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Integrating Geographic Information Systems and hemispherical photography in the assessment of canopy light profiles in a vineyard

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ABSTRACT

The light conditions in a vineyard primarily depend on the latitude of the vineyard and day of the year. Based on these parameters, the exact daily Sun path can be calculated with astronomical functions. However, effective Sun hours also depend on the topography of the territory, both for direct and diffuse radiation, as a result of the presence of hills and mountains on the Sun path (direct radiation) or, in general, reducing the sky fraction (diffuse radiation). A 360° orographic profile can be assessed by topographic survey, by using hemispherical pictures or Geographic Information Systems (GIS) and Digital Elevation Models (DEM). Moreover, row orientation, vine spacing, trellis system and height, leaf area density, exposure side, etc. further affect the light micro-climate within the canopy and, particularly, at bunch level, which may have consequences for the temperature and composition of the berries.

In the present work two grapevine row orientations (NS and EW) were used to integrate various tools (Photovoltaic Geographical Information System, Visual Basic functions for the calculation of solar position and radiation, and results from the processing of hemispherical pictures) into an Excel Worksheet, called "SunMask", that can be used as a new multi-purpose tool to 1) quickly calculate both the astronomic and the topographic sunrise, sunset, and maximum potential day length, 2) evaluate the effect of row orientation and canopy dimensions on the transmittance of the direct solar beam at high temporal resolution and, finally, 3) separate the effect of topographic and canopy masks on the Sun hours under clear-sky conditions.

By combining the different tools in SunMask, both the astronomic and topographic (as affected by the surrounding hills and mountains) sunrise, sunset, and maximum potential day length can be quickly and easily calculated for every specific vineyard terroir/location at any date or time in Europe, Africa and Asia. In addition, the software allows the evaluation of the effect of the canopy mask on the transmittance of the direct solar beam. SunMask will be a very important asset to improve information regarding radiation profiles of vineyards at *meso*- and micro-levels. It will be most valuable in the assessment of terroir suitability for vineyard establishment as well as for viticulture practice choices and the management of grapevine canopies.

1. Introduction

Light availability is a critical factor to be considered in the assessment of site suitability for viticulture, the structuring of vineyard establishment (row orientation, vine and row spacing, trellis system, height of the canopy), and canopy management (pruning, leaf removal, and shoot topping). However, although solar radiation is the driving factor for photosynthesis, maximum light interception is not always considered to be ideal. In fact, direct light absorbed by both leaves and berries causes an increase in temperature above air temperature as a result of energy balances (Draganov et al., 1975; Cola et al., 2009). Excessive heat can limit photosynthetic activity (Zulini et al., 2007; Hunter and Bonnardot 2011; Hochberg et al., 2015), increase leaf and berry respiration (Atkin et al., 2005), lead to sunburn on berries when coupled with high light intensity (Hulands et al., 2014), and affect grape composition detrimentally (Chorti et al., 2010; Ozden 2014; Sweetman et al., 2014).

Hochberg et al. (2015) suggested that the optimal growth temperatures of grapevines are cultivar dependent; a reduction of

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primary sugar concentration (glucose, fructose and sucrose) was more noticeable in Shiraz than in Cabernet Sauvignon. Zhang and Keller (2015) reported that berry transpiration seemed determined both by external factors (air temperature and relative humidity) and cultivar-specific internal factors (berry surface area and cuticular conductance). As all physiological processes are integrated, it would be very difficult to determine the real temperature-dependence ranges for optimal functioning of all the different physiological processes in the grapevine, especially under field conditions (Hunter and Bonnardot, 2011).

Spayd et al. (2002) separated sunlight and temperature effects on the composition of *Vitis vinifera* cv. Merlot grapes and found that exposure to sunlight increased total berry skin monomeric anthocyanin and flavonol concentrations regardless of temperature, in both years of study. Excessive absolute berry temperature, rather than the difference between berry temperature and ambient temperature, reduced anthocyanin concentrations in sun-exposed berries.

Giacosa et al. (2015) showed little influence of vineyard row orientation on grape quality parameters. An increase in the total titratable acidity for the East–West orientation, with respect to the North–South, was found. No effect on the mechanical properties of the skins or on anthocyanin concentration was observed. The main differences were related to the ripeness level of the grape. The riper grapes showed an increase in soluble sugars and pH, a decrease in titratable acidity and anthocyanin concentration, and lower values of skin mechanical property parameters related to skin softness, i.e. break force and energy.

Hunter et al. (2016) described the *meso*- and microclimatic conditions according to four row orientations, in the same experimental vineyard of the present work. In particular, photosynthetic active radiation measured on top of canopies was highest during the period November to January (Southern Hemisphere). Seasonal patterns of photosynthetic active radiation (PAR received in bunch zones at canopy microclimate level after being filtered by astronomic and topographic factors as well as adjacent canopies) showed that EW orientated rows maintained lower interior canopy interception than other row orientations; it decreased during the season as canopies developed, generally peaking just after mid-day. The NS orientation displayed highest values in the form of two clear peaks in morning and in afternoon, respectively, whereas NE-SW and NW-SE orientations showed peaks primarily in afternoon and morning, respectively. Average radiation reflection from soil (measured in the bunch zone) during the grape ripening period showed more or less similar trends, but interception shifted towards afternoon for NS and NE-SW orientations, whereas EW and NW-SE orientations showed uniform trends with optima at mid-day. Interestingly, in comparison to other orientations, EW orientated vine rows captured largest portion of total radiation received in the bunch zone from soil reflected radiation. Canopy interior temperature profiles did not show marked differences between treatments, except for respectively slightly lower and higher morning temperatures of EW and NS row orientations. Leaves of EW orientated vines had highest average photosynthesis, corresponding to stomatal conductance and transpiration. Most uniform canopy photosynthesis occurred for NS and NW-SE orientations. Photosynthesis trends practically demonstrated mirror diurnal images for canopy sides of each orientation.

Daily light availability in a vineyard depends first on the latitude of the site, and, secondly, on the date of the year, cloud cover, turbidity of the atmosphere, soil topography, and finally on the position in the canopy.

Based on geographic coordinates and day of the year, the exact daily Sun path can be calculated with astronomical functions as well as the times for sunrise/sunset, day length and solar noon. Both web-services and stand-alone software/applications to calculate the most important daily solar phases for a selected site are available. These applications mostly assume an ideal situation, where no hills or mountains obscure the view and where the flat horizon is at the same altitude than the observer. If the horizon in the direction of sunrise or sunset is at a higher altitude than that of the observer, the sunrise will be later and sunset earlier than listed. The reverse is also true: on a high mountain with the horizon below the observer, the sunrise will be earlier and the sunset later than listed. The maximum daily Sun hours received at a particular site therefore depend on the topography of the territory and the presence of hills and mountains on the Sun path (direct radiation) or, in general, the reduction of the sky fraction as a result of, e.g. cloudiness and air turbidity (diffuse radiation). To evaluate the effect of hills and mountains on the effective day length in a vineyard (*meso*-climate), the visible horizon should be evaluated and considered.

A 360° sky-ground profile can be created by topographic survey, by using hemispherical pictures and segmentation (Cornall et al., 2006; Cescatti, 2007) or Geographic Information Systems (GIS) tools, such as the "out_viewshed_raster" function (ESRI ArcGIS Solar Radiation Graphics) and r.horizon module (GRASS GIS; Neteler et al., 2012), which compute horizon angle height around a single point from a Digital Elevation Model (DEM).

Moving from above, into the canopy, i.e. to grape bunch level, the assessment of the light profile becomes more and more complex. Within the vineyard, row orientation, vine spacing, trellis system, canopy height and density, canopy management (topping, leaf removal) and tillage practices further affect the effective radiation available at bunch level.

The spatial distribution of leaves and stems in a canopy can be addressed using 3D modelling (Louarn et al., 2008; López-Lozano et al., 2009) and hemispherical photography (Cescatti and Zorer 2003; Phattaralerphong et al., 2006; Thimonier et al., 2010; Zorer et al., 2013).

In the present work, we integrate tools of the web application Photovoltaic Geographical Information System (PVGIS ©European Communities, 2001–2015), Visual Basic functions for solar position and radiation (SolRad, Washington State University, Washington State, USA), and, finally, results from the processing of hemispherical pictures at various levels and positions in differently orientated canopies (Gap Light Analyzer, Simon Fraser University, British Columbia, Canada) into a new multi-purpose Excel Worksheet tool, called SunMask, in order to 1) quickly calculate both the astronomic and the topographic sunrise, sunset, and maximum potential day length, as affected by the surrounding hills and mountains, 2) evaluate the effect of the canopy mask on the transmittance of the direct solar beam at high temporal resolution and, finally, 3) separate the effect of topographic and canopy masks on the Sun hours under clear-sky conditions.

2. Material and methods

2.1. Experimental site

A 3 ha vertically shoot positioned vineyard of *Vitis vinifera* L. cv. Shiraz (clone SH 9C), grafted onto rootstock 101–14 Mgt, was planted in 2003 at the ARC Infruitec–Nietvoorbij experiment farm in the Robertson wine region (−33.826° latitude North; 19.880° longitude East) of the Western Cape Province (South Africa) to four different row orientations (NS, EW, NE-SW, NW-SE) and five replicates for each orientation. Only NS and EW row orientations were considered in this study. The cordon height of the vines was 0.8 m and the average canopy height on the Vertical Shoot Position (VSP) trellis was approximately 1.2 m, with approximately 4 leaf layers from side to side.