Agricultural and Forest Meteorology 185 (2014) 26–36

Contents lists available at ScienceDirect

Agricultural and Forest Meteorology

journal homepage: www.elsevier.com/locate/agrformet

Climate factors driving wine production in the Portuguese Minho region

H. Fraga*, A.C. Malheiro, J. Moutinho-Pereira, J.A. Santos

Centre for the Research and Technology of Agro-Environmental and Biological Sciences, University of Trás-os-Montes e Alto Douro, P.O. Box 1013, 5001-801 Vila Real, Portugal

ARTICLE INFO

Article history:
Received 11 April 2013
Received in revised form 26 September 2013
Accepted 11 November 2013

Keywords:
Wine production modeling
Climatic factors
Weather regimes
Logistic regression
Minho Wine Region
Portugal

ABSTRACT

Establishing the role of climate on wine production is one major goal of the winemaking sector. Portuguese viticulture plays a key role in national exports of agro-food products. The Minho Wine Region, in particular, produces a unique wine type 'Vinho Verde' that has been taking its stand as a prominent international brand. The present study aims at improving the understanding of climate-yield relationships in this region. A long wine production series (1945–2010) is used and some transformations are undertaken for robust statistical relationships. A stepwise methodology is applied to select regressors for logistic modeling of production classes (low, normal and high). New weather regimes are developed to assess large-scale atmospheric forcing and cycles in production are isolated by a spectral analysis. Ten regressors are selected: dryness and hydrothermal indices, 3-yr lagged production, mean temperatures in March and June, precipitation in June and frequencies of occurrence of two regimes in May, and of one in February and September. Overall, moderate water stress during the growing season, high production 3-yrs before, cool weather in February–March, settled-warm weather in May, warm moist weather in June and relatively cool conditions preceding harvest are generally favorable to high wine production. Some of these relationships demonstrate the singularity of Minho Wine Region and justify the present study. The model shows high skill (72% after cross-validation), stressing not only the important role played by atmospheric conditions, but also its value for prediction and management.

1. Introduction

Wine production from *Vitis vinifera* L. is largely controlled by atmospheric forcings, since wine type, yield and quality are strongly dependent on weather conditions, mainly during the growing season (Jones and Davis, 2000a; Malheiro et al., 2010). In fact, a 10 °C base temperature is needed for the growing season onset (Winkler, 1974), which should be preferably preceded by a period of moderate cool weather, enabling an adequate bud dormancy (Webb et al., 2007). Vine phenophases (e.g. budburst, flowering and veraison) are triggered by adequate air temperatures, precipitation and solar exposures (Fraga et al., 2012a; Jones et al., 2005). Furthermore, due to the very specific climatic demands of grapevines, suitable viticultural zones are restricted to relatively narrow areas where mean near-surface air temperatures range from 12 to 22 °C during the growing season (Jones, 2006), which makes this crop particularly suited for warm temperate climates. However, heat stress, with temperatures above 35 °C, can severely damage grapevine leaves and grapes (Chuine et al., 2004; Crespy, 1987).

Precipitation is also a central atmospheric element, as it widely governs soil moisture and grapevine water potential, particularly in vineyards without irrigation. Low water availability can lead to a wide range of effects, though largely dependent on the stage of plant development (Austin and Bondari, 1988). For instance, severe water stress during the early stages may considerably delay growth and grapevine development (Hardie and Considine, 1976). In contrast, high soil moisture throughout the growing season may cause excessive vigor, increased risks of pests and diseases and other problems related to wine quality and to the balance between its chemical compounds (During, 1986; Magalhães, 2008). Overall, high-quality and well-balanced wines are commonly associated with mild water stress during the maturation period (from veraison onwards) and to relatively cool and moderately wet weather during the early stages (Koundouras et al., 1999; Storchi et al., 2005; van Leeuwen et al., 2004). Although these basic requirements are dependent on vine variety, they are fulfilled by Mediterranean-like rainfall regimes.

A favorable and regular climate is also crucial to stabilize yields, while high inter-annual variability in atmospheric conditions can

Abbreviations: MWR, Minho Wine Region; WP, wine production; T_{min}, minimum temperature; T_{avr}, mean temperature; T_{max}, maximum temperature; P, precipitation; HyI, Hydrothermal Index; DI, Dryness Index.

* Corresponding author. Tel.: +351 259350389; fax: +351 259 350 480.
E-mail address: hfraga@utad.pt (H. Fraga).

0168-1923/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.agrformet.2013.11.003

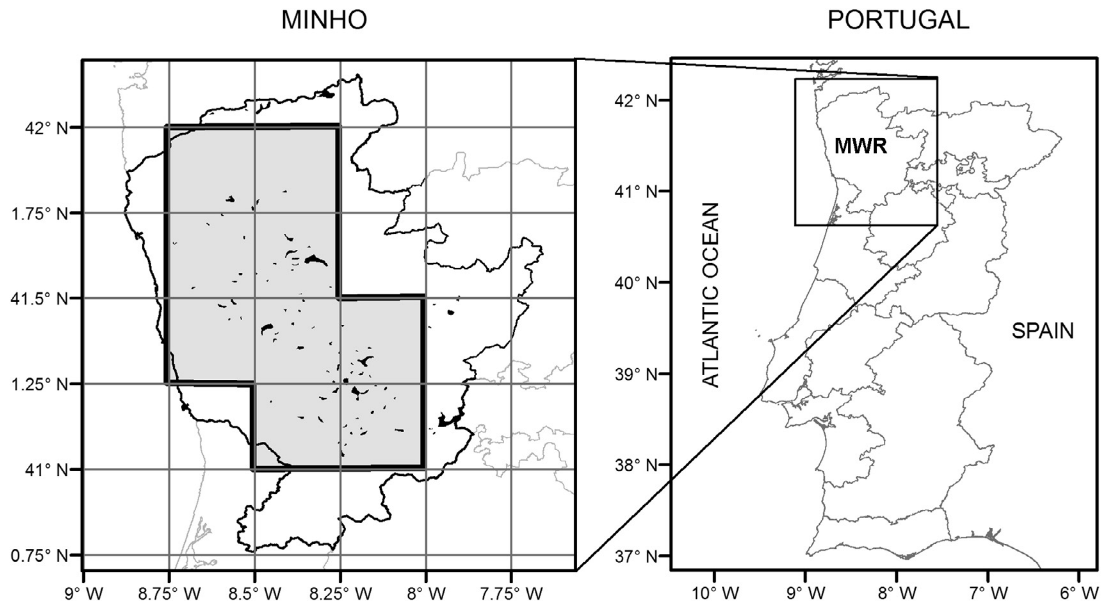

Fig. 1. Right panel: map showing the geographical location of the Minho Wine Region (MWR) in northwestern Portugal, along with the other Portuguese wine regions. Left panel: magnified map of the MWR. Grid boxes represent the E-OBS original resolution of 0.25° latitude × 0.25° longitude. Highlighted grid boxes show where data was extracted for area-mean computations. The main current vineyard land cover is also shown in black stipple.

strongly influence winegrape quality (Jones and Goodrich, 2008). Furthermore, extreme weather events, such as hail and frost during the growing season, can have harmful impacts on vineyards, thus contributing to noteworthy fluctuations in yield and wine quality. Taking into account all the aforementioned climatic influences in viticultural production, further knowledge into these relationships is of foremost relevance for modern wine industry, which aims at stabilizing wine production (WP) and quality for brand marketing.

Apart from the direct influence of near-surface temperatures and precipitation, other factors, such as weather regimes may also play a key role in yield prediction, as they combine several elements in their typical atmospheric conditions (e.g. temperature, precipitation, wind, humidity and solar radiation). Furthermore, viticultural bioclimatic indices are often used when assessing climatic suitability of a given region to winegrape zoning (Jones et al., 2010). Well-known bioclimatic indices accounting for water availability, such as the Hydrothermal Index (HyI; Branas et al., 1946) and the Dryness Index (DI; Riou et al., 1994), should also be tested as potential predictors of grapevine yield. Other factors, such as variability in wine production resulting from commercial cycles, economic fluctuations or even physiological constraints, may result in regular oscillations in the annual yield series. This information may also be relevant for WP modeling.

More specifically, Portugal (the 11th wine producer in the world; OIV, 2012) is divided into several wine growing areas, with the Minho Wine Region (MWR henceforth) located in the very northwestern part of the country (Fig. 1). MWR covers a broad area of about 8.8×10^3 km^2 that geographically coincides with the 'Vinhos Verdes' Appellation of Origin. Regarding its topography, MWR has a rather irregular terrain, with elevations ranging from 0 to approximately 1500 m asl, characterized by a compact valley system with a predominance of deep granitic soils (Magalhães, 2008). Despite having a Mediterranean climate, the Atlantic influences are noteworthy. The relatively high exposure to maritime winds, high annual precipitations (1200–2400 mm) and mild summers (summer mean temperatures ranging from 18 to 22 °C), explains the distinctiveness of the MWR, setting it apart from other Portuguese wine regions (e.g. Alentejo, Douro), where heat and water stresses can be important limiting factors of WP. In fact, Fraga et al. (2012b) showed that the MWR depicts the highest HyI and DI values of all Portuguese winemaking regions. Another distinctive characteristic of the MWR is its relatively low yearly solar insolation when compared to other Portuguese regions (<2500 h). In response to these climatic features, traditional training systems, such as pergola, stakes and tall growing vines ('enforcado'), are still used today, which are rare in the rest of the country. Most wines are usually made from earlier maturity varieties (e.g. Alvarinho, Alvarelhão, Trajadura), with a predominance of white varieties, as a response to moderate humidity levels in summer, which enhance the risk of trunk and leaf diseases (IVV, 2011). All these characteristics explain the typicity of its famous 'Vinho Verde' wine, which is largely consumed, representing the country's second most exported wine, right after Port Wine (IVV, 2011).

Previous studies have revealed that monthly temperatures and precipitations are significantly correlated with grapevine yield in the nearby Douro Wine Region, Portugal (Gouveia et al., 2011; Santos et al., 2013). However, due to the aforementioned climatic specificities of MWR, this climate-yield linkage can significantly differ from other Portuguese regions and needs to be studied separately. The present study aims to examine the influence of climate on WP of MWR. So this study addresses the effects of climate on the WP of this distinct region. The objectives are three-fold: (1) Quantify the cycles in wine production (WP) in the region over the last 60 years. (2) Differentiate the climate of the region into a set of distinct weather regimes, and determine their relationship to WP. (3) Develop a multinomial logistic model using weather data, previous WP and weather regimes to predict classes of WP values.

2. Materials and methods

2.1. Wine production data

A relatively long time series of WP (in hl) in MWR, from 1945 to 2010 (66 years), is provided by the Portuguese '*Instituto da Vinha e do Vinho*'. This data is annually reported by producers directly to this governmental institution. The current vineyard land coverage is of about 22×10^3 ha (Fig. 1), estimated using the Corine Land Cover (EEA, 2002), which has previously shown a good accuracy