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Assessment of an empirical spatial prediction model of vine water status for irrigation management in a grapevine field

C. Acevedo-Opazo[a], H. Valdés-Gómez[b,*], J.A. Taylor[c], A. Avalo[a], N. Verdugo-Vásquez[a], M. Araya[a], F. Jara-Rojas[a], B. Tisseyre[d]

[a] Universidad de Talca, Facultad de Ciencias Agrarias, CITRA, 2 Norte, 685 Talca, Chile
[b] Universidad de Talca, Facultad de Ciencias Agrarias, CITRA-CTVV, 2 Norte, 685 Talca, Chile
[c] Cornell University, Department of Horticulture, CLEREL, 6592 West Main Road, Portland, NY 14769, USA
[d] Montpellier SupAgro/Irstea, UMR ITAP, Bât. 21, 2 Pl. Pierre Viala, Montpellier 34060, France

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ABSTRACT

This study proposes and evaluates an empirically derived spatial model to extrapolate midday stem water potential (MSWP) measurements over a furrow irrigated grapevine field from a single reference site. The methodology used to build the model has previously been used successfully under non-irrigated conditions in France with pre-dawn leaf water potential. It has not previously been applied on irrigated vineyards with moderate water restriction and using MSWP. The precision of the model was calibrated and validated using a database of MSWP measurements collected from a commercial Cabernet Sauvignon (*Vitis vinifera* L.) vineyard located in the Maule Region, Chile, at various times during the 2009–2010, 2010–2011 and 2011–2012 growing seasons. The proposed spatial model was able to predict the spatial variability of MSWP with an RMSE < 0.12 MPa. Also, the model significantly improved the prediction of MSWP ($r^2 = 0.76$) compared to the conventional monitoring carried out by winegrowers ($r^2 \leq 0.48$) under conditions of absent to severe water restriction (>−0.5 to −1.3 MPa). The choice of the reference site for vine water status monitoring is important regardless of the method used. Results also showed that irrigation practices may impose a specific soil moisture regime in parts of the field; thus the selection of a reference site that is representative of the field conditions is very important for good model performance under irrigated conditions. Variability in soil and ground cover properties, rather than vine vigour, appeared to be the best information for assisting in the correct location of reference sites.

1. Introduction

In a recent study, Acevedo-Opazo et al. (2010b) discussed the importance of monitoring the spatial variability of vine water status for scheduling differential field management due to the known effects of vine water status on yield and grape quality (Acevedo-Opazo et al., 2010a; Champagnol, 1984; Dry and Loveys, 1998; Ojeda et al., 2004; Seguin, 1983). In the case of irrigated vineyards, several studies have shown that water potential measurements are the preferred method for controlling irrigation, particularly when regulated deficit irrigation (RDI) is a common management practice (Acevedo-Opazo et al., 2010a; Acevedo-Opazo et al., 2008b; Girona et al., 2006; Ojeda et al., 2002). Vine irrigation management can then be aimed at maintaining the water potential between an optimal range of values (that varies depending on the variety and the type of management) during the major vine phenological periods in order to produce good quality grapes. In a related body of work, spatial prediction models to extrapolate vine water status measurements over a whole field from a single reference site have also been proposed (Acevedo-Opazo et al., 2008a; Acevedo-Opazo et al., 2010b). The application of these spatial models has enabled the characterization of the spatial variability of vine water status within a field. Acevedo-Opazo et al. (2008b) proposed that, at the within-field level, the spatial model took into account the relative difference in vine water status between a reference point and all other sites across the vine field. Subsequent work has shown that the vine water status response between the reference site and any other point in the field was linear and temporally stable under non-irrigated conditions (Acevedo-Opazo et al., 2010b).

Once calibrated, the model is able to spatially extrapolate vine water status over the whole field at a given date from only one reference measurement at that date. The model developed was tested successfully in non-irrigated vine fields in France and the results showed that the model accuracy increased with increasing water restriction during the season. In such conditions, the predawn leaf water potential (PLWP) was used as standard measure

* Corresponding author. Tel.: +56 71 200426; fax: +56 71 201695.
E-mail address: hevaldes@utalca.cl (H. Valdés-Gómez).

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to characterize vine water status. PLWP is widely used to monitor the water status of non-irrigated vineyards (Ojeda et al., 2002; Tisseyre et al., 2005, 2007; Tregoat et al., 2002). From a practical standpoint, the proposed approach has limitations since in non-irrigated conditions its main use is to make a selection of the harvest quality at the within-field level. Several authors have proposed optimal plant water status ranges at specific phenological stages (Ojeda et al., 2004; Pellegrino et al., 2006). Therefore, for each site of the field it becomes possible to identify the dynamic of the plant water status and the resulting quality that is expected. Under irrigated conditions, the spatial extrapolation approach proposed has a greater interest since it may be used for irrigation decision-making.

The advantage of the proposed spatial model of plant water status is that once it is calibrated, it provides a method that minimizes the cost of acquisition of the information, since only one measurement on the site of reference is necessary, while providing a relevant spatial estimation of the plant water status over the whole field. However, according to Acevedo-Opazo et al. (2010b), some assumptions must be respected for the implementation of the model. The spatial structure of the PLWP measurements and the linear relationship between the reference point and any other point in the field is assumed to be due to spatial differences in the plant available water content of the soil, which itself is a factor of soil type, rooting depth and landscape position. However there are other factors that may affect the linear relationship between the reference site and the other sites of the field. These factors include possible differences in the plant material (variety and rootstock), vine age, vine training system, cultural practices (such as fertilization), disease infestation and micro/meso-climate. It is assumed that these factors are either uniform (e.g. vine age, trellis) or exhibit a low level of spatial variability that does not affect the spatial structure of the vine water status (e.g. pest/disease pressure) at the field scale (<5 ha). However, under irrigated conditions, it is possible that irrigation practices could significantly affect the spatial structure of plant water status due to heterogeneous water application, particularly in gravitational systems, i.e. the spatial structure of the plant available water in the soil could be a result of management rather than environmental variability. It is therefore of interest to test the approach developed by Acevedo-Opazo et al. (2010b) under irrigated conditions to see if accurate plant water status maps can be generated and then used effectively for site-specific irrigation and vine management.

As was stated above, the use of such a model in irrigated vineyards raises several questions that need to be considered:

(i) Irrigation strategies may affect both the linear relationship between two sites and the temporal stability of this relationship;
(ii) Irrigation leads to more moderate water restrictions than those observed in non-irrigated Mediterranean conditions where vines experience significant water restriction towards the end of the growing season. Therefore, in irrigated conditions, the spatial structure may be more difficult to identify or of little value compared to the current traditional approach of irrigation management that is based on a field average of plant water status measurements from a couple of sites;
(iii) The moderate water restriction generally observed in irrigated conditions often requires the use of midday stem water potential (MSWP) measurements (Girona et al., 2006; Ojeda et al., 2002) instead of PLWP. MSWP is a preferred physiological indicator of plant water status under irrigated conditions, as PLWP has been reported as an inadequate indicator of plant water status for drip-irrigated grapevines (Acevedo-Opazo et al., 2008b). The use of MSWP as a reference measurement has not been previously tested in the proposed extrapolation model (Acevedo-Opazo et al., 2010a; Acevedo-Opazo et al., 2008b; Girona et al., 2006; Ojeda et al., 2002).

Therefore the objective of this work is to investigate the feasibility of extrapolating individual MSWP measurements to several unsampled locations in an irrigated Cabernet Sauvignon field using the methodology proposed by Acevedo-Opazo et al. (2010b). Scientific questions that will be addressed in this paper include: do the temporally stable linear spatial relationships observed between PLWP measurements in non-irrigated vineyards exist for MSWP measurements in irrigated vineyards?; are these relationships sufficiently accurate and robust enough to be used for irrigation decision-making, especially compared to a more conventional (non-spatial) decision-making?; and, are there particular vine or vineyard properties that can assist in identifying suitable (or unsuitable) sites for reference measurements for these spatial models (and for conventional non-spatial methods)? This last question seeks to use the information from this spatial analysis to improve current non-spatial approaches to irrigation decision-making if the spatial model is not considered feasible or preferable.

2. Materials and methods

2.1. Experimental field

The data was collected from a 1.6 ha Cabernet Sauvignon (*Vitis vinifera*) field that is part of the University of Talca's experimental vineyard (Maule Valley, Chile; 35°22.2′ S, 71°35.39′ W, WGS84, 121 m.a.s.l.) during the 2009–2010, 2010–2011 and 2011–2012 growing seasons. This region is characterized by Mediterranean climatic conditions. The vineyard soil is classified as Ultic Haploxeralfs (clay loam texture) (Soil Survey Staff, 1999) and has an average slope of ~1%. The vineyard was planted in 1998 using own-rooted plants with a spacing of 1.5 m between vines and 3.0 m between rows that are orientated E-W. The vines were trained in a vertical shoot positioned system with a total height above the ground of 2.0 m. Vines were irrigated using furrow irrigation, five, four and five times in the 2009–2010, 2010–2011 and 2011–2012 seasons, respectively. Total irrigation ranged between 360 mm to 450 mm. Irrigation was considerable higher than the within-season rainfall, which ranged from 10 to 100 mm and occurred predominantly early in the season. The vineyard was managed using the standard agricultural practices for commercial vineyards in central Chile (canopy management, fertilization, pest and disease control, pruning and irrigation) over the three years of the experimentation. Within the field, two regular grids were defined, one of 59 measurement sites (Grid 1) and other of 18 sites (Grid 2) (Fig. 1). Each grid point was represented by four vines within the row (two vines either side of the grid point). Field boundaries and the within-field sampling sites were geo-referenced using a differential global positioning system (DGPS) receiver (Trimble, Pathfinder ProXRS, Sunnyvale, California, USA) and stored as Eastings and Northings coordinates (Datum WGS84, Projection UTM, Zone 19) to allow mapping and spatial analysis. The elevation of each point in Grid 1 was also obtained from the DGPS receiver.

An automatic weather station (Adcon Telemetry, A730, Klosterneuburg, Austria) installed above a grass cover next to the experimental field was used to measure air temperature, relative humidity, solar radiation, precipitation, wind velocity and direction at 30 min intervals. The sensors were located 2.5 m above the ground, with the exception of the temperature and relative humidity sensors that were located 1.5 m above the ground. This