FUTURE SCENARIOS FOR VITICULTURAL CLIMATIC ZONING IN EUROPE

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ABSTRACT
Climate is one of the main conditioning factors of winemaking. In this context, bioclimatic indices are a useful zoning tool, allowing the description of the suitability of a particular region for wine production. In this study, we compute climatic indices for Europe, characterize regions with different viticultural aptitude, and assess possible variations in these regions under a future climate conditions using a state-of-the-art regional climate model. The indices are calculated from climatic variables (mostly daily temperatures and precipitation) obtained from the regional climate model COSMO-CLM for recent and future climate conditions. Maps of theses indices for recent decades (1961-2000) and for the XXI century (following the SRES A1B scenario) are considered to identify possible changes. Results show that climate change is projected to have a significant negative impact in wine quality by increased dryness and cumulative thermal effects during growing seasons in Southern European regions (e.g. Portugal, Spain and Italy). These changes represent an important constraint to grapevine growth and development, making crucial adaptation/mitigation strategies to be adopted. On the other hand, regions of western and central Europe (e.g. southern Britain, northern France and Germany) will benefit from this scenario both in wine quality, and in new potential areas for viticulture. This approach provides a macro-characterization of European areas where grapevines may preferentially grow, as well as their projected changes, and is thus a valuable tool for viticultural zoning in a changing climate.

KEYWORD
Viticultural zoning – scenarios – Europe – climate change – CLM

INTRODUCTION
Winemaking has a predominant economic, social and environmental relevance in Europe. Studies addressing the influence of climate variability and change in viticulture are particularly pertinent, as climate is the dominant factor from grapevine yield and quality (e.g. van Leeuwen *et al.*, 2004) to its geographic worldwide distribution (Jones, 2006). In fact, *Vitis vinifera* has well-defined climatic requirements; it is a heat demanding crop, needing proper high radiation intensities and temperatures, not only during its vegetative growth and development, but also for berry maturation and it is highly sensitive to frost occurrences in winter and spring (Magalhães, 2008). Due to these very selective requirements, most wine-producing areas are geographically located between latitudes 30-50º of the Northern Hemisphere (Spellman, 1999), where the "warm temperate climates" (Kottek *et al.*, 2006), including the Mediterranean type, are found. These

climates roughly correspond to the belt limited by the 10-20ºC annual isotherms (Spellman, 1999) or, as more recently defined, to the April-October 12-22°C isotherms (Jones, 2006).

In the next decades, a significant temperature increase is expected over Europe, particularly for the summer periods, while precipitation is projected to diminish significantly (Meehl *et al*., 2007). Further, the recent climatic trends recorded are in line with the future projections (Meehl *et al*., 2007). Therefore, some wine regions, e.g. in Southern Europe, may be already near the limit of ideal conditions for high-quality wine production (e.g. Jones *et al*., 2005). Conversely, a changed environment may allow some of the northern regions (e.g. Southern England) to become more relevant in terms of viticulture. Thus, climate change may have both positive and negative impacts on viticulture, depending on the geographical area (e.g. Jones *et al*., 2005).

Taking into account the interactions between wine-grape climatic needs and its growing cycle, some climate-based indices ("bioclimatic indices") have been developed. One of the earliest indices was the heat unit concept, using a growing degrees base of 10°C (Amerine and Winkler, 1944). Other indices also include radiation (e.g. Branas, 1974) or precipitation (e.g. Branas *et al*., 1946), besides thermal information. In this context, the bioclimatic indices are a widely used tool in viticultural zoning by allowing the assessment of the potential suitability of a particular region for an economically-sustained wine production.

The main objectives of the present study are threefold: i) to determine the spatial patterns in Europe of a set of appropriate bioclimatic indices for the recent-past period (1961-2000) and a future periods in the XXI century considering regional climate model datasets, ii) to characterise regions with diverse grape suitability and, iii) to identify possible future geographical variations in these regions by analysing significant changes in the index patterns.

MATERIALS AND METHODS

To analyse the effect of predicted global warming on the geography of European winegrape growing zoning, four bioclimatic indices were selected: 1) Latitude-temperature index (LTI) (Kenny and Shao, 1992), 2) Winkler index (WI) from April to October (Winkler *et al*., 1974), 3) Branas Heliothermic index (BHI) (Branas, 1974) and, 4) Hydrothermic index of Branas, Bernon and Levadoux (HyI) (Branas *et al*., 1946).

The indices are calculated using simulated daily maximum and minimum temperatures and daily precipitation totals obtained from the regional model COSMO-CLM (Consortium for Small Scale Modelling - Climate version of the Lokal-Modell; Böhm *et al*., 2006). Gridded climatic data is available with a spatial resolution of 0.165º latitude-longitude (grid size of about 20 km). Astronomical insolation for BHI computation is estimated by using the solar declination and the time of the year (Allen *et al*., 1998). All bioclimatic indices are calculated on a daily basis. A two-member ensemble simulation of the past climate (1960-2000) and for the XXI century (2001-2100; A1B) following the SRES A1B scenario (Nakićenović *et al*., 2000) are considered. Wine indices over the European sector (35-60ºN; 10ºW-35ºE) are compared for the recent-past (1960-2000) versus two future periods (2011-2040 and 2041-2070).

RESULTS AND DISCUSSION

Different bioclimatic indices were used to map macroclimate winegrape suitability across Europe for a recent-past period and for future periods under a climate change scenario (Fig. 1, 2). The patterns of LTI are scaled in such a way that the intervals correspond to the climatic groups defined by Kenny and Shao (1992). A region is considered unsuitable for vine growing when LTI is < 380, which for current climate conditions, roughly corresponds to regions northward of the 52ºN parallel (Fig. 1). For 2041-2070, this northern limit of wine production suitability is displaced northward to 55ºN. Similar expansions can also be found in the other groups, with obvious exceptions over mountainous areas. Therefore, the projected climate change is expected to have a positive thermal effect on grapevine growing and wine quality over most of Europe, with the clearest exception of high-latitude or high-altitude regions, where thermal conditions will remain far below the minimum climatic needs for an adequate vegetative development.

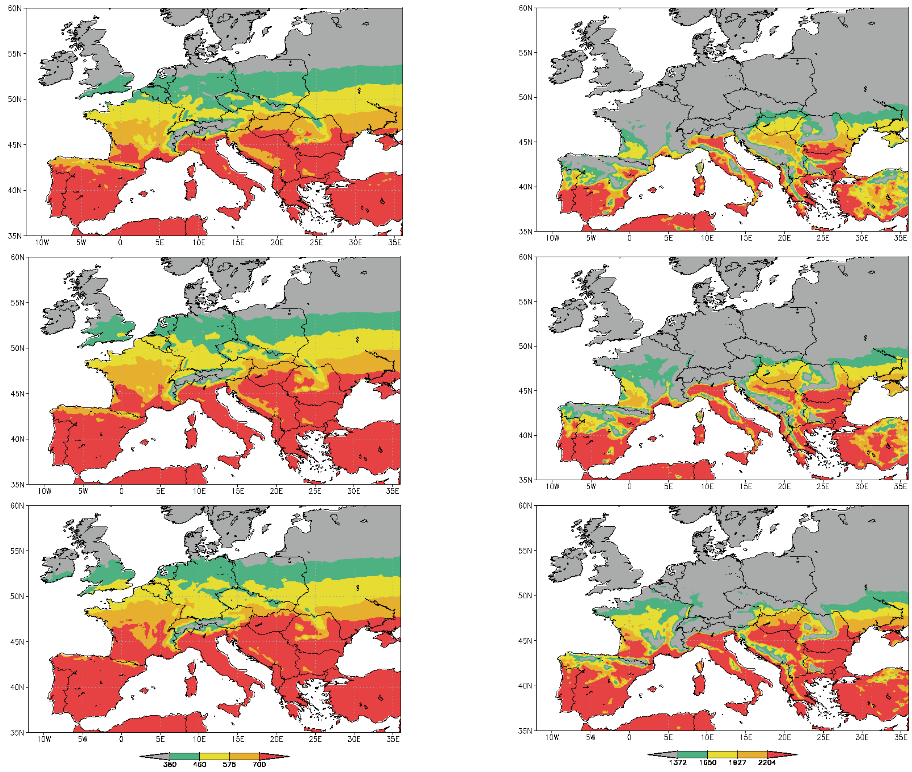

Fig. 1 *On the left*: Latitude-temperature index for: 1960-2000 (*top panel*); b) 2011-2040 (*middle panel*) and c) 2041-2070 (*bottom panel*). *On the right*: the same for the Winkler index.

These results are in agreement with Kenny and Harrison (1992) and Jones *et al*. (2005). This index, however, may be not suitable for evaluating seasonal differences in heat accumulation (Jackson, 2001). Conversely, LTI is particularly functional for discerning between cool climate areas, particularly those in Region I of Winkler classification. The classical Winkler Index, WI (Winkler *et al*., 1974), which integrates heat accumulation variations, is generally in agreement with the LTI results, though with better geographical definition, showing much higher values over Southern Europe, particularly over south-western Iberia and parts of Italy (Fig. 1). In fact, WI has been found to be accurate for comparing seasons, e.g. for discriminating intermediate through hot regions (e.g. southern Europe) (Jackson, 2001).

The scale in Fig. 1 corresponds to the five climatic regions defined by Amerine and Winkler (1944): from Region I (Cool) to Region V (Very hot). High values of WI reveal suitable areas for grapevine with late maturation, while low values fit for early maturation varieties. With some few exceptions, all classes but Region I (< 1372ºC) can be found over Southern Europe in present climate conditions. For future climate conditions, a slight northward displacement of these categories is found, e.g. for some areas in Central Europe, while the coolest region remains largely unchanged. Most latitudes above 50ºN remain keyed as having "cool" climates, being thus mostly unfavourable to wine production. Conversely, climate regions over Southern Europe are expected to change dramatically to warmer classifications (cf. Fig. 1). These predicted changes are indeed new challenges that can be a real threat for this sector if suitable adaptation measures are not timely planned. For instance, it will be necessary to implement vineyard irrigation in hot and dry climates for most of Southern Europe during the XXI century (Schultz, 2000). Further, some regions of Southern Europe may become excessively warm and dry for producing high-quality wines (Kenny and Harrison, 1992; Jones *et al.*, 2005).

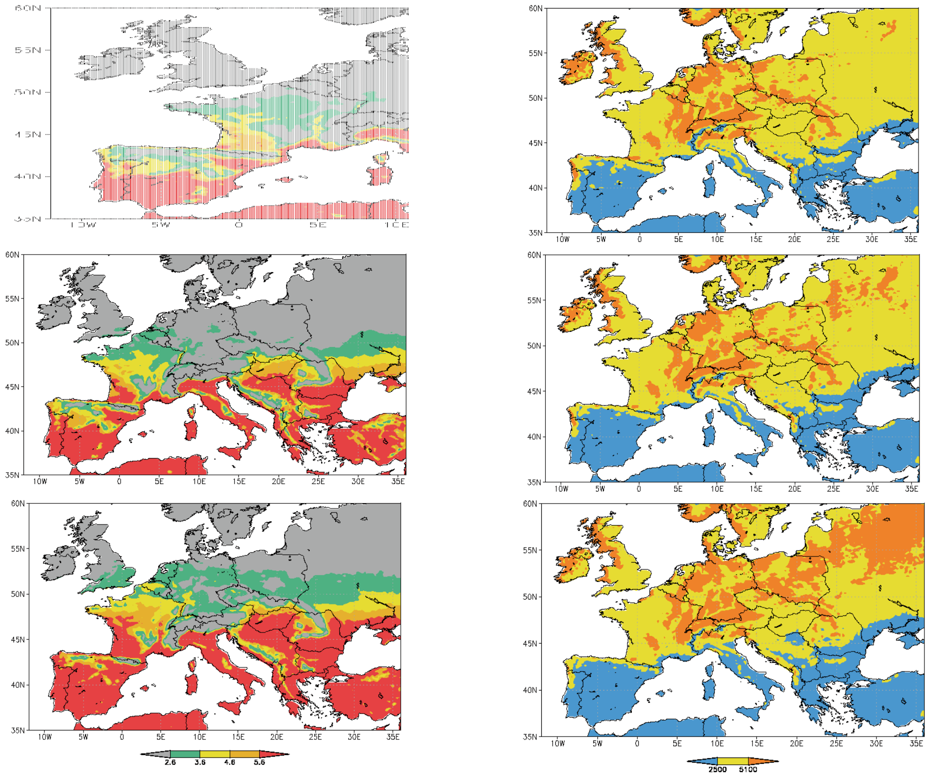

Fig. 2 As in Fig. 1, but now for the Branas Heliothermic index (*on the left*) and for the Hydrothermic index of Branas, Bernon and Levadoux (*on the right*).

The Branas Heliothermic index (BHI) has the advantage of integrating radiation (astronomical insolation) besides temperature (Branas, 1974), both variables having a strong influence on grape development and quality (e.g. Spellman, 1999). Values below 2.6 ºC.h are considered the lower threshold defining the northern limit of wine production viability in Western Europe (Carbonneau, 2003). In fact, BHI depicts values below this threshold over most of central and northern Europe, both in recent decades and the XXI century (Fig. 2), whereas it reveals high values over large areas of southern Europe (mainly over some parts of southern Iberia, Italy and the Balkans). Nevertheless, the latitudinal increase in day length (higher astronomical insolation) leads to an important weakening of the north-south contrast in the classification when compared with WI. In fact, at mid-latitudes, this index reveals grapevine growing suitability over several areas that were not identified by the WI, including northern and central parts of France and some parts of south-western Germany that are renowned wine producing areas. For future climate conditions, a significant northward extension of the regions with wine-producing potential is projected, being particularly meaningful over large areas of southern England, Belgium, the Netherlands, Germany, Czech Republic and southern Poland. These results are especially significant when taking into account the efficiency of the BHI in viticultural zoning.

Changes in precipitation might also have an important impact on viticultural zoning: for example, excessive dryness usually compels irrigation, while excessive precipitation, air humidity and soil moisture can expose grapevines to diseases and pests. Therefore, bioclimatic indices were developed that combine temperature and precipitation, e.g. for estimations of risk diseases such as downy mildew (Carbonneau, 2003). We consider the Hydrothermic index of Branas, Bernon and Levadoux, HyI (Branas *et al*., 1946). The risk of contamination by downy mildew is considered low when HyI has values below 2500ºC.mm and high when is higher than 5100ºC.mm. The patterns of HyI show that all areas with a Mediterranean-type climate present low risks of contamination, both for recent and future conditions, whilst high- and mid-latitude Europe present moderate to high risks, with an increasing trend over Central and Eastern Europe. This situation is particularly relevant for mid-latitude areas, where thermal conditions tend to be gradually favourable to wine production. Here, the climate warming is not accompanied by a beneficial decrease in precipitation, which increases the risk of grapevine attack by this disease. This can be a limitation to wine production, in spite of the general improvement in the thermal conditions. The projected enhancement of dryness in Southern Europe further decreases this risk, but might force the development of expansive and environmentally unsustainable irrigation techniques in several regions where they are not currently implemented.

CONCLUSIONS

Macroclimate maps show that under changed climate significant shifts and/or expansions in the European viticultural zoning can be expected. Negative impacts on wine quality by increased cumulative thermal and dryness effects during growing seasons in Southern European regions (e.g. Portugal, Spain and Italy) may happen. This is an important constraint to grapevine growth and development, making the development of adequate adaptation and/or mitigation measures of vital importance for this key economical sector. On the other hand, regions of western and central Europe (e.g. southern Britain, northern France and Germany) will benefit from changed conditions, both in terms of wine quality and in emerging new areas for viticulture. This approach also provides a macro-characterization of the European areas, where grapevines may grow in an economically-sustained manner, as well as their projected changes under anthropogenic forcing. Thus, these indices are a valuable tool for viticultural zoning in a changing global climate. Further bioclimatic indices will be analysed to improve this study.

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