A COMMENT ON INTER-FIELD SPATIAL EXTRAPOLATION OF VINE (*VITIS VINIFERA* L.) WATER STATUS

TAYLOR J.A.[1]*, ACEVEDO-OPAZO C.[2], GUILLAUME S.[3], OJEDA H.[4] and TISSEYRE B.[5]

1: INRA, UMR LISAH, Bât. 24, 2 Pl. Pierre Viala, 34060 Montpellier, France
2: Universidad de Talca, Facultad de Ciencias Agrarias, CITRA, Casilla 747, Talca, Chile
3: Cemagref, UMR ITAP, 34196 Montpellier, France
4: INRA, Experimental Station of Pech Rouge, 11430 Gruissan, France
5: UMR ITAP, Montpellier SupAgro/Cemagref, Bât. 21, 2 place Pierre Viala 34060 Montpellier, France

Abstract

Aim: Recent work has identified strong intra-field relationships of pre-dawn leaf water potential (Ψ_{PD}) between paired sites. This study investigates if these relationships exist at the inter-field level when soil types between fields are constant or different in a vineyard in Southern France.

Method and result: Nine fields were sampled for Ψ_{PD} on 6 dates over two growing seasons. When general assumptions of uniformity in climate, growing conditions and soil moisture were able to be met, a linear relationship between the mean Ψ_{PD} responses of different fields was observed. The relationship was no longer linear when the soil moisture regime between fields differed.

Conclusion: The results indicate that it should be possible to extrapolate a reference Ψ_{PD} value across a production region (syndicate/co-operative) defined on a similar soil type.

Significance and impact of study: These intra-field relationships may minimise the need for Ψ_{PD} sampling to define irrigation/crop management in areas planted to similar soil types. The poor fit between fields with differing soil moisture regimes indicates that the original intra-field model may be flawed in larger fields or vineyards with heterogeneous soil moisture conditions.

Key words: pre-dawn leaf water potential, soil moisture, spatial variability

Résumé

Objectifs: Un article scientifique récent a mis en évidence l'existence d'une relation linéaire entre deux mesures de potentiel hydrique de base (Ψ_{PD}) effectuées sur deux sites différents à l'intérieur d'une même parcelle. Ce travail a pour objectif d'étudier l'existence d'une telle relation entre parcelles.

Méthodes et résultats: Les mesures de Ψ_{PD} ont été effectuées sur neuf parcelles différentes. Six dates de mesure réparties sur deux années consécutives ont été considérées. Dans un contexte où les hypothèses relatives à l'uniformité des conditions climatiques et des pratiques culturales peuvent être considérées comme acceptables, une relation linéaire a été mise en évidence entre les parcelles. Cette relation linéaire est altérée lorsque le fonctionnement hydrique des sols diffère trop d'une parcelle à l'autre, par exemple en présence d'une nappe d'eau superficielle.

Conclusion: La relation linéaire des Ψ_{PD} mise en évidence au niveau intra-parcellaire par des travaux précédents peut être extrapolée à une échelle inter-parcellaire lorsque les parcelles appartiennent à la même unité pédologique (UP) ou lorsque les UP présentent des fonctionnements hydriques similaires.

Signification et impact de l'étude: Une fois caractérisée, la relation inter-parcelle identifiée permet de minimiser le nombre de mesures Ψ_{PD} nécessaires pour le suivi de l'état hydrique de la vigne. Dans ces conditions, les résultats montrent qu'il est possible d'extrapoler spatialement une Ψ_{PD} à un territoire plus vaste que la parcelle (vignoble, bassin versant). Cette approche n'est plus pertinente lorsque le territoire considéré s'étend sur des UP présentant des fonctionnements hydriques différents.

Mots clés: potentiel hydrique de base, humidité du sol, variabilité spatiale

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*Corresponding author: jtesque@yahoo.com

INTRODUCTION

In a recent paper, Acevedo-Opazo *et al.* (2010a) demonstrated that the seasonal evolution of pre-dawn leaf water potential (Ψ_{PD}) between any two sites within a field was linear. The slope of this relationship was shown to be site-specific but temporally stable over a period of two seasons. The practical implication was that the Ψ_{PD} value of any unknown site (s_i) within a field could be predicted from a single reference site (s_{re}) provided that the site-specific co-efficient between s_i and s_{re} was known.

The results presented by Acevedo-Opazo *et al.* (2010a) were limited to intra-field measurements in small fields (~1 ha) from a vineyard in the south of France; however, in their model development they explicitly hypothesised that the domain (D) for this relationship may be larger, that is, across several fields or a whole vineyard. The conditions of this hypothesis were the presence of a homogeneous climate and production/management practices, including cultivar, rootstock, vine age, trellising and disease management.

In this short communication, the approach outlined in Acevedo-Opazo *et al.* (2010a) is used to investigate if linear Ψ_{PD} relationships exist at the inter-field scale. This analysis is performed in the same vineyard as the original study (i.e., a vineyard with small fields); however, the outcome will have implications for vineyards with both small and large fields. By investigating linear inter-field relationships it will be possible to:

a) identify the relevance of extrapolating Ψ_{PD} values between fields in French (or other small-scale) production systems, with implications for how Ψ_{PD} and irrigation may be managed within a co-operative or syndicate structure, and

b) hypothesise if the results are likely to be reproducible in production systems with greater inter-field soil variability (generally larger fields) such as those in Australia and North and South America.

METHODS

1. Model and theory

The proposed linear model (Eq. 1, using the notation of Acevedo-Opazo *et al.* 2010a) provides an estimation of the predicted plant water status $\hat{z}(s_i, t_j)$ at a location s_i (with $s_i \in \mathrm{D}$ and $s_i \neq s_{re}$) at time t_j from a measurement at a reference location at the same time ($z_{re}(s_{re}, t_j)$) using a site-specific coefficient a_{si}, which is able to model the difference in plant water status between s_i and s_{re}.

$$\hat{z}(s_i, t_j) = a_{si} \bullet z_{re}(s_{re}, t_j), \quad s_{re} \in \mathrm{D}, \quad \forall s_i \in \mathrm{D}, \quad a_{si} \in \Re \quad (1)$$

a_{si} is considered to be dependent on differences in permanent attributes (soil water availability, soil depth, topography, etc.) between locations s_i and s_{re}.

When considering an inter-field relationship, it is possible to define the unknown and reference locations in terms of individual site values or mean field values. That is, as indicated in Figure 1, a Ψ_{PD} value from a reference site ($z_{re}(s_{re}, t_i)$) in one field may be used to extrapolate Ψ_{PD} to an unknown site ($\hat{z}(s_i, t_j)$) in another

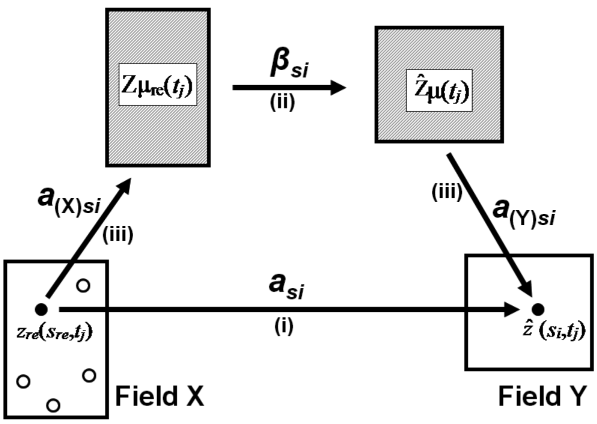

Figure 1 - Schematic relationship extrapolating (i) between two individual sites in different fields, (ii) between two field means and (iii) from an individual site to a field mean (or vice versa) within the same field.

Shaded polygons indicate a field mean either measured ($Z\mu_{re}(t_j)$) or unknown ($\hat{Z}\mu(t_i)$).

Solid circles (●) indicate the location to either extrapolate to $\hat{z}(s_i, t_j)$ or extrapolate from $z_{re}(s_{re}, t_j)$.

Open circles (○) indicate values also included in the estimation of the reference field mean ($Z\mu_{re}(t_j)$).

field (individual site values) or the mean Ψ_{PD} response of a reference field ($Z\mu_{re}(t_j)$) may be used to extrapolate the unknown mean Ψ_{PD} response ($\hat{Z}\mu(t_j)$) of another field (mean field values). This second case is likely to be much more practical in a commercial production system as the mean field estimate requires less intensive *a priori* data collection and, given current management practices, most producers would prefer information that permits the extrapolation of a mean Ψ_{PD} response from one field to another. It is possible to aggregate or disaggregate between field means and individual site values if the field mean is considered as the reference value (Fig. 1) as the linear operators are multiplicative. The following analysis will focus on the linearity between field means (β_{si}). Validating β_{si} simultaneously validates a_{si}.

2. Data

The data used for this analysis were new data collected in the Pech Rouge vineyard in Gruissan, Aude, France. A detailed description can be found in Taylor *et al.* (2010). Briefly, nine non-contiguous fields were sampled for Ψ_{PD} at two dates in 2006 and four dates in 2007. The nine fields were split evenly between three soil units; a) Littoral - Endosalic Arenosols with a shallow watertable, b) La Clape - Calcisols (skeletic) and, c) Colombier - Calcisols/Regosols (clayic) (IUSS Working Group WRB, 2006). Three sampling sites, stratified by vegetative expression, were selected per field and either nine (2006) or five (2007) measurements were taken at each site. This gave 27 (2006) or 15 (2007) measurements per field to estimate the field mean. Acevedo-Opazo *et al.* (2010a) demonstrated that the intra-field relationship was season independent; therefore, the two years were combined to form a single database of six measurement dates totalling 54 mean field values. The cultivars differed over the survey fields, however, previous work (Taylor *et al.*, 2010) has shown that cultivar differences exhibit a small effect on Ψ_{PD} compared with vegetative expression and edaphic differences.

3. Analysis

Following the methodology of Acevedo-Opazo *et al.* (2010a), a linear regression, constrained to pass through the origin, was performed between the mean response for each pair of fields and the fits (r^2) and slopes (β_{si}) were recorded.

Equation 2 was used to compute the standard error of calibration (SEC) between any two fields (X and Y). The $SEC_{X(Y)}$ results were then averaged within and between each of the soil units. A cross-validation approach was not employed here since the number of data (6 dates) is limited.

$$SEC_{X(Y)} = \sqrt{\frac{\sum_{j=1}^{m}\left[Z\mu_{re}(t_j) - \hat{Z}\mu(t_j)\right]}{m-1}} \qquad (2)$$

where m is the number of measurement dates ($m = 6$), $Z\mu_{re}(t_j)$ is the measured mean Ψ_{PD} of Field X and $\hat{Z}\mu(t_j)$ is the extrapolated mean Ψ_{PD} of Field Y.

RESULTS

The mean field Ψ_{PD} values ranged from low (-0.12 MPa) to extreme (-1.13 MPa) water stress over all dates and from -0.23 to -1.13 MPa for the late season

Table 1 - Fits (r^2) and slopes (β_{si}) of the linear relationships between the nine survey fields.

Fields are grouped according to soil type. The left-bottom half shows the r^2 values with values between fields on the same soil type shown in bold and any other value > 0.80 shown in italics. The top-right half (shaded in grey) shows the β_{si} values again with values within soil types shown in bold.

	Littoral (Sand)			La Clape (Limestone)			Colombier (Marlstone)		
	Field A	Field B	Field C	Field D	Field E	Field F	Field G	Field H	Field I
Field A		**1.00**	**0.82**	0.19	0.35	0.28	0.30	0.23	0.34
Field B	**0.86**		**0.58**	0.12	0.25	0.20	0.14	0.14	0.21
Field C	**0.53**	**0.30**		0.25	0.39	0.32	0.53	0.33	0.44
Field D	0.35	0.16	0.72		**1.58**	**1.22**	1.72	0.97	1.56
Field E	0.44	0.26	0.70	**0.98**		**0.77**	1.00	0.57	0.95
Field F	0.49	0.29	0.79	**0.97**	**0.98**		1.37	0.81	1.27
Field G	0.22	0.05	*0.87*	0.77	0.67	0.75		**0.58**	**0.78**
Field H	0.37	0.15	*0.93*	0.67	0.59	0.71	**0.93**		**1.28**
Field I	0.42	0.18	*0.87*	*0.93*	*0.88*	*0.94*	**0.90**	**0.88**	

measurements. This indicates that there was a large difference in mean plant response (and soil moisture regime) between the selected fields. Fields with a similar level of water stress will have a β_{si} of ~1. The large range of β_{si} values (Table 1) reflects the high level of variance in mean Ψ_{PD} within the survey.

The r^2 values of the linear fits between the nine fields, grouped according to soil units, are shown in Table 1. Moderate to strong linear relationships were observed between fields within and between the La Clape and Colombier units (r^2 in [0.59, 0.98]) even though there were different levels of water stress experienced ($0.57 \leq \beta_{si} \leq 1.72$). All these fields relied on stored soil moisture and experienced moderate to high late-season water stress ($\Psi_{PD} < -0.57$ MPa). Within the Littoral unit the relationship between fields was not as strong (r^2 in [0.30, 0.86]) especially between Field C and the other fields (A and B). This is due to a variable watertable depth within this soil unit that created different soil moisture regimes. Fields A and B had a strong relationship and similar soil moisture regime ($r^2 = 0.86$; $\beta_{si} = 1.00$) while Field C exhibited more linear relationships (r^2 in [0.70, 0.93]) with fields of the other two soil units (D - I) than with Fields A and B.

The SEC analysis yielded a mean SEC of 0.064 MPa between fields on the same soil type and 0.096 MPa between fields on different soil types. These values are similar to the SEC values (0.090 and 0.087 MPa, respectively) obtained by the intra-field analysis of Acevedo-Opazo *et al.* (2010a).

DISCUSSION AND CONCLUSIONS

The results showed that extrapolations between fields on a similar soil type were likely to be more effective than extrapolations across soil types. However many of the fits between fields on different soil types were still similar to the median intra-field fit ($r^2 = 0.90$) identified by Acevedo-Opazo *et al.* (2010a). All fits between La Clape and Colombier fields were equal to or greater than the worst intra-field fit ($r^2 = 0.59$) from Acevedo-Opazo *et al.* (2010a). Extrapolation therefore appeared to be feasible between fields on different soil types if the general soil moisture regimes of the two soil types were similar. These linear relationships did breakdown when the soil moisture regimes were variable, even within soil units as in the case of the Littoral unit. While soil moisture differences in this vineyard are related to watertable fluctuations, the authors acknowledge that there are several other soil/landscape effects that could also influence plant available soil moisture, such as preferential subsurface flows or possible combinations of soil texture and effective rooting depth.

These results have several implications for global vineyard systems. In France, where cooperative/syndicate structures are often defined by soil units, a single (or several) reference field(s) could be used to extrapolate values across the co-operative/syndicate. This may make pre-dawn leaf water potential measurements viable, in terms of labour and expense, if the results and costs are spread over the co-operative/syndicate. In countries with larger vineyard fields, both intra- and inter-field Ψ_{PD} relationships will be dependent on the level and type of soil variation in the field. However, if the soil moisture regime is similar between all soil types within a field, then the linear relationships in Ψ_{PD} are expected to hold true.

More recent work (Acevedo-Opazo *et al.*, 2010b) has also shown that it is possible to spatialise these linear relationships using high to medium resolution ancillary data. However, their approach relies on a linear response, thus soil variation may be a severe constraint to the up-scaling of existing field-scale linear spatial models of Ψ_{PD} to vineyard and regional scales.

Finally, we note that this analysis has been performed with data from only six dates, which may mask some inaccuracies and inflate (or deflate) the values in Table 1. Nevertheless, the results obtained strongly support the existence of linear relationships in Ψ_{PD} between areas (or points) at scales larger than that of an individual field (of ~1 ha).

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