>
<td>●●</td>
<td>●</td>
</tr>
<tr>
<td>FVT</td>
<td>●</td>
<td></td>
</tr>
<tr>
<td>PVT</td>
<td>●●</td>
<td></td>
</tr>
<tr>
<td>Color</td>
<td>●●●●●●●●</td>
<td>●●●</td>
</tr>
<tr>
<td>Anthocyanins</td>
<td>●●●</td>
<td>●●</td>
</tr>
<tr>
<td>Phenols</td>
<td>●●●●●●</td>
<td>●●</td>
</tr>
<tr>
<td>Soil moisture</td>
<td>●</td>
<td>●●</td>
</tr>
<tr>
<td>Thermal</td>
<td>●</td>
<td>●●</td>
</tr>
<tr>
<td>LT50 1,2,3 (e.g. higher NDVI = more winter hardy)</td>
<td>●●●●●●●●●</td>
<td>●●●</td>
</tr>
</tbody>
</table>
Direct correlations

- UAV NDVI (and NIR) indices were correlated with vine size in 10/12 vineyards—5 each for Riesling and Cabernet franc.
- Other noteworthy associations between UAV NDVI and other variables included:
  - Proximally-sensed NDVI by Greenseeker (8/12)
  - Berry weight (7/10); yield (4/10) and clusters (3/10)
  - Transpiration rate (6/12); soil moisture (5/12); leaf $\psi$ (3/12)
  - LT50 1,2,3 (i.e. less winter hardy) (5/12)
  - TA (2/10)

Inverse correlations

- UAV NDVI (and NIR) indices were correlated with LT50 1,2, or 3 in 12 instances—8 for Riesling and 4 for Cabernet franc (i.e. more winter hardy).
- Other noteworthy inverse associations between UAV NDVI and other variables included:
  - FVT and/or PVT [Riesling] (3/5)
  - Brix (2/10) and pH (3/10)
  - Color (3/5), anthocyanins (3/5), and phenols (4/5) [Cabernet franc]
  - Soil moisture (3/12)
  - Thermal (3/12)
Buis Riesling maps
Buis Cabernet franc maps
In the Buis Riesling vineyard (e.g.), high UAV NDVI zones were:

- Low in thermal camera data and LT$_{50}$ (i.e. more winter hardy); high in NDVI by GreenSeeker NDVI, leaf $\psi$ (high water status), soil moisture, vine size, berry weight, and TA.

Low UAV NDVI zones on the west side of the vineyard corresponded closely with:

- Highest regions from the thermal camera and higher LT$_{50}$ (i.e. less winter hardy); lowest regions of GreenSeeker NDVI, leaf $\psi$ (low water status), soil moisture, vine size, berry weight, and TA.
Map comments contd.

**Cabernet franc**

- Maps showed clustering in the UAV data with low NDVI and high thermal zones in the south end of the block. Low NDVI corresponded to low Greenseeker NDVI areas, low soil moisture and leaf $\psi$ areas, low vine size and berry weight, and higher LT$_{50}$ zones (less winter hardy). These showed some spatial correlation with high TA and low Brix areas, but pH and overall yield were not strongly related spatially.

- In most other vineyards the UAV NDVI maps were comparable to GreenSeeker NDVI maps; e.g., Buis Cabernet franc, there were good spatial correlations between UAV and Greenseeker NDVI, leaf $\psi$, leaf transpiration, soil moisture, vine size, LT$_{50}$, TA, Brix, and pH.

**Overall**

- Thermal data maps occasionally were inversely correlated spatially with NDVI. Most frequent spatial correlations in Riesling with high UAV/GreenSeeker NDVI zones were: leaf $\psi$, transpiration, vine size, berry weight, and TA. Noteworthy inverse spatial correlations included: NDVI vs. FVT/PVT (Riesling) and color/anthocyanins/phenols (Cabernet franc).
NDVI vs. Virus Status-GVLR Virus Symptoms

- Riesling virus-free
- Riesling GVLR infected
- Cabernet franc virus-free
- Cabernet franc GVLR infected
NDVI vs. Virus Status-Cabernet franc

UAVs could track development of GVLR virus symptoms

31 July 2014

07 September 2014

29 September 2014

NDVI

- Green: 0.800 - 0.847
- Light Green: 0.700 - 0.799
- Yellow: 0.600 - 0.699
- Red: 0.469 - 0.599
NDVI vs. Virus Status
Chardonnay Musqué (A,B) and Pinot noir (C,D)

A: 14 August 2014
B: 06 October 2014
C: 01 August 2014
B: 06 October 2014
Suspected Spectral Bands
Naidu et al. 2009 (Merlot, Washington State)
Red Blotch and Spectral Signatures
Mehrubeoglu et al. 2016

Normalized and Smoothed Spectra

- green leaf
- red blotch
- sunburn
- reference panel
A: GVLR-3 from Vineyard #1. Intensities of RT-PCR product in lanes (2, 3, 4, 5, 6) are higher than the samples shown in B (below). (1: Marker, 7 & 8: +ve and -ve control, respectively). Remaining lanes are individual vines.

B: GVLR-3 from Vineyard #2. Lanes (1, 4, 6, 11, 12 and 13) are negative; the rest of samples are positive. As shown, intensity of RT-PCR product in some samples is less than others; e.g., lane 10 has less GVLR vs. the others. (7: Marker, 15 & 16: +ve and -ve control, respectively).
Main Spectral Signature Bands

“Vineyard #1” Niagara Peninsula 2016

Vineyard #1 Cabernet franc

550 nm (GREEN)

850 nm (NIR)
Possible Vegetative Indices

Presently being calculated and mapped

1. \( \text{NDVI}_{\text{red}} = \frac{\text{NIR} - \text{Red}}{\text{NIR} + \text{Red}} \)

2. \( \text{NDVI}_{\text{green}} = \frac{\text{NIR} - \text{Green}}{\text{NIR} + \text{Green}} \)

3. Red edge (REIP) = point between 680-750 nm where there is a sharp increase in reflection

4. Greenness ratio. Measures greenness of vegetation

\[ \text{Greenness Ratio (GR)} = \frac{R_{550}}{R_{770}} \]

where \( R_{770} = 760 \) to 780 nm (NIR); \( R_{550} = 540 \) to 560 nm (GREEN)
2016 Vineyard #3 Cabernet franc GLRaV-3 Infection vs. NDVI

NDVI from Drone

2016 Vineyard #3 Cabernet franc
(quantity cycle (Cq) values)
- 0.00 - 5.66
- 5.67 - 9.08
- 9.09 - 12.36
- 12.37 - 15.04
- 15.05 - 19.65
- 19.66 - 37.97

Low NDVI

Low GVLR
2016 Vineyard #1 Riesling GLRaV-3 Infection vs. NDVI

Low GVLR

Low NDVI

2016 Vineyard #1 Riesling
Virus Titer (quantification cycle (Cq) values)
- 0.00 - 9.60
- 9.61 - 13.34
- 13.35 - 14.46
- 14.47 - 14.84
- 14.85 - 15.21
- 15.22 - 31.79

2016 Vineyard #1 Riesling
NDVI from Drone
- 0.365 - 0.651
- 0.652 - 0.681
- 0.682 - 0.704
- 0.705 - 0.725
- 0.726 - 0.747
- 0.748 - 0.833
2016 Vineyard #3 Riesling GLRaV-3 Infection vs. NDVI

2016 Vineyard #3 Riesling
Virus Titer (quantification cycle (Cq) values)
- 0.00 - 23.73
- 23.74 - 28.27
- 28.28 - 29.47
- 29.48 - 30.40
- 30.41 - 31.47
- 31.48 - 34.00

2016 Vineyard #3 Riesling
NDVI from Drone
- 0.137 - 0.336
- 0.337 - 0.403
- 0.404 - 0.451
- 0.452 - 0.488
- 0.489 - 0.518
- 0.519 - 0.586
Cabernet franc Vineyard #3

R/NIR higher in non-GVLR

Green higher in non-GVLR
Cabernet franc Vineyard #1

Green higher in GVLR

R/NIR higher in GVLR
Cabernet franc Vineyard #3

R/NIR higher in non-GVLR

Green higher in non-GVLR
Riesling Vineyard #1

Green higher in GVLR

R/NIR higher in GVLR

Non-virused vines

GLRaV-3 infected vines

Wavelength in Nanometers
Riesling Vineyard #4

Green higher in non-GVLR

R/NIR higher in non-GVLR
Conclusions

- PCA showed several direct correlations between UAV NDVI and vine size, berry wt., yield/cluster no., soil moisture, leaf ψ, and transpiration rate.
- Inverse correlations of note included FVT/PVT (Riesling), color/anthocyanins/phenols (Cabernet franc), LT_{50} (more winter hardy).
- UAV and GreenSeeker data produced maps of similar configuration. There were many instances of spatial correlation between both these variables and leaf ψ, transpiration rate, soil moisture, LT_{50}, vine size, yield components, and berry composition.
- In most circumstances, zones of high NDVI were associated with high soil and vine water status, vine size and yield, and low Brix, but there were situations where this pattern was reversed.
- Overall use of UAVs may be able to delineate zones of differing vine size, yield, and berry wt., and possibly areas of different winter hardiness and berry composition.
- Use of UAVs and other spectral technologies for assessment of virus status is our next major focus—there are contradictory results and much more investigation is needed.