Agricultural and Forest Meteorology 247 (2017) 104–115

Contents lists available at ScienceDirect

Agricultural and Forest Meteorology

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

Projection of phenology response to climate change in rainfed vineyards in north-east Spain

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ARTICLE INFO

Keywords:
Climate change
Modelling
RCP4.5
RCP8.5 scenario
Vineyard
Water available

ABSTRACT

The aim of this research was to predict the changes in vine phenology of some white grape varieties when rainfed vineyards are subjected to climate change. The research was conducted in the north east of Spain, in an area with a Mediterranean climate. Temperature and precipitation changes under two Representative Concentration Pathway (RCP) scenarios – RCP4.5 and RCP8.5 – were simulated based on an ensemble of models. Water losses by runoff were predicted using the WEPP model and changes in evapotranspiration were estimated according to the predicted changes in temperature, wind speed and solar radiation for the same scenarios. Dates of budbreak, bloom, veraison and harvest of three varieties were evaluated: Chardonnay, during the period 1998–2012; and Parellada and Macabeo during the period 1998–2009. Projections for 2030, 2050 and 2070 were made based on the observed phenological dates and the heat accumulation needed to reach each stage and water available recorded in different periods along the growing cycle. An advance of all phenological dates was predicted, higher for veraison and harvest than for the earlier stages and higher for Parellada than for Macabeo and Chardonnay. These stages may advance up to 10 and 16 days, respectively, for 2050 and up to 12 and 20 days for 2070 under the RCP4.5 scenario. Under RCP8.5 scenario, the advance by 2070 could be up to 23 and 28 days. These changes resulted in a shortening of the periods between phenological dates (> 10 days), higher for Parellada than for Chardonnay and Macabeo. The results also showed an additional advance of bloom for Chardonnay and Macabeo associated with decreasing water available, and an advance of veraison and harvest for all three varieties, associated with decreasing water available, particularly between budbreak and bloom and between bloom and veraison, depending on the variety.

1. Introduction

Vines are one of the perennial crops that could be most affected by climate change. Vines are usually adapted to a range of temperatures, and both cool and warm extremes may have negative impacts on vines. On the one hand, climatic conditions affect physiology, productivity, and phenological cycle (Deis et al., 2015). In addition, increasing temperatures may produce higher water stress, which may affect phenology, and both grape yield and quality (van Leeuwen et al., 2009; Pieri et al., 2012; Fraga et al., 2016a). Different studies around the world have been carried out to evaluate and predict the effect of temperature changes on grapevine phenology (Duchêne and Schneider, 2005; Moriondo and Bindi, 2007; Sadras and Soar, 2009; Bock et al., 2011; Urhausen et al., 2011; Tomasi et al., 2011; Pieri et al., 2012; Jones and Alves, 2012; Webb et al., 2012; Ruml et al., 2016; among others) and also on production and quality (Downey et al., 2006; Cohen et al., 2008; Sadras and Moran, 2012; Iglesias et al., 2010; Salazar Parra et al., 2010; Back et al., 2013). The trends observed during recent years, with increasing average temperatures of about 2 °C during the grape growing season for period 1952–2006 (Ramos et al., 2008) draws our attention to their consequences and to the establishment of measures to mitigate these effects with changes in management (Boyer and Touzard, 2016; Ugaglia et al., 2016). In addition, the available water is another important issue. Although irrigation may be authorized in the Penedès DO when it is justified to improve grape quality (www.dopenedes.cat/consellregulador.php) in most cases, vines are not irrigated due to the scarcity of water. Thus, rainfall is the only water source for the crop, and in this respect both amount and distribution throughout the growing cycle have important consequences on grape ripening and the resulting wine quality. Of course, the effects may be different depending on the varieties grown.

Trends in precipitation are not as uniform as trends in temperature and depend on the specific characteristics of the climate (IPCC, 2014). In some areas, precipitation seems to increase while in other areas the trend is to decrease or not change. In particular, in the Mediterranean area, total precipitation seems not to have a clear trend. However,

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http://dx.doi.org/10.1016/j.agrformet.2017.07.022
Received 5 April 2017; Received in revised form 6 July 2017; Accepted 24 July 2017

changes in distribution during the year, have been observed (De Luis et al., 2009), which suggested a reduction of precipitation in spring, This implies less water available during the stages in which water needs are higher and in which deficits may have a negative and irreversible impact. It is of particular relevance when due to water scarcity most agriculture is undertaken in rainfed conditions.

On the other hand, land management also has a major influence. Most new vineyards are planted after land levelling to adapt the fields to the mechanization of almost all labour. In most cases the resulting levelled soils are poorer in organic matter, have a lower water retention capacity and are more susceptible to sealing, which means a reduction in water intake and storage (Ramos and Martínez-Casasnovas, 2006), and higher water deficits. Previous studies have shown the influence of land levelling on grape yield under different rainfall patterns which were up to 28% between levelled and unlevelled areas (Ramos, 2006). However, differences of up to 50% were observed between years with different climatic characteristics (Ramos and Martínez-Casasnovas, 2014). Thus, under a scenario of climate change, vineyards could be seriously affected due to higher evaporative demands and less water stored in the soil. The knowledge of the response of different varieties may be useful in order to establish strategies to reduce the impact.

Different studies have been undertaken in order to quantify the potential effects of temperature changes on vine phenology in different sites around the world (Webb et al., 2007; Caffarra et al., 2011; Parker et al., 2011; Mesterházy et al., 2014; Fraga et al., 2016a; Hall et al., 2016, among others). Some of these studies were based on relationships between the phenological dates and the average temperature and precipitation recorded in a given period within the growing cycle (Fraga et al., 2016a). Other studies are based on the effect of the accumulation of chilling and forcing units up to a critical forcing threshold (Caffarra et al., 2011; Parker et al., 2011; Hall et al., 2016).

The objective of this research was to predict the effects of the expected changes in temperature and precipitation under climate change on the phenology of three grape varieties cultivated in a Mediterranean climate area, where vines occupy about 80% of the cultivated surface. In the study area, vines are not irrigated due to the lack of water and in addition a significant amount of rain is lost by runoff. Predicted temperature and precipitation changes for 2030, 2050 and 2070 for two Representative Concentration Pathway (RCP) scenarios − RCP4.5 and RCP8.5, based on an ensemble of model projections were used. Additionally, the effect of available water was also analysed for different scenarios.

2. Material and methods

2.1. Study area

The field of the study is located in the Penedès Depression, between the pre-coastal mountain range (Serralada Pre-litoral) and the Mediterranean Sea in north east Spain (lat. 41.84°; long. −1.81°; elev. a.s.l. 320 m). About 40% of the area is dedicated to agriculture, whose main crop is vines (IDESCAT, 2009). The climate is Mediterranean with a maritime influence, characterized by two wet periods (spring and autumn) separated by hot, dry summers. High intensity rainfall events are usually recorded in autumn, of increasing intensity during recent years (Ramos and Durán, 2014).

One vineyard field, which was planted in 1989, was selected within the area. The field was levelled before vine plantation, which produced significant disturbance to the original soil profile. Within the vineyard, three areas were considered in this research, which were planted with Chardonnay, Macabeo and Parellada. According to Keys of Soil Taxonomy (Soil Survey Staff, 2014), soils in the studied vineyard were classified as *Typic Xerorthents*. Soils had a loamy or a loamy-sandy texture, with the average percentage of coarse elements ranging from 20 to 30% in the top horizon. The organic matter content was relatively low, ranging from 0.7 to 1.26%. The water retention capacity at −33 kPa ranged between 17.6 and 21.3%, while at −1500 kPa the value ranged between 8.5 and 11.2%. Soil depth ranged from 0.6 to 1.1 m. The lower soil depth corresponded to cut areas, while the higher values corresponded to areas filled after levelling. The soils were susceptible to sealing. The hydraulic conductivity of the seal, evaluated using simulated rainfall, ranged between 2.4 and 11.5 mm h^{-1}. Steady infiltration rates, also estimated using rainfall simulation, ranged between 10 and 24 mm h^{-1}.

Soil water was monitored at four depths (0–20, 20–40, 40–60, 60–80 cm) in the three zones planted with the three varieties every 15 days using Time Domain Reflectometry (TDR) IMKO tube–probes. The initial soil water level measured in the field was used to parametrize the initial saturation level, and the average soil water values for the profile were used to test the soil water simulations.

The plantation consists of trained vines in Lyre system, orientated NE-SW with 3.1 m between rows and 1.3 m between plants. The rootstock was R110 in all varieties, and vines had similar management. Due to the scarcity of water, the soil was bare most of the time with frequent tillage. Root development was mainly concentrated between 20 and 80 cm, (80% of roots were concentrated in this depth). The vines were pruned by hand. Ten nodes were left per plant.

2.2. Grape phenology

The phenological dates corresponding to budbreak (code 5 in scale BBCH), bloom (code 57 scale BBCH), veraison (code 81 in scale BBCH) and harvest, for three cultivars planted in the studied vineyard were analysed for the period 1998–2012 for Chardonnay and from 1998 to 2009 for Macabeo and Parellada. The phenological dates used in this study were those at which approximately 50% of plants had reached the corresponding phenological stage, and the harvest date was based on acidity and sugar contents. During the period in analysis, grapes were always used for the same purpose; mainly for the production of “cava”, Spanish sparkling wine produced following the Champanoise method.

2.3. Climatic data and analysis

Climatic data recorded at Els Hostalets de Pierola (HP: lat. 41.46°; long. −1.81°; elev. a.s.l. 326 m) were used in this analysis. The weather station at HP belongs to Institut Meteorologic de Catalunya and it was about 6 km far from the experimental field. The climatic data referred to the period analysed (1998–2012) included hourly maximum (Tmax), minimum (Tmin) and dew point temperature (Tdp), precipitation (P), solar radiation (SR), relative humidity (RH), wind velocity (WV) and direction (WD). The average temperatures and precipitation referred to each growing cycle was analysed taking into account the phenological dates recorded in Section 2.2. In addition, crop evapotranspiration (ETc) was evaluated taking into account the reference evapotranspiration calculated according to the Penman Monteith equation, and the crop coefficients proposed by Allen et al. (1998), modified for water stress conditions. For the identification of chilling and warming periods, daily chill and heat accumulations were analysed from the dormand period. Daily chill accumulation (in Chill Portions) was calculated according to the Dynamic Model (Fishman et al., 1987) using hourly temperature data. Heat unit accumulation (in Growing Degree Hours) was calculated according to Anderson et al. (1986), using a base temperature of 4 °C and an optimum temperature of 26 °C (Parker et al., 2011). The chill and heat phases were determined by analysing the relationship between budbreak dates and the means of 10 days of daily chill and heat units from September 15th (of the precedent year of recorded budbreak) to April 30th, using a Partial Least Squares (PLS) regression. Negative correlation coefficients were interpreted as periods that produced advance of budbreak.

Once delimited the chill and heat phases, these thermal requirements were expressed in GDD calculated as the difference between the daily mean temperature and the base temperature critical for effective