GRAPEVINE PRODUCTIVITY MODELLING IN THE PORTUGUESE DOURO REGION

J. A. Santos (1), A. C. Malheiro (1), M. K. Karremann (2), J. G. Pinto (2)
(1) Centre for Research and Technology of Agro-Environment and Biological Sciences (CITAB), University of Trás-os-Montes e Alto Douro, 5001-801 Vila Real, Portugal (jsantos@utad.pt)
(2) Institute for Geophysics and Meteorology, University of Cologne, Kerpener Str. 13, 50923 Cologne, Germany

ABSTRACT

In Portugal, and particularly in the Demarcated Region of Douro (DDR), wine production has a great tradition, producing the unique and worldwide famous Port wine as well as other remarkably good table wines. In this study the impact of projected climate change to wine production is analysed for the DDR. A statistical grapevine yield model (GYM) is developed using climate parameters as predictors. Statistically significant correlations are identified between annual yield and monthly mean temperatures and monthly precipitation totals during the growing cycle of grapevines. Close relationships between these climatic elements are found that influence the annual yield, with the GYM explaining over 50% of the total variance in the yield time series in recent decades. Furthermore, results point out a clear relationship between the vegetative cycle of grapevines and their basic climatic requirements: anomalously high (low) precipitations in March, during bud break, shoot and inflorescence development are favourable (adverse) to yield, while anomalously high temperatures in May (bloom) and June (berry development) favour yield. The GYM is applied to output from the regional climate model COSMO-CLM, which is shown to skilfully reproduce the GYM predictors. Considering ensemble simulations under the A1B emission scenario, a slight upward trend in yield is estimated to occur until about 2050, followed by a steep and continuous increase until the end of the 21st century, when yield is projected to be about 800 kg/ha above its current values. The results emphasise the potential of using GYM coupled with regional atmospheric models to assess variations in grapevine yield owed to climate change. Complementary studies are in process in order to evaluate possible phenological shifts and wine quality impacts.

KEYWORD

Grapevine – Douro – Portugal – yield modelling – climate scenarios – CLM

INTRODUCTION

Portugal ranks in the eleventh position of wine-producing countries (approximately 3% of global production in 2006) and fifth in the European Union (over 4% of EU production in 2007) (IVV, 2008). The Douro Region produces the unique and world famous Port Wine (approximately 50% of the regional wine volume) and other remarkably high-quality table wines. Located in North-eastern Portugal, in a very mountainous region within the Douro River basin, the Demarcated Region of Douro (DRD) spreads over a total area of approximately 250 000 ha (Fig. 1), from which around 16% is planted with vineyards. The geomorphology of DRD consists essentially of schist with occasional outcrops of granite. The prevailing Mediterranean climate is particularly favourable to the production of balanced composition wines. Climate-mean annual precipitation values vary from 400-900 mm, with only about 30% falling from April to September, whereas climate-mean monthly temperatures range from 5-8ºC up to 21-24ºC. According to the climate maturity grouping (Jones *et al.*, 2005), the growing season can be defined as "warm" (April-October mean temperature of about 18ºC). In terms of phenology, depending upon the variety and site, budburst typically occurs in March, followed by flowering/blooming in May, véraison (berries start to soften and turn colour and signal the beginning of the ripening process) in July and ripe maturation in September (Malheiro, 2005).

Atmospheric factors strongly control grapevine growth and development by primarily affecting photosynthetic rates. Photosynthesis is also stimulated by increasing CO_2 concentration, which may result in greater accumulation of total biomass (Tate, 2001). Other effects of temperature increases may result in a general anticipation of the phenological events, which may lead to undesirable grape and wine characteristics (Jones, 2006). Climate change imposes an additional challenge for wine production, as global instrumental atmospheric records reveal significant climate change signals (Trenberth *et al.*, 2007). Moreover, above average global warming and drying are predicted for Southern Europe (Meehl *et al.*, 2007). These projected changes might have significant impacts in wine production and quality (Schultz, 2000). In fact, weather and climate are among the environmental factors that most influence the quality and characteristics of grapes and wines (Spellman, 1999). While extreme weather events may cause important yield losses, changes in climate may modify the grapevine phenological cycle, disease/pest patterns, ripening potential, wine characteristics and yield (Jones *et al.*, 2005).

The growing season average temperatures have risen over the past 50 years in several high-quality wine regions (Jones *et al.*, 2005). Therefore, some wine regions in Southern Europe may already be at the limit of ideal conditions for high-quality production. Other works also referred the possibility of changing geographical locations of production due to changes in temperature, precipitation or increased CO_2 (Schultz, 2000). The observed and predicted warming over the last and future years can both have benefits and disadvantages on viticulture depending on the region. Most of the earlier regional studies have discussed the impact of climate change on wine quality (Orlandini *et al.*, 2005; White *et al.*, 2006) and on yield (Bindi *et al.*, 1996; Lobell *et al.*, 2006) considering GCM scenarios. However, the relatively coarse spatial resolution of these models is a clear limitation for a small and hilly region such as the Douro valley, for which a downscaling strategy considering a regional climate model (RCM) is more appropriate. Taking into account that wine production is the leading economic activity in DRD, both the development of a statistical approach for regional grapevine yield modelling and the assessment of the potential changes in yield under human-induced climate change are of utmost relevance for this region.

MATERIALS AND METHODS

The grapevine yield time series for the DRD was provided by the Portuguese Institute for Statistics (INE; http://www.ine.pt/) for 1986-2008 (23 years). Plant productivity is controlled by a large variety of factors, but only the atmospheric factors are considered here. Daily time series of precipitation and temperature recorded at the meteorological station of Vila Real (within the DRD at 41.3ºN and 7.7ºW) are used for the yield modelling. Future grapevine yield projections are carried out using climate model data: two ensemble simulations of the recent-past climate (1960-2000; C20; Lautenschlager *et al.*, 2009a,b) with and two integrations (2001-2100; Lautenschlager *et al.*, 2009c,d) under the IPCC A1B scenario (Nakićenović *et al.* 2000).

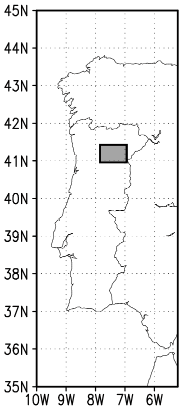

Fig. 1 Map showing the geographical location of the Douro Valley (DV; grey box)

The COSMO-CLM (Consortium for Small-scale Modelling, hereafter CLM; Böhm *et al.*, 2006) was nested in ECHAM5/MPI-OM1 (Roeckner *et al.*, 2006) for downscaling purposes (approximate resolution of 18 km. Only data for the Douro Valley sector (DV: 41.0-41.4ºN; 7.0-7.8ºW; Fig. 1) was extracted. Area-means of the atmospheric variables were then computed for the yield modelling. Several atmospheric variables were considered in an exploratory study, but only monthly mean temperatures (T) and monthly precipitation totals (R) show statistically significant correlations with yield.

RESULTS AND DISCUSSION

Grapevine yield shows strong inter-annual variability in 1986-2008 (Fig. 2). In fact, in 1988 or 1998 the yield was slightly above 1500 kg/ha (two lowest values), while in 1990 it exceeded 4500 kg/ha (nearly three times higher than the lowest values). This remarkably high variability has important economic implications in the wine production sector, particularly due to the high irregularity of the production combined with the absence of reliable and timely predictions of yield. According to the Spearman and Mann-Kendall non-parametric trend tests, there is no statistically significant trend at a significance level of 5%.

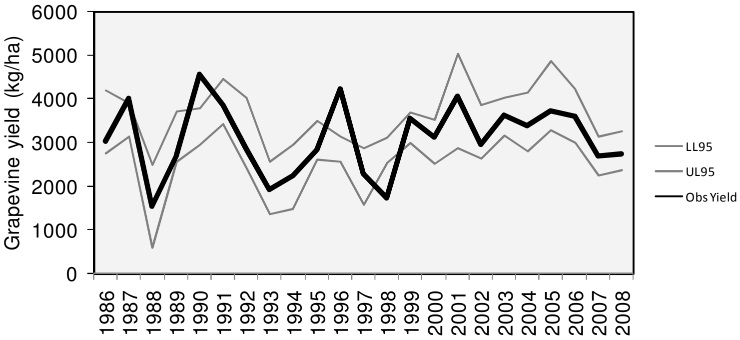

Fig. 2 Observed grapevine yield (Obs Yield) in the DRD in 1986-2008 and the corresponding 95% lower (LL95) and upper (UL95) confidence levels of the modelled time series

A multivariate linear regression model is adjusted to grapevine yield time series using the full set of selected potential predictors (monthly mean temperatures and monthly precipitation totals) in 1986-2008. A stepwise methodology is applied to select the most significant predictors: March (R-March), May (R-May) and June (R-June) precipitation totals and May (T-May) and June (T-June) monthly mean temperatures (5 predictors). The *R*-squared statistic between observed and modelled grapevine yield is 62%, highlighting the high skill of the model when taking into account the complexity of the governing processes. The time series of the modelled yield is in good agreement with observations, i.e., the observed yields are within the 95% confidence interval of modelled yield (Fig. 2), despite some noteworthy discrepancies in 1990 and 1996, where the modelled value is clearly underestimated, and the overestimation of the very low yield in 1998. These discrepancies are related to extreme daily atmospheric events that are not taken into account in the model. The values of the regression coefficients (not shown) show that anomalously high (low) precipitation in March (May and June) is favourable to yield, whilst anomalously high temperatures in May and June favour yield. These results are in agreement with previous studies (e.g. Ramos *et al.*, 2008) and with the critical stages of the grapevine vegetative cycle; high precipitation in early spring (shoot and inflorescence development) and relatively low precipitation and high temperatures in late spring (flowering in May and berry development in June) are favourable to grapevine yield.

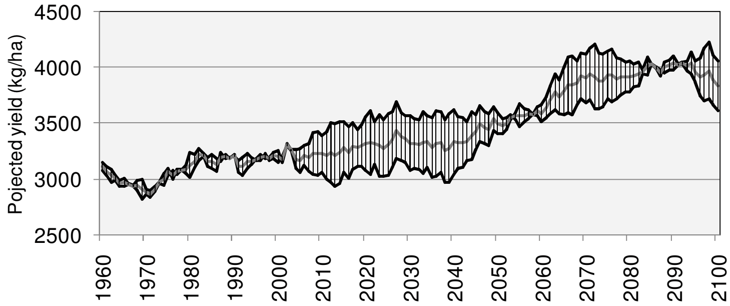

Fig. 3 Future scenario for GYM-derived grapevine yield in DV, based on the A1B SRES emission scenario from CLM. Black curve represents the two-member ensemble mean and lines within grey curves represent the total range within the ensemble. All time series were previously filtered using an 11-year centred moving average

The high skill of GYM using observational data enables its application to RCM data. Changes in predictors during the 21st century show that there is a sustained decrease (increase) in precipitation (temperatures) in May and June, though March precipitation does not undergo significant changes (not shown). These projected changes in predictors have direct implications in the modelled yield. Reduction in May and June precipitation, stabilization of March precipitation and increases in May and June temperatures jointly imply an increase in projected yield. In fact, combining all changes in the five predictors, GYM-derived yield is expected to undergo a sustained upward trend. This upward trend can be analysed in greater detail by plotting the time series of the projected yield (Fig. 3). An 11-year centered moving average (low-pass filter) was applied beforehand to the projected time series, reducing irrelevant high-frequency variability. During the first half of the 21st century there is a slightly positive trend that is replaced by a much steeper upward trend in the period 2050-2080, followed by a gradual stabilization.

CONCLUSIONS

Results show that anomalously high March rainfall (during budburst, shoot and inflorescence development) and anomalously high temperatures and low precipitation totals in May and June (May: flowering, and June: berry development) tend to favour grapevine yield. The wine production sector in the DRD faces other challenges related to the impacts of climate change. Our yield estimates based on CLM data and under the A1B scenario reveal that the current yields are expected to increase about 800 kg/ha until the end of the 21st century. Larger grape yields are generally associated with higher economic risk (Webb *et al.*, 2008) and poorer wine quality by affecting the leaf area/fruit weight ratio (Jackson and Lombard, 1993). Although the present predictions are far below the imposed legal limit of 7500 kg/ha for the DRD, in a warmer environment the harvest date may be brought forward into warmer periods of the year (Jones, 2006), which might lead to unbalanced wines with little acidity and excessive alcohol, particularly in the eastern and warmer part of the DRD (*Upper Douro*). The projected rise in CO_2 concentration can also produce an increase in net photosynthesis, biomass and grapevine yield (Moutinho-Pereira *et al.*, 2009). In the present study, the influence of CO_2 enrichment is only included through its influence on the large scale meteorological elements (temperature and precipitation). The direct influence of enhanced CO_2 on plant physiology/primary production was not taken into account. Under future climate conditions the effect of the increasing CO_2 concentration could be potentially added to the yield estimations, but as the quantification of this factor is still far from being confirmed. Nevertheless, the present outcomes state that taking into account recent-past relationships between yield, a limited number of atmospheric factors and a GCM/RCM combination, grapevine yield in the DRD is expected to undergo an upward trend until the end of this century, which might be further enhanced by the projected upward trend in the CO_2 concentration.

ACKNOWLEDGMENTS

Part of this study was supported by the project SUVIDUR – *Sustentabilidade da Viticultura de Encosta nas Regiões do Douro e do Duero*. Programa Operacional de Cooperação Transfronteiriça Espanha-Portugal (POCTEP). We thank the MPI for Meteorology (Hamburg, Germany), the German Federal Environment Agency, the WDCC/CERA database and the COSMO-CLM consortium for providing the ECHAM5 and the COSMO-CLM data.

BIBLIOGRAPHY

Bindi M., Fibbi L., Gozzini B., Orlandini S., Miglietta F., 1996. Modelling the impact of future climate scenarios on yield and yield variability of grapevine. Clim. Res. 7: 213-224.

Böhm U., Kücken M., Ahrens W., Block A., Hauffe D., Keuler K., Rockel B., Will A., 2006. CLM- The Climate Version of LM: Brief Description and Long- Term Applications. COSMO Newsletter 6: 225–235.

IVV, 2008. Vinhos e Aguardentes de Portugal, Anuário'08. Ministério da Agricultura, do Desenvolvimento Rural e das Pescas: Instituto da Vinha e do Vinho, Lisboa.

Jackson D.I., Lombard P.B., 1993. Environmental and management practices affecting grape composition and wine quality – a review. Am. J. Enol. Viticult. 44: 409-430.

Jones G.V., White M.A., Cooper O.R., Storchmann K., 2005. Climate change and global wine quality. Clim. Change 73: 319-343.

Jones G.V., 2006. Climate and terroir: Impacts of climate variability and change on wine. In Fine Wine and Terroir - The Geoscience Perspective. Macqueen, R.W., and Meinert, L.D., (eds.), Geoscience Canada Reprint Series Number 9, Geological Association of Canada, St. John's, Newfoundland.

Lautenschlager M. and co-authors (2009a) Climate Simulation with CLM, Climate of the 20th Century run no.1, Data Stream 3: European region MPI-M/MaD. World Data Center for Climate. [doi:10.1594/WDCC/CLM_C20_1_D3]

Lautenschlager M. and co-authors (2009b) Climate Simulation with CLM, Climate of the 20th Century run no.2, Data Stream 3: European region MPI-M/MaD. World Data Center for Climate. [doi:10.1594/WDCC/CLM_C20_2_D3]

Lautenschlager M. and co-authors (2009c) Climate Simulation with CLM, Climate Simulation with CLM, Scenario A1B run no.1, Data Stream 3: European region MPI-M/MaD. World Data Center for Climate. [doi: 10.1594/WDCC/CLM_A1B_1_D3]

Lautenschlager M. and co-authors (2009d) Climate Simulation with CLM, Climate Simulation with CLM, Scenario A1B run no.2, Data Stream 3: European region MPI-M/MaD. World Data Center for Climate. [doi: 10.1594/WDCC/CLM_A1B_2_D3]

Lobell D.B., Field C.B., Cahill K.N., Bonfils C., 2006. Impacts of future climate change on California perennial crop yields: Model projections with climate and crop uncertainties. Agric. For. Meteorol. 141: 208-218.

Malheiro A.N.C., 2005. Microclimate, yield and water-use of vineyards in the Douro Region, Portugal. Dissertation, Cranfield University, UK.

Meehl G.A. *et al.*, 2007. Global Climate Projections. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (eds. Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K. B., Tignor, M. and Miller, H. L.). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Moutinho-Pereira J., Gonçalves B., Bacelar E., Cunha J.B., Coutinho J., Correia C.M., 2009. Effects of elevated CO_2 on grapevine (*Vitis vinifera* L.): Physiological and yield attributes. Vitis 48: 159-165.

Nakićenović N. *et al.*, 2000. IPCC Special Report on Emissions Scenarios. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Orlandini S., Grifoni D., Mancini M., Barcaioli G., Crisci A., 2005. Analisi degli effetti della variabilità meteo-climatica sulla qualità del Brunello di Montalcino. Riv. Italiana Agrometeorol. 2: 37-44.

Ramos M.C., Jones G.V., Martínez-Casasnovas J.A., 2008. Structure and trends in climate parameters affecting winegrape production in northeast Spain. Clim. Res. 38: 1-15.

Roeckner E *et al.*, 2006. Sensitivity of simulated climate to horizontal and vertical resolution in the ECHAM5 Atmosphere Model. J. Climate 19: 3771–3791.

Schultz H.R., 2000. Climate change and viticulture: a European perspective on climatology, carbon dioxide and UV-B effects. Aust. J. Grape Wine Res. 6: 2-12.

Spellman G., 1999. Wine, weather and climate. Weather 54: 230-239.

Tate A.B., 2001. Global warming's impact on wine. J. Wine Res. 12: 95-109.

Trenberth K.E. *et al.*, 2007. Observations: Surface and Atmospheric Climate Change. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor, and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Webb L.B., Whetton P.H., Barlow E.W.R., 2008. Modelling the relationship between climate, winegrape price and winegrape quality in Australia. Clim. Res. 36: 89-98.

White M.A., Diffenbaugh N.S., Jones G.V., Pal J.S., Giorgi F., 2006. Extreme heat reduces and shifts United States premium wine production in the 21st century. Proc. Natl. Acad. Sci. 103: 11217-11222.