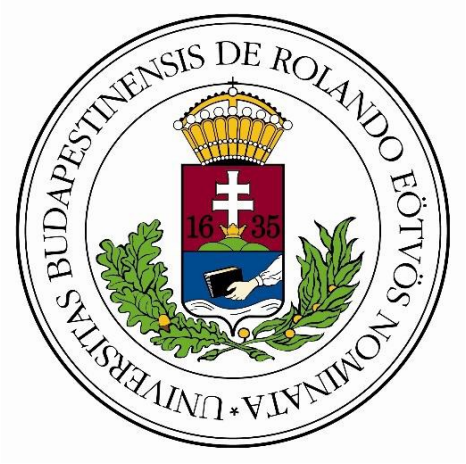

Agro-climatological characterisation of Sopron and Zala wine-growing regions and responses of grapevines (*Vitis vinifera* L.) to climate change

Thesis of the PhD dissertation

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1. Investigated problems, objectives

Climate change is one of the economic, natural, environmental and social challenges in the 21th century. Climate change has several effects on agriculture, including viticulture too.
Climate is an abiotic factor, which is a primary determinant of viticulture and efficiency of vineyards for grape varieties. Due to climate change, the growing season can change, e.g. start of the phenological phases, length of growing season, quality and quantity of crops, etc.
The quality and the quantity of the grapevine depend considerably on the micro- and mesoclimatic conditions of the region in question.
The objective of my work is to examine the response of the most common grape varieties to the climate change in the field of Sopron and Zala wine regions. During the investigation, I sought to find out how climate change has regionally changed the climatic conditions of the two wine regions from the point of view of successful grape growing and how the most common varieties responded to possible changes and a ripening index has been developed for scientists, decision-makers, politicians and farmers, which will eventually be applicable to all grape varieties.

2. The objectives of the investigation

1. A comprehensive climate analysis in the field of Sopron and Zala wine-growing regions (1986-2015)

2. Origination of an integrated climate indicator system for the two wine-growing regions

3. A phenological investigation on the cultivated grape varieties, which are cultivated in the largest rate. These phenological stations are: bud break, flowering, veraison, ripening and harvest.

4. Analysis of the Péczely's large-scale situations 60 and 30 days before the harvests

5. Origination of such a new Ripening Index, which will help to plan the optimum harvest time to the farmers and scientists.

3. Tools and methods

For the purposes of the research, the data of the calibrated meteorological stations were used, which are located near and in the area of the Sopron and Zala wine-growing regions. 32 meteorological stations are used during the investigation. Among them the ones situated in Sopron, Szombathely, Körmend, Kőszeg, Nagykanizsa, Iklódbördőce, Keszthely, Sármellék belong to the Hungarian Meteorological Service (OMSZ).

I have my own calibrated private stations installed in districts of Zala wine-growing region, in Csörnyeföld, Letenye, Nagykanizsa, Lovászi, Lenti, Lentihegy, Zalaapáti, Keszthely, Lendva (Lendava) and Varasd (*Varaždin)*, as well as in Kőszeghegyalja-Vaskeresztes in the Sopron wine-growing region, in Sopronfalva, Ágfalva, Kőszeg (Kőszegfalva), Velem, Szombathely, Vaskeresztes and Bozsok and near to the Austrian-Hungarian border in Burgenland.

The examination of the general climate parameters is not sufficient for the description of the conditions of a certain production place because they only show a superficial character. This is the reason why special parameters and indicators have been created, many of which are used in agro-climatic researches on the whole, and some indicators are applied specifically for the examination of particular production places or wine regions.

The specifically executed phenological research has been started at the wineries in the Zala wine-growing region in 2006 and the research has been continued from the 2010's in Sopron too. The six most frequent wine grape varieties are examined (Pinot Gris, Welschriesling, Müller-Thurgau, Zweigelt, Királyleányka and Blaufränkisch).

Regarding the change of the climate parameters, the analysed period is 1986-2015 (the examination results of the phenological thread are not exact when being "laid" between 1981 and 2010). Bud break, flowering, veraison, ripening and harvest were investigated among the phenological phases.

The sugar content was examined too. For this test, the winegrowers give us data and a database was created by me about the cyclonic and anticyclonic days, 60 days preceding the harvests, based on Péczely's large-scale weather types.

One of the main goals was to create a new Ripening (maturity) Index (*RI*). The test and calculation of the Ripening Index have begun in 2013 and in Zala and Sopron it lasts today too.

Calculation:

$$Ri = (Tmax_{01.08-15.09} + Tmed_{01.08-15.09}) \pm Tmin_t$$

$\mathbf{T_{max}}$= average maximum temperatures in April and May (5 cm, 50 cm, 200 cm)

$\mathbf{T_{med}}$= average daily temperatures in April and May (5 cm, 50 cm, 200 cm)

$\mathbf{T_{mint}}$= lowest daily temperature in April and May (5 cm, 50 cm, 200 cm).

If the temperatures were below 3 ºC during the maturation, the process of this phonological phase may stop. It has to correlate to the precipitation. Ripening Index is determinated by the exposition, soil, elevation, and gradient. It is very important that the meteorological stations should install near to the vine.

Classification of the values:

I. 0-46 slow maturation

II. 46,1-49 normal maturation

III. 49,1-58 fast maturation (best vintages)

IV. 58,1- extreme fast maturation.

3. Summary of the new and novel scientific results

1. The mean temperature significantly increased between 1986 and 2015 in the field of the investigated region. Eight of the ten warmest years have been measured after 1990. The temperature rise is 0.65 ºC/10 years. Average temperatures are somewhat different during the growing and dormancy periods, but the increase is clear between 1986 and 2015, the most intense increase is observed (0.6 °C / 10 years) in the second half of the growing season.

2. In the 30 years between 1986 and 2015, change in the annual precipitation has not been observed, significant change has not occurred. The fallen precipitation has increased by 20-22 % during the dormancy period, and it has decreased by 17-20 % during the growing season.

3. The soil moisture has been analysed in accordance with the precipitation. Minimal soil moisture is generally at the end of July and August and the maximal one is at the end of December, which is different to the other Hungarian landscapes.

4. Over the past 30 years a significant change has been observed in the next climate indices: Huglin-index, Growing Degree Days, summer days, hot days, heat days, Harvest Maximum Temperature, Growing Season Average Minimum Temperature, Growing Season Average Maximum Temperature, Growing Season Average Temperature, Ripening Temperature, tropical nights, July mean temperature, frost days, etc. Among the precipitation extremities, the number of days with high rainfall has significantly changed, in addition, the number and length of dry days have increased.

5. The heat and radiation supply has improved in the investigated regions, which is one of the positive effects of climate change in West Hungary.

6. The bud break begins 7 days earlier, the time between the bud break and the flowering has shortened by 4.5 days. The total time of the flowering has shortened by 6.5 days. Although the flowering happens earlier, the massive proportion (55-60 %) is reached 2-3 days later. The shift of the veraison is 8 days, and at this phenological phase, it was difficult to summarize the accurate changes, as there may be significant differences in 1-2 grape varieties.

7. Harvests happen 11 days earlier respect to the previous period (all varieties). In the case of the five most common varieties, the change is 6.5 days in Sopron and 5.5 days in Zala.

8. The shift in the harvest time is due mainly to the blocking anticyclones in summer. By the increase of the proportion of the anticyclonic days, the sugar accumulation in the must at the moment of the harvest is increasing. Considering the period since 1996, the number of anticyclonic days was very high in 2003, 2006, 2011, 2012, 2017 and 2018.
The relationship between the proportion of anticyclonic days in the 60 days preceding the harvests and accumulation of sugar in the must is significant.

9. One of the main goals of my research was to develop a new ripening (maturation) index for scientists, decision makers and farmers. Three grape varieties were observed for the index. These are Blaufränkisch, Zweigelt and Pinot gris. Based on the ripening index, for the period 2013 to 2017, the index shows a close correlation with the real values. During the period from 2013 to 2017, with the ripening index it can be stated that in the two wine-growing regions, average and fast-growing years were the most common. It was detected an extremely rapid maturation in early varieties in 2018.

4. List of scientific publications related to the PhD thesis

Released publications

[1] Kovács Erik, Puskás János, Pozsgai Andrea, Kozma Katalin: Shift in the annual growth cycle of Grapevines (*Vitis vinifera* L.) in West Hungary. Applied Ecology and Environmental Research: doi: 10.15666/aeer/1602_20292042, (2018)
[2] Kovács Erik, Puskás János, Pozsgai Andrea: Positive Effects of Climate Change on the Field of Sopron Wine-Growing Region in Hungary. Perspectives on Atmospheric Sciences. Springer: doi:10.1007/978-3-319-35095-0_86, (2017)
[3] Kovács Erik, Puskás, János, Bán Zsombor Balázs, Kozma Katalin: Agroklimatológiai vizsgálatok Kőszeghegyalján és Vas-hegyen. Légkör 63 (2): 68-74, (2018)
[4] Kovács Erik, Puskás János: A regionális éghajlatváltozás egyik lehetséges nyertese a Soproni borvidék. Kertgazdaság 48 (4): 51-65, (2016)
[5] Kovács Erik, Puskás János: A szőlő fenológiájának tanulmányozása a Zalai dombvidéken. Kertgazdaság 46 (1): 38-47, (2014)
[6] Kovács Erik, Puskás János: Az éghajlati paraméterek és a szőlő fenológiai vizsgálata Kerkamente, Muramente és Muravidék területén. Légkör 58 (4): 156-160, (2014)
[7] Kovács Erik, Milei Melitta: Positive Effects of Climate Change on Some Climate Indicators on the Field of Zala Wine Region in Hungary. NymE Savaria Egyetemi Központ Tudományos Közleményei Természettudományok 16: 23-34, (2016)
[8] Kovács Erik, Puskás János: A makroszinoptikus időjárási típusok és a mustfok kapcsolata. Szőlő-Levél Szakfolyóirat 4 (7): 8-11, (2014)
[9] Kovács Erik, Kopecskó Zsanett, Puskás János: Impact of Climate Change on Wine Regions of the Western Part of the Carpathian Basin. NymE Savaria Egyetemi Központ Tudományos Közleményei Természettudományok 15: 71-89, (2014)
[10] Kovács Erik, Puskás János: Vas megye éghajlata. ELTE Savaria Természettudományi és Sporttudományi Közlemények 17: 31-45, (2018)

Book(s) (not released yet)

[11] Kovács Erik, Puskás János: Vas megye éghajlata. In: Csapó Tamás: Vas megye földrajza. Szakkönyv könyvfejezet. (in press)

Conference presentations and abstracts

[12] Kovács Erik, Puskás János: Changes in extreme climate parameters on the Western part of the Carpathian Basin since 1950. 14th International Conference on Applications of Natural, Technological and Economic Sciences. Szombathely, 27-33, (2015)

[13] Kovács Erik, Puskás János: Regional Effects of Climate Change on the Field of Sopron Wine-Growing Region. XI. Regionális Természettudományi Konferencia. NymE-TTK Szombathely, (2016)
[14] Puskás János, Tar Károly, Szepesi J, Kovács Erik: Statistical Investigation of Subalternation of the Daily Mean Wind Speed on the North-West Region of Carpathian Basin. COMECAP 2014: 12th International Conference of Meteorology, Climatology and Physics of the Athmosphere. Heraklion (Görögország), 85-89, (2014)
[15] Kovács Erik, Puskás János: Az éghajlatváltozás pozitív hatásai a Kárpát-medence nyugati borvidékein az elmúlt 30 évben. 15th International Conference on Applications of Natural, Technological and Economic Sciences. Szombathely, 259-265, (2016)
[16] Kovács Erik, Puskás János: A borszőlő termeszthetőségi feltételeinek lehetséges változásai az éghajlatváltozás függvényében a Zalai Borvidék területén. 13th International Conference on Applications of Natural, Technological and Economic Sciences. Szombathely-Sopron, 37-44, (2014)
[17] Kovács Erik, Puskás János, Pozsgai Andrea: Positive Effects of Climate Change on the Field of Sopron Wine-Growing Region in Hungary. COMECAP 2016: 13th International Conference of Meteorology, Climatology and Physics of the Athmosphere, Thesszaloniki (Görögország), 6-7, (2016)
[18] Kovács Erik, Milei Melitta: A szőlő tenyészidejének változása a Kerka- és Muramenti Hegyközség területén. 5. Szőlő és Klíma Konferencia. Kőszeg, 30-36, (2013)
[19] Kovács Erik: Az éghajlatváltozás és a borszőlő fenofázisai közötti kapcsolat vizsgálata a Zalai Borvidék területén. 6. Szőlő és Klíma Konferencia. Kőszeg, CD-ROM forrás, (2014)
[20] Kovács Erik: Effects of Climate Change on the Kőszeg –Vaskeresztes WIne-Growing Region (1901-2014): 7. Szőlő és Klíma Konferencia. Kőszeg, 8-9, (2015)
[21] Puskás János, Kovács Erik, Unger István: A must minősége Kőszegen, az időjárás és a szüret időpontja függvényében. 8. Szőlő és Klíma Konferencia. Kőszeg (in press), (2016)
[22] Kovács Erik, Bán Zsombor Balázs, Kozma Katalin: Agroklimatológiai vizsgálatok Kőszeghegyalján és Vas-hegyen. 9. Szőlő és Klíma Konferencia. Kőszeg (in press), (2018)
[23] Kovács Erik, Puskás János: Az éghajlatváltozás egyik regionális hatása a *Vitis vinifera* L. szüretidejének eltolódása Nyugat-Magyarország borvidékein. XIV. Kárpát-medencei Környezettudományi Konferencia, Gödöllő (2018. április 5-7., poszter), (2018)
[24] Kovács Erik, Puskás János, Kozma Katalin: Early Phenological Responses of Grapevine to Climate Change in West Hungary. 14th International Conference on Meteorology, Climatology and Atmospheric Physics. Alexandroupolis (Görögország), (2018. október 15-17.)
[25] Kovács Erik, Puskás János, Milei Melitta: Az éghajlatváltozás pozitív hatása Kőszeghegyalján. II. Gazdálkodás és Menedzsment Tudományos Konferencia. Környezettudományi szekció, Kecskeméti Főiskola (2015. augusztus 27.), (2015)