Temporal evolution of within-season vineyard canopy response from a proximal sensing system

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Abstract

A weekly survey of canopy NDVI with a proximal-mounted canopy sensor was undertaken in a cool-climate juicegrape vineyard. Sensing was performed at different positions in the canopy. Sensing around the top-wire led to saturation problems, however sensing in the growing region of the canopy led to consistently non-saturated results throughout the season. With this directed sensing, a spatial pattern in NDVI 2-4 weeks after flowering could be generated that approximated the spatial pattern in NDVI at the end of the season. This is earlier than has been previously reported and may allow for proactive within-season canopy management.

Keywords: Greenseeker, NDVI, time series, position sensing

Introduction

Canopy sensing in vineyards has generally been performed using remote-sensing platforms (aerial or satellite) in warm to hot climates. Under these conditions, several studies have shown that correlations between vegetative indices (e.g. the normalised differences vegetation index (NDVI)) and production increase throughout the season and are generally strongest in the period between veraison and harvest (e.g. Hall *et al.*, 2011). For this reason, most (remote) canopy sensing in vineyards is performed at or after veraison. However, imaging late in the season precludes the opportunity to perform corrective, differential management within the season. Furthermore, in cool to cold climate vineyard production systems, remote sensing is not always feasible due to the persistence of a vigorous inter-row cover crop throughout the season and increased incidence of cloud cover.

Vineyards are routinely traversed by ground vehicles during the season. In the past 2-5 years, more interest has been shown in deploying tractor-mounted proximal canopy sensing systems into vineyards (e.g. Stamatiadis *et al.*, 2010). Unlike remote systems that obtain an overhead view, proximal sensing systems can be targeted at specific sections of the canopy. This may permit canopy vigour data, and its relationship to production, to be measured and mapped much earlier in the season. Tractor-mounted proximal sensing also permits multiple passes through the vineyard to be obtained over a season. Typically, management practices occur at or near key physiological times, so canopy data can be collected at these times. An automated tractor-mounted system means there is little direct running cost to data acquisition for the grower. The primary cost will be in capital equipment, data processing and analysis. Early and mid-season repeatable low-cost canopy data may encourage pro-active within-season management.

This paper will look at some of the issues of deploying proximal canopy sensors into vineyards; how canopy vigour (expressed here as NDVI) evolves over the season; and if the canopy vigour early in the season is indicative of the late season canopy vigour that has been related to vine size (Bramley *et al.*, 2011; Taylor and Bates, 2013). In particular, the issue with saturation of the canopy sensor signal will be investigated.

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Materials and methods

Data collection

In this study, the canopy of a 2 ha block of juicegrapes (Concord, *Vitis labruscana* cv. Bailey) on a top-wire sprawl system in a cold climate region (Lake Erie, North America) was sensed weekly with a commercially available proximal canopy sensor, the N-Tech Greenseeker RT100 (NTech Industries Inc., Ukiah, CA, USA). Sensing was undertaken from 2 weeks after budburst until 2 weeks after veraison (or May 14^{th} to August 20^{th}). The Greenseeker is an active (light emitting) sensor that records the reflectance from an object in the Red (R) and Near Infrared (NIR) portion of the electro-magnetic spectrum. With this band data, NDVI ([NIR-R]/[NIR+R]) (Rouse *et al.*, 1973) is calculated and recorded. Connecting the sensor output to a GPS and data logger allows the NDVI to be mapped. The Greenseeker recorded NDVI at 10 Hz, whilst the DGPS recorded position at 1 Hz. This discrepancy was fixed in the post-processing (data analysis).

The Greenseeker sensor was mounted on an all-terrain vehicle (ATV) and the sensor output logged with a Trimble GeoXM (2005 Series) datalogger. The datalogger contains an inbuilt WAAS-enabled differential GPS receiver. The Greenseeker sensor was mounted in one of three orientations depending on the stage of vine development (Figure 1). Early in the season (May 15^{th} to June 11^{th}), the sensor was side-mounted and directed at the cordon (top) wire where early growth was occurring. From June 4^{th} (5 weeks after bud-break and the first sensing after bloom), side-mounted sensing was also performed lower in the canopy at ~0.8 m above the ground. This was approximately the same height as the bottom wire in the trellis. From June 12^{th}, the sensing of the top-wire portion of the canopy was switched from a side-view to an overhead view to align with the orientation of a remote sensor. The ATV speed was kept to ~5 km/h, which is the typical speed of tractors during many vineyard operations.

For the top-wire and the initial bottom-wire side-view sensing, the Greenseeker was mounted at a horizontal distance of ~1.2 m from the actual trellis wire. As the canopy developed and expanded out from the centre line of the trellis, the Greenseeker was shifted to a distance of ~1.8 m from the trellis wire. This change was done at June 19^{th}. The overhead sensing was restricted in height to ~0.5-0.7 m above the canopy due to restrictions with the ATV. The distance to the target in the overhead configuration was less than that recommended (0.8-1.2 m) (NTech Industries Inc., 2006). In the recommended target range, the sensor has a footprint of ~0.6 m by 0.01 m (Drissi *et al.*, 2009). The overhead configuration would have a footprint less than this. However, the footprint would still be restricted to the canopy only, as the canopy width is >0.6 m beyond 30 days after flowering.

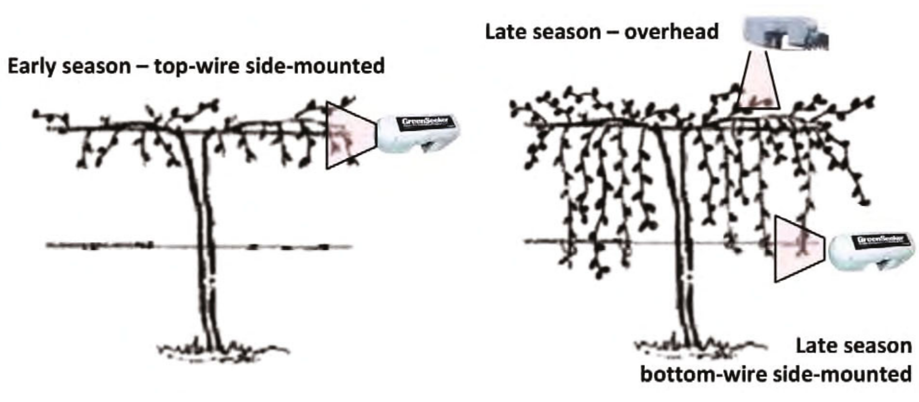

Figure 1. A schematic diagram of the orientation of the sensor relative to the canopy early and late in the season.

Data analysis

The raw data were cleaned prior to analysis and interpolation. The GPS data (Latitude/Longitude; WGS84) were converted into Eastings/Northings (UTM WGS84 Zone 17N). The 10 Hz NDVI data were spaced evenly between the 1 Hz GPS locations. Data clean-up was performed by removing any NDVI or Latitude/Longitude outliers. The NDVI trimming was done according to the distribution of the data but was generally restricted to 0.3-1.0 for early season data and 0.6-1.0 for later season data. The vineyard rows are oriented N-S, so points were trimmed to 180° or 360° (±20°) based on the GPS heading. Finally, the GPS receiver was located in the centre of the inter-row, while the Greenseeker was sensing the canopy (row). The GPS locations were therefore adjusted to align with the row (not the inter-row) according to direction of travel and the distance of the sensor from the canopy. The trimmed data files for each date (and orientation on a date) were interpolated onto a common regular 2.74 m grid. This equals the row spacing in the vineyard. Interpolation was performed using block-kriging (8.25 m or 3 rows) with a local variogram in VESPER (Minasny *et al.*, 2005). This large block size was used to smooth the output and show the trend in data. An analysis of the spatial variability in vine size in this block indicated that inter-vine variation is very high and aggregation should be done over at least three vines (~8 m) to reveal the underlying spatial trends (Taylor and Bates, 2012).

Summary statistics were obtained for each date (mean (μ), standard deviation (σ) and skewness (γ_1)). The data from each day and orientation was also correlated (Pearson's analysis) to the low side-mounted NDVI response on August 20th. This was the last measurement taken in the season, 2 weeks after veraison. This was chosen as the 'reference' data set as existing data from previous years has shown that late-season, side-mounted, lower-canopy NDVI data is correlated with vine size in this field (unpublished data, Lake Erie Research and Extension Program, Cornell University). The data collected in this year was checked for data quality/suitability and spatial patterns before being accepted as a reference data set. Unfortunately, at the time of writing, pruning weight data from the current season was not available for validation.

Results and discussion

Early season sensing

An issue with data quality when sensing early in the season is the potential for overlapping responses due to the high canopy porosity i.e. the sensor receives a signal from 2 (or more) rows. For this reason, a backdrop has usually been used in other side-mounted applications of proximal sensors (e.g. Drissi *et al.*, 2009). However, similar to the results reported by Mazzetto *et al.* (2010), this was not observed to be a problem when using the Greenseeker sensor. Gaps in the canopy were recorded as missing values (default value of -0.899). The sensor was not sensitive enough to view the response in the neighbouring row (a distance of ~4 m). Figure 2 shows histograms from the side top-wire imaging early in the season (May 15th, May 30th and June 11th). All distributions are tri-modal, showing an absence of green material (-0.899), a presence of green material (>0.2) and a mixed response (averaged over areas with and without green material) (-0.45-0.1). The percentage of an absent or mixed response decreases as the canopy (and season) develops. The distribution (and mean) of the actual NDVI response is also increasing towards a saturation of 1.

The results here indicate that it is feasible to obtain early season NDVI measurements by directing the proximal sensor at the developing part of the canopy as soon as it starts to develop. However, the value of sensing at this stage is still uncertain (see results and discussion to follow). What is clear is that the NDVI response early in the season is quite unique. In the following results, the NDVI values that are indicative of missing canopy or a mixed response (NDVI<0.3) have been removed in the data trimming. Thus the following results are derived from only a part of the data, especially for the May and early June measurements. This may not be the correct approach and further analysis of the (spatial) information in the none/mixed response is needed. Alternative methods of

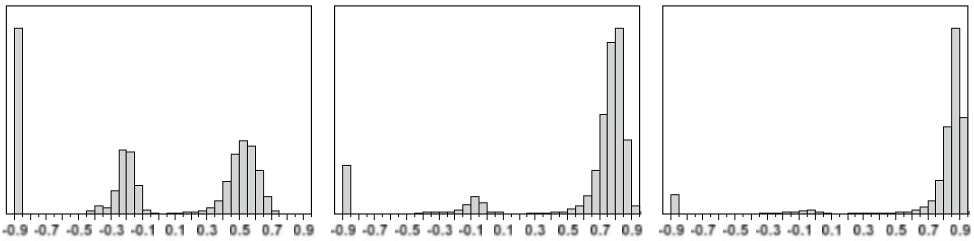

Figure 2. Distribution of the raw NDVI trimmed to coincide with the vine rows. Data has not been trimmed on the NDVI response. Data is shown for May 15th (left), May 30th (centre) and June 11th (right) which is approximately at two week intervals after budburst (May 1st).

data interpolation may be preferred. While the Greenseeker system could be deployed early in the season, care may be needed with other proximal canopy systems. Some other sensors (e.g. Crop Circle ACS-470, Holland Scientific Inc., Lincoln, NE, USA) are able to operate at greater separation distances between the target and the sensor than the Greenseeker sensor.

Temporal response over the season

The trend in the NDVI response for the top-wire (side-mounted or overhead) and bottom-wire (side-mounted) sensing is shown in Figure 3. The field mean (μ), the standard deviation (σ) and the skewness (γ_1) is plotted for each date. A trend line (spline) has been fitted to the mean response (Figure 3a). The trend to saturation of the NDVI response with the top-wire sensing is clearly obvious with saturation occurring by bloom. Although NDVI values range from 0-1, typically the maximum observed is ~0.94 with this sensor. It can also be seen that when saturation occurs (DOY 181), the data are exhibiting negative skewness ($\gamma_1<-1$) and a reduced variance (σ). In contrast, the bottom-wire signal does not reach signal saturation, but a plateau at a mean NDVI of ~0.8. Even though the mean response is high, the data are not skewed ($-0.5<\gamma_1<0.5$) and the σ does not decrease with an increasing μ.

In Figure 3a, some key physiological dates are indicated – bloom at May 30th (DOY 151), 30 days after bloom (DOY 181) and verasion, August 7th (DOY 219). Typically in these production systems, most vineyard operations are done at approximately 2 week intervals from bud-break up to 30 days

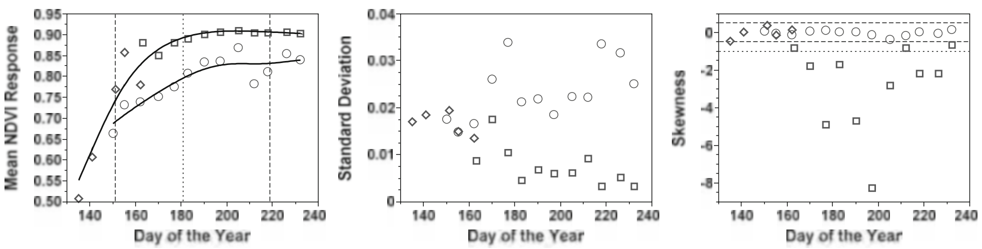

Figure 3. Temporal evolution of the statistics associated with the canopy sensing surveys. Plots show the evolution of the mean response, the standard deviation and the skewness for different orientations of the proximal sensor. For each plot ◊ indicates top-wire side-mounted orientation, ☐ indicates top-wire overhead orientation and O indicates bottom-wire side mounted-orientation. Dotted lines in the mean NDVI plot represent bloom (DOY 151), 30 days after bloom (DOY 181) and veraison (DOY 219). Dotted lines in the skewness plot indicate a range of ±0.5 and ±1.0.

after bloom. Beyond 30 days after bloom, growers try to minimise any vine management. Therefore, if data is to be collected during normal operations, it needs to be collected before this key time. However, depending on the inter-row management (e.g. weed management) employed by the grower, tractors may sporadically pass through the vineyard later in the season.

Correlation with late season response

The temporal trend in correlation with the August 20th data is very different when the orientation of the sensor changes (Figure 4). As expected the lower bottom-wire response around veraison is very similar to the late-season lower bottom-wire response. However, the bottom-wire response around bloom (DOY 151) is also strongly correlated with the final response (r=0.75). Since NDVI at and after veraison is related to vine size in this system, this result strongly suggests that an NDVI map generated at bloom may also be a good indicator of vine size (and variation). This differs from the general belief that imaging only relates to vine size late in the season. There is one anomalous result with the bottom-wire sensing. The correlation dips two weeks before veraison (DOY 205). The reason for this is unclear but is possibly due to weather conditions at this time. Further investigations into possible causes are underway.

For the top-wire sensing, the correlation with the late season NDVI response peaks in the two weeks after flowering. The correlation is not as strong (r=0.5-0.6) as the bottom-wire response. This period corresponds with the period where the canopy around the top-wire is still actively growing and the NDVI response is neither skewed nor reduced in variance (Figure 3). The top-wire response at this time may provide supplementary or complementary information to the bottom-wire response from later in the season on vine size. At this early stage of the season, the unsaturated top-wire gives the best correlation with the end of season response. When pruning weight data is collected for the field from this season, the value of this earlier, but lower, correlation will be assessed to see if it is relevant for a potential management decision.

Figure 5 provides examples of the maps generated from the proximal canopy sensor at different times and with different orientations. This visualises the correlations of some key dates and sensor orientations. The reference image, bottom-wire August 20th data, is shown in Figure 5a. The comparable overhead image on August 20th is shown in Figure 5b. This is strongly saturated and skewed (Figure 3). The July 2nd bottom-wire sensed NDVI is shown in Figure 5c. This equates to

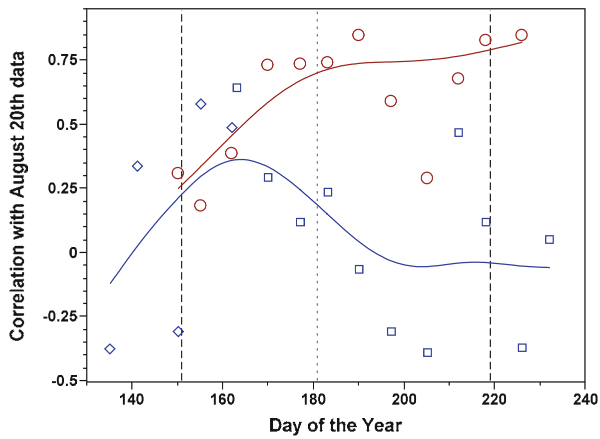

Figure 4. Temporal evolution of the correlation between top-wire and bottom-wire sensing of the canopy with the reference NDVI data from August 20th (bottom-wire orientation). Symbols and dashed lines are the same as for Figure 3.

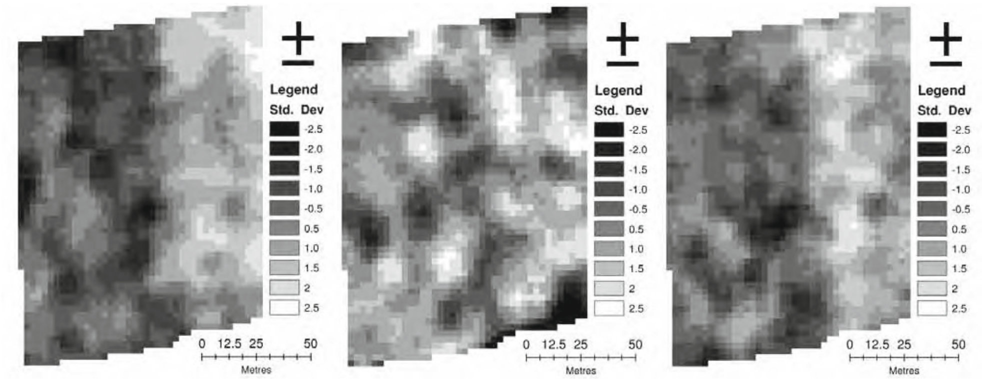

Figure 5. NDVI maps derived from a proximal-mounted NDVI sensor. Left: NDVI sensed low in the canopy on August 20th, 2012; Centre: NDVI sensed from overhead the canopy on August 20th, 2012; Right: NDVI sensed low in the canopy on July 2nd, 2012.

the data collected at ~30 days after bloom (DOY 181). All images are shown in increments of 0.5 standard deviations. The July 2nd m ap is visually similar to the reference map (Figure 5a) as expected from the correlation results (Figure 4). It shows the higher response in the eastern half of the field and similarities in the patches of high and low response in the western half of the field.

General discussion

The results presented here are encouraging for the application of a proximal canopy sensor mid-season for vine size estimation in Concord production. However, this is only a single season study to date. The same type of study will be undertaken in the following years to determine if the promising results found in this year (2012) are repeated. The analysis to date has also only focused on a 'snapshot' of NDVI response at each date. The data set however comprises a time-series, within which rates of change of response may be indicative of production parameters including vine size. Future work will incorporate this aspect.

This initial work has been performed in juice grape production systems. However, the real value of an early to mid-season estimation of spatial variation in vine size will be in winegrape production systems. These are higher value systems with quality dependent on the ratio of vine size (leaf area) to crop size (yield). The sprawl trellis system used in juicegrape production is also widely used in winegrapes. Thus the results obtained from proximally sensing different regions of the canopy should be transferable to sprawl systems in winegrapes. The application of directed proximal sensing in other trellis systems, e.g. vertical shoot positioning (VSP) systems, also presents some other challenges to early season sensing, which will be explored in the coming years. The hand-held results of Drissi *et al.* (2009) would support the possible extension of this work into VSP.

Conclusions

Proximal-mounted canopy sensors provide greater flexibility for targeting the developing regions of the vine canopy. By targeting growing regions, the canopy NDVI can be sensed earlier in the season and related to a late season response, allowing for within-season management, such as crop load (ratio of leaf to fruit) management in the vineyard. Thus proximal-sensed systems provide potentially greater temporal flexibility in collecting relevant canopy vigour information than previously reported aerial/satellite-mounted systems. There appears to be a greater opportunity for canopy sensing in the period between bloom and verasion that has not previously been explored in the literature, which corresponds with the timing of preferred within-season management.

Acknowledgements

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