The effect of topography on the spatial variability of grapevine vegetative and reproductive components

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Abstract

Topography variation is one of the main causes for vineyard variability. Terrain attributes, such as slope, altitude and aspect are highly variable and have an impact on soil depth, water holding capacity, air and soil temperature, radiation exposure, among other factors. Patterns of topographic variability tend to be stable over time, therefore recognizing such patterns can potentially provide the winegrower with relevant economic returns. A study was conducted in 2015, in a vineyard located at Tapada da Ajuda, Lisbon (slope range from 7% to 9%; southern orientation). Four white varieties (*Alvarinho*, *Viosinho*, *Encruzado* and *Arinto*) were analyzed regarding their vegetative development, yield and grape quality. This study had two main objectives: (i) to evaluate the magnitude of the spatial variability among varieties and (ii) to evaluate the effect of the terrain position (TP) in each variety, individually. Smart points (SP) were selected for each variety, organized according to their slope position (uphill, mid-slope and downhill) and vegetative and reproductive data was collected at relevant phenological stages (pre-flowering, flowering, veraison and full maturation). *Alvarinho* and *Arinto* varieties presented the highest spatial variability, regardless of their position along the slope. Yield and leaf-to-fruit ratio were the most variable parameters (coefficient of variation>30% in all varieties) with no correlation with TP. *Encruzado* showed higher vegetative development (+36% leaf area index and +18% exposed leaf area) in downhill SPs, while *Arinto* presented higher bud burst percentage (+49%) and lower water-shoot development (-30%) in downhill SPs. In these cases, canopy development parameters were influenced by TP. Such information can be used for a differentiated scheduling of canopy management activities e.g. canopy thinning and water-shoot removal, tasks that are expensive and time consuming. This study created a basis for further research that can lead to more accurate vineyard design planning and management.

Keywords: Precision viticulture, vineyard spatial variability, topographic position, slope.

Resumo

Efeito da topografia sobre a variabilidade espacial dos componentes vegetativo e reprodutivo da videira

A variação topográfica consiste numa das principais causas de variabilidade espacial na vinha. Atributos topográficos como o declive, a altitude e a orientação são muito variáveis e têm impacto na profundidade dos solos e respetiva capacidade de retenção de água, temperatura do ar e do solo, exposição solar, entre outros fatores. Os padrões de variabilidade topográfica tendem a ser constantes ao longo do tempo, por isso o reconhecimento de tais padrões poderá ter um impacto benéfico na gestão da vinha e trazer ao viticultor retornos económicos interessantes. Em 2015 foi instalado um ensaio numa vinha localizada na Tapada da Ajuda, Instituto Superior de Agronomia, Lisboa (declive entre 7% a 9%; orientação sul). Foram estudadas quatro castas (*Alvarinho, Viosinho, Encruzado* e *Arinto*), tendo em conta o seu desenvolvimento vegetativo, produção e composição da uva. Este estudo teve dois objetivos principais: (i) avaliar a magnitude da variabilidade espacial entre castas e (ii) avaliar o efeito da posição topográfica (TP) em cada casta, individualmente. As unidades experimentais (SP) foram selecionadas tendo em conta o seu posicionamento ao longo da encosta (montante, meia encosta e a jusante da encosta) onde foram colhidos dados referentes ao desenvolvimento vegetativo, produção e composição das uvas, durante estados fenológicos relevantes (botões florais separados, floração, pintor e maturação), dependendo do parâmetro medido. As castas *Alvarinho* e *Arinto* apresentaram a maior variabilidade espacial, quando analisada independentemente da sua posição ao longo da encosta. A produção total de uva e o rácio folha/fruto foram os parâmetros com maior variabilidade em todas as castas (coeficiente de variação >30% em todos os casos), no entanto, sem correlação com a TP. A casta *Encruzado* apresentou maior desenvolvimento vegetativo (+36% área foliar e +18% de superfície foliar exposta) em SPs a jusante da encosta. A casta *Arinto* apresentou maior percentagem de abrolhamento (+49%) e menor percentagem de sarmentos ladrões (-30%) em SPs a jusante da encosta. Em ambos os casos os parâmetros indicadores do desenvolvimento vegetativo foram influenciados pela posição topográfica das plantas. Esta informação pode ser útil para gerir diferenciadamente as operações culturais, por exemplo tarefas caras e morosas como a desponta e o esladroamento, permitindo uma melhoria da planificação e gestão da vinha.

Palavras-chave: viticultura de precisão variabilidade espacial da vinha, posição topográfica, declividade do solo

Introduction

Spatial variability in vineyards has always been known to exist and has been demonstrated in several works in terms of yield (Bramley & Hamilton, 2004, 2007; Bramley, 2009), vegetative development (Johnson *et al.*, 2003; Bramley & Hamilton, 2007; Acevedo-Opazo, 2008) and grape composition (Bramley, 2005). Such variation has an impact on final wine quality and yield and thus on the economic value of the vineyard plots (Bramley & Hamilton, 2004). Precision Viticulture (PV) approaches bring ways to identify this variability, enabling technical decision making to become more robust and targeted (Lamb & Bramley, 2001) with potential benefits regarding inter-annual production stability, traceability of the productive process, efficient use of resources and identification of zones with different grape composition (Braga, 2009). Different vineyards or plots may be managed to achieve different goals, such as higher yields, regardless of quality, or higher quality in limited yields. To achieve such goals, one of the core steps that allow PV approaches is to study the possible causes that affect spatial variability.

The vegetative and reproductive performance variability in a vineyard is mainly driven by the variation of the topography (Bramley, 2009), while patterns of this variation tend to be stable through time. Although vineyards have always been known to be spatially variable, due to the lack of tools or methods to accurately observe and measure this variation, winegrowers conventionally manage vineyards as if they were homogenous (Bramley, 2005). A management focused on identifying differential performing zones is more appropriate than the uniform and more conventional approach and has the potential to provide relevant economic benefits (Bramley *et al.*, 2005).

In regions located at very low latitudes, typically, higher altitudes are preferable when planning vineyard sites, while the opposite is true for higher latitude regions (Goldammer, 2015). This has to do with the decrease in temperature as the elevation increases, causing some sites to only be acceptable for viticulture practices if their elevation allows it (Goldammer, 2015). In other regions where such extreme conditions are not present, altitude variations may still have an impact on several features such as sugar levels and total acidity (Stajnko *et al.,* 2010). Apart from temperature variation, uphill zones tend to have shallower soils and thus less soil water holding capacity. In non-irrigated vineyards, this difference might impact water availability in a way that may influence grape sugar concentration (Stajnko *et al.,* 2010) or vegetative development. Yield can also be affected by soil depth variability resulting from plant position along the slope, where downhill positioned grapevines will commonly have higher yield values, as compared to uphill ones (Bramley & Hamilton, 2005).

While some topography effect trends tend to be consistent from region to region, different varieties may behave differently when subject to variable terrain positions (TP). The purpose of the present study is twofold: the first objective is to evaluate the magnitude of the spatial variability among four Portuguese varieties (*Alvarinho*, *Viosinho*, *Encruzado* and *Arinto*) and the second one is to evaluate the effect of the TP in each variety.

Materials and methods

Site description

The work reported here was carried out in 2015, in a vineyard located at Tapada da Ajuda, within the Lisbon wine region. The vineyard, with an area of 1.7 ha, was planted in 2006 with a density of 4000 plants/ha (spacing of 2.5m between and 1.0 m in row), spur pruned and trained on unilateral Royat cordon system using vertical shoot positioning with two pairs of movable wires. The vineyard presents a slope range from 7% to 9%, a southern orientation and is located approximately 50 m above sea level.

Four white varieties (*Alvarinho*, *Viosinho*, *Encruzado* and *Arinto*) were analyzed regarding their vegetative development, yield and grape quality. Out of the varieties studied, *Encruzado* is crafted on 1103Paulsen rootstock, while the remaining ones are crafted on 110Ritcher rootstock. The vineyard presents a drip irrigation system and is fertilized according to needs shown by systematic petiole analysis throughout the growing cycle. Differences in nutritive needs were not observed (visually) among experimental units.

The *Alvarinho*, *Viosinho, Encruzado and Arinto* varieties presented an altitude difference of -9.26m, -7.05m, -5.71m and -4.15m, respectively, between the highest and the lowest SP.

Smart points (SP) were selected in a single row for each variety, organized according to their slope position (uphill, mid-slope and downhill) in a total of 84 grapevines (14 SPs, 6 plants each). Soil differences along the rows were not significant (data not shown) and thus not taken into account.

Data collection

The phenological development of all grapevines was observed individually, every week, throughout the whole trial. The number of spurs and buds, trunk height, arm length, grapevine base diameter, number of shoots, water shoots and number of inflorescences were collected only once, either at the beginning of the vegetative development or at the visible inflorescences stage, because of its temporal stability during the length of this trial. The bud burst percentage and the percentage of water-shoots was calculated. Leaf area (LA) and exposed leaf area (ELA) were estimated 2 weeks before the beginning of flowering, at full flowering and at the veraison, using the methods developed by Lopes & Pinto (2005). After veraison, for four consecutive weeks, grape maturity was evaluated by: must volume, total soluble soils (TSS, expressed in ^{o}Brix), potential alcohol, total acidity and pH. At harvest, the total yield, the cluster number and weight and the average grape weight was accounted for. The leaf-to-fruit ratio was also calculated. In total, 23 parameters were evaluated, some of them more than once, making a total of 26 analyzed variables.

Statistics

All data were subject to a descriptive statistical analysis. The main parameter used for discussion was the coefficient of variation (CV). CVs between 10% and 29% were considered variable, while CVs equal or higher than 30% were considered highly variable (Gomes, 1990). This analysis was done independently of the plants' terrain position and was used for purposes related to the first objective of this work: overall vineyard spatial variability.

The same data were then subject to an analysis of variance (ANOVA) to verify if there were significant differences between SPs of the same variety and if so, if these differences were correlated to the terrain position variation.

Results and discussion

Concerning the first objective of this work – the total spatial variability regardless of the TP – the variability encountered was very significant, as all varieties presented a high number of parameters with CV values higher than 10%. *Viosinho* variety showed the most homogeneous behavior across all parameters, while *Alvarinho* and *Arinto* varieties presented the highest spatial variability. Yield and leaf-to-fruit ratio were the most variable parameters (coefficient of variation>30% in all varieties). The ability for grapevines to ripen their fruits adequately is mainly determined by their leaf area, especially the one directly exposed to sunlight (Kliewer and Dokoozlian, 2005). Thus, leaf-to-fruit ratio is an indicator of potential grape quality as it reflects grape maturation values and final grape composition, namely the concentration of TSS (Kliewer and Weaver, 1971). However, while this ratio was highly variable in this study, it showed no apparent impact on TSS (expressed in ^{o}Brix) as well as other fruit quality parameters (Table 1).

Regarding the effect of the TP, some parameters showed statistically different values among SPs, however not all of these presented a correlation with the TP variation.

The *Viosinho* variety presented no parameters which variability was correlated to the TP variation. No data is shown for this variety due to the lack of relevant results.

For the *Alvarinho* variety only one minor case was observed, concerning the effect of the TP, showing a faster phenological development of the grapevines located in the downhill SP during the first 10 weeks (up until the visible inflorescences stage), after which there was a homogenization and the phenological development of all SPs was statistically the same from then on. No data is shown for this variety due to the lack of relevant results.

For the *Encruzado* variety its altitude variation was enough to cause a significant difference in the LA development two weeks before the flowering stage, with the SPs located downhill having higher values, +36% (Table 2). For the same variety, the same altitude difference caused a higher ELA development (+18%, Table 2) also in the downhill SP, at the flowering stage up until the veraison stage, when the last vegetative measures were collected. As the ELA is mainly affected by the canopy height, higher ELA values are related to a taller canopy. Such information has an impact on leaf-to-fruit ratio variability and is valuable for canopy management practices such as trimming and moving the trellis wires. Both ELA and LA are related to vegetation development. A probable cause for this variety to have shown higher values in downhill zones might be related to a higher soil water capacity within these SPs, sufficient to promote significant differences especially in early stages of development (pre-flowering and flowering) when irrigation was not a factor yet, as the vineyard was not irrigated until mid May 2015 - in general this date corresponded to when the fruit development started for most varieties (BBCH stage 71 – fruit setting).

As for the *Arinto* variety, a higher bud burst percentage and a lower percentage of water-shoots were observed at downhill SPs (+49% and -30%, respectively, Table 3). A higher number of water-shoots might result either on denser vegetation or higher amounts of time spend on desuckering. Higher vegetative density can have an impact on canopy microclimate, decreasing air flow inside the canopy while causing less cluster exposure, thus potentially affecting grape composition and health. Higher amounts of time desuckering means higher labor costs.

Conclusions

Regarding the first objective, this study shows that,– general vineyard spatial variability –, the *Viosinho* variety stood out by showing a very homogeneous behavior, while *Alvarinho* and *Arinto* varieties presented highly heterogeneous trends. It also showed that leaf-to-fruit ratio was the parameter with the highest variability, while grape quality variables were homogeneous, which brings into question its viability as a safe indicator of potential grape quality.

Concerning the second objective – effect of the terrain position –, it is possible to conclude that canopy development can be spatially variable in very mild slope conditions (up to 9%), meaning that in more extreme ones, the spatial variability might reach much higher proportions. With this new information, the scheduling of practices such as trimming, training, pruning, water-shoot removal, or even irrigation management, could be optimized and specified for a particular vineyard or vineyard plot, taking into account its terrain position.

Further work is required to fully validate this study, particularly with respect to the extrapolation of this trial to other locations, other varieties and growing seasons.

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Table 1 - Comparison between leaf-to-fruit ratio (L/F ratio) measured at the veraison stage and quality parameters (Brix, pH and total acidity) analyzed at full maturation, regarding their CV.

Variety	L/F ratio (veraison)	CV	ºBrix	CV	pH	CV	Total acidity	CV
Alvarinho	1.24	117%	22.63	5%	3.31	1%	7.95	4%
Viosinho	0.59	47%	22.90	4%	3.35	3%	5.21	5%
Encruzado	0.44	36%	20.40	1%	3.32	3%	5.70	5%
Arinto	0.84	49%	20.53	2%	3.30	2%	7.80	5%

Table 2 - Effect of the terrain position on the total and exposed leaf area at different phenological stages for the *Encruzado* variety. Means within a column followed by a different letter are significantly different at $P<0.05$.

Smartpoint	Leaf area (m2) Pre-flowering	Exposed leaf area (m2/ha) Flowering	Exposed leaf area (m2/ha) Verasion
Uphill SP	3,97a	7280a	8793a
Mid-slope SP	5,08b	7813a	10028b
Downhill SP	5,39b	8593b	9993b

Table 3 - Effect of the terrain position on bud burst and water-shoot percentage for the *Arinto* variety. Means within a column followed by a different letter are significantly different at $P<0.05$.

Smartpoint	Bud burst percentage (%)	Percentage of water-shoots (%)
Uphill SP	74a	49a
Mid-slope SP	103b	19b
Downhill SP	123b	28b