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Full Length Research Paper

Climate change and grapevine growth in the southernmost Finland

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The study charted the suitability of existing environmental conditions in the southernmost Finland for growing grapevines (*Vitis vinifera* L.). It examined the effect of snow layer and covers on the earth's surface and soil temperatures, compared the growing conditions in the Helsinki region (Tuusula) to the growing conditions at viticulture locations in continental Europe and the Swiss mountains, and assessed how the predicted climate change would promote viticulture in southernmost Finland. According to the Heliothermal Index (HI) and Amerine-Winkler Index, Tuusula, Neunbrandenburg, Freyburg and Herrlisheim-prés-Colmar are all classified as 'very cool' viticulture climates. Based on the Cool Night Index (CI), Tuusula was classified as 'very cool nights', but other locations were classified as 'cool nights'. In the Helsinki region, the current length of the growing season, effective temperature sum, number of hours of sunshine, solar radiation and soil temperature are sufficient for growing many *V. vinifera* and hybrid cultivars and correspond to vineyard climate conditions in the Copenhagen region and high-altitude vineyards in Valais. The predicted 2°C temperature increase by the RPC2.6 scenario would bring to the Helsinki area temperatures found currently in the northern viticulture areas of central Europe and make viticulture possible with more *V. vinifera* cultivars.

Keywords: Northern viticulture, viticulture climate classification, climate change, growing season, air temperature, snow cover.

INTRODUCTION

The growth cycle of the grapevine and climate conditions of southern Finland

In northern Europe, viticulture is limited by the shorter growing seasons and cooler climate compared to central and southern Europe. The thermal growing season begins when the average temperature of the day rises permanently over 5°C, and it ends when it consistently drops below 5°C. According to the Köppen (1900) and Geiger (1961) climate classification, the temperate zone's cool area (*Dfb*) within southern Finland, southern Sweden, Denmark and the Baltic countries, the growing season is 180 – 200 days (Chmielewski and Rötzer, 2001; Rötzer and Chmielewski, 2001). From the first outbreak of the vine buds to the calculated leaf fall, the growing season should last about 200 days, so that cultivation of the most of European *V. vinifera* cultivars would be possible (Bauer, 2002; Bauer et al., 2015).

In this region, however, the fairly short growing season is compensated with a long day, abundant sunlight and solar radiation that contribute to the growth of the vine and the ripening of berries and higher sugar levels, especially in cooler growing regions (Abeysinghe et al., 2016). When leaves shading the fruits are removed, the berries receive more solar radiation, their internal temperature increases, promoting maturation and increasing the concentration of sugars (Bauer, 2015).

The Finnish Meteorological Institute's (FIM, 2004) long-term study of the 180-day growing season in southern Finland, shows that the number of sunlight hours (an average 1400 hours) is equal to a 210-day growing season (an average 1400 hours), at a level latitude as Krems, Austria (Bauer, 2015) and Bordeaux, France (Meteo-France, 2012). In Stockholm, Oslo, and Helsinki (60°N), the solar radiation energy of 0.0216 MJ/cm²/month would be enough at the beginning of March for vine flowering and photosynthesis, but the snow cover reflects part of the sunlight and prevents the air and land from warming. On the other hand, early spring snow cover effectively protects the vines and roots from freeze damage and ground frost (Karvonen, 2008).

In Nordic regions, the bud break of the vine has historically been delayed in the spring through March, due to the low ground and night temperatures. In Denmark. Skane, and the southernmost Finland, snow cover has become rare in March. Since the solar radiation energy is increased in these regions, the April strength is 0.0378 MJ/cm²/month, the vine liquid circulation starts and the buds tend to swell during April and early May. In June, the shoots grow rapidly and blooming begins in June or July when the sun's light energy is 0.0612 MJ /cm²/month (FIM, 2012).

In the current wine-growing areas, the bud-break, flowering, veraison and harvesting have all been occurring earlier, and after harvesting the leaf-fall occurs later. This is due to the lengthening of the growing season and the earlier spring. During the longer growing season, carbohydrates are sufficient not only for canopy growth, reproduction and yield potential, but also for the strengthening of the grapevine structure. After the growing season, during the longer period between the harvest and the leaf-fall, carbohydrates continue to accumulate in the trunk of the grapevine, increasing its winter resistance and promoting blooming, veraison and yield potential during the next growth cycle (Hall et al., 2016). In Nordic regions, the time between the harvest and leaf-fall is rather short, so lengthening this period would significantly contribute to canopy growth and wine production.

The northern border of European grapevine cultivation is currently 52°N latitude (Bauer et al., 2015), but as a consequence of global warming (IPCC, 2001; IPCC, 2007; Zorida, 2012) and its resultant prolonging of the growing season (Menzel et al., 2003; Menzel et al., 2008), hybridized European grapevines can be professionally grown considerably further north than 52°N latitude thanks to North American or Asian grapevine species. Various pure *V. vinifera* vine cultivars have been found suitable for cultivation in Nordic regions during the last 20 years (Stock et al., 2005), but the most successful hybrids are derived from crosses of *V. vinifera* with *V. amurensis* Rupr., *V. labrusca* L. and *V. riparia* Michx. (Cindrić et al., 2000).

Both experimental and permanent grapevine cultivation currently occurs in Szczecin, Poland (53°25'N), the Copenhagen region (55°33'N), the Stockholm region (59°10'N), and the Helsinki areas surrounding 60°10'N. In Denmark, cultivation is approved for 48 vine cultivars. The most popular of them are hybrid cultivars Ortega, Rondo, Leon Milot, Madelaine Angevine, Solaris and Phoenix, all of which have a good cold resistance and fast growth period for bud break and berry ripening (Bentzen and Smith, 2009). The total area under grapes in northern Europe is of the order of 100 – 200 hectares (Föreningensvenskt vin, 2017), which is tiny when compared to the French, Spanish and Italian total of 3 million hectares, where 56% of the world's wine is produced (Bauer, 2002).

Elsewhere in the Köppen-Geiger climate zone *Dfb*, the explorer Jacques Cartier is known to have started cultivating *V. riparia* in Quebec in 1535, but the professional cultivation did not begin until 1982. Production has increased reaching in 2012, 64 vineyards on 500 hectares and 1.2 million bottles (Outreville, 2017). In Quebec's wine growing regions (46°N) the grapevine has had to adapt to extreme conditions. Winters and the spring, through April, are much colder, but the summers are hotter than in northern Europe and the Baltic region. During the growing season, there is an average of 1,150 – 1,426 hours of sunshine.

Effect of snow layer and covers on earth's surface and soil temperatures

The northern European climate cycle has been that of a long and snowy winter, which in central and southern Europe has been seen to hamper northern European grapevine cultivation. However, in northern Europe, the differences of the winters in the southern and northern parts is almost as large as between central Europe's northern and southern parts. In the 2000s, in southern Finland, snow and ice cover has shortened by 3 – 6 weeks over the past 50 years, and in the winter months, temperatures have varied considerably (Ilmasto-opas, 2010). This has been attributed partly to global warming in the Baltic Sea area (HELCOM, 2007), and partly to changing wind and ocean currents in the North Atlantic (Kerr, 2004).

According to FIM's statistics, the winter snow cover of southern Finland has ranged in recent years from 10 cm to almost a meter thick. From 2006 through 2008, the winters had little snow and the winter of 2008 was so mild that, in southern Finland, where ploughing could be started already in February. Thereafter, the winters of 2009 and 2011 were cold, long, and with a lot of snow. Snow layer thickness in February 2010 was 73 cm. In February 2011, it was 66 cm and in southern Finland the temperature was below -30°C (Solantie, 2010; FIM, 2012).

The winter resistance of the grapevine depends on several factors, such as to tolerate freezing and sub-freezing temperatures, flood resistance, and the individual plant's tolerance against plant diseases and pests. Common to these situations is oxidative stress that leads to weakening of plant cells and plant growth and a decrease in stress tolerance. This vicious cycle can lead to gradual death of the plant. The use of toxic chemicals against plant diseases for a long period of time may increase the oxidative stress caused by winter (Smallwood et al., 1999).

In Quebec, Siberia, and other regions with harsh winters where temperatures may reach -40°C, the vines survive over the winter only when there is a thick layer of snow. Snow fences are built in the middle of the vineyard in order to collect snow blown by the wind and increase the snow layer thickness. In these areas, in the next few decades, the problem for grapevine cultivation may become the reduction of snow due to global warming, but cold periods will still occur. (Cahill and Field, 2008).

In early winter before the hard ground frost, if plenty of snowfall occurs, the thick snow layer is a good insulator, that reduces the surface icing, prevents the formation of frost layer in the soil, and protects roots against frost damages. Under a thick snow layer, the coldest ground and surface temperatures remain above -5°C, which is the threshold for damage to plant roots of *V. labrusca*, a relative hardy species (Ahmedullah and Kawakami, 1986). Heavy snow also protects the basal parts of grapevine from frost damage. Increased winter snow cover in the cooler growing regions such as Canada, Siberia, and China is desired.

In northern Europe and the Baltic countries, the snow always covers the earth's surface in winter right down to the southern parts few months. Snow cover is not rare also in central and southern European vineyards, although it is thin and short lived. When the protective effect is low and the temperatures are below -20°C, vines are damaged in whole or in part. In Europe, snow cover is more common in the higher altitudes. For example, vineyards in Heidadorf, Switzerland vineyards, located above 1,150 m and experience an annual snowfall of 100 – 110 cm, that remains from November to March (MeteoSwiss, 1961 – 1990).

Grapevine growth in the Baltic Sea region (55 – 60°N latitude) is planned for the relatively short growing season of 180 – 200 days (Rötzer and Chmielewski, 2001). The vine is protected at the beginning of the growing season by covering the soil surface with black plastic polyethylene film and frost gauze, growing vines in unheated greenhouses, using grass and mulch covers, utilizing house walls, implementing various protective structures, and cultivating tunnels (Sölva, 1970). Covering units used for protection of vines in winter, such as clear light-transmitting acrylic polycarbonate sheets (greenhouse plastic), do not significantly contribute to the increase of outputs. In addition, the different wavelengths of light transmission from coloured plastic film have been tested and were found to have a positive effect on vine growth (Todic et al., 2008).

Black plastic film raises the temperature of the ground by 3 – 4°C, retains moisture and promotes the growth of roots and shoots (Bauer, 2015). The most common industrially produced artificial cover is a thin black polyethylene film. Black plastic covers do not pass sunlight but collect the sun's radiant energy which heats the soil and extends the 180 – 200 days growing season by 2 – 4 weeks in Nordic regions (Ibanez et al., 2011; Bauer et al., 2015). However, all coverings are not always useful according to some experiments.

A study in Sweden (Hablingbo, 57°N) and Northern Germany (Meclenburg-Vorpommern, 54°N), found coverings will protect vines against frost damage in the winter, but in the spring they will cause harm. Especially under a black plastic ethylene film, the ground is warming up too early in the spring, early growth shoots may freeze in spring frost. The same study has been found that the high-carbohydrate content in wood material of vines protects from vines frost and spring frost better than covering (Flick, 2010). Compared to the bare ground, foam insulation wrap has increased the daytime maximum temperature of vine stems, but decreased the night time minimum temperatures. The mounded sawdust covering and thick soil layer protected best young grapevine stems from cold damages (Bowen et al., 2017).

Outdoor cultivation using warm water irrigation for heating the soil in the spring has shown that the temperature rise of 1 – 2 in the Baltic Sea region's increases the growing season by 2 – 3 weeks (Karvonen, 2002). The same effect for earlier growth is foreseen for the future, as melting snow cover in March will allow for solar radiation to heat the soil. This phenomenon has been observed in the unheated greenhouses covered with greenhouse plastic foil. When the soil surface inside of greenhouse remains without snow cover throughout the winter, the exposed surface absorbs solar radiation energy more efficiently than the surrounding open-air, snow covered surface (Rader et al., 2013). Now, in the Baltic Sea region, snow is often still present at the beginning of April and reflecting solar radiation back into space.

The earlier warming of unheated greenhouses earlier warming in the spring is comparable to the greenhouse effect of global warming, namely, short-wave solar radiation passes through a clear greenhouse plastic, but not much of the long-wave infrared or thermal radiation escapes, so the temperature rises within the greenhouse (Schroeder, 2000). As a result, in the spring, grapevine growth in an unheated greenhouse begins 2 – 3 weeks earlier than in the open. The disadvantage is that in summer the internal temperature can rise to 55°C, which is dangerously high for the vines. Nevertheless, this may be periodically used to control phytopathogenic pests (McGullock,1978).

Plastic-covered tunnels have similar effects to those of unheated greenhouses, but they are little used for grapevine in southern Finland. Protective building structures and walls are considered to promote vine growth because they provide protection from cold winds and enable the accumulation of snow cover to protect the soil from frost and freezing. A thick layer of snow helps regulate the ground surface temperature and is good winter protection for the grapevines, especially at higher latitudes. According to Zhang (2005), under a 10 to 25 cm snow layer, the ground temperature is 9°C higher than the bare ground from November to March. If the snow layer thickness increases from 25 cm to 50 cm, the average ground temperature increases by 3.6°C compared to the bare ground, which would keep the ground surface temperature at 0°C or slightly below at moderate freezing temperatures.

The wine-growing conditions in the Helsinki region in comparison to those of the Danish Baltic Sea coastal region and the mountain regions of Switzerland

In Europe, the growing season is shortened in the higher degrees of latitude to North and longitudes to the East. The climate and vegetation zones do not precisely follow the latitude and longitude. Discrepancies are due to the latitude, proximity to the sea, currents and winds (Köppen, 1900; Geiger, 1961; Peel et al., 2007). Mountainous regions have more rain and are colder than the same latitude at sea level, where water minimizes fluctuations in temperature between summer and winter.

Rötzer and Chmielewski (2001) showed that one degree of north latitude shortens the growing season by 2.4 calendar days, one degree of longitude to the east by 0.7 days, and for every 100m increase 4.1 calendar days in Europe. Their study shows that besides the geographical growing site, the altitude (a.m.s.l.) significantly impacts the growing season and climate zone. The temperate climate zone (*Dfb*) around the Baltic Sea region locating at 50 – 60 m a.m.s.l. extends 1,000 km toward Krakow in the south, locating in the Tatra Mountain region, and the temperate climate zone (*Cbf*) exists as far as 1,600 km from the Baltic Sea region to the south in the Rhodope Mountains in the Plovdiv region.

Due to the earlier mentioned reasons, grapevine cultivation does not depend exclusively on a southern or western geographical location for growth, but also on the altitude above sea level, the local microclimates, latitudes and longitudes, and wind and rain. Vineyards in the mountain areas of Switzerland, in Denmark at 20 – 30 m above sea level, and in southern Finland near sea level represent wine cultivation in Europe's exceptional regions (high in the mountains in the south and close to sea level in the north). However, according to the study of Rötzer and Chmielewski (2001) and the Köppen climate classification, they have quite equal climates.

Valais, Switzerland has continental Europe's highest vineyard in the traditional Unterstalten wine region (St. JodernKellerei, 2013), and its highest point is 1,150 m above mean sea level. Wine has been cultivated in Valais for 2200 years (Valais, Switzerland's vinous pleasures, 2013). By way of comparison, in Denmark, there are signs of wine cultivation in the medieval warm period (Gladstones, 2011), but it disappeared and is only now returning. Finland's earliest wine cultivation occurred in the late 1700s (Justander, 1786).

Unterstalten at 1,150 m a.m.s.l., belongs to the same category *Dfb* as Tuusula 1,500 km further north, and 63 m a.m.s.l., and Copenhagen, Ålsgårde 1,000 km further north 30 m a.m.s.l. Localities with a temperate continental climate, have four seasons, winter snow cover, and west winds blowing plenty of rainfall from the Atlantic (Kottek et al., 2006; MeteoSwiss, 2016 and 2017).

The Valais region receives considerably less precipitation than other areas of Switzerland, with 500–600 mm/year, as also found in Tuusula and Ålsgårde. The highland climate is an exceptional in the valleys between the Swiss Alps (McKnight and Hess, 2000), as the north and south winds bring little rainfall. The Alpine Föhn wind blowing across the mountains bring snowfalls and fog in the summer, but the valleys have dry, hot air and an Indian summer in the autumn.

According to Soil Taxonomy's temperature soil classification system, Tuusula belonged to the soil temperature class 'frigid', and Ålsgård and Unterstalten, belong to the soil temperature class 'mesic' (Soil Survey Staff, 1999). After the first decade of the 21st century, the Finnish global temperature has increased by 0.3°C to the1.5°C, above the average for the years 1971 – 2000 (FIM, 2010), bringing Tuusula to the 'mesic' class.

Temperature, wind, rainfall, seasonal cycle, and the soil temperature classify Tuusula, Ålsgård, and Unterstalten, as close to each other, despite their geographical distance. For these reasons, in the period 2012 – 2013, a study was made on how much their climatic and growing conditions differed from one another in a one-year cycle and what advantages and disadvantages the northern localities might have over those 1,100 – 1,500 km further south, high in the mountains.

Impact of climate change on vine growing conditions in the Helsinki region

The European grapevine has acclimatized with high and low global temperatures and moved as the climate warms or cools, from south to north, or from north to south (Gladstones, 2011). Wars have been devastating for wine production, which almost completely ceased in Germany during the First and Second World Wars (Anderson and Pinella, 2017). In England, vines were grown from years 1000 – 1200, but due to the sudden cooling of climate ended it until 1960s. Now, at the beginning of a new warm-season vine cultivation is returning back to its former place England (Jones et al., 2005; Skelton, 2017). As a result of global warming a French champagne house will start sparkling wine production in England in 2023 (Smithers, 2017).

During the Roman Empire, the north border of their vineyards reached 50°N latitude (Cologne, Freiburg, Saale-Unstrut, London 51°N). The latitude of 50°N has been regarded as the northern boundary of professional vine cultivation, but as a result of global warming, cultivation is expanding towards the north and north-east Europe. While these new conditions, the climate temperature, soil, and precipitation would be suitable for cultivation of wine, the vine has to adapt to long days at the high latitudes (50 – 60°N latitude), and relatively large inter annual temperature variations.

Southern and south-western Finland greenhouse estates have grown European vines for nearly 250 years (Justander, 1786). Even on open land, attempts have been made to grow the very robust North American *Vitisriparia* L.and *Vitis labrusca* L. for 100 years in southern Finland (Reuter, 1904). Later, Finnish open-air vine growing experiments have been published in a few studies (Meurman, 1957; Saario, 1991). The vine cultivars used in these experiments are not current cultivars, but old cultivars that have disappeared from professional wine growing, grown only by hobby wine growers in gardens.

Vine cultivars are sensitive to temperature changes and the wine-growing area's vine cultivar selection must be replaced or modified if the climate warms or cools by only 1°C (Keller, 2010), as has happened in parts of Europe, North

America, and Australia. At Justander's time (1786), the Hungarian wine region's temperature was apparently the same as today in the southernmost Finland, and as the temperature rose, many old cultivars disappeared. The average temperature of the German wine-growing area from March to October was 12.5 – 13.5°C, from 1650 to 2000, but has risen 0.8 – 1.0°C since 2000 (Met Office Hadley Center, 2017).

In the Bohemia region of the Czech Republic, the climate impact on the temperature of the first grape harvest day has been monitored from 1499 to 2015. The earliest harvest was 11 September, 1540, and the latest date was 2 November, 1919. Normally, the harvest has been in the second half of October. The warmest 30-year period of 514 years was 1986 to 2015, and the average global temperature was 0.7°C above average in 1961 through 1990. It is attributed to global warming, and as a result, wine production has shifted to the north side of Prague close to the German border (Mozny et al., 2016). Grape harvest dates have been investigated in France and Switzerland from 1600 to 2007 using historical harvest and climate data. Early harvests have occurred with warmer temperatures (6 days/°C) and are delayed by wet conditions (+0.07 days/mm; +1.68 days PDSI-1) during spring and summer. In recent decades (1981 – 2007), climate change has fundamentally altered the climatic drivers of early wine grape harvests in France, with possible ramifications for viticulture management and wine quality (Cook and Wolkowich, 2016).

The rise of temperature during the past 55 years of 1.2°C has allowed wine-growing in several new areas and with the predicted rise by 2050 of 2.04°C, this movement will continue to move (Keller, 2010). New areas of northern Germany, Denmark, and southern Sweden initiated commercial vine cultivation in the late 1990s. In Finland experiments on *V. vinifera* and its hybrids were started in the 1990s, and they have reached up to 63°N in Vaasa. On the basis of the gained experience, vine is becoming a new northern European crop and its growing areas can be extended into central Finland by 2050, if the climate scenarios are realized.

Northern Hemisphere air temperature was at a low point in 1500s when it was 0.65°C degrees lower than the average of the years 1881–1980 (Stocker et al., 2013. Then, it increased between 1980 – 2012 from 0.65 to 1.06°C. Beginning in the 2000s, the Finnish climate has warmed 0.6°C above the 160-year average (Tietäväinen et al., 2010). Warming has been most noticeable in the winter and spring (Jylhä et al., 2009). In the Helsinki area (Tuusula), temperatures are still rising, and in the 2005 – 2014 decade, the average temperature was 0.7°C higher than the 1971 to 2010 average (Karvonen, 2015).

Global warming has been predicted using the SRES (Special Report on Emission Scenarios) and the RCP (Representative Concentration Pathways) scenario groups derived from the increase in population and consumption growth and increased water vapor concentration, CO_2, CH_4 and N_2O emissions (IPCC, 2007). All RCP scenarios predict that a rise of more than 2°C in the earth's surface temperature by the end of the century, from 2081 to2100, is more likely than not. RCP 2.6 predicts an increase of 1°C andRCP8.5 predicts a 4°C temperature rise in the earth's climate (IPCC, 2013; Yangyang et al., 2017).

In the Arctic, the air temperature increase is anticipated to be greatest in the winter months (Samuelsson et al., 2011) and in all seasons, the temperature at the higher latitudes would rise by 2 – 4°C (IPCC, 2014), extending the growing season from 20 to 40 days. When this occurs, not all of the current crops will have enough time to adapt to the new climate, and they will need to be replaced with new crops.

RCP2.6 scenario predicts that every 1°C temperature rise will extend the Tuusula growing season by 9 – 11 days and climatic zones will move 500 km to the north.A2°C increase in average annual air temperature, measured during 1961 – 1990 in northern Europe, could bring the current average annual Danish air temperature up to the same latitudes as Vaasa, Jyväskylä and Kuopio in Finland by 2071 – 2100.

The Earth's global temperature has fluctuated greatly in the course of history, the early Christian era had nearly the same temperatures as now in the early 2000s. The warm episodes have recurred at intervals of about a thousand years. The warm period before the last one occurred about 1000 – 1100 AD, which was when viticulture is expected to have spread on the east of the east coasts of the Baltic Sea (Gladstones, 2011; IPCC, 2013).

The projected rapid global warming has inspired a considerable amount of research on viticulture, since 2000. Marx et al. (2017) documented 1039 publications in the Web of Science database (WoS) between 1974 and 1995 ad with a sharp rise after 2007. Between 1974 and 1995 there were 11 publications, but between 2011 and 2015 there were 100 – 150 publications per year. Most climate change and viticulture studies have been published in the USA, Spain, and Italy in journals relating to agriculture, environment, and ecology.

AIM OF THE STUDY

The study sought to identify the existing possibility of subsequent planting of vines in southern Finland in the Helsinki region (Tuusula, 60°24'N, 25°01'E, 63 m a.m.s.l.). During 2002 – 2011, a 10-year study of grapevine cultivation was undertaken, researching long-term growth cycle, followed by 1 to 4 years of monitoring, investigating the protective effect of snow cover and other cover types, and comparing the differences between southern Finland and mainland Europe growth and environmental conditions.

1) The current growth and environmental conditions

The study was conducted during 2002 – 2011, in Tuusula vineyards of the annual growth cycle stages and environmental growth factors in the onset of fluid circulation to the beginning of harvest to determine the correlating with the length of the growing season, the effective temperature in the growing season and the number of sunshine hours in June, July, and August.

2) The effect snow and coverings on the ground surface and soil temperature

By measuring the thickness of snow layer, air and ground surface temperature, the effect of snow layer thickness on earth's surface temperatures during the hard freezing winter periods was estimated along with the effect of commonly used protective covers on soil temperature at planting depth and the differences between the protective effects.

3) Comparison of Finland´s growing and environmental conditions to other cold-climate regions in Europe

The study aimed to clarify whether the climate and environmental conditions in 2012 – 2013 deviate in the vineyards of Valais, Switzerland, Unterstalten region situated above 800 – 1,150 m, with the Copenhagen area (Ålsgårde) further north at 1,100 km, and the Helsinki region (Tuusula) at 1,500 km.

4) How will climate change affect the southernmost Finland's wine-growing conditions

Estimates of the current climatic and wine-growing conditions of the Helsinki region (Tuusula) and what they would be after the predicted 2°C temperature rise compared to the growth conditions of Neubrandenburg, Freyburg and Herrlisheim-près-Colmar were made using the Multicriteria Climatic Glassification indices (*Geoviticulture MCC System*) of Tornietto and Carbonneau (2004).

MATERIAL AND METHODS

Table 1

Plant material and field conditions

The winter-resistant black-grape hybrid clones *V. vinifera* L. cv. 'Nordica' (*V. vinifera* x *V. labrusca*), *V. vinifera* L. cv. 'Zilga' (*Dvietes 4–2–08*) [*Smuglyanka x DvietesZila*] x *Jubileinaja Novgoroda*) and *V. vinifera* L. cv. 'Rondo' ([*Précoce de Maligre* x *V. amurensis*Rupr.] x *St Laurent*) were monitored in this study during 2002 – 2011 on the vineyard (400 m^2) located in the flat in the open without protective structures 200 m from the Rusutjärvi lake, having a surface area of 5 km^2.

All cultivars included in the study (100 plants) grown on their own roots were planted between 1996 – 1997 at a depth of 40 cm with a row spacing of 1.5 – 2.0 m and an inter-plant spacing of 2.0 m in sandy clay soil with a high organic matter content of 6 – 8% and a pH level ranging from 5.8 to 6.2 at the planting depth. Compost fertilizer and grass clippings were used, supplemented with mineral fertilizer containing phosphorus and potassium (GreenCare “Garden autumn” mineral fertilizer; (PK [Ca], [Mg], [S], [4-17], [2], [2.5], [13]).

During 2002 – 2011, the average annual air temperature, the start and end dates of the thermal growing season, the length of growing season, the effective temperature sum and sunshine hours during the growing season were based on

Table 1. Abbreviations and explanations.

a.m.s.l.	abovemeansealevel
^{0}Brix	Degrees °Brix = sugar content measurements in aqueous solution
Cfb	Temperateoceanicclimate
Dfb	Warm summer humidclimate
E–L no	Eichhorn–Lorenzphenologicalstages 01 – 38
FMI	FinnishMeteorological Institute
’frigid’	The frigid soil temperature regime has mean annual soil temperatures of greater than 0°C, but less than 8°C, with a difference between mean summer and mean winter soil temperatures greater than 5°C at 50 cm below the surface, and warm summer temperatures.
GDD	Growing degree day; °C□d (5°C basis) or (10°C basis)
HELCOM	Baltic Marine Environmental Protection Commission – Helsinki Commission
IPCC	Intergovernmental Panel on Climate Change
’mesic’	The mesic soil temperature regime has mean annual soil temperatures of 8°C or more, but less than 15°C, and the difference between mean summer and mean winter soil temperatures is greater than 5°C at 50 cm below the surface
Macroclimate	the overall climate of a region usually a large geographic area
Mesoclimate	The climate of small areas of the earth's surface; it may not be representative of the general climate of the district
Microclimate	The essentially uniform local climate of a usually small site or habitat
PDSI	PalmerDrought Severity Index
RCP	RepresentativeConcentrationPathways
RCP2.6	Zero emissions after 2070, so that warming does not exceed 2°C pre-industrial levels
RCP6.0	Medium-high emission scenario that stabilizes radiative forcing at 6.0 W/m^2 in the year 2100 without ever exceeding that value
RCP8.5	Emissions are not limited *i.e.* high emission scenario that stabilizes radiative forcing at 8.5 W/m^{2}in the year 2100 without ever exceeding that value
SE	Solarenergy
S mean	mean thickness of snow layer
SRES	Special Reports on Emissions Scenarios
T air max	Maximum air temperature
T air min	Minimum air temperature
T earth’smax	Maximum earth’ssurfacetemperature
T earth’s min	Minimum earth’s surfacetemperature
WoS	Web of Science database is an online subscription-based citation indexing service (formerly Thomson Reuters)

statistics from the Finnish Meteorological Institute. Grapevine growth stages were determined by the Eichhorn-Lorenz phenological stages (Eichhorn and Lorenz, 1977). The date on which the berries matured was the date when the Brix value of the berries reached 16°Brix.

Effect of snow layer and covers on ground surface and soil temperatures

The study compared the effects of snowfall on earth’s surface temperatures below the snow layer using measurements taken over two consecutive winters with little snow and two consecutive winters with heavy snow (Table 2). The air and ground surface temperatures of the winters with little snow (2006– 2007 and 2007 – 2008) were monitored at a height of 150 cm for air and 0 cm for earth’s surface. Moisture- and sunlight-resistant electronic thermometers were used for the measurements, saving the maximum and minimum temperatures in their memory during the observation periods (*Waterproof In-Out Door Max-Min Thermometer with Hygrometer, Shenzhen, Hong Tong Yuan Technology Ltd., Shenzhen, China*). The thickness of the snow cover was measured manually in cm using a vertically erected measuring stick at the observation site (Kaukoranta and Niinimäki, 2010). The observations were recorded every 2 – 3 days during the winters.

Table 2.

From the observations, monthly averages were calculated and the lowest and highest monthly

Table 2. Snow and frost conditions in the 2006– 2008 and 2009–2011 winters.

Winter	Snowconditions	Freezingconditions
2006 – 2007	Little snow	Moderate frost
2007 – 2008	Little snow	Moderate frost
2009 – 2010	Plenty of snow	Heavyfrost
2010 – 2011	Plenty of snow	Heavyfrost

temperatures were recorded for subsequent review. The air and soil temperatures measured during 2006– 2007 and 2007 – 2008 (light snowfall) were compared to corresponding measurements during 2009 – 2010 and 2010 – 2011 (heavy snowfall)**.**

The effect of protective covers in the planting depth of grapevines in the vineyard was studied by placing a water-tight thermo logger (*Thermo Button 21G, Proges-Plus, France*) at a depth of 40 cm in the bare ground, grass-covered ground, under black plastic polyethylene foils and greenhouse transparent plastic sheets and in soil next to the house wall. The thermo loggers registered and recorded the temperatures in their memory 12 times a day throughout the year (from 1 January to 31 December). In 2014, the mean air temperature was 7.2°C, annual rainfall was 650 mm, and the permanent snow cover only in February was 2 – 33 cm.

The wine-growing conditions in the Helsinki region in comparison to those of the Danish Baltic Sea coastal region and the mountain regions of Switzerland

Year-round monitoring of soil temperature, air temperature, and snow cover investigated the growth conditions of Continental Europe's highest above-mean sea level vineyard in Unterstalten (Switzerland), and the growth conditions of the vineyards locating in the Baltic Sea Region in Ålsgårde (Denmark) and Tuusula (Finland) (Table 3).

Table 3.

Soil and air temperatures were measured at the same time throughout the year (from 20 October 2012 to 20 October 2013) at all three locations. Soil temperatures were measured using a moisture-proof *Thermo Button Temperature Data Loggers type 22L* (www.plug-and-track.com), which saved all temperature data in its memory. Changes in temperature, snow cover winter thickness and length of day were measured using data from the Finnish Meteorological Institute (www.fmi.fi) and the International Foreca Weather Service (www.foreca.fi).

Temperature data were registered by the thermologgers in Unterstalten, Ålsgårde and Tuusula, placed at depths of 20 cm and 40 cm (also on the ground surface at 0 cm in Unterstalten), and they calculated the averages $\bar{X}$ and standard deviations *SD* of the temperatures during the summer months, growing seasons and the whole year. Using the daily maximum-minimum temperatures, the average temperatures and standard deviations of summer months, growing seasons and the whole year were calculated separately. The average snow cover thickness was calculated from 12 measurements taken each winter month. The maximum amount of sunlight hours per month in Unterstalten and Ålsgårde were compared to the corresponding sunlight hours in Tuusula during the growing season.

Impact of climate change on grapevine growing conditions in the Helsinki region

The data was collected from four locations situated between 48° and 60° latitudes in the same temperate climate zone (Table 4). Tuusula represents the location where viticulture is at an experimental stage; in Neubrandenburg, professional viticulture is beginning and in Freyburg and Herrlisheim-près-Colmar, viticulture began 1000 years ago.

Table 4.

In Tuusula, Neubrandenburg, Freyburg and Herrlisheim-près-Colmar, the maximum and

Table 3. Study locations and grape varieties.

Locality	Country	LatitudeLongitude	Altitude	To Unterstalten	Grape variety
Unterstalten	Switzerland	46°15'38''N, 07°54'04''E	1,150 m	0 km	Heida, Sylvaner, Muscat, Pinot noir, Camey
Ålsgårde	Denmark	56°04'36''N, 12°32'13''E	32 m	1,100 km	Madelaine Angevine, Solaris, Ortega, Kerner
Tuusula	Finland	60°24'10''N, 25°01'45''E	63 m	1,540 km	Solaris, Zilga, Nordica

Table 4. Observation sites.

Community	Country	Location	Landscape	Above mean sea level (m)	Distance to Herrlisheim-prés-Colmar (km)
Herlisheim-prés-Colmar	France	48°01'N, 07°19'E	Rhinevalley	196	0
Freyburg	Germany	51°13'N, 11°46'E	Unstrutvalley	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	1,390

minimum air temperatures were obtained from daily recordings of Finnish, German and French meteorological institutes (Finnish Meteorological Institute, Deutscher Wetterdiens, and Meteo-France) between 1 September 2014 and 31 August 2015. These data were used to calculate the averages of air temperatures per month and year, standard deviations and statistical differences and the lowest air temperatures during the year. Thermo loggers (*Thermo Button 21G, Proges-Plus, France*), which were placed in the soil of vineyards at a depth of 40 cm, registered soil moisture and temperatures between 1 September 2014 and 31 August 2015. In Tuusula, Freyburg and Herrlisheim-près-Colmar, the soil temperatures were measured during the same period, also at a depth of 20 cm.

On the bases of four Represenative Concentration Pathways (RCP) climate scenario groups (RCP2.6, RCP4.5, RCP6.5 and RCP8.5), the effects of global warming on viticulture in Tuusula, Freyburg, Neubrandenburg and Herrlisheim-près-Colmar were evaluated for the coming decades. The current climate and environmental conditions of these locations were estimated by indices of the Multicriteria Climatic Classification System (*Geoviticulture MCC System*), published by Tornietto and Carbonneau (2004). The Dryness Index (DI) indicates the potential of the soil water balance, the Huglin Index (HI) the temperature sum required for the ripening of the grapes, and the Cool Night Index (CI) the effect of the night temperatures during the ripening of the grapes.

STATISTICAL TREATMENT

The dependences and statistical significances between growth factors, such as length of growing seasons, annual mean temperatures, effective temperature sum of the growing season (5°C or 10°C basis), sunshine hours, and the correlation between the thicknesses of the snow cover and the air temperature were reported using the Pearson correlation coefficient R^2. The difference to zero was tested with test quantity t and calculated with the formula:

$$t = R\sqrt{n-2/1-R^2}$$

when the degrees of freedom (*df*) were $n - 2$. The *P*-value corresponding to the observed test quantity was extracted from the t distribution. $P<0.05$ was statistically significant.

Two tailed Student's t-tests were used to estimate the statistical significance of $P<0.05$.

$t = \bar{X} - \bar{Y}/SE$ and

$SE = \sqrt{SDx/nx + SDy/ny}$ standard error

As part of the t-test, $\bar{X}$ was the mean value of one of the variables, *SDx* is standard deviation, and *nx* was the sample size. $\bar{Y}$ was the mean of the other variables, *SDy* was the standard deviation, and *ny* was the sample size

or

$$t = \frac{\bar{X} - \bar{Y}}{V^{\frac{1}{2}}}$$

where *V* was an estimate of the variance of random error variance (square magnitude of the error). The difference was statistically significant (95% level), when$t$> │2│ (rule of thumb) and P<0.05.

RESULTS

The growth cycle of the grapevine and climate conditions of southern Finland

Growth cycle

Table 5

During 2002 – 2011, the grapevine buds began to swell and break between 1 May and 16 May and opened into shoots a few days later. Blooming began between 16 June and 9 July lasting from 9 to18 days (Table 5). The period from blooming to start of harvest (16°*Brix*) lasted three months (Table 6).

Table 6

The interval between bud break and the first blooming lasted 51 ± 7 days (range 36 – 67 days), and the total growth cycle from the bud break to the harvest took an average of 138 ± 9 days (range 129 – 158 days) or 4.5 – 5.5 months (Table 6).

The growing season

The average length of the thermal growing season (5°C□day) over the ten-year period was198 ± 18 days, the shortest being 169 days (2009) and the longest 229 days (2008). The effective temperature sum during the growing season was 1608 ± 131°C□d (5°C basis) or 794 ± 121°C□d (10°C basis). Over a three-year it was more than 1700C□d(5°C basis) and over a four-year period more than 900°C□d (10°C basis). The highest effective temperature sum, 1829°C□d (5°basis) or 934°C□d (10°C basis), was in 2011.

Table 7

The average number of sunshine hours during the growing season was 1447 ± 117 h (range 1290 – 1661 h) and the average solar radiation energy was 2094 ± 127 MJ/m^2. The average temperatures over ten years was 6.7 ± 0.5°C (Table 7).

The correlation between the growing seasons and climate factors

The number of sunshine hours and the solar radiation energy had a significant mutual correlation (R^2= 80; P<0.001). A moderate correlation (R^2= 40 – 50; P<0.02) was observed between the number of sunshine hours and CDD (5°C basis) and solar radiation energy and CDD (5°C basis).

Table 8

Other climate factors, such as the length of the growing season and length of the annual growth cycle and the length of the growing season and CDD (5°C basis), showed no significant correlation (P>0.1) (Table 8)

The effect of snow layer and covers on earth's surface and soil temperature

The effect of thin snow cover on soil temperature

Table 9

There was no statistically significant difference between the thicknesses of the snow covers of the 2006 – 2007 and 2007 – 2008 winters (*t=1.2727, P>0.1*), even though the snow cover was slightly thicker and the air significantly colder in the winter of 2007 – 2008 (*t = 2.9122, P<0.05*) than in the winter of 2006 –2007.

Table 10

The thin snow cover of the 2006 – 2007 and 2007 – 2008 winters could not retain the temperature of the earth's surface; instead, it fell to -10.8°C during the coldest month, *i.e*. March, of the winter of 2006 – 2007, when the average thickness of the snow cover was 3 cm and the air temperature, at its lowest, -16.1°C (Tables 9 and 10).

The effect of thick snow covers on ground temperature

Table 11

There was no statistically significant difference between the thicknesses of the snow covers of the 2009 – 2010 and 2010 – 2011 winters, which had abundant snow (*t = 0.7867, P > 0.1*), just as there wasn't between their lowest air temperatures either (*t=0.9311, P>0.1*). The snow cover of the earth's

Table 5. Stages of annual growth cycle of grapevine in Helsinki-Vantaa area (Tuusula) 60°24’10´´N, 25°25'45´’E) during 2002 – 2011.

Year	Budbreak[a]	Blooming[b]	Veraison[c]	Harvest[d]
2002	1 May	16 June – 28 June	2 August	14 September
2003	16 May	9 July – 23 July	16 August	22 September
2004	2 May	8 July – 26 July	9 August	7 October
2005	6 May	1 July – 15 July	27 July	30 September
2006	12 May.	30 June – 12 July	7 August	19 September
2007	11 May	2 July – 14 July	22 August	18 September
2008	14 May	1 July − 14 July	9 August	1 October
2009	12 May	20 June – 29 June	6 August	22 September
2010	11 May	29 June − 14 July	10 August	28 September
2011	8 May	25 June – 10 July	6 August	19 September

[a]E-L number 4 (Green tip; first leaf tissue visible), [b]E-L number 18 (Inflorescence well developed, flower caps in place, but color fading from green), [c]E-L number 35 (Berries begin to change color), [d]E-L number 38 (Berries harvest ripe). E-L number (Eichhorn-Lorenznumber) for grapevine growth stages. Modified from Eichhorn-Lorenz (1977) by Coombe (1995).

Table 6. Lengths of stages of annual growth cycle of grapevine in Helsinki-Vantaa area (Tuusula 60°24´10’’N, 25°25’45’’E) during 2002 – 2011.

Year	Bud break to start of blooming*	Start of blooming to start of veraison*	Start of veraison to start of harvest*	Total growthcycle*
2002	47	47	43	137
2003	54	38	37	129
2004	67	32	59	158
2005	56	26	65	147
2006	49	39	43	131
2007	52	51	27	130
2008	48	39	52	139
2009	39	57	37	133
2010	49	42	49	140
2011	48	42	44	134
$\bar{X}\pm SD$	51±7	41±8	47±10	138±9
Median	49	41	46	136

*days

surface thickened over the course of the winter and reached 60 – 67 cm in both winters in February-March. Despite the March frosts of less than -30°C in the winter of 2009 – 2010, the ground temperature remained at -0.5°C under the 60 cm snow cover (Tables 11 and 12).

Table 12

The effect of covers on the soil temperature at a depth of 40 cm

Using a black plastic polyethylene film as a cover raised the annual average soil temperature at a depth of 40 cm by 0.4°C in comparison with bare earth, which was statistically significant (*P<0.05*), black plastic polyethylene film used as additional cover for soil covered in grass did not affect the soil temperature at a depth of 40 cm (Tables 13 and 14) (Figure 1). Clear greenhouse acrylic polycarbonate sheets spread over the ground did not increase the temperature of bare earth or grass-covered soil significantly.

Table 13

Table 14

Figure 1

The vine growth conditions in the Helsinki region in comparison to those of the Danish Baltic Sea coastal region and mountain regions of Switzerland

Soil temperatures

In a comparison between the Helsinki region (Tuusula), the Copenhagen region (Ålsgårde) and Switzerland (Unterstalten), the annual soil temperature averages at depths of 20 cm and 40

Table 7. Annual average temperatures, lengths of growing seasons, temperature sums of growing seasons, sunshine hours and solar radiation in Helsinki-Vantaa area during 2002 –2011.

Year	AAT* °C	First and last days of GS[a]	GS[b] days	GDD[c] °C□d (5°C basis)	GDD[c] °C□d (10°Cbaisi)	SH[d] during GS	SE[e] during GS
2002	6.0	10 Apr. – 2 Oct.	176	1669	940	1661	3168
2003	6.2	16 Apr. – 14Oct.	182	1489	723	1310	2721
2004	7.1	15 Apr. – 27 Oct.	196	1424	634	1290	2729
2005	6.6	13 Apr. – 15 Nov.	217	1607	750	1501	2949
2006	6.7	22 Apr. – 27 Oct.	189	1763	915	1599	2991
2007	7.0	11 Apr. – 1 Nov.	205	1592	766	1428	2914
2008	7.6	1 Apr. – 15 Nov.	229	1474	619	1428	2902
2009	6.2	23 Apr. – 8 Oct.	169	1491	719	1334	2798
2010	5.9	10 Apr. – 4 Nov.	209	1711	939	1401	2978
2011	7.2	4 Apr. – 8 Nov.	208	1829	934	1518	2888
$\bar{X}$±*SD*	6.7± 0.5		198 ±18	1608±131	794±121	1447±117	2904±127
Median	6.7		205	1600	758	1428	2908

Abbreviations: Apr. (April), Aug. (August), Oct. (October), Nov. (November)*annual average temperature,[a]growing season,
[b]length of growing season, [c]growing degree days (+5°Cdays and +10°Cdays), [d]number of sunshine hours, [e]solar energy (MJ/m²).

Table 8. Correlation coefficients and significances between growth factors during growing seasons in Helsinki-Vantaa area during 2002 – 2011.

Growthfactors	*n**	Growthfactors	*R*	*R²*	*t*	*P*
Sunshinehours	10	solarradiation	0.89	0.80	5.6288	<0.001
Sunshinehours	10	GDD**	0.72	0.52	2.9394	<0.02
Solarradiation	10	GDD**	0.61	0.37	2.1737	<0.02
Annualaveragetemperature	10	length of growingseason	0.37	0.14	1.1285	<0.1
Annualaveragetemperature	10	GDD**	0.37	0.14	1.1285	<0.1
Length of growingseason	10	annualgrowthcycle	0.30	0.09	0.3145	>0.2
Length of growingseason	10	GDD**	0.10	0.01	0.2843	>0.2

*the sample size, statistically significant $P \leq 0.05$
**growing degree days:°C□d(5°C basis)

Table 9. The monthly mean values of snow layer thickness and the lowest and highest air and earth's surface temperatures in winter 2006 – 2007 in the Helsinki–Vantaa area.

Month	S mean cm	T air min°C	T earth's surface min °C	T air max°C	T earth's surface max°C
November	11	-6.1	-5.8	4.6	3.6
December	1	-8.1	-7.2	8.4	7.5
January	24	-7.2	-6.8	5.9	3.8
February	16	-10.6	-7.6	2.4	2.1
March	3	-16.1	-10.8	16.1	12.1
April	1	-6.8	-5.2	20.9	16.9
$\bar{X}$	9	-9.0	-7.4	9.7	7.7
SD	±9	±3.5	±1.8	±6.6	±5.3

S mean = mean thickness of snow layer, T air min = minimum air temperature, T earth's surface min = minimum earth's surface temperature, T air max = maximum air temperature, T earth's surface max = maximum earth's surface temperature.

cm were significantly lower in Tuusula than in Unterstalten and Ålsgårde (*P<0.001*).

Table 15

Table 16

During the growing season (from 15 April to 15 October), there were no significant differences in the soil temperatures of Ålsgårde and Unterstalten at depths of 20 cm and 40 cm (*P>0.05*), but in the summer months (June, July and August) the soil temperatures of Ålsgårde were significantly higher than those of Unterstalten (*P<0.001*) (Tables 15 and 16).

Solar radiation energy and the length of the day

In Tuusula, the solar radiation energy level was 3 kWh/m² lower per month from June to August than

Table 10. The monthly mean values of snow layer thickness and the lowest and highest air and earth's surface temperatures in winter 2007 – 2008 in the Helsinki-Vantaa area.

Month	S mean cm	T air min °C	T earth's surface min °C	T air max °C	T earth's surface max °C
November	12	-8.1	-3.9	7.7	4.8
December	10	-12.7	-7.6	8.2	1.5
January	18	-25.4	-8.7	2.9	-1.9
February	25	-19.4	-10.6	1.8	-2.5
March	32	-23.1	-7.8	13.3	-3.1
April	1	-15.1	-4.2	9.0	-0.9
$\bar{X}$	16	-17.3	-7.1	7.2	0.4
SD	±10	± 6.0	±2.4	±3.9	±2.7

Table 11. The monthly mean values of snow layer thickness and the lowest and highest air and earth's surface temperatures in winter 2009 – 2010 in the Helsinki area.

Month	S mean cm	T air min°C	T earth's surface min°C	T air max°C	T earth's surface max°C
November	1	-15.5	-3.3	12.5	2.8
December	19	-16.3	-2.6	6.4	-1.5
January	42	-25.1	-1.4	4.4	-0.5
February	60	-30.7	-0.5	7.7	0.0
March	61	-27.4	-0.5	19.9	0.0
April	18	-7.7	-0.3	22.0	0.9
$\bar{X}$	33	-20.5	-2.1	12.1	0.3
SD	±23	±8.0	±1.7	±6.7	±1.3

Table 12. The monthly mean values of snow layer thickness and the lowest and highest air and earth's surface temperatures in winter 2010 – 2011 in the Helsinki area.

Month	S mean cm	T air min°C	T earth's surface min°C	Tair max°C	T earth's surface max°C
November	8	-11.0	-3.5	8.1	5.1
December	34	-6.5	-1.9	9.5	6.6
January	55	-26.6	-1.9	1.8	0.2
February	66	-25.0	-1.3	2.3	0.1
March	67	-19.9	-0.7	16.5	0.4
April	32	-8.0	-1.3	18.3	0.6
$\bar{X}$	43	-16.2	-1.8	9.4	2.2
SD	±21	±8.0	±0.9	±6.3	±2.6

Table 13. Subsoil temperatures measured throughout the year at a depth of 40 cm in a vineyard under black plastic foil, under transparent greenhouse plastic foil, alongside the wall of a building, and in a grass-covered and bare vineyard's soil.

	Black plasticfoil	Greenhouseplasticfoil	Building wall	Vineyard's soil	
				grass cover	bare
Temperatures	ºC	ºC	ºC	°C	°C
Mean	7.52	7.34	6.23	7.43	7.14
SD	±6.11	±5.99	±5.35	±6.17	±5.68

in Ålsgårde and 18 kWh/m² lower than in Unterstalten. The difference between Tuusula and Unterstalten in the lengths of the days was the greatest on June 17, when the day in Tuusula was

Table 14. The statistical significance between mean annual temperatures measured under covers vs. bare earth's surface in a vineyard, and alongside the wall of a building at a depth of 40 cm.

Covers and building wall	Vineyard	*n*	*t*	*P*	Significance
Black plastic foil	Bare surface	2920	2.4627	<0.05	*s*
Greenhouse plastic foil	Baresurface	2920	1.3089	>0.05	*ns*
Building wall	Baresurafce	2920	6.3063	<0.05	*s*
Black plasticfoil	Grass cover	2920	0.5604	> 0.05	*ns*
Greenhouseplasticfoil	Grass cover	2920	0.5660	> 0.05	*ns*
Building wall	Grass cover	2920	7.9418	< 0.05	*s*

n = sample size, *s* = statistical significant; *ns* = no statistical significant.

Table 15. Vineyard soil temperatures at a depth of 20 cm in 2012 – 2013.

Period		[a]Tuus	[b]Unter	[a]Tuus/[b] Unter		[c]Ålsg	[a]Tuus/[c]Ålsg		[c]Ålsg/[b]Unter	
	n	°C	°C	*t*	*P*	°C	*t*	*P*	*t*	*P*
June 1– Aug 31	519	15.6 ±1.2	17.3 ±2.2	15.455	<0.001	17.9 ±1.4	30.9523	<0.001	4.9825	<0.001
April 15– Oct 15	1038	12.4 ±4.3	15.2 ±3.3	16.6272	<0.001	15.4 ±3.3	17.8359	<0.001	1.3812	>0.05
Oct 20 – Oct 20	2047	7.1 ±6.3	9.5 ±6.1	12.3963	<0.001	9.3 ±7.1	10.7787	<0.001	0.7042	>0.05

Notes: [a]Tuusula, [b]Unterstalten, [c]Ålsgårde.

Table 16. Vineyard soil temperatures at a depth of 40 cm in 2012 – 2013.

Period		[a]Tuus	[b]Unter	[a]Tuus/ [b]Unter		[c]Ålsg	[a]Tuus/[c]Ålsg		[c]Ålsg/[b]Unter	
	n	°C	°C	*t*	*P*	°C	*t*	*P*	t	*P*
June 1– Aug 31	519	14.9 ±1.0	17.0 ±2.2	18.850	<0.001	17.4 ±1.1	39.877	<0.001	3.690	<0.001
April 15- Oct 15	1038	11.9 ±4.2	14.8 ±3.3	18.105	<0.001	14.9 ±3.2	18.315	<0.001	0.709	>0.05
Oct 20- Oct 20	2047	7.1 ±5.9	9.7 ±6.1	14.594	<0.001	9.3 ±6.7	10.138	<0.001	2.497	<0.05

Notes: [a]Tuusula, [b]Unterstalten, [c]Ålsgårde.

3 hours 19 minutes longer than that in Unterstalten and 1 h 31 minutes longer than that in Ålsgårde (Figure 2).

Figure 2
Air temperatures

At the beginning of the growing season, the annual air temperature averages in Tuusula were higher than in Unterstalten and Ålsgårde (Figure 3), but the highest air temperature averages of the growing season (15 April 15 – 15 October) were measured in Ålsgårde. There was no significant difference in the growing season temperatures between Tuusula and Unterstalten (*P>0.05*). In Tuusula, the air temperature averages of the summer months (June, July and August) were higher than those in Ålsgårdeand Unterstalten (Table 17).

Figure 3

Table 17
Figure 4

Because of the cold periods in January and March, the average of the annual air temperatures in Tuusula was the lowest, at 5.0°C. It was 1.8°C lower than in Unterstalten and 3°C lower than in Ålsgårde. The differences were not significant between Tuusula and Unterstalten (*P>0.05*), but the annual average of Ålsgårde was significantly higher than that of Unterstalten (*P<0.05*) (Figure 4 and Table 17).

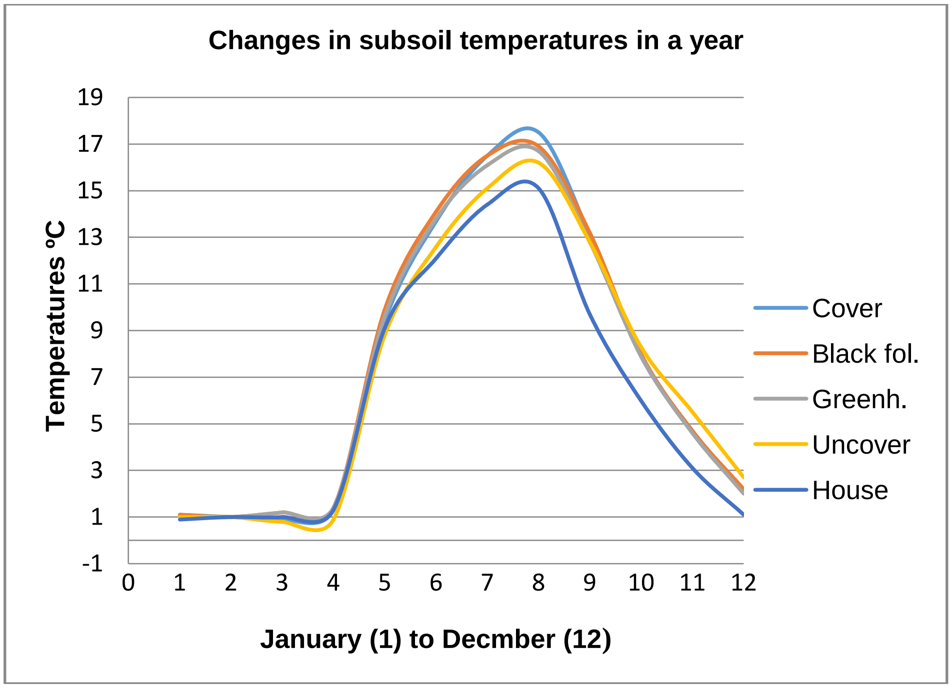

Figure 1. Vineyard subsoil temperatures at a depth of 40 cm under grass cover (shown here as 'cover'), black plastic foil ('Blackfol.'), greenhouse plastic foil ('Greenh.'), bare earth's surface ('uncover'), and alongside the wall of a building ('House').

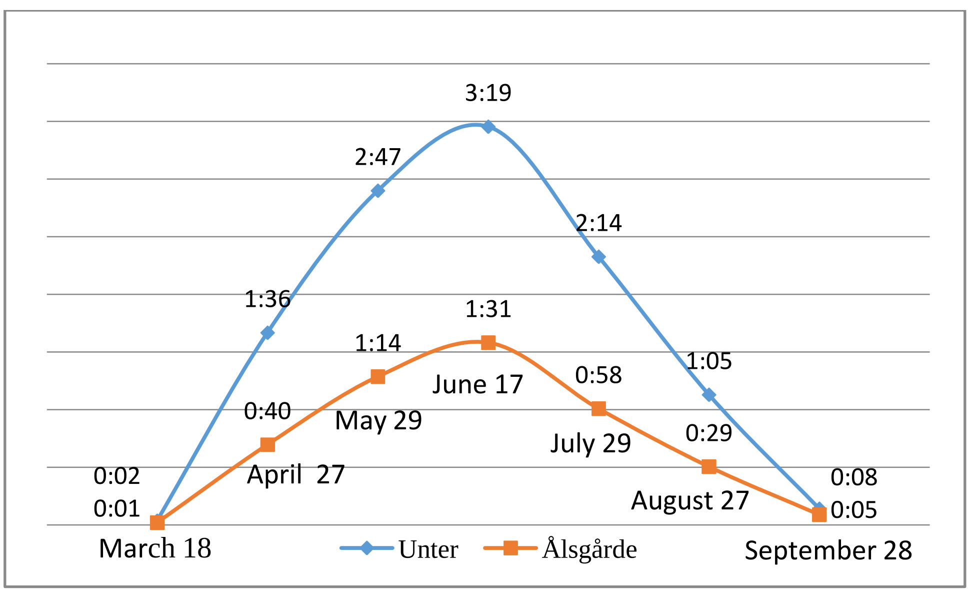

Figure 2. Monthly maximum differences in lengths of day between Unter (Unterstalten) and Tuusula, and Ålsgårde and Tuusula (h:min).

Snow cover thickness and its effect on the ground temperature

There was no permanent snow cover in Ålsgarde through the whole winter (Figure 5). In Unterstalten, the ground temperature was at its lowest, from -1.0 to -1.5°C, under a snow cover of 61 cm in February, which was the coldest month in the locality. In Tuusula, Ålsgårde and Unterstalten the annual averages of the soil temperatures at

Table 17. Local air temperatures in Tuusula, Unterstalten and Ålsgårde.

Period		[a]Tuus	[b]Unter	[a]Tuus/ [b]Unter		[c]Ålsg	[a]Tuus/[c]Ålsg		[c]Ålsg/[b]Unter	
	n	°C	°C	*t*	*P*	°C	*t*	*P*	t	*P*
June 1– Aug 31	91	17.3 ±2.5	15.5 ±2.7	4.6668	<0.001	16.8 ±2.3	1.4041	>0.05	3.4965	<0.001
April 15- Oct 15	181	13.8 ±5.2	13.1 ±4.2	1.4090	>0.05	14.4 ±3.7	1.2650	>0.05	3.1227	<0.001
Oct 20- Oct 20	365	5.0 ±10.5	6.8 ±7.9	1.1617	>0.05	8.0 ±7.7	4.4021	<0.001	2.1544	<0.05

Notes: [a]Tuusula, [b]Unterstalten, [c]Ålsgårde

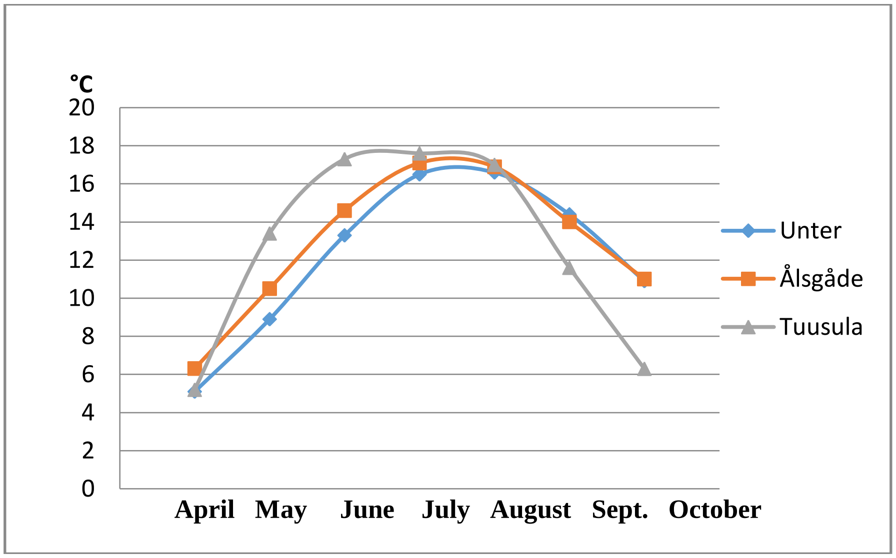

Figure 3. Average monthly air temperatures of the growing season in Unter (Unterstalten), Ålsgårde and Tuusula.

depths of 20 cm and 40 cm were higher than the annual averages of the air temperatures. The temperature remained at above zero for the whole time at depths of 20 cm and 40 cm, at a level of0.5–1.0°C.

Figure 5

Impact of climate change on wine growing conditions in the Helsinki region

Current ground temperatures at depths of 20 cm and 40 cm in different localities

The average air temperature of the Helsinki region (Tuusula) was more than 5°C lower than that of Alsace (Herrlisheim-prés-Colmar) and the annual averages of the soil temperatures at depths of 20 cm and 40 cm nearly 5°C lower (Tables 18 and 19). The soil temperature measured in Tuusula at a depth of 20 cm was 0.5°C at its lowest (10 January 10 – 28 February), Freyburg 2.0°C (7 February – 9 February) and in Herrlisheim-prés-Colmar 1.0°C (12 February – 14 February).

Table 18

In Tuusula, the soil temperature at a depth of 40 cm was 1.0°C at its lowest (10 January – 28 February), in Neubrandenburg 1.0°C (17 February – 19 February), in Freyburg 2.5°C (7 February – 9 February) and in Herrlisheim-prés-Colmar 1.5°C (8 February – 13 February). The ground temperature in Tuusula, Neubrandenburg, Freyburg and Herrlisheim-prés-Colmar did not fall below 0°C at depths of 20 cm and 40 cm. According to Table 19, there was no significant difference between temperatures measured at depths of 20 cm and 40 cm ($P>0.05$).

Table 19

The climatic factors of different localities

The frost-free growing period of Tuusula was 171 days and shorter than in the other localities. The

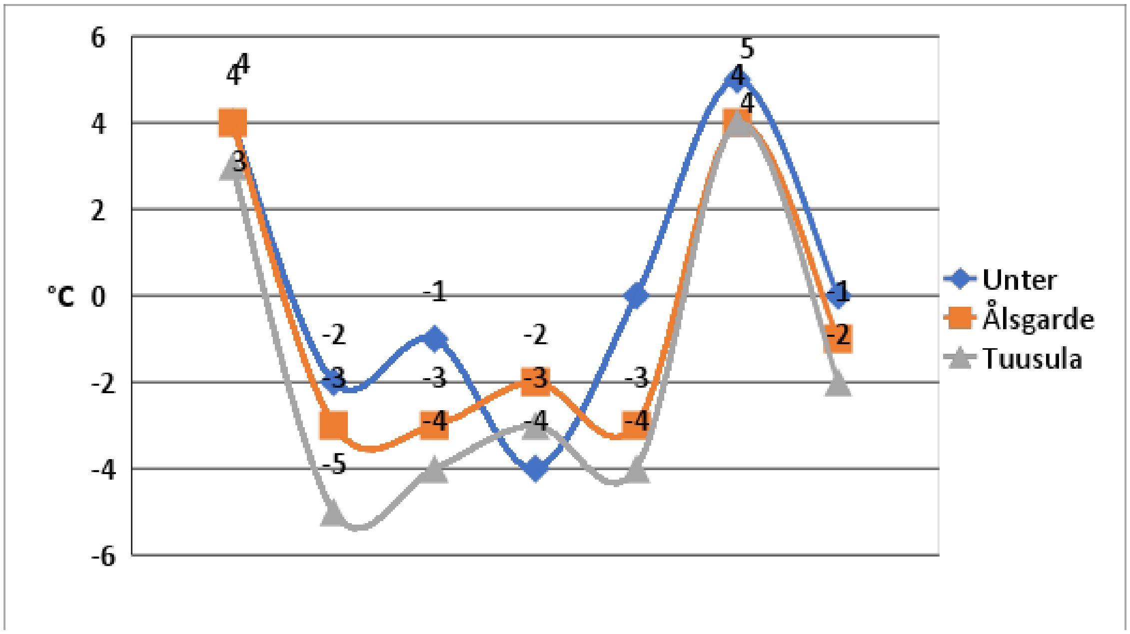

Figure 4. Average monthly air temperatures in 2012–2013 in Ålsgårde, Unter (Unterstalten) and Tuusula, and mean value of the 6 months.

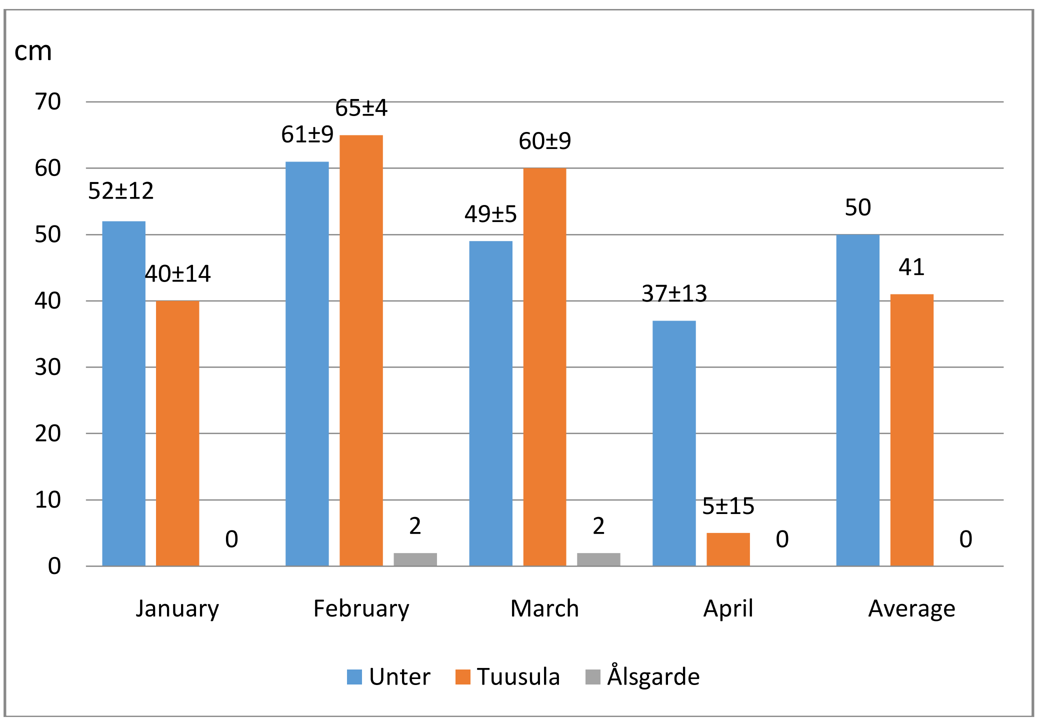

Figure 5. Average depths (± *SD*) of snow layer of four winter months in Unter (Unterstalten), Tuusula and Ålsgårde in 2013.

number of days of 10°C or over in the growing season was also smaller than in the other localities. The average air temperature of the growing season in Tuusula, 12.5°C, was 1.3 – 3.2°C lower than in the other localities. The average air temperature of the growing season in Tuusula shown in Table 20, 12.5°C, was 1.3 – 3.2°C lower than in the other localities (Table 20)

Table 19. Differences in temperatures at 20 cm and 40 cm depths in Tuusula, Freyburg and Herrlisheim-prés-Comar.

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

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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

Table 20. Comparison of Climatic Classification system (*Geoviticulture MCC System*) indexes and climatic conditions in growing season between Tuusula, Neubrandenburg, Freyburg and Herrlisheim-prés-Comar in 2015.

	Tuusula	Neubandenburg	Freyburg	HerrlisheimprésColmar
Huglin Index (HI)	818x1.12=916	1118x1.06=1185	1272x1.06=1348	1272x1.06=1348
Amerine-Winkler Index, GDD[1)]	633	806	854	1066
Cold Night Index (CI)	10.4	12.1	12.4	12.2
Hydrothermal Index (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 (Amerine and Winkler 1944), [2)]Growing season April 1 – September 30, [3)]Tuusula: June 24 – July 7; Neubrandenburg, Freyburg and Herrlisheimprés Colmar: June 15 – 30.

because in 2015 the temperature of the summer months was the coolest in decades. In 2014, the temperature of the growing season in Tuusula would have been as high as in Freyburg and Herrlisheim-prés-Colmar.

The climate classification of wine cultivation in Tuusula

The Multicriteria Climatic Classification System (*Geoviticulture MCC System*) was applied in the

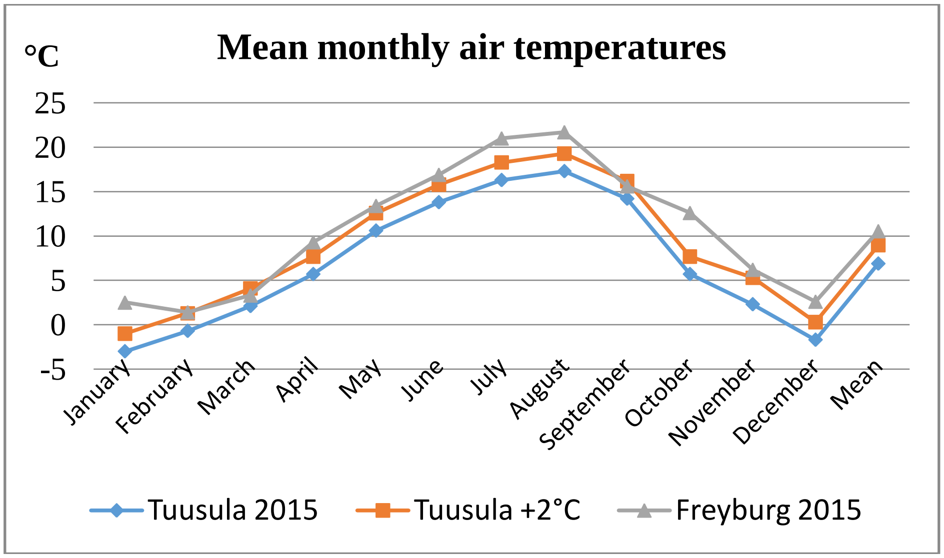

Figure 6. Monthly mean air temperatures in Tuusula in 2015 and after the predicted 2°C rise in annual mean air temperature, compared to the air temperatures in Freyburg in 2015.

classification. According to the Heliothermal Index (HI) and the Amerine-Winkler Index, Tuusula, Neubrandenburg, Freyburg and Herrlisheim-prés-Colmar are in the wine cultivation climate class 'very cool'. On the basis of the Cool Night index (CI), Tuusula is in the class 'very cool nights', but the other localities are in the 'cool nights' group. On the basis of the Dryness Index (DI), the potential water balance of Tuusula was in the range 'moderately dry – subhumid'. The Hydrothermic Index (HyI) of Tuusula was slightly lower than that of the other localities (Table 20).

Table 20

The change in the temperature of the climate of Tuusula, according to the scenarios RCP2.6 and RCP4.5

According to the scenarios RCP2.6 and RCP4.5, based on moderate emissions, the annual average temperature of the climate of northern Europe is predicted to increase by 2°C by 2100. This would increase the air temperature of Tuusula to the same level from March to June as it is currently in Freyburg, Germany, in the Saale-Unstrut wine cultivation area. The temperatures of the middle of the summer and autumn would remain slightly lower (Figure 6).

Figure 6

DISCUSSION

During the growth cycle of the grapevine in this study, the hybrid clones *V. vinifera* L. cv. 'Nordica', *V. vinifera* L. cv. 'Zilga' and *V. vinifera* L. cv. 'Rondo' were followed from the bud swelling (E–L No. 4) to harvest (E–L No. 38) according to the Eichhorn-Lorenz phenological stages (Eichhorn and Lorenz, 1977). The total growth cycle averaged 138 days (129 – 158 days). The period from veraison (E–L No. 35) to the ripening of the grapes (E–L No. 38) lasted an average of 47 days. The growth period from the bud swelling to the ripening of the grapes was at least one month shorter, and the time from veraison to harvest was at least two weeks shorter than the corresponding clones in the cooler German wine regions (Johnson, 1994; Robinson, 2006). Later, Coombe (2004) added the period from the grape ripening to the fall of leaves (E–L No. 47) to the growth cycle, which could last until the end of November in Europe.

The growth cycle of the grapevine, even in the same variety and growth location, has considerable annual fluctuations (Jones and Goodrich, 2008), as shown in Tables 5 and 6; and the lengths of the growth cycle stages may variate more than one week between years. In the spring, based on the algorithm derived from air temperatures, the bud break of the grapevine can be calculated with an accuracy of ±2.5 days (Nendel, 2010). In cool regions, the growth cycle of the grapevine may be longer than in warm regions (Robinson, 2006). In Tuusula, the whole growth cycle of the grapevine was several weeks shorter than in the cool regions of central Europe, where the average annual temperature is 1.5 – 2°C higher than in Tuusula, because the long day can speed up the ripening of the grapes, especially toward the end of the growth cycle.

According to Bauer (2015), a growing season of at least 180 days is sufficient for maturation of the grapes monitored in this study. In Nordic-Baltic regions, however, it requires a mild winter and a warm growing season. With less than 180 days, the effective temperature sum during a growing season under 1600°C□d (5°C basis) and a Huglin Index (HI) (Huglin and Schneider, 1998) of less than 900 are insufficient for the maturation of grapes, and part of the crop remains unripe. In the past, the cooler areas of the Loire had the same risk, but after the climate warmed, the risk was gone (Daux et al., 2012). Unripe grapes have not been misspent, but were used to produce verjuice, i.e., vinegary grape juice to give a sour flavour to food (Beer, 2012).

The sufficient high effective temperature sum has proven to be a more important factor in grape maturation than the long growing season, as shown in Tables 7 and 8. In 2008, the harvest began no earlier than October 1, even though the growing season was the longest and the average annual temperature of 7.6°C the highest in the 10-year follow-up period, but the effective temperature sum was only 1474°C□d (5°C basis). For comparison, the growing season in 2011 was nearly as long as 208 days, but the effective temperature sum was as high as 1829°C□d (5°C basis), and the Huglin Index was 1082 on the central European level (Huglin and Schneider, 1998), and harvest began on 19 September.

In 2008, the growing season was lengthened and the annual average air temperature heightened by an exceptionally mild spring, which is predicted to become more common as a result of climate change in the Nordic countries. It can thus be concluded that the long growing seasons, caused only by mild spring temperatures, will not promote viticulture, but that warm summers and the high effective temperature sums during growing seasons and growth cycles are more important. This is seen in the wine growing regions of Quebec and Siberia, which differ from other wine-growing regions: the winters are very cold and snowy, but the summers are hot (Yaschenko, 2006). However, the disappearance of the snow cover in March may contribute to the warming of the soil and the start of grapevine growth. Quebec's wine-growing area has annual average temperatures of 2 – 3°C, lower than the annual average air temperatures in southern Finland, but its number of sunshine hours is 150 – 200 h less than in southern Finland (Outreville, 2017).

Hard vine-growing conditions differ significantly from the environment and the growing conditions that Bauer et al. (2015) reported from central Europe. Quebec's wine growing has, however, initiated with the original North American cultivars, which have been crossed by European *V. vinifera* L. seedlings in order to improve the quality of the wine. Correspondingly, the cold resistance of the European *V. vinifera* seedlings have been improved by crossing them with North American *V. riparia*or *V. labruska* or East Asian *V. amurensis*. In the crossing, 12.5% of *V. amurens is* crossed with *V. vinifera* have already significantly increased in cold and fungicide resistance (Cindrić et al., 2000).

During the growing season, climate factors influencing the growth cycle of the grapevine were considerably variable over the years. The smallest variation during the growing season was found in solar radiation energy. Few climate factors were observed to have expected mutual dependence. The most significant dependence was between the hours of sunshine and solar radiation energy (R^2 = 0.80; t = 5.6288, $P<0.001$). Significant dependence occurred between the sunshine hours and the effective temperature sum of the growing season (R^2 = 0.52; t = 2.9394, $P<0.02$). Other climatic factors did not have as significant a mutual dependence (Karvonen, 2014).

The length of the grapevine growth cycle did not depend on the length of the growing season, as stated earlier, but the effective temperature sum, the number of sunshine hours and solar radiation energy had the most noticeable effect on it. Likewise, the early bud swelling did not affect the maturation of the grapes and the start of the harvest, as Bootsma (1994) and Briffa et al. (1995) previously stated. This is probably because between the beginning of circulation and the end of maturation, there are so many independent or non-independent climatic or growth factors that their mutual interactions are impossible to define.

In winter, the soil and snow layer protect the part of the trunk below the ground surface and the grapevine roots from freezing. Therefore, finding a suitable planting depth is fundamental. The roots of cultivars planted deep below the frost line of the soil remain intact if the soil temperature remains at 0°C or above, even during cold, snow-free winters. On the other hand, it must be remembered that the deeper the grapevine is planted, the slower the soil temperature rises after the winter, delaying the fluid circulation and growth of cultivars in spring and the start of ripening and harvest.

In Finland, winter temperatures and snow layer thickness vary from year to year. In southern Finland, the snow cover thickness varies from 20 to 80 cm depending on the winter. In mild winters, the earth's snow cover is thin and may remain on the ground for only a few weeks before melting away. In general, people think that snow cover prevents grapevine cultivation in Nordic regions. However, the snow is the northern wine grower's friend, not the enemy, because the thick snow cover effectively protects the vine and its lower parts from freezing, and the colder the winter, the thicker the snow cover.

Quebec is a good example that the months of withstanding severe frosts do not hamper grapevine cultivation if winter snow cover is thick enough and nature can be utilized. Excluding the winter months in the Quebec City area, where the average temperatures are -15°C, Quebec vineyards' lowest measured temperature in January was -36.1°C, with an average of -12.8°C, and the thicknesses of the snow cover are 200 – 300 cm (Outreville, 2017). In the summer months, the monthly mean air temperatures have been above 25°C, and during the day it can be higher than 40°C (Meteorological Service of Canada, 2016). Equally harsh winters or hot summers almost never occur in the Baltic Sea region.

Air temperature and snow cover thickness have a significant correlation (R^2 = 0.58 – 0.74), *i.e.*, in very cold winters, crop-protective snow cover increased. In snowy cold winters, when the thickness of the snow cover was 70 – 80 cm, the earth's surface temperature of -2.0°C was maintained throughout the winter. During the exceptional snowless winter of 2008, the lowest temperature in January was -25.4°C, with a minimum ground temperature of -8.7°C 18 cm below the snow cover, but at a depth of 40 cm, the soil temperature remained over 1°C, and the grapevines were not significantly affected (Karvonen, 2013).

The snow layer and the soil together protect the vine roots in winter. Despite a slim 10 – 32 cm thick snow layer, the soil frost layer in the southern parts of the Nordic-Baltic region often does not extend to a depth of 40 cm (Karvonen, 2002; Karvonen, 2008) because the mild winters have less snow cover. Then, a mere surface layer is sufficient as a protective insulator, preventing root systems from freezing. A critical situation in vine cultivation occurs during early winter when 2 – 3 weeks of hard frost comes and the earth's surface is still bare, allowing for possible root damage (Guo et al., 1978).

Hard frosts, heavy snowfalls, and cold spells can also occur in the central European wine-growing regions in late spring. They are shorter in duration than in Nordic countries, but may hinder bud outbreak or shoot growth and possibly delay the ripening of the grapes in autumn. The last spring frost in 2011 in the Czech Republic occurred at the beginning of May. Temperatures dipping to -7°C and a snowfall of 70 cm were measured on 4 May in the Litomerice region (Czech Hydrometeorological Institute, 2011). However, this short cold period lasted for only a few days and did not significantly injure the vines, and their growth continued in the summer as usual.

The effect of the covers and black plastic polyethylene film on the growing place extends below the soil surface, elevating temperatures to the planting depth. The film promotes the growth of 1 – 2-year-old vines during summer because it raises the soil temperature while maintaining the moisture of the soil (Sölva, 1970; Bauer, 2002; Branas, 1969). In the 2014 – 2015 growing season, the effect of 0.07 mm thick black polyethylene film on the ground soil temperature at a depth of 40 cm was monitored. Fluctuations between soil temperature and the seasons become smaller the deeper you go. The soil temperature differences between winter and summer are minor at a depth of 7 m, but at a planting depth of 40 cm, they are also somewhat smaller and slower to grow than on the ground surface (Lemmelä et al., 1981).

In the Helsinki region, due to the slowing effect of the soil layer on the soil temperature changes, the vineyard's bare soil temperature reached its maximum in summer at a depth of 40 cm, about two months later than the air temperature. Under black plastic ethylene film, soil temperature remained constant throughout the year, averaging 0.4°C higher than the uncovered soil (Karvonen, 2016). The difference is not very drastic, but it was statistically significant and may promote the growth of young grapevines during the growing season. The temperature in the grass-covered soil at a depth of 40 cm was not significantly changed by using the black plastic film covering.

Clear greenhouse acrylic polycarbonate sheets did not raise the soil temperature in the same manner as the black plastic polyethylene film because it has a glossy finish surface and does not absorb the solar radiant energy in the same manner, but it reflects a large part of the radiation. The greenhouse plastic raises the temperature of the soil and the environment when used only in greenhouses' roof and wall structures, where it works just like the atmosphere in the natural greenhouse effect, raising the temperature of the greenhouse in early spring by passing through warming short-wave solar radiation energy and preventing the long-wave ultraviolet radiation and heat from escaping. As a result, in cold greenhouses as well, the temperature increases so much in March and April that the growth period is extended 10 – 40 days (Novello and de Palma, 2008).

In cooler regions, the vines are grown along the southern walls of buildings because they are regarded to be considerably warmer than other environments for growth, and grapevines are believedto benefit from the protection afforded by the wall (Hoare, 1841). This The temperature near the walls may be higher than the air temperature in the nearby open field because the wall material stores heat and provides wind protection, but it has no impact on the soil temperature, and at the foot of building walls, soil temperature may be lower than in the surrounding open field soil (Karvonen 2016). One reason for this may be cold remaining stone in the foot of the building and the sand and gravel used around the base of the building. In the sandy and gravel soil, albedo is more powerful when the solar radiation energy is less absorbed into the soil.

In comparison, air and soil temperature differences between Ålsgårde in the Copenhagen region, the Unterstalten region in the canton of Valais in Switzerland, and Tuusula in the Helsinki region proved to be quite small. The main differences were in the day length and the snow cover thickness. In Tuusula, Ålsgårde and Unterstalten, day length and air temperature increased at the same rate until April-May and peaked during the summer months. Almost throughout the entire growing period, from March 18 to September 28, Tuusula's day length was the longest compared to the other localities.

The variance in day length in Tuusula, Ålsgårde and Unterstalten was the greatest in June, when the day in Tuusula was more than three hours longer than in Unterstalten. The impact of day length and sunshine could happen so that the average air temperature during the summer months (June, July and August) was significantly higher in Tuusula than in Unterstalten and Ålsgårde ($P<0.05$ to 0.001). Apparently, the long days compensate for the shorter growing season in Nordic regions, and air and soil temperatures are increasing at the same time during the summer months.

In Tuusula, Unterstalten and Ålsgårde, snow cover thickness was monitored from January to April. In Unterstalten, snow cover was thickest in January (mean 52 cm) and in Tuusula in February (average 65 cm). In Unterstalten, snow cover remained until the end of April, but in Tuusula, it quickly melted away at the end of March. Ålsgårde did not have a permanent snow cover throughout the winter. In Tuusula, average annual air and soil temperatures were lower than in Unterstalten, but there were no significant differences between Ålsgårde and Unterstalten.

Rötzer and Chmielewski (2001) proved that the conclusions on the effects of latitude and longitude on climate and growth conditions are somewhat correct in this study, as in the Köppen-Geiger climate classification. In consequence, global warming, climate and soil temperature classifications of Unterstalten, Ålsgårde and Tuusula may change after a few decades, which is indicated by melting glaciers in the Alps (Zeiz and Foppa, 2007), the rising of the tree line (Leonelli et al., 2011; Rubel et al. 2017), and the shortening of the ice-covered period of the lakes in Finland (Korhonen, 2005).

The current Danish climate and growing conditions correspond to the central European highaltitude vineyard climate and growing conditions. Near Ålsgårde at sea level, environmental conditions for wine growing were even more favorable than at 1,100 km further south, but at 1,150 m above mean sea level in Unterstalten (Karvonen, 2014). Spring and autumn temperatures in Tuusula were slightly lower than other places, but this is compensated with high temperatures in the summer months and the longest days during the growing season. In these new areas, rapidly growing hybrid cultivars are possible, as in Unterstalten in the canton of Valais in Switzerland.

According to the RCP2.6 scenario, the average annual air temperature of the climate in southern Finland would increase by 2°C at a maximum and could even fall to the level of 1986 – 2005 by the end of 2100 if all emissions were to cease. Even zero emissions should increase the average annual temperature of the Helsinki region and

Tuusula to 8 – 9°C, close to temperatures in many existing central European wine-growing regions. Based on RCP4.5 scenarios' climate model, the annual air temperature in Tuusula would increase by 2.5 to 3.0°C from the 1986 – 2005 average by 2081 – 2100.

At the beginning of the millennium, the climate had warmed slightly slower than predicted by climate models, most probably because of a random variation caused by a cooling climate, where the eastern parts of the Pacific Ocean cooled and the heat moved deeper into the sea. Other reasons include the excessive sensitivity of the climate models to greenhouse gas emissions, and the climate forcing of the model simulations have not been correct. Apparently, global warming will continue, either faster or slower, despite the limitation of greenhouse gases (Vaidyanathan, 2016).

Climate change and sew viticulture regions have been reviewed by Fraga (2014). The predicted climate change gives a reason to look at how the growing conditions of today's grapevines differ at a latitude of 48 – 60°N at the extremities of the same climate zone as the Helsinki region (Finland), the Mecklenburg-Vorpommern region (Germany), the Saale-Instrut region (Germany) and the Alsace region (France), and how global warming would change them. In the Mecklenburg-Vorpommern region, wine growing is experimental, but in the Alsace and Saale-Instrut regions, wine has been grown for a thousand years.

The present study compared the current vineyard climate and growth conditions in the Helsinki region in southern Finland (60°N) to the growth conditions in Neubrandenburg (53°N) and Freyburg (51°N) in northern Germany, as well as in Herrlisheim-près-Colmar (48°N) in the Alsace region in France. According to the Köppen-Geiger climate classification (Köppen, 1900; Geiger, 1961),Tuusula in the Helsinki region belongs to the cool area of the temperate climate zone (*Dfb*) and Neubrandenburg, Freyburg and Herrlisheim-près-Colmar to the warm area of the temperate climate zone (*Cfb*).

The situation of vineyards above mean sea level ranged from 53 to 242 m, and the maximum distance between the locations was 1,390 km (between Tuusula and Herrlisheim-près-Colmar). During the growing season, the longest days are in Tuusula and the shortest in Herrlisheim-près-Colmar. In the mid-summer months, solar radiation energy in southern Finland was higher than in northern Germany (Lindfors et al., 2014). In 2001 – 2012 in June, July and August, the average solar radiation energy in Tuusula was 481 kWh/m^2, in Neubrandenburg 477 kWh/m^2, in Freyburg 474 kWh/m^2 and in Herrlisheim-près-Colmar 505 kWh/m^2 (EC, 2016).

According to the Eichhorn-Lorenz phenological stages of the grapevine (Eichhorn and Lorenz, 1977), the growth stage (E–L No. 17) in Tuusula was on 4 June, the same as in Herrlisheim-près-Colmar, despite the fact that on 26 May, Tuusula's growth was 9 days behind Herrlisheim-près-Colmar's. The difference between growth stages in Tuusula, Neubrandenburg and Freyburg was less than a week, so the differences in development were small between localities and could be further shortened if spring comes early and the winters become milder. If this happens, the resulting mature grapes in the southernmost parts of Finland will be more successful.

A large part of the success of wine growing depends on local climatic conditions and soil temperature, frost, precipitation and regional macro-, meso-, and micro-climates. The climatic conditions are classified using Multicriteria Climatic Classification System (*Geoviticulture MCC System*) Indices. The HuglinIndex (Huglin and Schneider, 1998) classifies the conditions of the growing season according to the accumulation of air temperatures during the growing season and takes into account the long days of the northern wine-growing areas. The Cool Night Index (CI) classifies regions based on the lowest night temperatures during the ripening period. The Drought Index (Dryness Index, DI) indicates the potential soil water retention ability and water balance (Li and Zhou, 2014).

According the indices of the *Geoviticulture MCC System* (Tornietto and Carbonneau, 2004), the climatic conditions in the localities of this study differed somewhat from each other during the growing season of 2015. The Huglin Index (HI) indicated that all the localities belonged to the 'very cool' wine-growing climate category. According to the Cool Night Index (CI), Tuusula belonged to the category of 'very cool nights', but other locations were in a warmer 'cool nights' category. On the basis of the Dryness Index (DI) (Tornietto and Carbonneau, 2004), Tuusula's potential water balance was between 'moderately dry and subhumid'.

In addition to the indices, the air and soil temperatures of each locality were monitored for two years. The frost-free growing season of

Tuusula lasted 171 days, which was shorter than in other localities. This is due to the autumn frost, which occurs annually in Tuusuladuring one or two nights in mid-September and early October, when the temperature falls to about -1°C. The next night frost might be as late as November. Due to this short period of cold weather in September or October, the number of growing season days at +10°C or higher was also less than in other places.

Average winter soil temperatures at planting depths of 20 cm and 40 cm in Tuusula were significantly lower than in Neubrandenburg, Freyburg, and Herrlisheim-près-Colmar. The lowest soil temperature at a planting depth of 40 cm in each place was more than 1°C so that the risk of root freezing was small. During the second week of 2016 in Tuusula, the ground surface was still free of snow, and freezing temperatures were from -19 to -24°C. The lowest temperature at 20 cm depth was -0.6°C, so there was a risk of surface root freezing. Tuusula's coldest winter periods lasted for several weeks, but elsewhere only a few days to 2 weeks (Karvonen, 2017).

If the annual average air temperature permanently rose more than 5°C in Finland, the growing season would extend from 1 to 1.5 months. According to some climate scenarios, the air temperature in the Helsinki region could rise to twice as much as Earth's temperature (Ruosteenoja et al., 2005; Ruosteenoja et al., 2010). The effects of the predicted 2°C rise of the annual average air temperature in the Tuusula climate are presented in the Results. In the autumn, the temperature rise in Tuusula would be lower and would fall in October more sharply than in Freyburg, but the autumn frost would no longer endanger the growth and ripening of the grapes in autumn.

CONCLUSIONS

This study followed the annual cycle of four rapid-maturing, winter-tolerant and rich-in-yield hybrid grapevine cultivars in Tuusula, which have been grown at a latitude of 59 – 60°N in Sweden and Finland (Flen, Stockholm, Turku and Helsinki) for the last 10 – 20 years. The 2°C global warming increase has been predicted to promote wine-growing conditions in southern Finland and to move cultivation further north to central Finland before the end of this century.

In southern Finland's Helsinki region, the total growth cycle of the grapevine from the start of bud break to harvesting lasted 4 – 5 months, and from the beginning of flowering to harvest lasted approximately 3 months. Based on the results, it can be concluded that the already existing growth conditions of the grapevine can be harvest productive in southern Finland and in other regions in southern Sweden, southern Norway, and Denmark.

In the Nordic countries, little-snow winters are generally mild. During cold winters, the thick snow layer effectively protects the ground surface and the topsoil from frost action. In very cold winters (from-25.0°C to -27.4°C), a 60 – 70 cm thick layer of snow maintains the ground temperature between -0.5°C and -1.3°C. Around 60 cm, the snow layer protects the topsoil and the basal region of the trunk of grapevines slightly below or above the soil level, and also prevents the roots of the canopy from freezing, even when the air temperature is below -30°C. Thus, during cold winters with a thin snow cover of less than 30 cm, the earth's surface temperature was lowered to -10.8°C. When the hard frost continues for several weeks, the roots or part of the roots of the grapevine can be destroyed.

In southern regions of the Nordic countries, severe cold frosts have become rare, and when the ground is snowless, sudden hard frosts can cause root damages that occur in the spring, and the grapevines die soon after the swelling of the buds and after the beginning of shoot growth. In many cooler growing regions such as Switzerland, Canada and Siberia, successful vine growth is possible thanks to thick snow cover, but in the future, a lack of snow can lead to a retrogress of viticulture.

Covers, greenhouses and protective structures have raised or lowered the soil temperature of the vineyard in accordance with the requirements of the growing season. In this study, the effect of black plastic polyethylene film, greenhouse acrylic polycarbonate sheets, and grass-covered and uncovered earth on the temperature of the vineyard subsoil was compared. Only the black plastic film significantly increased the subsoil temperature at a planting depth of 40 cm.

In the Helsinki and Copenhagen regions, theclimate and growing conditions of vineyards locating near sea level corresponded to climate and growth conditions of vineyards locating in high mountains in central Europe. In the Copenhagen region, the environmental conditions of Ålsgårde were even more favourable than in Switzerland at 1,150 m above mean sea level in Unterstalten. The annual averages of air and soil temperatures in Tuusula in the Helsinki region were significantly lower than Unterstalten and Ålsgårde, but in Tuusula, air temperature averages during the summer months (June, July and August) were significantly higher, and the days were longer than in Unterstalten and Ålsgårde.

According to the Multicriteria Climatic Classification System *(Geoviticulture MCC System*), Tuusula belongs to the category of 'very cool', and the maturation of vines is decisively promoted by a good local microclimate. The lowest air temperature was in Tuusula at -17°C and in Neubrandenburg, Freyburg and Herrlisheim-près-Colmar, it was between -4.1 and -6.1°C. The subsoil temperatures at a planting depth of 40 cm remained in Tuusula, Neubrandenburg, Freyburg and Herrlisheim-près-Colmar at 1°C or above, so the risk of root freezing was low in all locations.

In Tuusula, the grapevine root system was exposed to a higher abiotic stress arising from lower winter temperatures than elsewhere. Based on the precipitation in the growing season, Tuusula is categorised as 'moderately dry-subhumid', which is sufficient for wine growing. The predicted 2°C rise of climate temperature would bring the temperatures of the Helsinki region close to Freyburg temperatures. At that time, the Tuusula growing season could begin as early as March, 3 – 4 weeks earlier than at present, which is sufficient for almost all currently cultivated European *V. vinifera* varieties.

In the Baltic Sea region, wine growing with suitable varieties is already possible, and with the predicted climate warming, the breeding of suitable grapevines for a cool climate will promote it. The grapevines must be adapted for a cool climate and the long summer days and have a good cold resistance, so not all southern European varieties are suitable for new areas. In addition, the growth location must be as warm as possible, with soil suitable for cultivation and an optimum local microclimate.

REFERENCES

Abeysinghe SK, Greer DH, Rogiers SY (2016). The interaction of temperature and light on yield and berry composition of *Vitis vinifera* 'Shiraz' under field conditions. Acta Hortic. 1115:119–125.http://dx.doi.org/10.17660/ActaHortic.2016.1115.18.

Ahmedullah M, Kawakami A (1986). Evaluation of laboratory tests for determination of the lethal temperature of *Vitis labruscana* Bayley Concord roots exposed to subzero temperatures. Vitis 5:142–145.

Amerine MA, Winkler AJ (1944). Comparison and quality of must and wines of Californian grapes. Hilgardia. 15: 493–675.

Anderson K, Pinella V (2017). Annual database of global wine markets, 1835 to 2015, freely available in Excel files at the University of Adelaide's Wine Economics Research Centre, www.adelaide.edu.au/wine-econ/databases.

Bauer K (2002). Weinbau. 7th edn. Leoboldsdorf, Austria: ÖsterreichischerAgrarverlag, pp. 116–127.

Bauer K, Regner F, Shildiger B (2015). Weinbau, 10thedn. Leoboldsdorf, Austria: ÖsterreichischerAgrarverlag, pp. 138–139, 144, 148–149

Beer M (2012). Maggie´s Verjuice Cookbook. Canberra, Australia: Penguin Books, pp. 50–61.

Bentzen J, Smith V (2009). Wine production in Denmark. Do the characteristics of the vineyards affect the changes for awards? Working paper 09–21. Department of Economics, Aarhus School of Business, Aarhus University, Denmark.

Bootsma A (1994). Long Term (100 yr) climatic trends for agriculture at selected locations in Canada. Clim. Change 26:65–88.

Bowen P, Estergaard B, Bogdanoff C (2016). Effects of protective covers on the temperature of young grapevine stems and roots in winter. 68 ASEV National Confrence 26–29 June, 2017, American Society for Enology and Viticulture, Abstracts. Bellevue, Washington, USA. p. 91.

Branas J (1969). Concerning the use of plastics. Prog. Agr. et Vitic. (Montpellier) 86:63–73.

Briffa KR, Schriee van der G, Jones PD (2009). Wet and dry summers in Europe since 1750:evidence of increasing drought. International J. Climatol. 29:1883–2001.

Cahill KN, Field CB (2008). Clinical Change Science. Practical Winery and Vineyard Journal March/April. Stanford University and Carnegie Institution for Science, Stanford, CA. kncahil@stanford.edu.

Chmielewski FM, Rötzer T (2001). Response of tree phenology to climate change across Europe. Agric. For.Meteorol. 108:101–112.http://doi.org/

10.1016/S0168-1923(01)00233-7.
Cindric P, Korac N, Kovac V (2000). Grape breeding in the Vojvodina province.Acta Hortic. 528:499–504,Doi: 10.17660/ActaHortic.2000.528.72.
Cook BI, Wolkowich EM (2016). Climate Change decouples drought from early wine grape harvests in France. Nat. Clim. Change 6: 715–719, Doi:10.1038/nclimate2960.
Coombe BG (2004). Grapevine Growth Stages. The modified E-L-system. Viticulture, Volume 1, Resources, 2ndedn. Adelaide, Vinetitles, p.153.
Currie JA (1984). Gas diffusion through soil crumbs: The effects of compaction and wetting. Eur. J. Soil Sci.35:1–10. Doi:10.1111/j.1365-2389.1984.tb00253.x Czech Hydrometeorological Institute (2011). Statistics.
Daux V, Garcia de Cortazar-Atauri I, Yion P, Chuine I, Garnier E, Le Roy Ladurie E, Mestre O, Tardaguila J (2012). An open-access database of grape harvest dates for climate research: data description and quality assessment. Clim. Past 8:1403–1418. Doi:10.5194/cp-8-1403-2012
Deutscher Wetterdienst (2017). http://www.dwd.de/DE/presse/pressemitteilungen/presse-mitteilungen_archiv_2017_node.htm.
EC (2016). Photovoltaic Geographical Information System–Interactive maps. Available at re.jrc.ec.europ.eu/pvgis/apps4/pvest.php.
Eichhorn KW, Lorenz DH (1977). Phänologische Entwicklung der Rebe. Nachr. Dtsch.Pflanzenschutzd. 29:119–120.
FIM (2004). Climate. Weather in recent years. Weather in normal period.
FIM (2010). Tiedotea rkisto (Newsletter Archive).
FIM (2012). Annual average temperatures, growing seasons, growing degree days (GDD+5°C), sunshine hours and solar radiation during growing seasons in 2002–2011.
FIM (2012). Seasons in Finland: Winter. Available at www.finnishmeteorologicalinstitute/snowstatistics.fi.
Flick G (2010). Strategienzum Schutz vorSpätfröstenbeiRebanlagen in Norddeutschland und Schweden. DeutschesWeinbau-Jahrbuch 61:33–42 (Abstract in English). http://www.vitis-vea.de/Englisch/info.php?auswahl=61951.
Fraga HJC (2014).Viticultural zoning in Europe: Climate scenarios and adaption measures. Doctoral thesis. Universidade de Trás-os-Montes e Alto Dauro, Portugal pp. 22, 33, 39–44.
Föreningensvensktvin (2017).www.svensktvin.se.
Geiger R (1961). Überarbeitete Neuausgabe von Geiger. R: Köppen-Geiger/Klima der Erde (Wandkarte 1:16 Mill.). Gotha, Germany: Klett-Perthes Verlag.
Gladstones J (2011). Wine, terroir and climate change, Kent town, South Australia: Wakefield Press, pp. 133–142.
Guo X, Fu W, Wang G (1987). Studies on cold hardiness of grapevine roots. Vitis 26:162–170.
Hall A, Mathews AJ, Holzapfel BP (2011). Potential effect of atmospheric warming on grapevine phenology and post-harvest heat accumulation across a range of climates. Int. J. Biometeorol. 60(9):1405–1422.
HELCOM (2007). Climate Change in the Baltic Sea Area – Helcom Thematic Assessment in 2007. Baltic Sea environmental proceedings No. 111. Springer Earth System Sciences, Berlin–Heidelberg.
Hoare C (1841). A practical treatise on the cultivation of the grape vine on the open walls. 3thedn. London, England: Longman, Brown, Green, Longmans, pp. 41–50.
Huglin P, Schneider C (1998).Nouveau mode d'évaluation des possibilités héliothermique d'un milieu viti-cole. Biologie et écologie de la vigne, 2ndedn. Paris, France: Lavosier, p. 292.
Ibanez S, Perez JL, Peregrina F, Garcia-Escudero E (2011). Utilication de Cubiertas Vegetalesen Vinedos de la D.O.Ca. Rioja (Espana). Bull. de l´OIV 84:247–256.
Ilmasto-opas (2010). https://ilmasto-opas.fi/fi/datat/vaikutukset#SykeDataPlace:vaikutukset
IPCC (2001). Climate change 2001: 3rd Assessment Report. Cambridge: Cambridge University Press, pp. 85–99.
IPCC (2007). Climate change 2007. Impacts, Adaptation and Vulnerability, The Physical Science Basis. Summary for Policymakers, Working group I. Cambridge: Cambridge University Press, pp. 14–22.https://www.ipcc.ch/pdf/assessment-report/ar4/wg2/ar4_wg2_full_report.pdf.
IPCC (2013). 5th Assessment Report, Climate Change. The Physical Science Basis, AR5, fig. 5.7. https://www.google.fi/?gfe_rd=cr&ei=cXrwWI7CBKyr8wfJu4vYDQ#q=IPCC+(2013)+Fifth+Assessment+Report,+Climate+Change+2013:+The+Physical+Science+Basis,+AR5,+fig.+5.7.
IPCC (2014). Climate Change, Summary for

Policymakers. Cambridge: Cambridge University Press, pp. 65–76.
Johnson H (1994). Wine and Weather. The World Atlas of Wine, 4thedn. Great Britain: Reed Consumer Books Ltd, Michael Beazley, pp. 58–75.
Jones GV, Goodrich GB (2008). Influence of climate variability on wine region in the Western USA and on the wine quality in the Napa Valley. Clim. Res. 35:241–254, Doi: 10.3354/cr00708.
Justander JG (1786).Vitis vinifera L. Specimen Calenterii florae et faunae Aboensis. (in Latin).
Jylhä K, Ruosteenoja K, Räisänen J, Venäläinen A, Tuomenvirta H, Ruokolainen L, Saku S, Seitola T (2009). Arvioita Suomen muuttuvasta ilmastosta sopeutumistutkimuksia varten, ACCLIM-hankkeen raportti 2009 (Thechanging climate in Finland: Estimates for adaptationstudies 2009. ACCLIM-project report 2009), Finnish Meteorological Institute, Reports 2009:4. Helsinki, Finland: Yliopistopaino, p. 102. (in Finnish, extended abstract and captions for figures and tables also in English).
Karvonen J (2002). Outdoor viticulture in Finland. BSc Thesis. Häme Polytechnic, Mustiala, Finland. pp. 39–48.
Karvonen J (2008). Soil temperature and grapevine growth in Finland. MSc thesis. Faculty of Agriculture and Forestry, The University of Helsinki, Finland, (in Finnish with English summary). pp. 1–67.
Karvonen J (2013). Effect of snow layer on ground surface temperature in cool wine growing regions, Electronic Journal of Polish Agricultural Universities 16(3) (on line).
Karvonen J (2014). The annual growth cycle of grapevines in Southern Finland. Vitis 53(4):175–180.
Karvonen J (2014). Northern European viticulture compared to Central European high altitude viticulture: annual growth cycle of grapevines in the years 2012–2013. Int. J. Wine Res. 2014:6:1–7.
Karvonen J (2015). Does Climate Change Allow Grapevine Growing in the Southernmost Finland? IJAIR 4(1):2319–1473.
Karvonen J (2016). Effect of covers on the vineyard subsoil temperature, Agric.Sci.(Plovdiv) 20(8):87–92.
Karvonen J (2017). Impact of climate change on winegrowing conditions in southernmost Finland (Tuusula), Int. J. Enol. Vitic. 4(4):169–178.
Kaukoranta JP, Niinimäki N (2010). Lumen syvyyden mittaaminen Ilmatieteen laitoksen havaintoasemilla. Ilmastokatsaus 1.Helsinki:Ilmatieteenlaitos, pp. 3–15.
Keller M (2010). Managing grapevines to optimize fruit development in a challenging environment: a climate change primer for viticulturists. Austr. J. Grape and Wine Res. 16:56–69, Doi: 10.1111/j.1755-0238.2009.00077.x
Kerr RA (2004). A slowing Cog in the North Atlantic Occean´s Climate Machine. Science 304:371–372.
Korhonen J (2005). Suomen vesistöjen jääolot. In: Suomen ympäristö 751, Helsinki: Suomen ympäristökeskus,pp. 100–102.
Kottek M, Grieser J, Beck C, Rudolf P, Rubel F (2006). World Map of the Köppen-Geiger climate classification updated. Meteorol. Z. 15(3):259–263.
Köppen W (1900).Versucheiner Klassifikation der Klimate, vorzugsweisenachihren Beziehungenzur Pflanzenwelt. Geogr. Z. 6:593–611, 657–679.
Lemmelä R, Sucksdorff Y, Gilman K (1981).Annual variation of soil temperature at a depth of 20–700 cm in an experimental field in Hyrylä, South-Finland during 1969–1973. Geophysica 17:143–154.
Leonelli G, Pelfini M, Morra di Cella U, Carvaglia V (2011). Climate Warming and the Recent Treeline Shift in the European Alps: The Role of Geomorphological Factors in High-Altitude Sites. Ambio 40(3):264–273. Doi: 10.1007/s13280-010-0096-2.
Li Y, Zhou M (2014). Trends in Dryness Index Based on Potential Evapotranspiration and Precipitation over 1961–2099 in Xinjiang, China. Adv.Meteorol. Article ID 548230doi.org/10.1155/2014/548230.
Lindfors A, Riihelä A, Aarva A, Latikka J, Kotro J (2014).
Solar radiation in Östersundom. Helsinki: Finland. Finnish Meteorological Institute. Reports 2014:5 (Abstract in English).
Marx W, Haunschild R, Bornmann L (2017). Climate change and viticulture – a quantitative analysis of a highly dynamic research field. Vitis 56:35–43,doi: 10.5073/vitis.2017.56.35-43.
McGullagh J (1978). The Solar Greenhouse Book. 1stedn. Emmaus, PA: Rodale Press, pp. 240–256.
McKnight TL and Hess D (2000). Foehn/Chinoonk Winds. Physical Geography: A Landscape

Appreciation. Upper Saddle River, NJ: Prentice Hall, p. 132 .
Menzel A, Jakobi G, Ahas R, Scheifinger H, Estrella N (2003). Variations of the climatological growing (1951 – 2000) in Germany compared in other countries. Int. J. Climatol. 23:793–795.
Menzel A, Estrella N, Heitland W, Susnik A, Schleip C, Dose V (2008). Bayesian analysis on the species-specific lengthening of the growing season in two European Countries and the influence of insect pest. Int. J. Biometeorol. 52:209–216.
Met Office Hadley Centre (2017). Met Office Hadley Centre Central England Temperature. http://www.metoffice.gov.uk/hadobs/hadcet/data/download.html.
Meteo-France (2010). Annual Report 2010, http://files.meteofrance.com/files/guides/25428-48.pdf
Meteorological Service of Canada (2016). Historical climate date. http://climate.weather.gc.ca/index_e.html.
MeteoSwiss, (2016). Standard period 1961–2010. www.meteoswiss.admin.ch/home/climate/past/
MeteoSwiss (2016). Klima-Normwerte 1961–1990, Visp, www.meteoswiss.admin.ch/files/kd/climsheet/de/VIS_norm6190.pdf.
MeteoSwiss (2017).http://www.meteoswiss.admin.ch/home/climate/past/climate-of-switzerl and.htm.
Meurman O (1957). Vindruvor på friland. Trädgårdsnytt. 11:1–3. (in Swedish).
Možný M, Brázdil R, Dobrovolný P, Trnka M (2016). April–August temperatures in the Czech Lands, 1499–2015, reconstructed from grape-harvest dates. Clim. Past 12:1421–434. doi:10.5194/cp-12-1421-2016.
Nendel C (2010). Grapevine bud break prediction for cool winter climates. Int. J. Biometeorol. 54(3):231–241,Doi:10.1007/s00484-009-0274-8
Novello V, de Palma L (2008). Growing grapes under cover. Acta Hortic, 785:353–362. Doi: 10.17660/Acta Hortic.2008.785.44.
Outreville JF (2017). Wine production in Quebec: a restatement. American Association of Wine Economists, Working paper No 209 Economicspp. 2–10, http://www.wine-conomics.org/aawe/wp-content/uploads/2017/01/AAWE_WP209.pdf.
Peel MC, Finlayson BL, McMahon TA (2007).Updated world map of the Köppen-Geiger classification. Hydrol. Earth System Sci. 11:1633–1644.
Rader J, Handeen D, Virajita S (2013). Cold Climate Greenhouse Resource. A guidebook for designing and building a cold-climate greenhouse, University of Minnesota, p. 24.
Reuter E (1904). Report from the occurrence of pest insects in Finland. Maanviljely Hallituksen Tiedotuksia No. 73, Helsinki, pp. 9-30 (in Finnish).
Robinson J (2006). The Oxford Companion to Wine, 3rd edn. Oxford University Press, pp 317–324.
Rubel F, Brugger K, Haslinger K, Auer I (2017). Climate of the European Alps: Shift of very high resolution Köppen-Geiger climate zones 1800–2000. Meteorol. Z. 26:6–9.Doi: 10.1127/metz/2016/0816.
Ruosteenoja K, Jylhä K, Tuomenvirta H (2005). Climate Scenarios for FINADABT Studies of climate change adaption. FINADABT Working Paper No. 15, Helsinki: Finnish Environment Institute Mimeographs No. 345, p. 32.https://helda.helsinki.fi/bitstream/handle/10138/41061/SYKEmo_345 .pdf? sequence=1.
Ruosteenoja K, Räisänen J, Pirinen P (2011). Projected changes in thermal seasons and the growing season in Finland. Int. J. Climatol. 31(10): 1473-487. Doi: 10.1002/joc.2171. ok
Rötzer T, Chmielewski FM (2001). Phenologicalmaps of Europe. Clim, Res. 18:249–255.
Saario M (1991). Viiniköynnös, sen menestyminen ja kasvattaminenSuomessa, (Vine, itssuccess and growth in Finland), MSc thesis. Faculty of Agriculture and Forestry, The University of Helsinki, Finland. pp. 20–41.
Samuelsson P, Jones C G, Willen U, Ullerstig A, Gollvik S, Hansson U, Jansson C, Kjellsröm E, Nikulin G, Wyser K (2011). The Rossby Centre Regional Climate model RCA3: model description and performance. Tellus A 63:4–24.
Schroeder DV (2000). An Introduction to Thermal Physics. Boston, MA, USA: Addison Wesley Publishing Company, pp. 305–307.
Skelton S (2017). Viticulture - An introduction to commercial grape growing for wine production. London, UK: Publisher Stephen Skelton, pp. 98–106.
Smallwood MF, Calvert CM, Bowles DJ (1999). Regulation of phenylpropanoid and flavonoid biosynthesis genes by UV-B in Arabidopsis. Plant responses to environmental stress., Oxford, England, UK: Bios Scientific Publishers Ltd, pp. 77–81.

Smithers R (2017).French champagne house Taittinger plants first vines in English soil. The Guardian 2017: May. https://www.theguardian.com/business/2017/may/07/champagne-taittinger-plants-first-vines-english-soil-sparkling-wine.

Soil Survey Staff (1999). Soil Taxonomy: A Basic System of Soil Classification for Making and Interpreting Soil Surveys. Agricultural Handbook No. 436*.* 2nd edn. Washington DC, Natural Resources Conservation Service, United States Department of Agriculture, pp. 112–113.

Solantie R (2010). Helmikuun lumipeitteen paksuus oli 73 cm. Helmikuun lumioloista Helsingin seudulla. Ilmatieteen laitos. Ilmastokatsaus 2:4

St. JodernKellerei - hoechsterWeinberg Europas (2013).

Availablefrom: http//:www.jodernkellerei.ch/content/hoechster_weinberg _europas.htlm.

Stock M, Gerstengarbe FV, Kartschall T, Werner PC (2005). Reliability of climate change impact assessments for viticulture. Acta Hortic. 689:29–39.

Sölva J (1970). Abdeckenmit Plastikfolienim Weinbau. Schweiz. Ztschr. f. Obst u. Weinbau(2)7:37. https://www.cabdirect.org/cabdirect/abstract/19729303403.

Tietäväinen H, Tuomenvirta H, Venäläinen A (2010). Annual and seasonal mean temperatures in Finland during the last 160 years based on gridded temperature data. International J. Climatol. 30(15): 2251–2254, Doi: 10.1002/joc.2046.

Todic S, Beslic Z, Vajuc A, Tesic T (2008). The effect of reflective plastic foils on berry quality of Cabernet Souvignon. Bulletin de IÓIV 81:165–170.

Tornietto J, Carbonneau A (2004). A multicriteria climate classification system for grape-growing regions worldwide. Agric. For. Meteorol. 124(1-2):81–97.

Vaidyanathan G (2016). Did Global Warming Slow Down in the 2000s, or Not? Scientific American, February 2016.

Valais Switzerland's vinous pleasures (2013).

Yangyang X, Veerabhadran R (2017). Well below 2°C: Mitigation strategies for avoiding dangerous to catastrophic climate changes. Proceedings of the National Academy of Science of the United States of America, Doi: 10.1073/pnas.1618481114.

Yaschenko T (2006). Byisk, Altai, Russia–varieties.Proceedings of the 1st International Conference of Grape growing and Winemaking in Northern Regions. November 9–11, 2006, LatvijasVinkopju un Vindaru Biedriba, Jurmala, Latvija, pp. 13–14.

Zhang T (2005). Influence of the seasonal snow cover on the ground thermal regime: an overview. Rev. Geophys. 43(4): RG4002.Doi:10.1029/2004RG000157.

Zhang Y, Ping J, Wang W, Sun Z, Wang Z (2007). Comparison of different soil-burry methods on the over-wintering of wine grape cultivars in Ningxia Autonomous Region. J. Fruit Sci. 04: 8–9.

Zeiz G, Foppa N (2007). National Climate Observing system (GCOS Switzerland), Publication of the Federal Office of Meteorology and Climatology MeteoSwiss and ProClim, pp. 31–92.

Zorida EA (2012). Basic introduction to climate modelling and its uncertainties. Climate Impacts on the Baltic Sea: From Science to Policy. Berlin-Heidelberg: Springer Earth System Sciences, pp. 105–129.