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Full Length Research Paper

Impact of climate change on winegrowing conditions in southernmost Finland (Tuusula)

Juha Karvonen

Department of Agricultural Sciences, Faculty of Agriculture and Forestry, University of Helsinki, 00014 Helsinki, Finland. Tel: +358400642378; E-mail: juha.i.karvonen@helsinki.fi

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According to the Köppen-Geiger climate classification, Tuusula belongs to the cold area (Dfb) of the temperate climate, and the Neubrandenburg, Freyburg, and Herrlisheim-prés-Colmar areas in Central Europe belong to the warm temperate climate (Cfb). Predicted global warming would increase the temperatures of the Dfb climate to the Cfb climate, which is suitable for winegrowing. According to the RCP2.6 climate scenario, the climate will become 2^0 C warmer in Tuusula by the end of 2100, which is close to the current Cfb climate. This study aimed to monitor air and soil temperatures and precipitation in 2014 ─ 2015 in Tuusula as well as in three other locations, and to evaluate the effects of a temperature increase predicted by RCP2.6 on the growth conditions in Tuusula. The soil temperature in Tuusula belongs to the "frigid" temperature regime, but the others belong to the higher "mesic". According to this study, all locations were classified as "very cool" for viticulture, and Tuusula's Cool Night Index was "very cool" while others were "cool". The Dryness Index in Tuusula was "moderately ─ dry-subhumid". Should the RCP2.6 scenario be realised, Tuusula's winegrowing conditions would be close to those in Freyburg, allowing for professional viticulture in southernmost Finland.

Key words: temperate climates, cool climate viticulture, air temperatures, soil temperature regimes, climate scenarios, *Geoviticulture MCC System*.

INTRODUCTION

Over thousands of years, the European grapevine (*Vitis vinifera* L.) has conquered new growing regions and has adapted to local climatic and growing conditions. When the Roman Empire collapsed, the northern border of the grapevine had reached 50°N latitude (Cologne, Freyburg, Saale-Unstrut, London, 51°N). In England, the grapevine was grown in the 11th ─ 13th centuries, but the sudden cooling of the climate and the puritanical administration ended this. With the beginning of a new warm era, the vine is returning to its previous growing places in England (Jones et al., 2005).

The global temperature has varied to a great extent during the climate history of the Earth. Not even during the last two millennia has the climate been nearly the same as at the beginning of the 21st century, but warmer and colder periods have alternated repeatedly. According to Stocker et al. (2013), the air temperature in the Northern Hemisphere was at its lowest in the 16th century, when it was 0.65°C lower than the average of the years 1881 – 1980; it rose by 0.65 ─ 1.06°C between 1880 and 2012.

Temperatures in winegrowing localities have varied in very broad limits as the occurrence of the vine and wine grape harvest dates centuries back (Cook and Wolkowich, 2016). Winter 1708 - 1709 was so cold that European waterways and the canals of Venice were frozen, and a large part of the vineyards were destroyed (Pain, 2009). In the "cold" years, the harvest occurred several weeks later than usual. In Alsace, the wine harvest has begun on September 16 (on average) in 1700 ─ 2005, but during the Little Ice Age in the 16th century, when the air temperature was 2°C lower than today, and during a cold period in the 1850s, it didn't happen until October. From the 1970s on, the harvest has gotten earlier as the climate has gotten warmer (Camps and Ramos, 2012; Daux et al., 2012).

In the greenhouses of manors in South and Southwest Finland, on the north side of 60^0 N, European vines have been grown for nearly 250 years (Justander, 1786), and the low temperature–resistant North American varieties *Vitis riparia* L.and *Vitis labruska* L. have also been tried in the open air for 100 years (Reuter, 1904; Meurman, 1957). These examples show that the grapevine can adapt over time to tolerate high- and low-climate temperatures, and it has moved from south to north or from north to south before, as the climate has warmed or cooled.

So far, 50°N has been considered the northern boundary of grapevine cultivation, which has begun to shift towards Northern and Northeastern Europe as a consequence of global warming. Even if the temperature, soil, and rainfall in these new conditions were suitable for viticulture, the grapevine would have to adapt to a long day and to large inter-annual fluctuations in temperature in the high latitudes of 50 ─ 60°N.

During a 160-year period of continuous temperature monitoring, a temperature increase became apparent in the 2000s, when the Finnish climate warmed to 0.6°C above the 160-year average. Warming has been most noticeable in the winter and spring. In the Helsinki area, temperatures are still rising, and in the most recent (2005─2014) gain in individual years, the average temperature has increased by 0.7^0 C compared with the 1971 ─ 2010 average (Tietäväinen et al., 2010).

Current global warming has been predicted with the help of SRES (Special Report on Emission Scenarios), which have been derived from CO_2, CH_4, and N_2O emissions, and the RCP (Representative Concentration Pathways)scenario group. Based on these, even the 1°C increase lengthens the growth period by 9 ─11 days, and climate zones move 500 km northwards (Cook and Wolkowich, 2016). If the climate rises by several degrees during this century, some of the current plant and animal species will not have time to adapt to the new climate and conditions. They end up in the wrong environment in a way, and they may become extinct.

With the realisation of global warming, South and Central European crops such as vines would replace or complement some of the northern varieties of agricultural plants. Winegrowing winners would be higher latitudes in Northern and Northeastern Europe (Ashenfelter and Storchmann, 2014;van Leeuwen and Darriet, 2016). Professional viticulture has already appeared in the Baltic Sea region in Northern Germany, Denmark, and in Southern Sweden. In Finland, experiments with *Vitis vinifera* L. and with some hybrid varieties were started as far north as 63°N latitude. These experiments suggest that the vine is becoming a new Northern European agricultural plant.

MATERIAL AND METHODS

The study was designed around four locations in the same temperate zone, and the following data were collected from each site: climate temperatures, temperatures at the grapevine planting depth, rainfall, and differences amongthe four places. Based on the results, the global grapevine growth zone to which these places belong was defined (Tornietto and Carbonneau, 2004), along with how the viticulture conditions in Southern Finland would change if the climate scenarios came true and the annual average temperature in Helsinki rose by 2°C. In this study, the four locations chosen were Tuusula (Helsinki region, Finland), Neubrandenburg (Mecklenburg-Vorpommern region, Germany), Freyburg (Saale-Unstrut region, Germany), and Herrlisheim-prés-Colmar (Alsace region, France) (Table 1). According to the Köppen-Geiger climate temperature classification, Tuusula and Neubrandenburg belong to the cold area of the temperate climate zone (Dbf), while Freyburg and Herrlisheim-prés-Colmar belong to the warm area of the temperate climate zone (Cfb) (Köppen, 1900; Geiger, 1961). The climate temperature classification of these regions was later revised (Kottek et al., 2006; Peel et al., 2007).

In Tuusula, the vineyard was located on flat land about 30 km from the sea; in Neubrandenburg, it was on a sheltered low hill 45 km from the sea; in Freyburg, it was on a southwest slope 200 m from the Unstrut River, and in Herrlisheim-prés-Colmar, it was on flat land in the Rhine Valley, 10 km from the Rhine River. In soil samples taken from depths of 30 - 40 cm in the vineyards, the pH of the soil in Tuusula was 6.9, and it was earthy clay loam.In Neubrandenburg, the pH of the soil was 7.4, and it was earthy loam. In Freyburg, the pH was 7.7, and the soil type was earthy clay loam, and in Herrlisheim-prés-Colmar, the pH was 7.7, and the soil was earthy clay loam. The pH of the Tuusula soil was low and the copper content of the soil in Herrlisheim-prés-Colmar was very high, but the earth types in each location were similar to each other.

Winds in the region are west winds in the summer, and the four seasons are clearly distinguishable from each other. The localities' height above sea level varied from 53 to 242 m,with their greatest distance being 1,390 km (Tuusula–Herrlisheim-prés-Colmar). Tuusula has the

Table 1. Observation sites.

Community	Country	Location	Landscape	Above sea level m	Distance to Herrlisheim-prés-Colmar km
Herlisheim-prés-Colmar	France	48°01'N, 07°19'E	Rhine valley	196	0
Freyburg	Germany	51°13'N, 11°46'E	Unstrut valley	110	360
Neubrandenburg	Germany	53°33'N 13°16'E	Lake land	53	550
Tuusula (Helsinki area)	Finland	60°24'N, 25°01'E	Costalarea	63	1390

longest days during the growing season, and Herrlisheim-prés-Colmar the shortest; the sun's radiant energy is higher in Tuusula than in North Germany (Lindfors et al., 2014), but only 5% lower than in Herrlisheim-prés-Colmar (Eumetsat, 2014).In 2001 - 2012, the average sun radiant energy in June, July, and August was 481 kWh/m^2 in Tuusula, 477 kWh/m^2 in Neubrandenburg, 474 kWh/m^2 in Freyburg, and 505 kWh/m^2 in Herrlisheim-prés-Colmar (Eumetsat, 2016).

The maximum and minimum temperatures of Tuusula, Neubrandenburg, Freyburg, and Herrlisheim-prés-Colmar were obtained from the daily observations of the meteorological institutes of Finland, Germany, and France (Finnish Meteorological Institute, Deutscher Wetterdienst, and Meteofrance) between September 1 and August 31, 2015, and they were used to calculate yearly and monthly averages of air temperatures, as well as standard deviations and statistical discrepancies and the annual lowest air temperatures.

For soil temperature measurements, loggers that register the soil's temperature and humidity (*Thermo Button 21G, Proges-Plus, France*)were placed 40 cm deep in the subsoil of the vineyards. They recorded the soil temperature every third hour between September 1, 2014 and August 31, 2015. The soil temperatures in Tuusula, Freyburg, and Herrlisheim-prés-Colmar were also measured at a depth of 20 cm. The annual and monthly averages, standard deviations, and statistical discrepancies, as well as the lowest soil temperatures of the year, could be calculated from the registered data. In order to calculate the statistical differences for each location's air and soil, *Student's t-test* was used. The interdependence of the air and soil temperatures was calculated with *Pearson's correlation coefficient.*

Based on RCP climate scenario groups RCP2.6, RCP4.5, RCP6.5 and RCP8.5, it was estimated that climate warming would affect grapevine growing in Tuusula in coming decades. The current climatic and environmental conditions of Tuusula, Neubrandenburg, Freyburg, and Herrlisheim-prés-Colmar were evaluated with Multicriteria Climatic Classification system indexes (*Geoviticulture MCC System*) (Tornietto and Carbonneau, 2004), which are used globally to classify viticulture conditions in the growth period of April 1─September 30. Of these indexes, the dryness index (DI) indicates the potential water balance of the soil. The Huglin index (HI) (Huglin and Schneider, 1998) classifies the growth conditions in the regions during the growing season according to the accumulated air temperature, and it also accounts for the long days in the viticulture regions in higher latitudes. The Cool Night Index (CI) classifies regions based on the lowest night-time temperatures during the ripening season.

RESULTS AND DISCUSSION

The climate in the Northern Hemisphere has been warming since the end of the 19th century by 0.7°C compared to the average in 1881 ─ 1980 (IPCC, 2013). In Finland, temperatures have been rising slowly since 1860. Within the last 100 years, the average annual air temperature in the southernmost parts of Finland has increased by 1°C (Tietäväinen et al., 2010). The increase has been most noticeable in spring and in winter. Despite this, the snow and cold in March still restrict photosynthesis until the second half of April (Peltola and Kellomäki, 2005). Despite the temperature increase, the average annual air temperatures in Tuusula are still significantly lower than the average annual air temperatures in Neubrandenburg, Freyburg, and Herrlisheim-prés-Colmar (P<0.05) (Table 2). In Tuusula, the average annual air temperatures were more than 5^0 C lower than in Herrlisheim-prés-Colmar.

Year-round average soil temperatures were measured in Tuusula, Freyburg, and Herrlisheim-prés-Colmar at 20 cm depth, and in Tuusula, Neubrandenburg, Freyburg, and Herrlisheim-prés-Colmar at 40 cm depth. The year-round average soil temperatures in Tuusula at depths of 20 cm and 40 cm were almost 5^0 C lower than in Herrlisheim-prés-Colmar. Compared to Freyburg, the

Table 2. Average air and soil temperatures in Tuusula, Neubrandenburg, Freyburg and Herrlisheim-prés-Comar. The soil temperatures were measured at a depth of 40 cm.

Locality	**Air temperature °C**	***n***	**Soil temperature °C**	***n***
Tuusula	6.9±7.0	730	7,6±6,1	2190
Neubrandenburg	9.8±6.3	730	10.8±6.2	2190
Freyburg	10.5±7.1	730	12.0±6.9	2190
Herrlisheim	12.2±7.1	730	12.4±6.5	2190
Tuusula><Freyburg air temperature		730	*t*	$P<0.05$
Freiburg><Herrlisheim air temperature		730	*t*	$P<0.05$

year-round average soil temperatures in Tuusula at depths of 20 cm and 40 cm were significantly lower than in Freyburg ($P<0.05$), but there were no statistically significant differences between Freyburg and Herrlisheim-prés-Colmar ($P>0.05$) (Tables 2 and 3). Based on monitoring by *Thermo Button 21G*, the soil temperature in Tuusula at 20 cm was 0.5°C at its lowest (January 10 ─ February 28); in Freyburg it was 2.0°C (February 7 ─ 9), and in Herrlisheim-prés-Colmar it was 1.0°C (February 12 ─14). At a depth of 40 cm, it was 1.0°C at the lowest in Tuusula, (January 10 ─ February 28), 1.0°C in Neubrandenburg (February 17 ─19), 2.5°C in Freyburg (February 7 ─ 9), and 1.5°C in Herrlisheim-prés-Colmar (February 8 ─ 13). These significant differences of air and soil temperatures show that, of the four localities, Tuusula still belongs to the colder climate and soil temperature classifications (Köppen, 1900; Geiger, 1961; Soil Survey Staff, 1999).

The classification of soil temperature in different regions on Earth has been based on annual and monthly average soil temperatures measured at a depth of 50 cm. The classification is also affected by soil types—mineral soil and organic soil—as well as by the location of the place. Based on the classification, soil in South Finland has belonged to the "cryic" temperature regime, where the average annual soil temperature is 0 - 8°C and the mean temperature of mineral soil in June, July, and August remains under 15°C. The classification of soil temperature in southernmost Finland is currently most likely "frigid", but Neubrandenburg, Freyburg, and Herrlisheim-prés-Colmar belong to the higher "mesic" (Soil Survey Staff, 1999).

In this study, the year-round average soil temperature at 40 cm depth was 7.6°C, and the average temperature in June, July, and August was 15.8°C. The difference of the measurement depths is 10 cm, which typically means less than 0.1°C difference between annual mean temperatures of the soil layers (Lemmelä et al., 1981). This minor difference has no significance. According to Table 3, there was also no significant difference between temperatures measured at 20 cm and 40 cm depths ($P>0.05$).

Soil temperature does not change linearly with depth from topsoil. According to a curve on soil temperature vs. soil depth drawn up by Lemmelä et al. (1981), the annual average temperature of topsoil (20 cm) rises until 40 cm, after which it begins to slowly decrease until 400 cm, and after that it rises again until 700 cm. At this depth, the temperature varies only by 0.82°C within a year. Based on this result and our own measurements, a planting depth of 40 cm is most suitable in the temperate zone.

From the point of view of the vine's winter hardiness, it was most important that in Tuusula (as in Neubrandenburg, Freyburg, and Herrlisheim-prés-Colmar) the soil temperature did not fall below 0°C at depths of20 cm and 40 cm in winter 2014; i.e., the danger of root freezing is low at the commonly used planting depth of 40 cm, even at high latitudes (Figure 1). However, abiotic stress caused by the cold is greater in the North because in the northernmost location, Tuusula, the lowest soil temperature was maintained continuously for nearly two months, while in contrast it only lasted for a few days.

There was a strong correlation between air and soil temperatures (0.96 - 0.99), so an increase of climate temperature directly impacts the rising of soil temperature. Variations of soil temperature are slower, and the monthly mean temperature of soil at a depth of 40 cm is at its highest only a month after the highest monthly air temperature average has been reached (Karvonen, 2016). The soil temperature's remaining above the air temperature in late autumn promotes the transition of the grapevine to winter dormancy.

Table 3. Differences in temperatures at 20 cm and 40 cm depths in Tuusula, Freyburg and Herrlisheim-prés-Colmar.

Locality	20 cm °C	40 cm °C	*n*	*t*	*P*
Tuusula	7.4±6,9	7.6±6,1	2190	1.41421	>0.05
Freyburg	11.8±6.5	12.0±6.9	2190	1,08449	>0,05
Herrlisheim	12,3±6,6	12,4±6,5	2190	0,50994	>0,05
Tuusula><Freiburg	20 cm		2190	16,83899	<0,05
Freiburg><Herrlisheim	20 cm,		2190	2,47725	>0,05
Tuusula><Freiburg	40 cm		2190	22,26184	<0,05
Freiburg><Herrlisheim	40 cm		2190	1,88535	>0,05

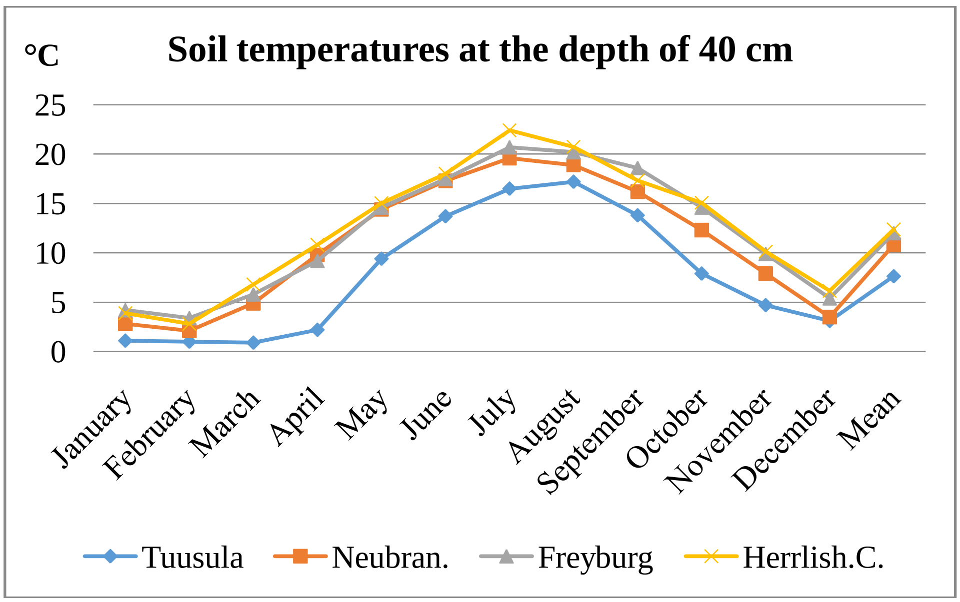

Figure 1. Average soil temperatures measured in Tuusula, Neubrandenburg, Freyburg and Herrlisheim-prés-Colmar.

If the soil temperature fell below zero earlier than the air temperature, it would result in root freezing and death of the plant.

The annual average soil temperature is 1°C higher at a depth of 50 cm than the average air temperature (Soil Survey Staff, 1999), but in the northern regions, the year-round average soil temperature is above 1°C (Mokma and Sprecher, 1995), sometimes even more than 2°C higher, than the year-round average air temperature (Yli-Halla and Mokma, 2001). In Tuusula in 2014 – 2015, the annual average soil temperature at 40 cm depth was 0.7°C higher than the average annual air temperature. The respective difference in Neubrandenburg was 1.0°C, 1.5°C in Freyburg, and 0.2°C in Herrlisheim-prés-Colmar; i.e., at the southernmost point in Herrlisheim-prés-Colmar, the differences were smallest (Table 2).

Indexes and weather conditions in the growing season (April 1 - September 30) are presented in Table 4. The Multicriteria Climatic Classification System (*Geoviticulture MCC System*) was used for the comparison (Tornietto and Carbonneau, 2004). According to the Heliothermal Index (HI) and the Amerine-Winkler Index (Amerine and Winkler, 1944), Tuusula, Neubrandenburg, Freyburg, and Herrlisheim-prés-Colmar belong to the "very cool" class of the viticultural climate. The Amerine-Winkler Index correlates well with the Heliothermal Index, although it has been calculated in a simpler way by adding the daily temperatures that exceed 10°C.

Table 4. Comparison of Climatic Classification system (*Geoviticulture MCC System*) indexes and climatic conditions in growing season between Tuusula, Neubrandenburg, Freyburg and Herrlisheim-prés-Colmar in 2015.

	Tuusula	Neubandenburg	Freyburg	Herrlisheimprés Colmar
Huglin (HI)	818x1.12=916	1118x1.06=1185	1272x1.06=1348	1272x1.06=1348
Amerine-Winklerindex, GDD[1)]	633	806	854	1066
Coldnightindex (CI)	10.4	12.1	12.4	12.2
Hydrothermalindex (HyI)	4103	4642	4779	5959
Dryness Index (DI)	51	-	-	-
GS[2)]-precipitation mm	331	324	323	370
Frost freedays	171	232	244	276
Lowesttemperature, °C	–17.0 (Jan. 12)	–4.1 (Febr. 5)	–5.2 (Febr. 5)	–6.1 (Jan. 6)
Blossomtimetemperature, °C	16.8[3)]	14.6	15.0	18.3
GS[2)]-average air temperature	12.5	13.8	14.3	15.7
T>10°C	99	127	142	157
Meantemperature 10 – 20 July	15.0	17.5	20.5	24.2

[1)]Growing degree days, [2)] Growing season April 1-September 30, [3)]Tuusula: June 24-July 7; Neubrandenburg, Freyburg and Herrlisheimprés Colmar: June 15-30.

According to the Cool Night Index (CI), Tuusula belonged in the “very cool nights”category, but the other localities were in the “cool nights” group. Based on the Dryness Index (DI), the potential water balance of Tuusula was between “moderately dry” and “subhumid”. The DI was not calculated for the other locations, but based on rainfall during the growing season, they probably belong to the same category. The Hydrothermic Index (HyI) rates the rainfall and temperature in a growth season (Branas et al., 1946). The HyI was lower in Tuusula than in the other locations, even though the difference in rainfalls was not more than a few tens of millimetres. Thus, the lower HyI of Tuusula is probably due to the lower temperatures during the growing season.

The frost-free growing season in Tuusula lasted 171 days, which was shorter than in every other place (Table 4). This is because of the early frost, which occurs in the locality at the turn of September and October. The air temperature decreases to around -1°Cfor 1 ─ 2 days, after which the next frost period will not occur until November. Due to the short cold period in September or October, there were also fewer days with 10°C or above in the other localities.

The average year-round temperatures in the growing season and in the winter months vary significantly from year to year. The average air temperature in the growing season was 12.5°C (Table 4), which was 1.3 – 3.2°C lower than in the other places because in 2015, the temperature of the summer months was the coolest in several decades. In 2014, it would have been as high as in Freyburg and Herrlisheim-prés-Colmar. Although winters in South Finland have become milder and there can only be -10°C in winter months, there can still be over -20°C for 1 ─ 2 weeks. Tuusula’s lowest temperature in 2015 was in January -17°C, which is, according to Bauer (2002) and Bauer et al. (2015), the lower limit of the frost hardiness of the grapevine, but even harder frosts have rarely frozen grapevines.

The temperature at the beginning and in the middle of the growing season (April 1–September 30) significantly affects the maturation of the grapes and the beginning of the harvest. In the growing season, the air temperature should not fall below 10°C for a long time so that it is possible to start the harvest on time (Jones et al., 2005). The effect of other meteorological factors is smaller. Table 4 shows that 45% of days during the growing season in Tuusula were under 10°C, so the grapevine was dormant for a large part of the growing season, but in Herrlisheim-prés-Colmar, only 13% of days fell to this temperature. Because of the coolness of the summer, the ripening of the harvest was badly delayed in 2015.

In France and Switzerland, a 1°C change in air temperatures in April–August advances or delays the commencement of the harvest by 10.2±0.9 days (Menzel, 2005; Cook and Wolkowich, 2016). The microclimates of plots located close to each other may differ from each other by even 1°C. For this reason, finding a micro-climatically warm growing place is essential in Northern Europe. A temperature that is 1°C higher compared to the surrounding environment lengthens the growing season by 1.5 weeks, increases the Huglin Index by 23%, and “moves” the growing place

500 km southwards.
Several alternative models derived from carbon dioxide and other greenhouse gas emissions and related factors (e.g., population growth and rising standards of living as well as the coal-intensity of energy production) are used in order to model, research, and predict the future climate. The scenarios consist of the averages of these models (RCP2.6; average of 27 models, RCP4.5; average of 35 models, RCP 6.0; average of 16 models, RCP 8.5; average of 35 models), which predict that the surface temperature of the Earth will increase by 0.3 ─ .7°C in the next 20 years (2016 - 2035) compared to the level of 1986 - 2005 (IPCC, 2013).

All RCP scenarios predict that the surface temperature of the Earth will likely increase by more than 2°C at the end of the century (2081 - 2100) rather than stay lower. In arctic regions, the increase in air temperature would be even higher, and the temperature in northern countries would increase by 2 – 4°C in all seasons (Climate Chance, 2014). In a model experiment based on scenario RPC4.5 in the latitude where Tuusula is located (60°N), the increase in temperature would be 2.5–3.0°C from the level of 1986 ─ 2005 until 2081 ─ 2100, but according to scenario RCP2.6, it would increase by 2°C at most, and it might even fall to the level of 1986 ─ 2005 by the end of year 2100.

Figure 2 shows how the climate temperature of Tuusula vineyard would change in 2100 if an increase of 2°C predicted by scenario RPC2.6 is added to the average temperature of each month, and how close it would come to the temperatures and growing conditions in the Freyburg vineyard:

1. Air temperatures in the spring months (March, April, and May) would come close to air temperatures in Freyburg. 2. The growing season could begin at the end of March, 3 ─ 4 weeks earlier than present.
3. Temperature peaks in the summer months would remain 2─ 3°C lower than temperatures in Freyburg, but they would suffice for the growth and maturation of grapes.
4. The daily mean temperature in the growing season would permanently be over 5°C.
5. The growing season would be extended by 1 ─ 1.5 months in the whole of Finland.
6. In autumn, the temperature increase would be smaller as Tuomenvirta (2004) has proposed, and the temperature in Tuusula would drop more sharply in October than in Freyburg, but the first early frost dated in this phase would no longer endanger the maturation of grapes in autumn.
7. Frosty periods would only occur in December and January.
8. The thermic winter in South Finland (daily average temperature permanently below 0°C) would be shortened by 2─3 months.
9. Southern Finland would become virtually free of snow.
10. Rainfall would increase by 20─25% in winter, 0 ─ 5% in summer, and by 10% yearly, or would be only slightly larger than present (Jylhä et al., 2009; Ruosteenoja et al., 2005; Ruosteenoja et al., 2011).

The scenarios are not, however, a law of nature, but an internally consistent estimate of future events, which also requires estimates of the future magnitude of emissions. A scenario is merely an estimate or a guess, the realisation of which is impossible to predict. Therefore, scenarios have had to be adjusted, and previous ones have been given up. If the consumption of fossil fuels remains high until the end of the century, then scenarios RCP8.5 and RCP6.0 suggest the surface temperature of Earth may rise by 6°C or more, but if their consumption can be brought to a decrease quickly, then the global temperature increase may even turn into a decline by the end of the century.

If the rise of the global surface temperature actualises by 2 ─ 4^0 C, the predicted climate warming and lengthening of the growing season will have a positive or negative impact on the growth of present crops and on the quantity and quality of the crop (Duchêne and Schneider, 2005). The winners will be northern regions, where climate temperature is becoming more favourable for winegrowing (Ashenfelter and Storchmann, 2014).The cooler climate and long daysduring the growing season may increase wine's functional antioxidant content, such as resveratrols, And may also maintain the alcoholic content of wines at a reasonable level. In today's winegrowing regions, the high sugar content of grapes is a problem that has arisen in addition to unfavourable impacts on climate. According to Sorio and Siadou-Martin (2017)**,** over the last 20 years, the alcohol content of wines has increased by 2% and are projected to rise by another 2% over the next 20 years, which may have significant detrimental effects on health.

CONCLUSIONS

In the study, the current climatic and growing conditions of a vineyard located in southernmost Finland, Helsinki region, Tuusula (60°N), were compared to the climatic and growing conditions in vineyards in Neubrandenburg (53°N) and Freyburg (51°N), located in North Germany, as well as in Herrlisheim-prés-Colmar (48°N), in the Alsace region in France. According to the Köppen-Geiger climate classification, the localities belonged to the temperate zone (Cfb or Dfb). Based on the climate scenario RCP2.6 (Representative Concentration Pathways), it was estimated how the viticulture conditions in Tuusula would change with the climate warming by 2°C by the end of 2100.

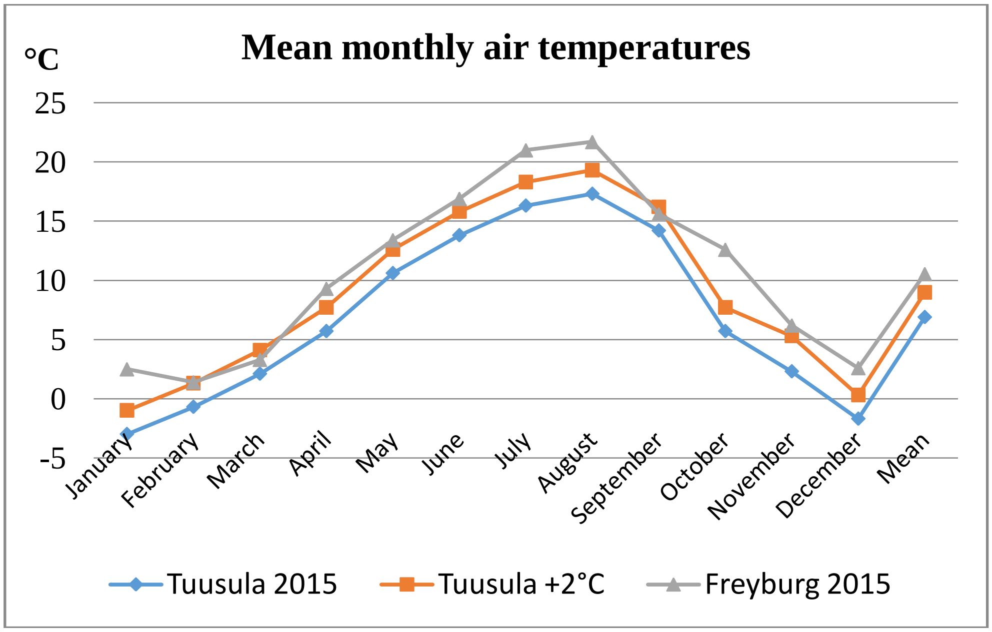

Figure 2. Monthly mean air temperatures in Tuusula in 2015 and after the predicted 2°C rise in annual mean air temperature, compared to the air temperatures in Freyburg in 2015.

Air and soil temperatures as well as rainfall were monitored during 2014─2015, from September to September. The temperature at a planting depth of 40 cm remained at 1°C or above in Neubrandenburg, Freyburg, and Herrlisheim-prés-Colmar, but in contrast to the others, the soil temperature remained at 1°C at 40 cm depth for nearly 2 months. In the soil temperature classification, Tuusula may be moving into the “frigid” regime, but the others belong to the higher “mesic” temperature regime.

According to the Climatic Classification System (*Geoviticulture MCC System*), in Southern Finland, the current winegrowing conditions in the Helsinki region belong to the “very cool” category, where the maturation of the crop requires a good local microclimate. A temperature that is 1°C above the surrounding area lengthens the growing season by 1.5 weeks. Based on the growing season rainfall, its category is between “moderatetely dry” and “subhumid”, which is sufficient for grapevine cultivation.

The lowest winter temperature in Tuusula was -17°C, and in Neubrandenburg, Freyburg, and Herrlisheim-prés-Colmar, the temperatures were between -4.1 and -6.1°C. The frost only lasted for a couple of days, but in Tuusula the air was clearly colder than in the other localities. The predicted 2°C temperature increase would bring the temperatures in the Helsinki region close to Freyburg temperatures, which means that the growing season in Tuusula could begin at the end of March, 3─4 weeks earlier than present, which would suffice for *Vitis vinifera* L. varieties today.

In general, northern winegrowing regions will benefit from global warming. A cooler climate than in the current southern winegrowing areas and long days during the growing season may increase wine’s health-promoting antioxidant content, may keep the wines lighter, and may decrease the alcoholic content of wines, which is predicted to be the consumer’s wish in the future.

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