Assessment of climate change impacts on water needs and growing cycle on grapevine in three DOs of NE Spain

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Keywords: *Vitis vinifera*, climate projections, agroclimatic indexes, water balance

Abstract

This study assessed the suitability of grapevine growing in three DOs of Catalonia (NE Spain) over the 21st century. An estimation of water needs and agroclimatic and phenological indicators was made. Climate change (CC) impacts were estimated at 1 km pixel resolution using temperature and precipitation projections and CC scenarios RCP 4.5 and RCP 8.5. Dynamics would be similar in the DOs studied although the magnitude of impact differs. Water needs would be 2 and 3 times greater than current water needs. Blooming date would advance from 3 to 6 weeks, harvest date from 1 to 2.5 months, resulting in growing cycles from 10 to 80 days shorter. Frost risk would decrease from 6 to 76%, the number of days with temperatures above 30ºC during ripening would rise from 48 to 500% and tropical nights at ripening would increase from 28 to 150. The impacts of CC in the three DOs could result in significant limitations for grapevine cultivation and wine production if adaptive strategies are not applied. This result could serve as a basis for the design of specific adaptation strategies to improve and maintain vineyards in the DOs studied and could be extrapolated to similar DOs and regions.

Introduction

In the Mediterranean region, vineyard is expected to be heavily impacted by climate change. The principal impacts would be changes in phenology and growing cycle, higher water demand and water scarcity, decreasing yields or soil salinity constraints. Consequently, grapevine production would be seriously affected. Diagnosing climate change impacts is extremely useful for proposing and executing adaptation strategies at the local/ regional scale to make vineyard more resilient.

In this study, three Mediterranean DOs were chosen to represent the diversity of the Mediterranean vineyard at a local scale. They feature a wide range of agroclimatic conditions in Catalonia, including inland vs. coastal differences.

The main goal of this study was assessing the suitability of grapevine growing in three DOs of Catalonia over the 21st century. The specifics goals of this study were mainly two:

(i) to estimate annual net hydric needs (NHN) of vineyard in three Mediterranean DOs for the baseline period and two future periods (2030s and 2070s) under two climate change scenarios, in order to assess agricultural suitability in terms of water requirements.

(ii) To estimate a set of agroclimatic parameters capable of indicating the consequences of climate change for crop phenology, growing cycle and grapevine quality, in order to better understand and manage the risks posed by climate change.

Material and methods

The study contains the area occupied by three DOs in Catalonia (NE Spain): Empordà, Pla de Bages and Penedès, located in the northeast extreme, central area and pre-coastal depression, respectively (Fig. 1). DO Pla de Bages has a Mediterranean mid-mountain continental climate with a strong thermal oscillation. DO Empordà is delimited in two geographically separated areas (Alt Empordà and Baix Empordà) and climate is Mediterranean coastal tempered with mild winters and hot summers. DO Penedès presents Mediterranean pre-coastal climate, also tempered by sea with mild winters and hot summers. In general, the three DOs present annual rainfall ranging from 500 to 650. Vineyard is widespread in DO Penedès presenting more than 26,600 ha, while DO Empordà and Pla de Bages present 2,114 and 441 ha, respectively.

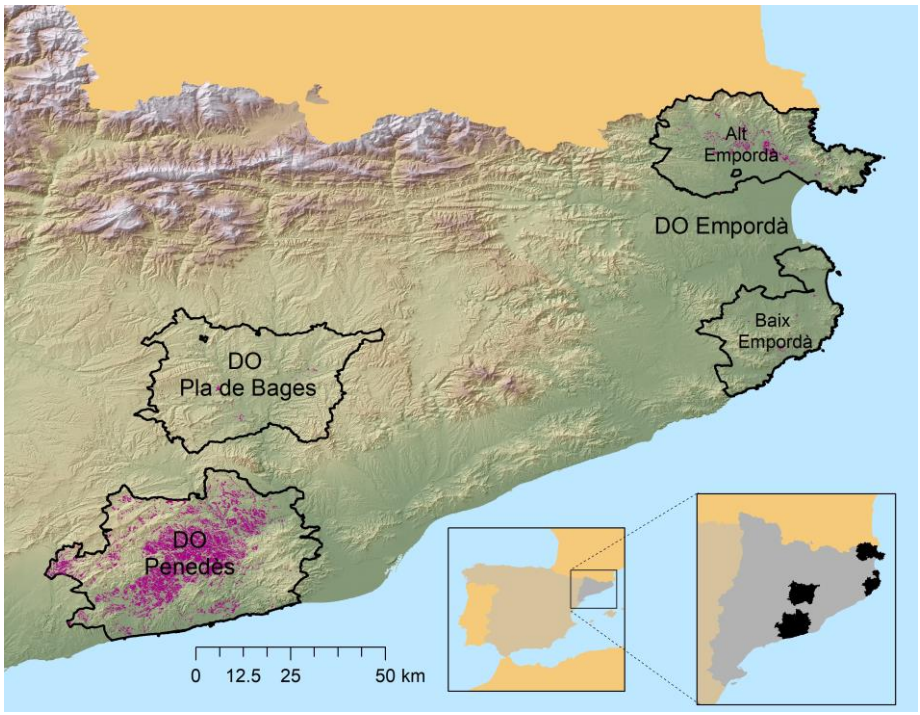

Figure 1. Location of the three vineyard DOs studied in Catalonia: DO Empordà (Alt and Baix Empordà), DO Pla de Bages and DO Penedès.
DOs are delineated in black and vineyard area is represented with purple colour.

Calculations were performed by using climatic data (daily basis data of accumulated precipitation, maximum temperature and minimum temperature) from simulations regionalized at 1 km spatial resolution for a control period (1971-2005) and for the whole 21st century (2006-2100) under two climate change scenarios: RCP 4.5 and RCP 8.5, stabilization and worst-case scenarios, respectively (IPCC, 2014). Crop water needs, phenological index and agroclimatic indicators were calculated for the three DOs at those pixels with presence of vineyard. Calculations were performed by pixel and by year, using the R programming language (R Core Team, 2020).
Methodology used for calculations of net hydric needs (NHN) followed the FAO-56 document (Allen et al., 1998), estimating potential evapotranspiration (ET_0) according to Hargreaves and Samani (1985), effective precipitation (Pef), potential crop evapotranspiration (ETc) and using the vineyard kc (ACA and IRTA, 2008). A daily water balance atmosphere-plant-soil was recurrently calculated to obtain actual evapotranspiration (ETa) from ETc, Pef ($mm \cdot day^{-1}$) and soil water content (SWC, $mm \cdot day^{-1}$).
Growing degree day accumulation (T^a threshold=10ºC) defining days elapsed between each phenological stage were calculated following Ramos et al. (2008) and based on phenological observations over Catalonia and several varieties between 2007 and 2010. Phenological indicators calculated were blooming date, harvest date and growing cycle duration. Regarding agroclimatic indicators, some of them were referred to a specific phase of the crop cycle: phase from veraison to ripening or ripening phase (phase III). Agroclimatic indicators calculated were DTR III (daily thermal amplitude, in ºC, during phase III), NT20 III (number of tropical nights during phase III or days with TN>20 °C) and TN III (mean value of minimum temperature, in ºC, during phase III).

Results and discussion

Results showed that NHN could rise 70-90 mm · year $^{-1}$ in DO Empordà, around 80 mm · year $^{-1}$ in DO Pla de Bages and Penedès at the end of the century (2070s) for the most dramatic scenario (RCP 8.5). These water needs increases supposes values 2 and 3 times greater than current water needs, ranging in average from 25-45 mm·year^{-1} (Fig. 2).

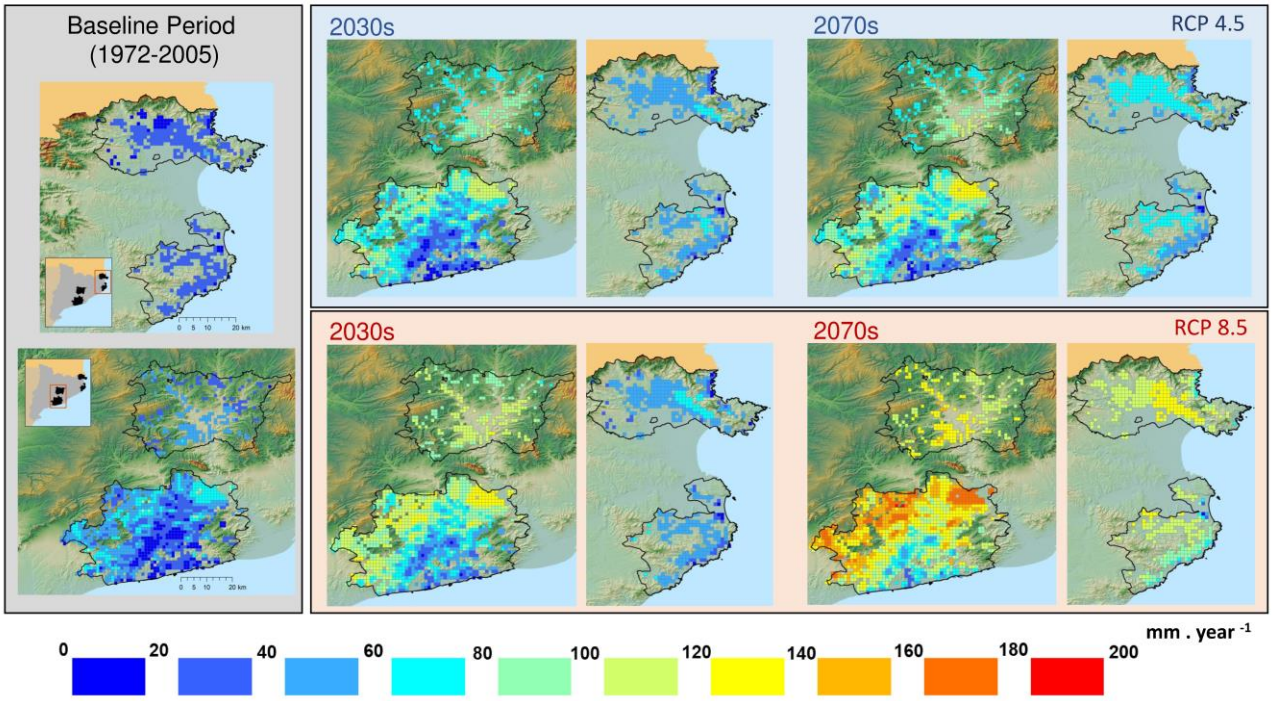

Figure 2. Projected net hydric needs (mm · year $^{-1}$) of three wine DOs in Catalonia (Empordà, Pla de Bages and Penedès) for two climate change scenarios: RCP 4.5 (blue) and RCP 8.5 (red) and two future decades: 2030s and 2070s (right). Baseline period (1972-2005) is showed at left.

Growing cycle could be shortened and advanced in the three DOs (Table 1). In fact, in the next decade (2030s) growing cycle could be shortened by about 1 month in DO Pla de Bages and DO Penedès and Baix Empordà for both climate change scenarios. At the end of the century, growing cycles could be up -57, -48 and -32 shorter than baseline period in DO Penedès, Pla de Bages and Baix Empordà. Nevertheless, Alt Empordà showed the smoothest growing cycle shortenings. Growing cycle advance was assessed by estimating blooming and harvest date. Blooming date could advance about 1 month in the three DOs in the 2070s for the most dramatic scenario. Moreover, harvest date could advance in average more than a month in most of the DOs for the next decade and from -45, -69, -87, -57 days in Alt Empordà, Baix Empordà, Pla de Bages and Penedès, respectively, for the 2070s, if RCP 8.5 scenario is considered.

Since temperature strongly affects quality parameters of grapes during the ripening phase, specific agroclimatic indicators have been calculated for this phenological state (from veraison to harvest). These indicators augmented in all DOs studied for both time horizons and both scenarios (Table 1). Tropical nights could rise about +5 and +10 days in Alt and Baix Empordà, respectively, for the next decade (Table 1). Penedès could increase as well tropical nights around +5 days for next decade. At the end of the century tropical nights could be +18 and +12 more than baseline period in DO Empordà and Penedès, if considering RCP 8.5 scenario. Pla de Bages, barely increased from +1 or +2 days for the next decades and +2 and +3 days in 2070's. Daily thermal amplitude could increase ranging from +1 to +2 at the end of the century for the dramatic scenario depending on the DO, presenting DO Pla de Bages the highest increases (Table 1). Daily minimum temperature could increase from +1.7 to +2.5 at the end of the century for the dramatic scenario depending on the DO, showing Baix Empordà the greatest increase (Table 1).

Results showed differences in how climate change impacts on each DO. For example, in Alt Empordà, impacts could appear later and smoother than in the other DOs, highlighting the importance of regionalization. Because of the temperature increase and because of the evaporative demand of the atmosphere together with the total

pluviometry stability, water balance is increasingly negative at the three DOs, showing that droughts would be more and more intense.

Table 1. Projected average values of phenological index and agroclimatic indicators for the baseline period (1972-2005) and future projections for two climate change scenarios (RCP) and two decades (2030s and 2070s).

Period		DO	Growing cycle (days)	Bloom date	Harvest date	Tropical nights (days)*	Daily thermal amplitude (ºC)*	Daily minimum temperature (ºC)*
Baseline (1972-2005)		AE	200.5	May 21st	September 29th	12.5	11.8	17.4
		BE	222.6	May 28th	October 27th	8.3	11.3	16.7
		PB	227.0	June 5th	November 19th	0.7	14.8	15.0
		PN	287.4	May 24th	October 14th	9.7	11.8	17.0
			Δ days	Δ days	Δ days	Δ days	Δ ºC	Δ ºC
			RCP 4.5 / RCP 8.5	RCP 4.5 / RCP 8.5	RCP 4.5 / RCP 8.5	RCP 4.5 / RCP 8.5	RCP 4.5 / RCP 8.5	RCP 4.5 / RCP 8.5
Future projections	2030s	AE	-11.1 / -7.0	-8.5 / -8.4	-19.9 / -21.8	+5.0 / +4.0	+0.6 / +0.5	+0.8 / +0.7
		BE	-25.5 / -25.5	-14.5 / -13.7	-43.1 / -45.4	+9.4 / +10.4	+0.1 / -0.2	+1.5 / +1.6
		PB	-35.1 / -38.6	-10.3 / -9.8	-50.8 / -54.6	+1.6 / +2.0	+0.6 / +0.3	+1.1 / +1.3
		PN	-28.9 / -31.5	-10.8 / -9.8	-29.0 / -31.5	+4.4 / +5.5	+0.4 / +0.1	+0.9 / +1.0
	2070s	AE	-12.8 / -16.3	-13.8 / -29.4	-30.2 / -45.4	+6.2 / +11.5	+1.0 / +1.7	+1.1 / +1.7
		BE	-29.2 / -32.3	-19.6 / -35.0	-53.5 / -69.0	+11.8 / +17.8	+0.5 / +0.9	+1.8 / +2.5
		PB	-41.2 / -48.1	-15.4 / -31.4	-67.0 / -86.7	+2.3 / +3.6	+1.0 / +1.9	+1.6 / +2.2
		PN	-40.4 / -57.1	-15.3 / -30.5	-40.3 / -57.1	+7.4 / +11.9	+0.8 / +1.2	+1.3 / +1.9

AE: Alt Empordà; BE: Baix Empordà; PB: Pla de Bages; PN: Penedès
*During ripening

Conclusion

This study shows significant water needs increases over the 21st century for vineyard in the three DOs studied, directly related with increased evapotranspiration during the growing season. The generalized NHN increase and the low water availability for irrigation will challenge the feasibility of maintaining grapevine production in the study area if no adaptations are implemented. Moreover, a general advancement and shortening of the growing cycle and changes in temperature during ripening affecting grapevine quality were estimated. These results represent a baseline to simulate adaptation strategies to design a more resilient vineyard.

Acknowledgments

This study has been conducted and funded within the framework of the project LIFE MIDMACC (LIFE18 CCA/ES/001099), DEMOS CLIMAVIT21 (Ref.: 056_2018) and DEMOS-SECAREGVIN (Ref.:058_2019) [Both funded through l'operació 01.02.01 de Transferència Tecnològica del Programa de desenvolupament rural de Catalunya 2014-2020. Dept. Acció Climàtica, Alimentació i Agenda Rural-GENCAT/FEADER]. We want to thank to DO Empordà, DO Pla de Bages and DO Penedès, Eulàlia Serra, Cristian Martínez-Rodríguez and, finally Rafael Poyatos for his inestimable help in elaborating the R scripts.

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