VERTICAL TEMPERATURE GRADIENT IN THE CANOPY PROVIDES OPPORTUNITIES TO ADAPT TRAINING SYSTEM IN A CLIMATE CHANGE CONTEXT

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Abstract

Aims: The aims of this study were (1) to measure the vertical temperature gradient in the vine canopy in parcels with different vineyard floor management practices and (2) to analyze the factors influencing this gradient. The objective was to investigate whether the increase of trunk height could be an adaptation strategy to reduce air temperature in the bunch zone in a context of climate change.

Methods and Results: The experiment for measuring the vertical temperature gradient has been set up in the Bordeaux area in 2016. Three replicates of four temperature sensors were installed on vine posts inside two adjacent vineyard parcels at different heights above ground: 30 cm, 60 cm, 90 cm and 120 cm. One parcel was managed with cover crop whereas in the other the soil was tilled.

The results of this study reveal an effect of measurement height and soil management modality on bioclimatic indices. The higher temperature sums are reached close to the ground, particularly on the parcel with cover crop. Only a small effect on delaying ripeness has been shown in this study. The increase of trunk height might minimize potential damage of both frost and heat wave events. Soil tilling also allows limiting spring frost risks.

In order to better understand the explanatory factors impacting the vertical temperature gradients, different climatic factors (average temperature, wind, precipitation, insolation fraction) and soil moisture were studied by using the data of the weather station of Saint-Emilion (Météo-France). A strong effect of soil moisture was shown on maximum temperature gradients. Projections of climate change agree on an increase in air temperature in the future. Assuming the same rainfall patterns, this increase of temperature is likely to reduce soil moisture, and increase vertical gradients in maximum temperature. Taking into account this evolution, the increase of trunk height could be a promising adaptation.

Conclusion: This study investigated the vertical temperature gradient and the driving factors for this gradient. Results show that rather than delaying the maturity, the increased of trunk height could be a solution to limit the negative impacts of frost and heat waves. This study also highlighted the impact of soil management and moisture on this gradient.

Significance and Impact of the Study: The recent evolution of climate already has an impact on vine development and grape composition and it becomes necessary to implement adaptation strategies. The training system is one of the first potential levers for adaptation, relatively easy to implement. This study provides results on the impact of an increased of trunk height and soil management on temperature in the canopy, particularly in the fruit zone, assuming temperature profiles would not change.

Keywords: Vineyard soil management, vertical temperature gradient, grapevine training system, climate change

Introduction

Temperature plays a major role in vine development and grape composition (Jones, 2018). Recent climate change (IPCC, 2013), characterized by an increase of air temperature especially during the grape ripening phase, already impacts vine development and grape composition. An advance of the different phenological stages has been observed (de Cortázar-Atauri *et al.,* 2017), as well as changes in grape composition and aromatic compounds in grapes and wines (Mira de Orduña, 2010). In this context, it becomes necessary for winemakers to implement adaptation strategies in order to produce wines while maintaining quality performances (van Leeuwen and Destrac-Irvine, 2017).

Soil type and soil management, as well as the proximity of the bunches to the ground, impact microclimate around the fruit zone (Cellier, 1991). A study of the vertical temperature gradient in vine parcels with different vineyard floor management strategies has been set up to investigate whether the increase of trunk height could be an adaptation strategy to reduce air temperature in the bunch zone in a context of climate change.

Materials and Methods

The experiment for measuring the vertical temperature gradient has been set up in the Bordeaux area in 2016. Three replicates of four temperature sensors Tinytag Talk2-TK-4023 (Gemini Data Loggers, UK) were installed on vine posts inside two adjacent vineyard parcels at different heights above ground: 30 cm, 60 cm, 90 cm and 120 cm. The data loggers recorded both minimum (Tn) and maximum (Tx) temperatures. Parcels are located on sandy-clay soil and were planted with Merlot in 1972 at a density of 6,000 vines per hectare. The vines are simple Guyot trained and the first supporting wire, which corresponds to the height of the bunches, is located 45 cm above the ground. The rows are planted in the North/South direction and vine spacings are 1.4 m (inter-row) by 1.2 m (inter-vine). One parcel was managed with cover crop (CoCr) whereas in the other the soil was tilled (Till). To quantify temperature differences between the sensors by modality and height, the Canopy Winkler degree day summation was used in this study (de Rességuier *et al.,* 2020). This index is based on the sum of mean temperatures above 10°C, from April 1st to October 31st (Winkler, 1974).

The GSR model was used to determine the impact of temperature on sugar content (Parker *et al.,* 2020). This model is based on a sum of daily mean temperatures above 0°C cumulated from the 91th day of the year (DOY). The sugar content is determined when the thermal sum reaches a threshold value specific for each grapevine variety. The threshold value for Merlot is 2,962 degree-days for 220 g/L of sugar concentration.

Data from the weather station of Saint-Emilion (Météo-France), located at 100 m from the study parcels was used to calculate the factors which may have an impact on vertical temperature gradient. The climatic factors described by Cantat *et al.* (2012) were calculated: average temperature, sunlight ratio, rainfall and wind at 10 m. Soil moisture was also estimated by using a soil water balance model (Lebon *et al.,* 2003).

The effects of height and vineyard floor management on vertical gradient of temperature and maturity were analyzed by using linear mixed-model (Pinheiro and Bates, 2000). Multiple comparisons were conducted using Tukey's HSD tests when a significant effect of height on the Canopy Winkler Index or GSR model was found. To test the effect of climatic variables on vertical temperature gradients, a linear mixed model was also used.

Results and Discussion

Vertical Temperature Gradient According to Vineyard Soil Management

Canopy Winkler Index was calculated for each sensor from 2016 to 2019. A significant effect of height and soil management on this bioclimatic index was found (Figure 1). Regardless of soil management, the higher temperature sums were located close to the ground and the tilled modality was warmer than the cover crop modality.

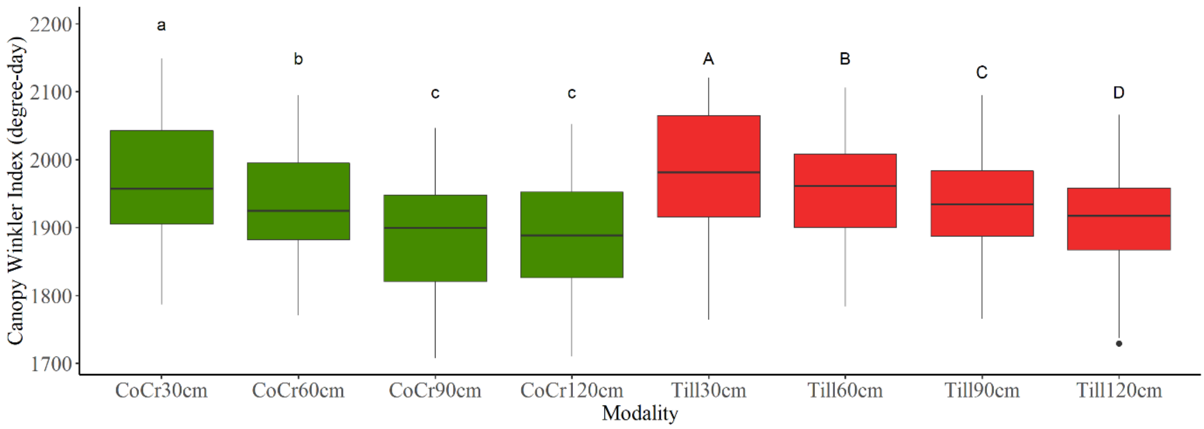

Figure 1: Boxplot of the Canopy Winkler Index from 2016 to 2019 according to height for each soil management modality. (n = 3 years * 3 replicates = 9 individuals / boxplot). The different letters indicate significant differences between heights. A separate model was used for each soil management modality.

Even if significant differences were found between heights, there were only 72 degree-days between 120 cm and 30 cm (modalities averaged). The impact on maturity calculated with the GSR model (220g/L of sugar for Merlot) was also limited, with three days of significant differences between 30 cm and 120 cm independently on the soil management modality.

According to these results, changing training system by an increase of trunk height, will not substantially delay the vegetative cycle in this context of climate change adaptation.

Temporal Analysis of Daily Vertical Gradients

A daily temperature analysis was carried out over 2018. Relative temperatures (e.g. 30-120 cm) were computed in order to neutralize daily temperature variations.

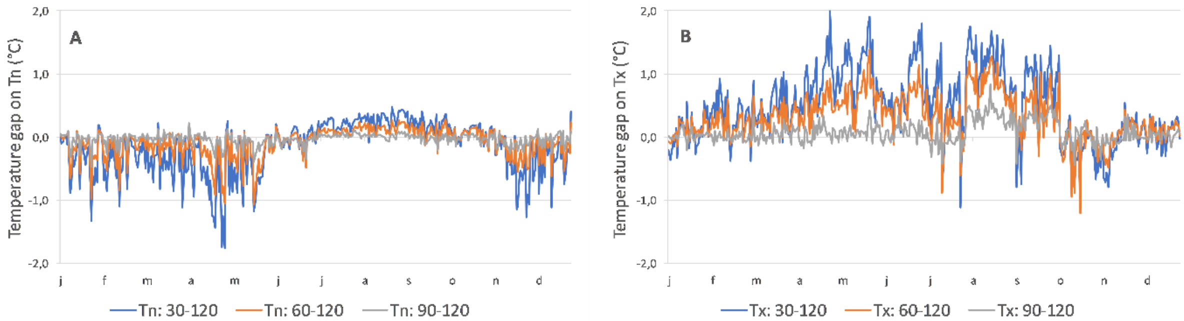

Figure 2: Daily relative minimum (A) and maximum (B) temperatures (30-120 cm, 60-120 cm, 90-120 cm) over 2018 averaged for both soil management modalities.

A strong vertical gradient on minimum temperature was highlighted from November to May with colder temperatures located close to the ground (Figure 2A). The gradient was particularly important in April (up to 2°C) during the sensitive phase after budburst, when spring frost events and damages are possible. In contrast, a very low and reversed gradient was observed between June and October. This is certainly due to the influence of the vegetation which limits night cooling, combined to higher radiation load and therefore heat storage in the soil. For maximum temperatures, the gradient was substantial from April through October (vegetative season) with warmer maximum temperatures located close to the ground, despite some very exceptional days of thermal inversions (Figure 2B). This gradient can reach 2°C, as with minimum temperature.

Impact of soil management on the vertical gradient of daily minimum and maximum temperature has been studied by using daily relative temperature between 30 and 120 cm (Figure 3).

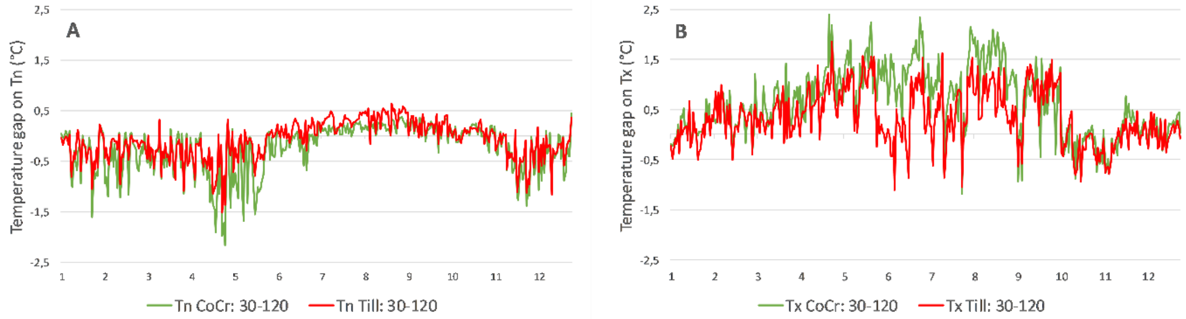

Figure 3: Daily relative minimum (A) and maximum (B) temperatures (30-120 cm) over 2018 by modality of soil management.

Regarding minimum temperature (Figure 3A), the kinetics between both modalities were similar, but the differences were greater for the cover crop modality in April, May and June. Risk of frost damage was greater on cover crop soil management. Cover crop could limit heat transport from the ground during the night (Cellier, 1991), but other effects not studied here such as soil moisture or soil compaction could have an impact.

For the maximum temperature (Figure 3B), warmer temperatures were located close to the ground on the cover crop modality especially between May and September. Here too, the soil moisture could impact surface temperature and the warming of air near the ground.

Analysis of the Vertical Gradient on Days of Extreme Temperatures

To measure the effect of height and soil management on vertical temperature gradient during days with extreme temperatures, a temperature analysis was carried out from 2016 to 2019.

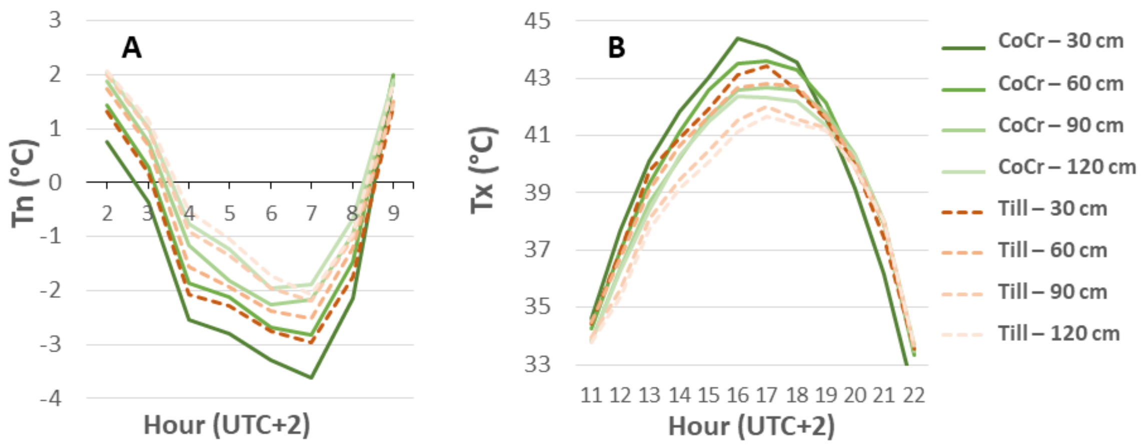

Figure 4: Hourly temperature distribution by height and soil management modality during the freezing night of April 27, 2017 (Tn, A) and during the heat wave of July 23, 2019 (Tx, B).

Analysis of the frost night of April 27, 2017 (Figure 4 A) reveals that independently on modality, temperatures near the ground were colder. The cover crop plot recorded a greater vertical gradient than tilled soil, and the temperatures in the fruit zone (45cm) were colder on the cover crop modality. Similar results were found for all the frost nights from 2016 to 2019 within the database (Tn < -2.5°C at 30 cm height (n=115)). The observed phenomenon is certainly due to grass which limits the rising heat from the soil during the night. Therefore, the increase in trunk height, associated with tilled soil, could be an adaptive solution to limit the risk of frost damage.

During the heat wave of July 23, 2019, regardless of the vineyard soil management, warmest temperatures were located close to the ground (Figure 4B). For this specific day an effect of soil modality was observed with the tilled modality being cooler than cover crop modality. Heat wave analyses from 2016 to 2019 (Tx > 38°C (n=48) at 30 cm height) reveal that the warmest maximum temperatures are always located at the lowest height but did not show a systematic effect of soil management. Therefore, the increase of trunk height could also reduce heat wave damages, such as scalding or aromatic profile alteration.

Factors Impacting Vertical Temperature Gradient

To determine the factors impacting vertical gradients during spring and summer for maximum temperatures and during spring for minimum temperatures, a statistical analysis was implemented (Table 1). Both soil management modalities were averaged. The explanatory factors selected were the wind at 10 m, the sunlight ratio, precipitation, average daily temperature (Tm) and soil moisture (synchronous daily data).

Table 1: Statistical results of models explaining vertical temperature gradients (30-120 cm) as a function of climatic variables and soil moisture, calculated from daily data from 2016 to 2018 (ns: not significant, ** significant at 0.01, *** significant at 0.001).

	Sunlight ratio	Tm	Precipitation	Wind at 10m	soil moisture
Tn Gradient (GrTn) 30cm-120cm spring (n=273)	*** GrTn ↗ when Sun ↗	*** GrTn ↘ when Tm ↗	ns	*** GrTn ↘ when wind ↗	*** GrTn ↘ when moist ↗
Tx Gradient (GrTx) 30cm-120cm spring (n=273)	*** GrTx ↗ when Sun ↗	ns	*** GrTx ↘ when preci ↗	ns	*** GrTx ↘ when moist ↗
Tx Gradient (GrTx) 30cm-120cm Summer (n=276)	*** GrTx ↗ when Sun ↗	** GrTx ↗ when Tm ↗	ns	*** GrTx ↗ when wind ↗	*** GrTx ↘ when moist ↗

A great effect of soil moisture and sunlight ratio on vertical gradient of maximum temperature was highlighted (Table 1). Dry soil and clear weather induce important amplitude on maximum temperature. High mean temperature during summer accentuated this effect.

Minimum temperature gradients during spring were dependent on soil moisture, wind and precipitations. Gradient of minimum temperature decreases with wind and high mean temperature and increases when the soil becomes drier (Table 1).

Conclusions

This study investigated the vertical temperature gradient and its driving factors. Results show that rather than delaying the maturity, the increase of trunk height could be a solution to limit the negative impacts of frost and heat waves. This study also highlighted the impact of soil management and moisture on this gradient. A tilled soil allows to limit spring frost risk.

The recent evolution of climate already has an impact on vine development and grape composition and implementing adaptation strategies becomes critical. Projections of climate change agree on an increase in air temperature in the future. Assuming maintained rainfall patterns, this increase of temperature is likely to reduce soil moisture, which increases vertical gradients in maximum temperature. For minimum temperatures the reduction of the gradient with the increase of mean temperature could compensate the effect of drought on this gradient. Taking into account this evolution, the increase of trunk height would be an adaptive solution to climate change.

In order to generalize the results obtained, this study will have to be repeated in other topographic situations in order to assess the effects of relief parameters on the vertical distribution of temperatures inside the canopy.

Acknowledgements

The authors would like to thank Emilie Gorisse, intern involved in this project in 2018, and the wine estate where the experiment took place for their cooperation. This research was supported by the Conseil Interprofessionnel du Vin de Bordeaux.

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