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The Impact of Climate and Soil Temperature Warming on Viticulture in Southern Finland, The Baltic Sea Region, and a Few Regions in Central Europe

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ABSTRACT

The aim of this study was to explore the current wine-growing possibilities in the Helsinki region in southernmost Finland along with Sweden, Norway, Denmark, and elsewhere in the Baltic Sea Region, referring to observations made in a few regions in Central Europe, and how predicted climate change will affect them. In the research, the changes of climate and soil temperatures were monitored using different temperature measurement methods in several localities in the Baltic Sea region during one growth cycle of vines and during several years. The results were compared both with each other and with the corresponding temperatures of a few Central European localities. Based on the results, the rise in climate temperature has increased the possibility to grow grapevines in open land in southern Finland and in the Baltic Sea region. In long-term monitoring, the annual averages of air temperatures have risen, many viticultural indices have been near the current Central European indices, the growing seasons have significantly increased in the length, the vines' growth cycle has accelerated, and the soil temperature classification has changed from the colder 'frigid' to the warmer 'mesic'.

Keywords: climate warming, cool climate viticulture, soil temperature, growing season, Baltic Sea Region

ABBREVIATIONS AND EXPLANATIONS

°Bx or °Brix	Degrees Brix = sugar content measurements in aqueous solution
°Brix18%	Sugar content 180g/litre
E–L no	Eichhorn–Lorenz phenological stages 01–38
FMI	Finnish Meteorological Institute
frigid and cryic	soil temperature regimes are associated with the cold and cool climate conditions of high latitudes or high mountain zones (most of Nordic countries)
mesic	soil temperature regime is associated with the temperate climate conditions (Central Europe)
GDD	Growing degree day; °C·d (5°C basis) or (10°C basis)
GS	Growing season i.e., sum of days, when the average temperature of 24 hours is above 5°C for at least five days in row
IPCC	Intergovernmental Panel on Climate Change
scenario	Climate scenarios paint different pictures of the future and help estimate how the climate would change in the future

e.g. RCP2.6-scenario	Zero emissions after 2070, so that warming does not exceed 2°C pre-industrial levels

CLIMATE CHANGE AND GRAPEVINE GROWING IN THE SOUTHERNMOST FINLAND

Introduction

The increasing levels of greenhouse gasses have caused the raise of earth's surface temperatures in the world. During the past 100 years, the annual mean air temperature in the southernmost parts of Finland (60°N; 24°E) has risen by 1°C (1). The current ever-increasing usage of fossil fuels has increased the global carbon dioxide concentration which has accelerated global warming together with the increase in the water vapour concentration in the air caused by this warming (2). According to the Rosby Centre's regional climate model, these greenhouse gases are predicted to raise the mean yearly temperatures of the Northern European climate by +4 °C by the year 2100. This increases in temperatures at its greatest during the winter months (3). The scenarios of the IPCC (Intergovernmental Panel on Climate Change) for the years from 1996 to 2013 predict similar changes if carbon-dioxide emissions are not greatly reduced.



Picture 1. Finland, Helsinki, and Baltic Sea Region

In Finland, a warming of the climate has been detectable since the years 1971–2000 as an increase in the annual mean air temperatures and an extension of growing season (4). At the same time, there has been a significant increase in temperature sums of growing degree days +5 °C and +10 °C (5). This has introduced to the southern regions of Finland and the other Nordic countries some new cultivated plant species for experimentation, such as corn and grapevine. In these regions, interest towards wine growing has increased year by year. The total

wine growing area in the Nordic Countries is estimated to be 300 to 500 hectares. Sweden and Denmark are already listed as EU wine-producing countries, and in Finland will also become a wine-producing country in the coming years.

The purpose of this study was to examine how much the climate and grapevine growing conditions, start of growth, and harvest ripening in Helsinki region differ from the growing conditions and growth cycle in Central Europe at the present time.

Material and Methods

The study was undertaken in three locations in Central and in one location in Northern Europe (Table 1). It studied the changes in the climatic temperature and growing season length in the Helsinki region over the past 15 years.

Table 1: Observation locations and grape varieties

Community	Country	Above sea level, m	Distance to Herrlisheim-pres-Colmar, km	Grape variety
Herrlisheim-pres-Colmar	France	240	0	Pinot Noir
Freyburg, Unstrut	Germany	110	360	Regent
Neubrandenburg	Germany	53	550	Regent
Helsinki region	Finland	63	1360	Rondo

In addition, a comparison was made of the air and soil temperatures in the Helsinki region from May to October with the temperatures of the three Central European areas, and the development of grapevine sprouts and blossoms was observed in these areas based on phenological observations (12 leaves separated, inflorescence well developed, single flowers separated; E-L number 17) (6). and harvest maturing was observed by measuring total grape sugar concentrations. Observations on air temperatures were based on the statistical data of the Finnish Meteorological Institute and Meteorological Servis Foreca (www.foreca.com). Soil temperature measurements were taken at depths of 20 cm and 40 cm using digital thermometers that recorded maximum and minimum temperatures (Waterproof In-Out Door Max-Min Thermometer with Hygrometer, Shenzhen Hong Tong Yuan Technology Ltd, China, Shenzhen). The total sugar content of the grapes (°Bx) was measured using a Brix refractometer (HR-180, Optika, Ponteranica, Italy). A statistical treatment was completed with a t-test:

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

As part of the t-test, $\bar{X}$ was the mean value of the variables, and $\bar{Y}$ was the mean value of the other variables, and V an estimate of the variance of random error. $P<0.05$ was used to estimate statistical significance.

Results and Discussion

The average temperature of the globe varies yearly approximately by a tenth of a degree. Disregarding this variation, the average temperature of the Earth has risen since 1880s approximately by 0.85 °C (7). This has occurred in the northern parts of the Europe as well. The

temperature of the Finnish climate over an observation period of 160 years has increased in the 21st century by 0.6 °C in comparison to the mean of 160 years, and this increase has been most obvious during spring (7). Tables 2 and 3 show that the yearly averages of the temperatures of the ten-year periods between 1971 to 2010 have constantly risen, and that the temperature averages of single years during the last ten-year period (2005 to 2014) have risen by 1.1°C in comparison to the average of years 1971 to 2000; this supports the results published by Tuomenvirta (8).

Finland is the northernmost agricultural country in the world, and due to its northern location, average temperatures in Finland vary more from one year and one decade to the next, than the global average temperatures. One reason for this is the low-pressure variations coming from the North Atlantic. The low-pressure areas that come to Finland via the northern route will raise the yearly temperature, but the low pressures arriving to the southern parts are replaced by easterly winds bringing cold air, which cause the temperature to drop (7). The noticeable increase by 1.1 °C in the Table 3 was apparently caused by a large deviation and was not statistically significant (P>0.05).

Table 2: Mean values of air temperature in the Helsinki region over a 40-year period (1971-2010) and the 10-year period (2005—2014)

Periods of ten years 1971–2010	Mean air temperatures (°C)	Years 2005–2014	Mean air temperatures (°C)
1971-1980	5.0	2005	6.6
1981-1990	5.3	2006	6.7
1991-2000	5.4	2007	7.0
2001-2010	6.0	2008	7.6
2011-2020	6.5[1)]	2009	6.2
2021-2030	6.8[1)]	2010	5.1
2031-2040	7.2[1)]	2011	7.2
2041-2050	7.5[1)]	2012	6.2
2070-2080	8.0[1)]	2013	6.6
2090-2100	8.8[1)]	2014	7.4

[1)]predicted mean air temperatures

The temperature of the Finnish climate is predicted to rise by 2 °C by the year 2050, and by 3 °C by the year 2080, at the same time as rainfall increases up to 30% (8, 9). Such a significant warming of the climate will allow for the profitable cultivation of plants thriving in mild climates, such as the grapevine, in southern Finland. Even today, a few hybrid vines will have time to ripen well in the Helsinki area (10). Should the yearly average temperature of southern Finnish climate rise 2 °C by the year 2050, the yearly mean temperature of the Helsinki region will reach 8 °C to 9 °C in 40 years, i.e., close to the temperatures of the current wine growing regions of Central Europe. Then it will be possible to grow regular fast ripening varieties, such as Chardonnay and Pinot noir (11). In the new growth condition, - thanks to the long day, humus-rich soil, and sufficient rainfall - the grapevine could produce even more abundant and superior quality crops than in the current wine-growing areas, where heat and drought would, according to forecasts, increase and hamper farming.

Table 3: Changes of air temperatures and lengths of growing seasons in the Helsinki region during the ten-year period (2005—2014) compared to the 30-year period (1971—2000)

Mean air temperature 1971–2000; 5.6±0.4 (°C)	Mean air temperature 2005–2014; 6.7±0.7 (°C)	Difference of mean values; 1.1 (°C)	Statistical significance t=1.5607; P>0.05
Mean length of growing season 2005 - 2014	Mean length of growing season 1971 - 2000	Diffference of mean values	Statistical significance
198±18days	171±15 days	27 days	t=5.5214; P<0.05

In this study, the lengthening of the growing season in the Helsinki region was demonstrated more clearly than the increase in climatic temperature. In comparison to the lengths of the growing seasons between 1971 and 2000, the growing periods' mean values during the past ten-year period have lengthened by 27 days, which is statistically significant (P<0.05). The lengthening of the growing period has manifested itself in earlier springs (7). According to Bauer (12), the grapevine requires, depending on variety, a growing season of approximately 200 days. Table 3 shows that the mean growing season length in the Helsinki region has been 198 days in the years 2005 to 2014, in 6 of these years it has been over 200 days (5), which should suffice for cultivating some Central-European *Vitis vinifera* -varieties.

Table 4: Mean monthly air temperatures.

Locality	May	June	July	August	September	October
Helsinki	10.9±4.2	13.9±4.6	19.8±3.0	17.2±3.9	12.1±3.3	5.7±4.3
Herrlesheim	14.3±2.9	18.6±3.2	20.2±2.5	17.7±2.7	15.1±2.4	12.5±2.9
Freyburg	12.5±3.6	16.6±4.1	20.0±2.8	16.9±2.9	15.8±2.6	12.6±2.8
Neubrandenburg	12.1±3.4	15.7±3.1	20.0±2.6	16.7±2.9	15.1±2.4	11.6±2.6

Tables 4 and 5 compare the six-month temperatures of the Helsinki region growing season to the temperatures of the three Central European comparison regions. It shows that the mean monthly temperatures in July and August in the Helsinki region are statistically not significantly different from those of the comparison regions (*P*>0.05). During other months, the differences between the temperatures of the Helsinki region and other regions are statistically significant, except for northern Neubrandenburg, where wine growing is being restarted. In 2014, June was exceptionally cold in southern Finland, but July and August were sweltering, as usual. During July and August, there were 44 days of hot weather, when the highest temperature of the day exceeded 25 °C and of which in 22 days temperatures exceeded 35 °C (13).

Taulukko 5: Statistical significance of mean air temperatures between localities during three midsummer months

Month	n	Helsinki ><Herrlisheim	Helsinki><Freyburg	Helsinki><Neubrandenburg
June	30	t=4.5988; *P*<0.05	t=2.4107; P<0.05	t=1.7822; P>0.05
July	31	t=0.5714; *P*>0.05	t=0.2702; P>0.05	t=0.2857; P>0.05
August	31	t=0.6849; *P*>0.05	t=0.3448; P>0.05	t=0.6579; P>0.05

In late May, early June of 2014 (25 May to 3 June), soil temperatures measured in Herrlisheim-prés-Colmar at depths of 20 cm and 40 cm were at least 2.5 °C higher than in other regions, due

to the earlier spring and shorter duration or lacking snow coverage. Moving northward, the temperatures of soil were lower due to the later than usual spring and warming of air temperature. In Helsinki region, the soil temperatures were clearly lower, even on 3 June than in other regions. Compared with the soil temperatures in Neubrandenburg, the differences at 20 cm and 40 cm depths were clearly the lowest as compared with others, *i.e.,* 0.6 °C to 1.2 °C (Table 6).

Table 6: Mean soil temperatures at the depths of 20 cm and 40 cm, grapevine grow sugar content of grapes (°Bx) and measurement dates.

Locality	Depthof 20 (cm); (°C)	Depth of 40 (cm);(°C)	Dates for temperatures	Eichhorn-Lorenz: 17	(°Bx)	Dates for (°Bx)
Helsinki	13.6	12.0	3 June	4 June	16.6±0.5	2 October
Herrlisheim	17.0	16.6	25 May	26 May	17.9±1.0	7 September
Freyburg	14.5	13.8	30 May	1 June	13.1±0.8	9 September
Neubrandenburg	14.2	13.2	1 June	1 June	13.0±1.3	9 September

Grapevine growth stage (6), which is equivalent to the BBCH scale 55 (14), was reached in the Helsinki region 9 days later than in Herrlisheim-prés-Colmar, and just 3 days later than in Freyburg and Neubrandenburg. Although during the vines' sprouting and inflorescence stages producing red wine grapes the regional differences were only 3 to 7 days, at the harvesting stage they were several weeks, based on the grape total sugar level (°Bx), this may be due at least in part to both climatic differences and different grape varieties (Tables 1 and 6). Based on observations, only a 3 to 4 days late blooming in the spring may delay even during a normal summer the ripening and harvesting of the grapes by 1 to 2 weeks in the autumn. During colder than usual summers, ripening of grapes may be delayed to even later date.

During the last 40 years, the temperatures of the Helsinki region have risen over 1 °C which is the equivalent of a lengthening of the growing season by 10 to 11 days (2). The temperature increase has been most obvious during the past 10 years. By the end of the century, and with the realisation of the IPCC A1B scenario, thermal growing seasons will get longer during the autumn and spring in the whole of Finland by a total of 35 to 40 days (9, 15). When at the same time snow coverage will diminish, the climates of southern parts of Finland and the other Nordic countries will change to resemble the current climate in central Europe (16).

CHANGES IN THE GRAPEVINE'S GROWTH CYCLE IN SOUTHERN FINLAND IN THE 2000S – COMPARISON BETWEEN TWO FIRST DECADES

Introduction

In recent decades, rising climate temperatures in the Northern hemisphere have advanced the spring and the start of plant growth (17). The average air temperature in Southern Finland has risen more than 2 °C between 1847 and 2013, which corresponds to an increase of 0.14 °C for each decade. Since 1960, the rise in air temperature has been faster than ever before and has occurred especially in November, December, and January (1). This has occurred as an earlier bud break and the start of flowering of the trees in the boreal zone. Between 1846 and 2005, they have occurred 3.3–11 days earlier per a hundred year (18). The global warming that has occurred and its predicted continuation will bring new plant and animal species and crops to

the north. Of these, the grapevine has already gained a good foothold in Denmark (19) and Swedish Skåne and is conquering Southern Norway and Southern Finland. Southern Finland, like all southern parts of Northern Europe, belongs to the cool-cold winegrowing area (20, 21, 22). According to the Huglin indices, only two very early ripening Vitis vinifera varieties can be grown to harvest-ripe in these areas (21). Instead, there are dozens of suitable hybrid varieties and new hybrid varieties are breeding continuously (23). The number of suitable Vitis vinifera varieties has also increased; Pinot Noir, Leon Millot, Madelaine Royal, and Rondo have thrived in the 2010s at 61° latitudes, and Rondo has become the most grown grapevine variety in Northern Europe. According to the Finnish Meteorological Institute, the temperature of the Finnish climate has risen by 0.2 °C every decade over the last 40 years (24), which, if continued, would increase the number of suitable *Vitis vinifera* -varieties and would move grapevine cultivation farther north. The purpose of this study was to find out how much the air temperature of the Helsinki region (60°N, 24°E) has risen and how the grapevine growth cycle has changed since the beginning of 2000 for two consecutive decades.

Material and Methods

The study was conducted in a vineyard located in the Helsinki region (60°24'N, 25°01'E) in Southern Finland. It compared the annual averages of climate temperatures and the lengths of growing seasons over the past decade (2010–2019) with the first decade (2000– 2009) of the 2000s. The average annual air temperatures and lengths of the growing seasons were based on the weather statistics of the Finnish Meteorological Institute. The bud burst and harvest-ripe berries of the monitored *Vitis vinifera* variety Rondo were based on the Eichhorn-Lorenz phenological stages (6). The sugar concentration of the grapes at harvest measured by the Brix refractometer was 18%. The statistical treatment was compiled with a paired t-test, where $P<0.05$ was used to estimate statistical significance.

Results and Discussion

During the 160-year monitoring of the Finnish climate, the climate has warmed by 0.6 °C since the beginning of the 2000s compared with the 160-year average (1), which indicates an accelerated rising of the climate temperature. The study evaluated the first two decades of the millennium and found that the temperature in the Helsinki region increased by 0.4 °C during the latter 10-year period (2010–2019) compared to the previous 10-year period (2000–2009) (Table 7). Compared to the results of Tietäväinen (1), this increase was more than twice higher per decade. It is also noteworthy that during 2010–2019, the average annual temperature of the climate exceeded seven times 7 °C and was close to 8 °C in 2015 (Table 7).

Table 7: Comparison of annual average air temperatures between 2000—2009 and 2010—2019

Year	Annual average air temperature °C	Year	Annual average air temperature °C
2000	7.2	2010	5.0
2001	5.9	2011	7.2
2002	6.1	2012	7.0
2003	5.6	2013	7.0
2004	6.2	2014	7.3
2005	6.6	2015	7.8

2006	6.7	2016	6.6
2007	7.0	2017	6.6
2008	7.8	2018	7.3
2009	6.2	2019	7.0
X̄ ±SD	6.5 ± 0.7		6.9 ± 0.7
Median	6.4		7.0

Statistical difference between averages: t =1.06851, *P*> 0.05

The climate of northern Europe is characterized by warm summer months with mild temperature fluctuations; winter months are cold with unstable temperatures with extreme fluctuations. Due to the cold winter months, the annual average air temperatures in the Helsinki region remain below 9 °C, which is considered one of the preconditions for the success of Vitis vinifera (25). In cool wine growing areas, an increase in temperature by 1 °C has been calculated to extend the growing season by 11 days (26), but in warm and hot areas, a rise in climate temperature may lead to a shorter growing season (27). In this study, the average growing season during 2010-2019 was only 1 day longer than the average for 2010-2009. Based on the median value, the lengthening of the growing season was more distinct (Table 8). There were large fluctuations of almost two months in the lengths of growing seasons during both periods. Therefore, there cannot be statistically significant differences over these short 10-year time periods. In addition, it has been stated that, between the lengths of the growing seasons and changes in climate temperatures, the correlation is poor (5).

Table 8: Comparison of lengths of growing seasons between two consecutive decades, average air temperature above 5 °C

Start and end dates of growing seasons	Year	Length of growing seasons, days	Year	Start and end dates of growing seasons	Length of growing seasons, days
21 Apr -20 Oct	2000	177	2010	10 Apr - 4 Nov	209
22 Apr -19 Oct	2001	175	2011	4 Apr - 8 Nov	208
10 Apr -2 Oct	2002	176	2012	21 Apr - 21Oct	185
16 Apr -14 Oct	2003	182	2013	23 Apr -13 Oct	176
15 Apr -27 Oct	2004	196	2014	17 Apr -14 Oct	182
13 Apr -15 Nov	2005	217	2015	8 Apr -5 Oct	191
22 Apr -27 Oct	2006	189	2016	6 Apr - 24 Oct	194
11 Apr -1 Nov	2007	205	2017	1 May -18 Oct	174
1 Apr -15 Nov	2008	229	2018	14 Apr -17 Nov	221
23 Apr -8 Oct	2009	169	2019	16 Apr - 28 Oct	195
X̄ ± SD		192 ± 20			193 ± 15
Median		186			191

Statistical difference between averages: t = 0.53453, *P*> 0.05

Only a rise in temperature of 1 °C over the next decades might result a clear prolongation of the growing season. The budburst of the grapevine is depending on the geographical location and elevation of the vineyard, local microclimate, and grape variety. In temperate zones of the Northern hemisphere, the vine buds break out between March and April (25). The budburst is also strongly dependent on the soil temperature (28). Therefore, in the cool and cold Northern

wine growing areas the buds do not break out until the soil temperature is over 7 °C in the depth of 40 cm (10). The budburst at the end of May also reduces the risk of the late frost. In this study, the budburst of *Vitis vinifera* Rondo was latest on 21 May. There were no significant differences between the average dates of budburst between the decades (2000–2009) and 2010–2019 (Table 9).

Table 9: Number of days before bud break after 30 April (E-L No 5)

Year	Number of days	Year	Number of days
2000	11	2010	11
2001	12	2011	8
2002	1	2012	9
2003	16	2013	14
2004	2	2014	13
2005	6	2015	15
2006	12	2016	11
2007	11	2017	21
2008	14	2018	11
2009	12	2019	8
$\bar{x}$ ±SD	10 ± 5	$\bar{x}$ ±SD	12 ± 4
Mean	12	Mean	11

Statistical difference between averages: t = 0.53453, $P > 0.05$

At the start of the grape harvest and growth cycle of grapes, there have always been big interannual variations, even in the same locality. Garnier et al. (29) investigated the beginning date of harvest from 1525 to 1847 in Besancon (France), and during that period, the interannual beginning of the harvest had fluctuated 66 days as a consequence of wars and years with an exceptional climate. After that, climate warming has promoted the grapes to harvest. During the last 40-year period (1975–2014), the grape harvest of Vitis vinifera varieties had advanced in South-western Germany by 26–27 days 17 (28). In the conducted study containing two consecutive decades, the onset of the grape harvest was reduced by 6 days, indicating a statistically significant earlier harvest ($P<0.05$). The biggest difference between the years was 21 days. In 2018 and 2019, grapes were harvested ripe already in the first week of September. From the results, it can be concluded that the grape harvest moved almost one week earlier as a consequence of climate warming in the cool climate of the Helsinki region (Table 10).

Table 10: Number of days before start of harvest after 31 August (E-L No 38)

Year	Number of days		Number of days
2000	27	2010	28
2001	31 (1 Oct)	2011	19
2002	14	2012	30
2003	22	2013	14
2004	36 (6 Oct)	2014	19
2005	30	2015	28
2006	19	2016	9
2007	18	2017	28

2008	31(1 Oct)	2018	8
2009	22	2019	7
X̄ ±SD	25 ± 7		19 ± 9
Median	24.5		19

Statistical difference between averages: t = 4.74345, *P*< 0.05

In Northern European cool climates, the growth cycle of the grapevine from the flowering to the harvest has been reported to last 100 days (30). However, it is influenced by the local climate, the temperature sum of growing season and the selection of grape variety (21).

Table 11: Comparison between the lengths of grapevine growth cycles from bud burst to harvest over two decades.

Year	Length of growth cycles days	Year	Length of growth cycles days
2000	144	2010	140
2001	142	2011	134
2002	139	2012	142
2003	127	2013	116
2004	157	2014	126
2005	147	2015	133
2006	130	2016	117
2007	130	2017	128
2008	140	2018	116
2009	133	2019	120
X̄ ±SD	139 ± 9	X̄ ±SD	128 ± 9
Median	140	Median	127

Statistical difference between averages: t= 8.19916, *P*< 0.05

According to Table 11, the growth cycle of the Vitis vinifera cultivar Vitis 'Rondo' from bud burst (E-L 5) to harvest (E-L 38 and ^{o}Brix18%) had declined during the second decade by an average of 11 days and a median of about 13 days. The difference is statistically significant (*P*<0.05) and is related to the significant earlier start of harvesting, which might have been promoted by the climate warming by 0.4 °C during the 10-year period. Due to the shortened growth cycle, it can be concluded that the period from the flowering to the harvest has been shortened to less than 100 days (30).

CASE REPORT: THE EFFECT OF A WARM SUMMER 2018 ON GRAPEVINE GROWTH IN SOUTHERN FINLAND

Introduction

The climate warming in the Northern Hemisphere has advanced the spring and starts the growth of plant (17). In Europe, this will influence the choice of agricultural crop varieties and crop rotation and move wine growing more to the north than the current latitude 50º north. In southern Finland, climate warming has occurred, as felt in several warm summers compared to long term averages (26). It has increased interest in wine growing in Finland up to the latitude 63° north. During warm summers, the effective temperature sums for the growing season and soil temperatures have risen while growing seasons have lengthened, which has

appeared as earlier bud break and harvest. Throughout Northern Europe, summer 2018 was exceptionally warm and long. According to the weather statistics of the Finnish Meteorological Institute (31), the Finnish summer heat record of 33.7 °C was measured on July 18, and the air temperature exceeded 25 °C on 40 days in July and August. The aim of the study was to point out how exceptional the summer 2018 was in southern Finland and how much the high temperatures of the 2018 growing season in the Helsinki region differed from the long-term averages and what effect the temperatures had on the growth cycle of grapevines.

Material and Methods

Indexes, air temperatures, and length of growing seasons based on the weather statistics of the Finnish Meteorological Institute from 1952–2018, and growth stages of the grapevines *Vitis vinifera* Rondo and Zilga based on phenological growth stages of the grapevine according to Eichhorn-Lorenz (6) and on the author's notes from years 2002–2018.

Results

In 2018, the Huglin Index was 90% and the Amerine-Winkler Index 47% higher. The growing season was over three weeks longer than the average of the years 1952–2018. Also, the average annual temperature of the climates, the average temperature of the growing season, the number of warm days over 10 °C, and the Hydrothermal Index exceeded the averages of the years 1952–2017.

Table 12: Grapevine growth indexes and air temperatures in 2018 and the average of the years 1952–2017 in Tuusula vineyard in the Helsinki region

Indexes	Tuusula 2018	Tuusula 1952–2017
Huglin Index	1521	801
Amerine-Winkler Index	904	616
Averageannual air temperature, °C	6.7	5.7
Growingseason's average temperature. °C	14.8	11.7
Growingseason, precipitation	258 mm	336 mm
Hydrothermal Index (HyI)	14.8°C x 258 mm = 3818°C mm	11.4°C x 336 mm = 3830°Cmm
Length of growing season	191 vrk (5°Cvrk)	168 vrk (5°Cvrk)
Number of days T over 10°C	142	114

In 2018, the budburst began (Eichhorn-Lorenz 5) on May 7, fruit setting (Eichhorn-Lorentz 27-29) was on July 5 and harvesting (Eichhorn-Lorenz 38) started on September 8, when the degree °Brix was 18–20%. The time periods between beginning of budburst and fruit setting, and between fruit setting and harvest, were shortened; total growth circulation from the beginning of budburst to the start of harvest was shortened in 2018 by almost two weeks compared to the average of the years 2002–2017.

Discussion

Finland's average annual air temperature rose by 2.3°C country-wide between the years 1847 and 2013 (24) is forecast to rise by 0.4 °C/decade (33). In the Helsinki region in southern Finland (60°N, 25°E), the warming air temperature has been most noticeable from November

to January and in spring from March to May. The air temperature in winter months is forecast to rise by 2–7 °C during the years 2040–2069 compared to the average from 1981 to 2010 (32**)**. This forecast raises the temperature in southern Finland to the level of existing central European wine-growing regions. During long-term follow-up between 1952 and 2000, the average annual air temperature exceeded 7°C only once, but between 2000 and 2018 it exceeded 7 °C six times. Summer 2018 was exceptionally warm. The average air temperature (15.3°C) in May was 4.9 °C higher than the previous 30-year period, and the average air temperature (21.2 °C) in the warmest month, July, was 3.5 °C higher than the average of that period **(26)**. Also, in Denmark's wine-growing locations were measured temperature records. In June, July, and August, the average air temperature was 17.7 °C, while the average air temperature in July was 19.2 °C, 3.6 °C above the long-term average (33). According to the climate classification indexes of Amerine-Winkler (20, 21), and Tornietto and Carbonneau (34) for grape-growing regions, the Helsinki region belongs to a cold climate region. The cold climate region refers to the extreme areas of a cool climate region, where early ripening hybrid varieties and suitable *Vitis vinifera* -varieties can be grown. The warm summer and long growing season of 2018 would also have allowed the farming of many *Vitis vinifera* -varieties such as Gewürtztraminer, Riesling, or Pinot Blanc in cold climate regions. Since 2000, summers almost as warm as in 2018 have become more frequent (5). They accelerate the growth cycle and as a result several purer *Vitis vinifera* -varieties can be grown.

SOIL TEMPERATURE AND OUTDOOR VITICULTURE IN SOUTHERN FINLAND

Introduction

Grapevine growing in greenhouses has been practiced in Finland over 200 years (35). Therefore, the grapevine is not any newcomer in Finnish gardens. The grapes grown in greenhouses have been used for decorations on festive tables or eaten as such, but not been used for vine making. In 1900s outdoor viticulture was also begun to experiment in Southern Finland at latitude below 63 ºN (36, 37). The grape varieties used for experiments survived well the cold of winter, but these varieties did not have enough time to ripen grapes during rather short boreal growing season. Grape breeding has since 1950s produced a lot of colder resistant and rapidly ripening new grape varieties as *Vitis vinifera* Rondo (http://wapedia.mobi/en/Rondo_(grape)), *Vitis vinifera* Siegerrebe (38) or *Vitis vinifera* Nordica (39), which are used for viticulture in Nordic Countries. These varieties could be used for outdoor viticulture and vine making in Southern Finland, too. Besides light, cultivation site, soil cultivation and air temperature, soil temperature in cultivation site has an important effect on grape growth and ripening of berries. The aim of this study was by measuring soil temperatures of grapevine cultivation site in Helsinki region in Tuusula and in some other sites planned for viticulture to estimate an optimal planting depth for grapevine in Southern Finland. The effect of changes in soil temperature on grapevine growth and development in a smaller vineyard in Tuusula was also monitored.

Material and Methods

Soil temperatures of the observation sites in Tuusula and Vehmersalmi were monitored round the year 2007 on earth´s surface at 0 cm and in soil at depths of 20 cm to 70 cm. The thermometers used for these purposes saved continuously into memory max/min soil

temperatures and they were registered weekly. In Juva and Jokioinen soil temperatures were based on the measurements performed by the Finnish Meteorological Institute.

In Tuusula the growing site was situated on a flat country surrounded by a high spruce hedge. This caused at the growing place unfavorable climatic conditions like a bottom of valley. In Vehmersalmi a measurement point of soil temperature was on a gentle slope facing to south and close to a larger lake. This place was more favorable for grape growing than the growing place in Tuusula notwithstanding its more northern situation. In Tuusula growth and development of a grape variety *Vitis vinifera* Nordica was followed and monitored throughout the growing season.

Results

The mean annual soil temperatures were less depending on the measurement depths at a depth of 20 cm and deeper until at a depth of 60 cm. Thereafter the mean soil temperatures distinctly increased. The lowest annual soil temperature at depths of a 20 cm until 50 cm remained at 0 ºC level or slightly below it. Deeper than 50 cm the lowest annual soil temperatures remained above 0 ºC (Table 13).

Table 13: Soil temperatures at different measurement localities in Finland. Soil temperatures were measured on the earth´s surface at a 0 cm and at depths of 20 cm to 70 cm below the soil surface.

Depth cm	Locality	Location	Mean ºC	Lowest annual temperature ºC
0	Tuusula [a]	60º41' N	8,1	-16,9
20	Tuusula [a]	"	6,8	-0,7
20	Jokioinen [b]	60º49' N	6,7	-1,6
20	Maaninka [b]	63º09' N	6,5	-0,8
40	Vehmersalmi [a]	62º52' N	7,4	0,2
50	Jokioinen [b]	60º49' N	6,7	-0,2
50	Maaninka [b]	63º09' N	6,5	0,0
60	Tuusula [a]	60º41' N	7,9	2,0
70	Tuusula [a]	"	8,8	2,7

The sources of the soil temperature data: a author´s data, b Finnish Meteorological Institute

Growth and development of grapevine was closely depending on changes in soil temperature during the growing season (Table 14).

Table 14: Growth and development of grapevine during changes of soil temperatures in Tuusula.

Dates	Observations	Lowest * soil temperature ºC	Highest * soil temperature ºC
May 2	No growth	0,1	6,1
May 12	Buds	5,9	6,7
May 22	Buds begin to break	7,6	8,3
June 5	Shoots begin to grow	6,4	9,1
June 11	Powerful shoots grow	8,1	9,1
June 13	Clusters are forming	8,5	10,2

June 30	Flowering of the vine	10,4	14,8
July 12	Flowering ends	13,0	16,2
September 16	The first frosty night	12,9	16,3
October 3	Harvesting ends	12,8	16,2
October 31	Dormancy of grapevine	8,4	11,3

* Lowest and highest temperatures were monitored during successive periods from May 2 until May 12, from May 22 until June 5, etc.

Discussion

In Central Europe soil temperatures in vineyard soils variate at a depth of 20 cm between +5 ºC and +6 ºC at their lowest in winter (40). In Southern Finland soil temperatures at the same depth are at lowest between -0,7 ºC and -1,6 ºC. Although in Central Europe it does not exist any peril of deep soil freezing the grapevines are planted to make sure at a depth of 40 cm. In boreal and hot climate grapevines are usually planted deeper than at a depth of 40 cm to protect plat roots for both too cold and too hot soil temperature. Mostly a planting depth of 50 cm is sufficient, but in extreme vine growing conditions as in Siberia and Inner Mongolia a planting depth can be even 100 cm (International Association for Northern Viticulture 2006).

In Northern Europe and Southern Finland is essential, that grapevine roots stay below soil freezing level in winter. A safe planting depth is very important therefore, that the severe frost does not injury the roots. In last few years the winters in Southern Finland have been mild. Long frost periods have not existed, and soil freezing has been just surficial or not at all (41). In Tuusula the lowest temperature on the earth´s surface was -16,1 ºC in 2007. The soil temperature fell at a depth of 20 cm to -0,7 ºC. These low and short-lasting surface and soil temperatures did not damage grapevines and their roots, but the plants began to grow normally in spring. Same timely soil temperature remained at a depth of 60 cm at 2 ºC.

The weeping and bud-break of grapevine began in Tuusula at soil temperatures +6 ºC to +8 ºC. These are the same vineyard soil temperatures, where weeping appears and buds begin to break in Central Europe (42a). In Southern Europe weeping and bud-break begins not until at a soil temperature of 10 ºC (42b). These can be caused by adaptation of same grape varieties to various climate and light differences between Southern and Central Europe. The climate of Central Europe is apparently closer to Northern Europe than Southern Europe. The grape growth continued until end of October, when the soil temperature was still 8.4 ºC to 11.3 ºC.

A COMPARISON OF VINEYARD SOIL TEMPERATURES AND GROWING CONDITIONS IN LOCALITIES IN SOUTHERN FINLAND, ESTONIA, LATVIA, AND CZECH REPUBLIC

Introduction

The outdoor cultivation of grapevines is expanding northwards. Its success depends on the temperature of the climate, the length of the growing season, and the temperature of the soil. The growing seasons of areas at the same altitude lengthen, and the soil grows warm earlier, as one moves south and west. This has been confirmed in studies by Värnik (43) and Koivisto (44), in which the Estonian (59°N), growing season is 3–4 days longer than in southernmost Finland (60°N). In Latvia (56°N), the growing season is 10–11 days, and in Central Europe (50°N) 3–4 weeks longer than in Southern Finland.

The length of the growing season is affected by the climate, air temperature, soil quality, and soil temperature. Air and soil temperatures are highly interdependent (45). Mokma & Sprecher (46) found that the mean annual ground temperature is 1°C higher than the climate mean for the year. As with climate, soils are classified into different categories. According to the U.S. Soil Taxonomy system (47), Finnish mineral agricultural soil belongs primarily to the 'cryic' temperature regime. The land is suitable for agricultural production, but its coldness limits the cultivation of crops such as corn and grapevines.

The area south of the 'cryic' regime belongs to the 'frigid' temperature regime, which includes lands south of the Gulf of Finland, as far as the latitude of Skåne. Of the Central European countries, a large proportion belong to a warmer 'mesic' soil temperature regime, but the mountainous areas used there for farming and grapevine cultivation also belong to the 'frigid' soil temperature regime. Yli-Halla et al. (48) considered whether the southernmost Finnish farmland belongs to the 'cryic' or 'frigid' regime and decided, by comparing Swedish and Finnish crop yields, that it still belongs within the 'cryic' regime.

The growing conditions can also be examined on the basis of vegetation zone division. According to the division of European vegetation zones, Finland's western and southern coasts belong to the temperate hemiboreal zone of deciduous and mixed forests (60–55ºN). Its climate is cooler than that of the temperate zone and the growing seasons are a little shorter. Southern Sweden, Southern Norway, and the Baltic states also belong to the hemiboreal zone (49). To its south is mainly deciduous forest and the temperate zone of broad-leaved deciduous trees, which is a traditional vine-growing area.

This study investigated the extent to which vineyard soil temperatures in Southern Finland (Tuusula 60°24'10''N, 25°01'45''E), Estonia (Pärnu 58°23'N, 24°30'E and Räpina 58°05'51''N, 27°27'54''E) and Latvia (Tervete 56°29'N, 23°25'E) differ from each other when measured at the same time, and how closely they correspond to the soil temperature regimes of the Soil Taxonomy system. In addition, five days of soil temperature measurements conducted in the vineyards of the Moravian wine region of the Czech Republic (49°13'59''N, 17°40'01''E), were used to evaluate the same time period within which the same soil temperature would be achieved in Southern Finland, Estonia and Latvia, and how great the difference might be between the growing seasons.

Material and Methods

Soil temperatures were recorded using temperature and humidity loggers (Thermo Button 21G, Proges-Plus, France) at the same time in Tuusula, Räpina, Pärnu and Tervete: from December 2009 to November 2010 in Tuusula (Southern Finland), Räpina. (Estonia), Pärnu (Estonia) and Tervete (Latvia), and from May 4 to 9 in Zlín in the Czech Republic. The loggers measured soil temperatures at one-minute intervals at depths of 25 cm and 45 cm, which they recorded to memory, from which the data were transferred for analysis to the Department of Applied Biology, Faculty of Agriculture and Forestry, University of Helsinki, Finland. At Zlín, soil temperature was measured using temperature sensors 25 cm below the surface (Waterproof In-Out Door Max-Min Thermometer with Hygrometer, Shenzhen Hong Tong Yuan Technology Ltd., Shenzhen, China), from which the maximum and minimum temperatures were saved to

the thermometer memory during the period 4–9 May 2010. Mean soil temperatures ($\bar{x}$) and standard deviations (*SD*) were calculated using an Excel spreadsheet. Two tailed TTEST (Student´s *t*-test) were used to estimate statistical significance (P = 0.05–0.001).

Results and Discussion

At Tuusula, Räpina, and Pärnu, soil temperatures at a depth of 25 cm remained at or above zero all winter. At this depth, ground temperatures at the locations, in degrees Celsius, differed only slightly until March, but the t-values were large and the differences statistically significant (P < 0.05–0.001). From April to August mean temperatures at 25 cm at Räpina and Pärnu were 3.4–3.5 °C higher than soil temperatures at Tuusula. This difference was considerable. The lowest temperatures were recorded in January, February, and March, and the highest in July. From September to November, the differences between the localities decreased, but the mean soil temperature at Tuusula was still significantly lower than at other locations (Table 15).

Table 15: Vineyard soil temperature changes at a depth of 25 cm in 2009–2010

	Tuusula		Räpina		Tuusula/Räpina		Pärnu		Tuusula/Pärnu	
	°C	*n*	°C	*n*	*t*	*P*	°C	*n*	*t*	*P*
Dec	1.6±0.9	124	1.5±1.7	124	0.058	>0.05	0.5±0.1	62	13.414	<0,001
Jan	0.5±0.0	124	0.0±0.0	124	-	-	1.0±0.1	124	55.679	<0.001
Feb	0.3±0.2	112	0.0±0.0	112	15.873	<0.001	0.0±0.0	112	15.873	<0.001
Mar	0.2±0.3	124	0.0±0.0	124	7.722	<0.001	1.0±0.1	124	28.268	<0.001
Apr	1.7±1.7	120	5.2±2.2	120	13.834	<0.001	5.1±1.3	120	17.347	<0.001
May	9.8±3.1	124	12.9±3.4	124	10.432	<0.001	10.9±3.2	124	2.794	<0.01
Jun	13.2±0.9	120	15.6±0.9	120	20.690	<0.001	13.6±1.1	120	2.985	<0.01
Jul	18.7±1.5	124	20.6±1.5	124	10.000	<0.001	19.1±1.6	124	2.174	<0.05
Aug	17.5±2.0	124	19.0±2.3	124	5.494	<0.001	17.7±1.9	124	0.806	>0.05
Sep	12.1±1.2	120	12.6±1.1	120	0.415	>0.05	12.4±1.1	120	2.113	<0.05
Oct	6.1±1.8	124	6.2±1.7	124	0.450	>0.05	6.6±1.1	124	2.762	<0.01
Nov	4.1±1.4	103	4.7±0.9	83	3.550	<0.001	6.3±3.1	29	3.667	<0.01

Mean soil temperatures in the summer months (June, July, and August) were slightly lower at a depth of 45 cm than at 25 cm (Table 16), and in the winter months of January, February and March mean temperatures at 45 cm remained at least 0.5°C higher than at 25 cm (Table 17). The marine climate of Pärnu may have kept the end of year temperatures higher than at other localities. Räpina, on the other hand, has a continental climate, with colder autumns and winters. Soil temperature differences for the winter months were statistically significant (P < 0.001). On this basis, the ground provides a good insulator against heat and cold. Forest fire studies have shown that even if the air temperature in a fire rises 815°C in 15 seconds, the temperature at a depth of 12 cm is 41ºC and at 25 cm it is 35ºC (50)

In the European boreal belt, at latitudes 60–63, the soil frost layer does not extend more than 40 cm below the surface (40), so most plants can survive there. The effect of the Gulf Stream means that in Finland and elsewhere in Northern Europe it is possible to cultivate plants that, in North America, are grown at latitudes 50–60 (51). In this study also, the soil temperature was maintained throughout the winter at zero degrees Celsius or above at depths of 25 cm and

45 cm. On this basis, soil temperature does not restrict the cultivation of suitable grapevine varieties in these areas. However, the short growing season and late spring mean that not all European grapevines can be made productive using outdoor cultivation.

In Southern Finland, planting depths of 40–45 cm can be considered safe for grapevines in normal winters. In addition, a thick layer of snow reduces the danger of frost damage to the vines, as the research of Zhang et al. (52) has shown. At this depth, the ground temperature in April is already so high (5–7°C) that the liquid circulation of the grapevines begins, at Räpina, Pärnu, and Tervete, at latest in the first half of the month and at Tuusula in the second half of the month.

Table 16: Vineyard soil temperature changes at a depth of 45 cm in 2009–2010

	Tuusula		Räpina		Tuusula/Räpina		Pärnu		Tuusula/Pärnu	
	°C	*n*	°C	*n*	*t*	*P*	°C	*n*	*t*	*P*
Dec	1.6±0.9	124	1.5±1.7	124	0.058	>0.05	0.5±0.1	62	13.414	<0,001
Jan	0.5±0.0	124	0.0±0.0	124	-	-	1.0±0.1	124	55.679	<0.001
Feb	0.3±0.2	112	0.0±0.0	112	15.873	<0.001	0.0±0.0	112	15.873	<0.001
Mar	0.2±0.3	124	0.0±0.0	124	7.722	<0.001	1.0±0.1	124	28.268	<0.001
Apr	1.7±1.7	120	5.2±2.2	120	13.834	<0.001	5.1±1.3	120	17.347	<0.001
May	9.8±3.1	124	12.9±3.4	124	10.432	<0.001	10.9±3.2	124	2.794	<0.01
Jun	13.2±0.9	120	15.6±0.9	120	20.690	<0.001	13.6±1.1	120	2.985	<0.01
Jul	18.7±1.5	124	20.6±1.5	124	10.000	<0.001	19.1±1.6	124	2.174	<0.05
Aug	17.5±2.0	124	19.0±2.3	124	5.494	<0.001	17.7±1.9	124	0.806	>0.05
Sep	12.1±1.2	120	12.6±1.1	120	0.415	>0.05	12.4±1.1	120	2.113	<0.05
Oct	6.1±1.8	124	6.2±1.7	124	0.450	>0.05	6.6±1.1	124	2.762	<0.01
Nov	4.1±1.4	103	4.7±0.9	83	3.550	<0.001	6.3±3.1	29	3.667	<0.01

Yli-Halla and Mokma (45) found soil temperatures averaging 9.3 °C from a depth of 50 cm at Jokioinen, Southern Finland (60°49'N, 23°30'E), and 6.4 ºC from the same depth at Anjala (60º41'N). They found mean soil temperatures of 0–8 ºC for the whole of Finland (48). These studies show that soil temperature differences may be considerable even in locations at the same latitude, but temperature differences are particularly large between the northernmost parts of Lapland and Southern Finland. The annual mean value of soil temperatures at Räpina, at a depth of 45 cm, was 1.4 °C higher than at Tuusula (Table 18). The north-south distance between the localities was 250 km (2.4° of latitude). Compared with the studies of Yli-Halla & Mokma (45), the soil temperature difference between Tuusula and Räpina was lower than between Jokioinen and Anjala, at the same latitude.

Table 17: Soil temperature differences between 25 and 45 cm depths for the three coldest months

Depth	25 cm		45 cm		Statistical significance	
Temperature	°C	*n*	°C	*n*	*t*	*P*
Tuusula						
Jan	0.5±0.0	124	1,4±0.2	123	50.11114	<0.001
Feb	0.3±0.2	112	1,0±0.0	111	37.03703	

Mar	0.2±0.3	124	1,0±0.0	123	29.73977	
Räpina						
Jan	0.0±0.0	124	1,4±0.2	123	77.7777	<0.001
Feb	0.0±0.0	112	1.0±0.0	111		
Mar	0.0±0.0	124	1.0±0.0	123		

It can be concluded that the success of the grapevine is affected, not only by the north-south or east-west geographical situation of the growth location, but also by the thermal conditions of the soil and the local climate.

Table 18: Soil temperature differences at depths of 25 and 45 cm in 2010

Depth	25 cm		45 cm		Statistical significance	
Temperature	°C	*n*	°C	*n*	*t*	*P*
Tuusula	7.2±6.8	1463	7.4±6.3	1460	0.8251	> 0.05
Räpinä	8.2±7.5	1463	8.8±6.9	1463	2.2556	< 0.01

Although climate and soil temperatures are strongly interdependent, there is a delay in the reaction of the land to rapid changes in air temperature. In contrast, a longer period of climate warming or cooling does raise or lower the soil temperature. Table 19 compares May soil temperatures from the Central European city of Zlín (49°13'59''N, 17°41'01''E, altitude 250 m), with three research localities. Zlín belongs to the Moravian wine-growing region in the Czech Republic. There, the soil temperature for 4–9 May was 13.0 ± 0.8 °C. At the same time, the soil temperatures at Tuusula, Räpina and Pärnu were half of that, and they reached the Zlín soil temperatures only 10–12 days later.

Table 19: Soil temperature differences at a depth of 25 cm by locality.

Locality	4–9 May temperature °C	*n*	Temperature 13.0±0.8 °C	Difference in days
Zlin	13.0±0.8	6	4–9 May	-
Tuusula	6.0±0.5	6	16–21 May	12
Räpinä	6.0±0.5	6	16–21 May	12
Pärnu	7.0±0.5	6	14–19 May	10

There appears to be a connection between the soil's storage of heat and the length of the growing season. In this study, soil temperatures in the southernmost location, Tervete, during the months of the growing season and throughout the year, were higher than in the northern locations; in other words, soil temperature rose, and the growing season became longer as one moved south. According to Rötzer & Chmielewski (53), the growing season is extended 2.4 days 100 km^{-1} moving from north to south, and 0.7 days 100 km^{-1} moving from east to west. On this basis, the growing seasons in Pärnu and Räpina should be 5–6 days longer and in Tervete 10–11 days longer than in Tuusula. Värnik (43) and Koivisto (44) came to a similar conclusion. The soil temperatures at the Tuusula vineyard in Southern Finland, at both 25 cm and 45 cm depth, were lower than at Räpina and Pärnu in Estonia, and at Tervete in Latvia, in the winter of 2009–2010. The mean soil temperature at Tuusula in April was 3.4–4.1 °C lower than at Räpina, Pärnu and Tervete, showing that growing seasons in Southern Finland and the Baltic states differ most in the spring. Thereafter, the differences were small, although still statistically significant. The

soil temperature at Tuusula still fits the lower 'cryic' temperature regime for arable land while Räpina, Pärnu and Tervete fit the warmer 'frigid' temperature regime; however, some areas in the southernmost part of Finland might also be termed 'frigid'. In May, soil temperatures in Tuusula, Räpina and Pärnu were 6–7 °C lower than in Zlín, in the Czech Republic, while the same soil temperature was not reached, in the former locations, until 10–12 days later. This also corresponds to differences between the spring growing seasons.

HOW SOIL TEMPERATURE REGIMES CHANGE IN SOUTHERN FINLAND AS THE CLIMATE WARMS

Introduction

The two criteria that define soil temperature regimes are the mean annual soil temperature and temperature difference, which are mean summer soil temperatures of June, July, and August compared with the mean winter soil temperatures of December, January, and February. In the cryic regime, the mean annual soil temperature at a depth of 50 cm from the soil surface is higher than 0 °C but lower than 8 °C, and the average summer temperature rises to 15 °C (48). The frigid temperature regime also has an average annual temperature of up to 8 °C, but the difference between the mean summer, and the mean winter soil temperatures is more than 6 °C, and the average summer temperature is at least 15 °C. In the mesic regime, the mean annual soil temperature is 8°C or higher but it remains lower than 15 °C, and the difference between the mean summer and mean winter soil temperatures is more than 6°C (47). If the mean summer air temperature in Finland increases by 1–2 °C, it shifts many soils from cryic or frigid to mesic. In the coming decades, global warming will shift the soil temperature zones in Europe to higher northern latitudes.

Material and Methods

The soil temperatures were recorded year-round using waterproof temperature and humidity loggers (Thermo Button 21G, Proges-Plus, France). The loggers at a depth of 50 cm measured soil temperatures at four-hour intervals, which they recorded into the memory; from there the, the data were transferred for analysis.

Results and Discussion

Besides mountainous areas, a large part of European soil has had the mesic temperature regime, whose northern border runs along the latitude of 58–59°N in the Baltic Countries and the southern part of the Scandinavian Peninsula (Table 20).

Table 20: Soil temperature at a soil depth of 50 cm and soil temperature regimes in three Central European and Baltic regions

Locality	Year	Mean annual soil temperature °C	Mean summer soil temperature °C	Mean winter soil temperature °C	Soil temperature regimes
Thann, Alsace, France	2016	13.5±6.3	21.1±2.4	6.5±2.1	mesic
Freyburg, Germany	2016	11,9±6.2	19.3 ±1.1	5.2±1.7	mesic

Räpina, Estonia	2010	8.8±6.9	18.1±2.6	0.5±0.9	mesic

Previously, Yli-Halla and Mokma (45) have estimated soil temperatures at a depth of 50 cm in Southern Finland in the Jokioinen and Anjala areas at the latitudes of 60–61°N based on the average annual air temperatures. The average soil temperature in Jokioinen was 5.9 °C in 1958–1970, and Anjala, it was 6.4 °C in 1982–1990. Correspond, the average annual air temperatures were 3.6 °C in Jokioinen and 4.2 °C in Anjala, and the average soil temperatures in the summer months were 13.7 °C in Jokioinen and 12.7 °C in Anjala.

According to results of Yli-Halla and Mokma (45), on the northern coast of the Gulf of Finland at a latitude of 60–61°N opposite Estonia, Southern Finland has had the colder cryic or frigid soil temperature regimes. In 2010–2019, the average air temperature was in southern Finland 6.9 ± 0.7 °C, and seven times 7 °C or higher. In 2017, the highest air temperature average was 7.8 °C (54). As the climate temperature has risen at least by 2 °C compared to the 1958–1970 and 1982–1990 averages, the coastal areas of Southern Finland have moved toward the warmer mesic soil temperature regimes (Table 21).

Table 21: Soil temperatures at a soil depth of 50 cm and soil temperature regimes in the Helsinki region (Tuusula) in Finland

Year	Mean annual soil temperature °C	Mean summer soil temperature °C	Mean winter soil temperature °C	Mean annual air temperature °C	Soil temperature regimes °C
2010	7.5±6.3	16.3 ±2.9	0.8±0.7	5.0*	frigid
2013	7.2±6.9	14.9±1.0	0.5±0.8	7.0	cryic
2016	8.0±6.7	15.6±1.5	0.7±1.4	6.8	mesic
2019	8.1±6.4	15.5±1.5	0.8±0.4	7.0	mesic

*2010 was an exceptionally cold winter with a thick snow layer of 65–70 cm and the air temperature at its lowest at -30°C.

In the same climate and at the same latitude, soil temperatures at 50 cm depth varies relatively little from year to year at the same latitude. Therefore, in the Helsinki region in Tuusula, mesic soil temperature regimes in 2016 and 2019 indicates a significant increase in climate and soil temperatures compared to the previous 20–40 years (45). Changes in the soil temperatures in the Helsinki region will continue to be monitored in the 2020s.

CONCLUSIONS

During the last twenty years, the raised climate temperature and the lengthening of the growing season have moved the grapevine's growing conditions of southern Finland, and the Baltic Sea Region closer and closer to the current growing conditions of Central Europe. Between the mean values of the climate temperatures of the two warmest summer months (July and August) of the Baltic Sea Region, there is no longer a big difference compared to Central European values as tens of years ago. On the other hand, the annual mean values of the soil temperatures are still clearly lower compared to the soil temperatures of traditional winegrowing areas in Central Europe. In winter in southern Finland, the soil temperature is zero at a depth of 25 cm and

above zero at a depth of 40 cm and deeper. In cold winters, the snow cover acts as a good insulator. These factors protect the root system from freezing. As the climate temperature rises, the soil temperatures also rise, which improves the vine root system, allowing it to survive the cold stress, and accelerates the growth of the vine in spring. As a result of climate warming, the current temperature classification of the soil in the Helsinki area, 'cryic-frigid', is rising to the higher temperature classification 'mesic', which further improves wine growing in the open land. The warmer climate temperature and longer growing season have encouraged farmers in southern Finland to try new cultivation plants, such as vines. Already, the growing season in southern Finland and the Baltic Sea Region is sufficiently long for the successful cultivation of many hybrid varieties but based on the sugar content of the grapes (°Bx), the harvest in the Helsinki region is several weeks later than in Central Europe. According to several climate scenarios, the climate temperature differences between Northern and Southern Europe will continue to decrease, and in Northern Europe, the selection of cultivated vine varieties will expand from hybrid varieties to purer Vitis vinifera -varieties. Based on the results, the rise of the climate temperature has in- creased the possibility to grow grapevines in open land in southern Finland and in the Baltic Sea Region. If the climate temperature in southern Finland and the Baltic region continues to rise by 0.4 °C per decade, the current mean annual air temperatures in Central Europe will be reached in 30–40 years, and the vine will become a conventional crop in these areas.

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