OPTICAL AND THERMAL APPLICATIONS IN GRAPEVINE (*VITIS VINIFERA* L.) RESEARCH – AN OVERVIEW AND SOME NOVEL APPROACHES

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Abstract: In this article, some optical and thermal applications in grapevine research are reviewed and methods to quantify the light and temperature regime around a grape bunch are discussed. This includes temperature measurement techniques (thermocouples and thermal imaging) as well as methods to quantify light quantity (hemispherical photography) as well as light quality (spectroradiometric applications) around a grape bunch. Available methods for real-time quantification of grapevine canopy size and density for application in variable rate technology sprayers are discussed, and a novel and simple approach of using opto-electronic sensors for quantification of grapevine canopy thickness and density is presented. Some scientific as well as practical applications of these individual techniques are discussed, along with their potential integration to improve knowledge of the grape bunch and canopy interaction with the environment.

Key words: Optical, thermal, *Vitis vinifera*, hemispherical photography, gap fraction.

1. INTRODUCTION

The wine industry plays an important role in South-Africa, growing in 2008 to an annual contribution to the economy of R26.2-billion or 2.2% of the gross domestic product (GDP) [1]. Wine and grapevine-related research contributes significantly to this thriving industry. Wine research is closely related to the monitoring of the grapevine and its environment. Novel techniques for quantifying and understanding the environment around a grape bunch are needed in research, especially due to the variable nature of a vineyard and its product [2, 3]. When considering sensor applications in grapevine research, an important consideration is the spatial and temporal scale at which these measurements are conducted, in and around the vineyard. On a macro-scale we can consider the interpolation of land surface temperature data from satellites using geographical information systems [4, 5]. This approach is also dependent on a sensor network for calibration purposes and can include satellite/aerial remote sensing techniques. On a meso-scale (on-farm or between-vineyard scale) we mostly deal with remote sensing technology (which can also be performed on proximal or canopy scale) as well as weather stations that are used to make meteorological observations. On a micro scale, measurements are made within or around the grapevine canopy, within or around a bunch or even within or around a single berry or leaf (also referred to as nano-scale measurements). If an analogy is to be made between a plant and sensors, it could be reasoned that a plant is an array of sensors able to react to light quantity and quality on a spatial and temporal basis, leading to physiological reactions affecting its growth, reproductive functionality and commercial quality. A complicating factor when using sensors in grapevine research is that we are dealing with effects of light quality and quantity on leaves and fruit in a spatially complex and temporally changing environment. The ideal sensor arrangement would be able to quantify, for instance in an imaging spectrometer arrangement, light quantity and quality over time in various positions within the canopy. Unfortunately, such an arrangement would be extremely expensive, especially if replication is required. For the moment at least, we can rely on sensors and modelling to get close to this goal, but certainly electronics and sensor technology could help in studying these interactions in a more efficient way, be it in terms of lower cost or higher resolution of the data generated. Another issue in using sensors in grapevine research is that sometimes care is not taken to understand the calibration conditions and measuring limits of the instruments. This is especially true when conducting light measurements, where the calibration of for instance pyranometers is done in high light environments comparable to the conditions that the sensor would encounter under clear skies. Measurements are then done inside canopies under low light conditions with different wavelength distribution and it is accepted that the calibration is still valid. While we are looking for improved solutions, this paper aims to expose the electronic engineering world to some of the applications and challenges of grapevine (and certainly also other fruit) research related to light and temperature applications in the hope of improving the scope of current, and the development of novel technology. The importance of optical/thermal sensors in current research can be narrowed down for the purpose of this paper to: a) improving sustainable viticultural practices (such as the efficiency of spray application), b) assessing the adaptation of the plant to a change in its environment (i.e. climate change and cultivar adaptation) and c) using sensors to support general grapevine management/decision making.

2. BUNCH LIGHT/TEMPERATURE QUANTIFICATION

2.1 Bunch temperature measurements

Thermocouples: Several types of thermocouples and logging devices are available, with their main advantage in grapevine research being the ability to measure temperature inside an organ/environment. It is therefore mostly used to measure soil, bunch or berry temperatures in microclimate studies. Thin-type thermocouples are 0.5 mm in diameter and 3.3 mm in length, compared to the standard type thermocouples that are 2.5 mm in diameter and 8 mm in length (Figure 1). The thinner thermocouples can be adapted for use with the same type of datalogger than the thicker type, and have obvious benefits when monitoring for instance grape berries, as the entry wound is minimal and the distance into the berry can be adjusted for different measurements.

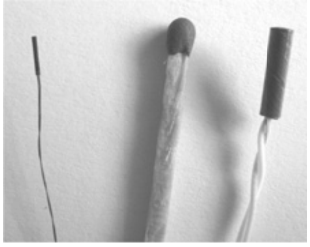

Figure 1: Thin (left) and thick (right) type thermocouples that can be used in grape berry temperature assessment.

Thermal imaging is used in grapevine studies for the detection of stress responses in grapevines under different irrigation regimes [6] as well as to detect pre-symptomatic increase or decrease in temperature in grapevine leaves infected with *Plasmopara viticola* [7]. It offers an advantage above conventional infrared thermometry, in the sense that it is possible to account for target background effects, but has the disadvantage that more extensive processing of the signal is required to achieve this. Another advantage over the use of thermocouples for bunch/berry temperature measurement is that it can be used to quantify target variability in temperature. Low-cost thermal imaging techniques are now within reach of most researchers in plant science. In Figure 2 a field set-up with a Raz-IR Nano thermal imager (SPI, Las Vegas, USA) is shown, and in Figure 3 bunch surface temperature differences between a shaded or exposed bunch, as well as temperature variability on the bunch are noticeable. The importance of assessing not only bunch mean temperature, but also variability in berry temperature is shown in Figure 4, where it is evident that just one hour change in irradiation and ambient temperature can affect bunch surface temperature variability.

Figure 2: Thermal imager set up for measurements of grape bunch temperatures.

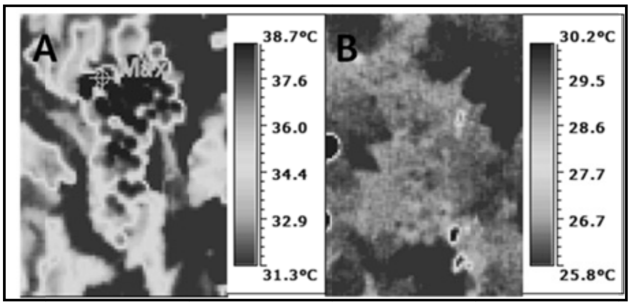

Figure 3: Thermograph of the eastern (A) *versus* western (B) side of a bunch in a north-south oriented row

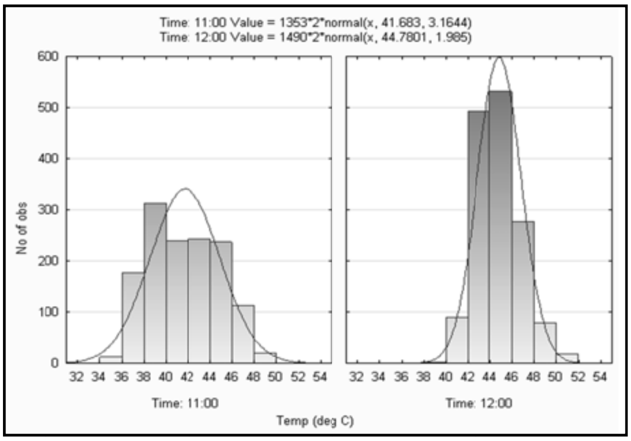

Figure 4: Histogram of "temperature pixels" assessed on the same bunch at 11:00 and 12:00 on the same day.

2.2 Bunch light quantity/quality measurements

Hemispherical photography: While ambient temperature is of importance to grape ripening processes, assessing fruit exposure to sunlight is also important due to the potential effect of radiation on berry temperature and composition, with potential effect on grape quality. Differences in temperature between ambient air and exposed fruit increase as solar radiation increase and wind speed decrease [8]. The light microclimate above bunches can be computed by means of hemispherical pictures (Figure 5) in order to assess the effect of row direction, canopy gap fraction and trellis height during different times of the day, or days within a growing season on the quantity of light received. It is possible to use a special lens (Fisheye Converter FC-E8 Nikon Corp., Tokyo, Japan) and camera (Coolpix 995, Nikon Corp., Tokyo, Japan) combination, and analyse the results using Gap Light Analyser software ver. 2·0 [9] in order to compute canopy gap fraction at 10-degree zenith and azimuth resolution as well as the annual percentage of incident direct and diffuse radiation.

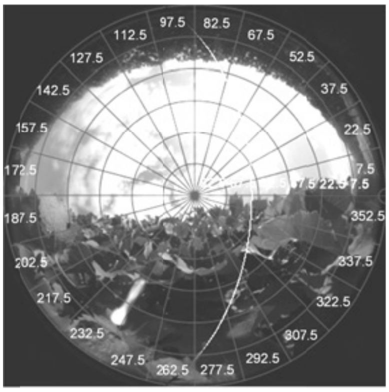

Figure 5: Hemispherical photograph taken in a north-south oriented vineyard row, with coordinate grid indicated. Sun path is indicated by the curved line across the grid.

Spectroradiometry can be used at all scale levels (aerial, satellite, canopy, leaf or bunch) to assess the spectral distribution of direct or diffuse light and also light reflected, transmitted or absorbed by different canopy elements. While pyranometers or quantum radiometers can aid in assessing total photosynthetically active radiation penetrating into a canopy, hemispherical photography can aid in modelling total radiation over time, as well as its potential reaction to a change in latitude/longitude as well as row direction. It is, however, also relevant to know how light penetrating into a canopy is affected in terms of spectral distribution, as the quality of light intercepted by leaves or fruit can affect their functioning through photon receptors able to differentiate between different wavelengths of light [10, 11].

3. CANOPY SIZE/DENSITY QUANTIFICATION

The gap fraction as well as leaf layer number (LLN) measurements are relevant in canopy microclimate studies, but also when considering light, air as well as spray penetration into a grapevine canopy. These parameters can be measured by way of point quadrat analysis [12], but this is a laborious method which is also prone to human error. It is also possible to quantify (by way of using a ruler or photographic techniques) the sunfleck pattern underneath a vineyard canopy [12], but this is also time-of-day and row direction dependent. Opto-electronic sensors therefore offer possibilities to simplify/automate these types of measurements.

3.1 Opto-electronic sensors

Several electronic sensors are available to aid in vineyard canopy size/density quantification utilising different technologies and requiring different types of signal processing. Wavelength-specific sensors are available, similar to those deployed on satellite/aerial platforms, but they can also be deployed at a proximal level (i.e. the Greenseeker™). These sensors use the red and infrared wavebands to assess plant health. Photographic techniques have also been used to assess canopy condition [13], but this approach requires extensive processing to be useful.

We developed a simple gap fraction sensor that uses laser diodes and photo transistors to assess canopy transmittance in beams perpendicular to the surface of the canopy (Figure 6 and Figure 7). The setup is very simple and inexpensive, but needs some alignment prior to operation (Figure 8). Also the test system has been designed to run on a pre-installed wire over the grapevine canopy, which is not optimal for extensive measurements. The test system was, however, designed as a proof of concept, and could be adapted to be mounted on a spray device after mechanical stabilisation, which will also address the beam centring issue. The goals of designing such a simple setup was to a) minimise cost, b) minimise signal processing and to c) mimic a beam, or then potentially a spray droplet's ability to penetrate through the canopy. The logic is that in forced spray systems, penetration through the canopy would potentially lead to wastage, and spray nozzles could be adapted to lower application where potential penetration could occur through the whole canopy.

As the penetration of light as well as spray droplets through a canopy would be dependent on canopy thickness as well, an experiment was done by mounting two optical (infrared) and one ultrasonic low-cost distance sensor onto the setup (Figure 9).

The test run was performed on canopies where the grapevines were subjected to canopy manipulation by way of early shoot removal (Figure 10). Half of the shoots were removed for three grapevines, leaving three vines in-between unaltered as controls.

Some results of a trial run are shown in Figure 11, from which it is evident that the ultrasonic beam performed quite well compared to the hand measurements and gap fraction results, but the optical (infrared) distance sensors were erratic. The shoot-thinned grapevines showed a much higher gap fraction than the unmodified vines.

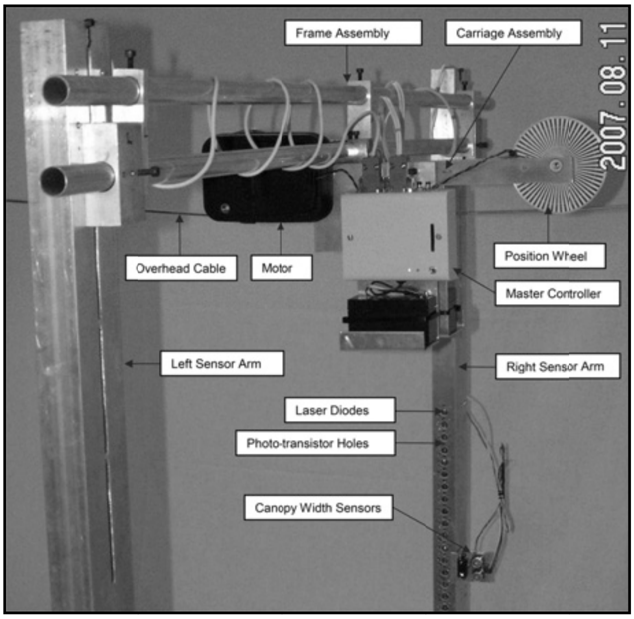

Figure 6: Canopy gap fraction analyser components.

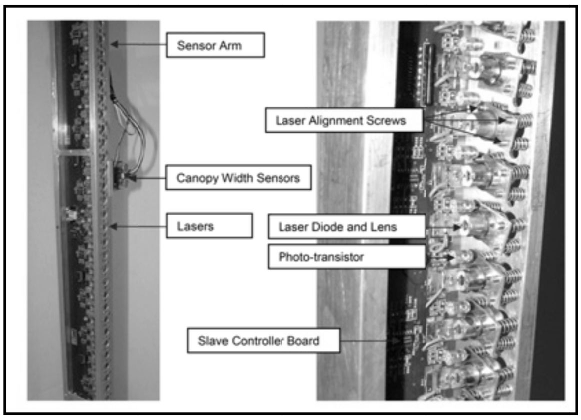

Figure 7: Detail of canopy gap analyser laser beam and photo transistor setup inside the sensor arms.

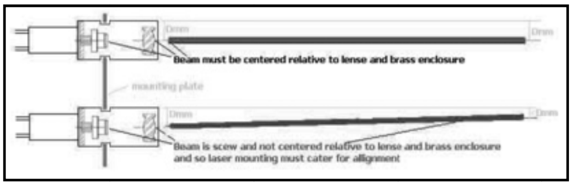

Figure 8: Beam centring to align it to the photo transistor holes.

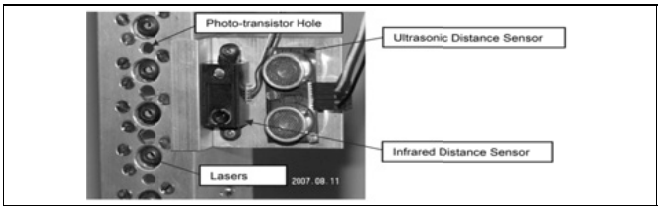

Figure 9: Ultrasonic and infrared (optical) distance sensors installed on the laser beam track to assess canopy thickness.

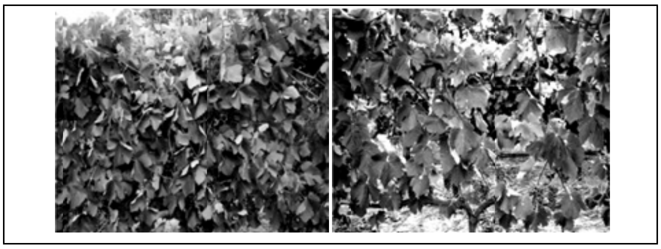

Figure 10: Unmodified (left) or early shoot thinned (right) grapevines used in test setup.

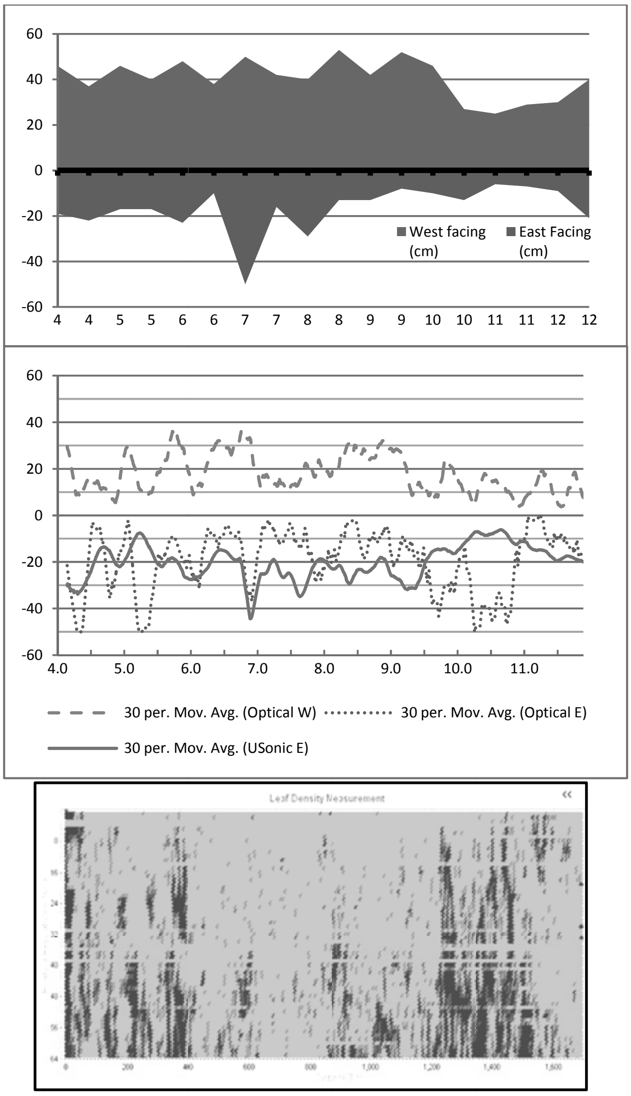

Figure 11: Top – hand measurements of canopy thickness; middle – ultrasonic and optical measurement of canopy thickness; bottom – gap fraction map showing gaps in darker pixels. The numbers on the x-axis correspond to grapevines 4, 5 and 6 (shoot thinned), grapevines 7, 8 and 9 (unmodified) and grapevines 10, 11 and 12 (shoot thinned).

4. SENSOR APPLICATIONS IN SUSTAINABLE VITICULTURE

One example of a macro/meso scale application of sensor technology is the initiative "Grapelook", co-funded by the Department of Agriculture, Western Cape, South Africa, and the European space agency (ESA). It is executed by WaterWatch (Netherlands) and the

University of Kwa-Zulu Natal in South Africa, with the aims of increasing water use efficiency in vineyards, promoting sustainable optimal resource utilization, reducing input costs (i.e. fertilizers) and protecting the environment [14]. The system provides an online interface where grape producers can access information such as leaf area index, crop coefficients, aspect, actual evapotranspiration, evapotranspiration deficit and biomass water use efficiency on maps utilising a Google Earth™ image as background.

An example of sensor applications for sustainable agriculture/viticulture on the meso-scale is the use of variable rate spraying. To this end, the method of assessing canopy dimensions/density real-time is of interest. Several options are available, including multi-band type sensors, photographic techniques, ultrasonic or infrared distance sensors, laser gap fraction analysis or LIDAR. Even though the gap fraction analysis system looks promising to use as a low-cost alternative, canopy profiling through the use of LIDAR would probably still offer the best way to combine canopy profiling and gap fraction analysis into one sensor. It has already shown promise for use in spray technology [15]. Preliminary results from some of these studies demonstrate reduction in spray drift, reduction in cost of application (savings on chemicals, but also less refill cycles) and therefore also reduced impact on the environment [16].

5. CONCLUSIONS AND FUTURE WORK

In combination, the technologies that are described in this paper can be powerful drivers to model berry temperature, as already proposed [17]. Furthermore, ways to profile and describe a grapevine canopy and therefore the bunch environment better and with more sampling points (such as when using LIDAR) can help us to better understand and quantify the variability that is often measured in grape temperature or light interception, and perform better measurements to compliment research on the microclimate level.

It is also necessary to find ways to describe the grapevine canopy light and temperature environment better, in order to add value to regional/macro scale analyses such as those performed when satellite data are interpolated. This could improve current available decision making tools by incorporating meso- and micro-scale variability in temperature/light into existing models and to set up new models for the future.

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