Zaldea G *et al.* (2021)
Notulae Botanicae Horti Agrobotanici Cluj-Napoca
Volume 49, Issue 4, Article number 12448
DOI:10.15835/nbha49412448
Research Article

Climate changes in recent decades, the evolution of the drought phenomenon and their influence on vineyards in north-eastern Romania

Gabi ZALDEA[1], Ancuta NECHITA[1*], Doina DAMIAN[1], Andreea D. GHIUR[1], Valeriu V. COTEA[2]

*[1]Research and Development Station for Viticulture and Winemaking Iași, 48 Mihail Sadoveanu Alley, 700489, Iasi, Romania; gabizaldea@yahoo.com; ancuta.vasile@gmail.com (*corresponding author); doinadamian@yahoo.com; andreea.ghiur@yahoo.com ;*
[2]Iasi University of Life Sciences, 3 Mihail Sadoveanu Alley, 700490, Iasi, Romania; vcotea@uaiasi.ro

Abstract

Unfavourable trends have been identified in the evolution of climate factors (temperatures, precipitation, etc.) over the past years, with a direct impact on the vegetative and productive potential of the vine. This calls for a reassessment of climate resources and the adaptation of cultivation technologies to the new conditions. Our paper analyses the climate data recorded between 1991 and 2020 for the Iaşi vineyard ecosystem, which allowed for the calculation of a series of bioclimatic indices and coefficients, deviations from the multiannual average values, soil moisture dynamics, and their influence on development of vegetation phenophases and grape production. The increasing tendency of the average annual temperature and the decreasing amounts of precipitation registered point to a marked warming of the vineyard climate, especially after 2000. The high values of temperatures, corroborated with the soil water deficit, determined an intensification of the atmospheric and pedological drought, a shift in vegetation phenophases, shortened development periods and a forced ripening of grapes, with a negative impact on yields, which fluctuated from one year to another. The analysis of the ecoclimate conditions over the past 30 years has highlighted an alternation of periods, a colder and wetter one between 1991 and 2006, and a warmer and dried one between 2007 and 2020.

Keywords: phenology; rainfall; soil moisture; temperatures; vineyards

Introduction

As experts argue, the worldwide climate change is expected to edge in the coming decades and will obviously influence the biology of horticultural species, especially vines (Jones and Webb, 2010; Van Leeuwen *et al.*, 2016; Georgakopoulos *et al.*, 2016, Piña-Rey *et al.*, 2020; Emadodin *et al.*, 2021).

Global warming is characterised by an increase in the average temperatures throughout the surface of the planet. Hence, mitigating this phenomenon is currently considered one of the most significant challenges for the scientific world. Computer-simulated climate scenarios have shown that in the long term, a 3-4 °C

Received: 22 Jul 2021. Received in revised form: 12 Nov 2021. Accepted: 15 Dec 2021. Published online: 15 Dec 2021.
From Volume 49, Issue 1, 2021, Notulae Botanicae Horti Agrobotanici Cluj-Napoca journal uses article numbers in place of the traditional method of continuous pagination through the volume. The journal will continue to appear quarterly, as before, with four annual numbers.

increase in global temperature is likely to affect agricultural crops, with a strong impact on the world economy (Jones *et al.*, 2005, White *et al.*, 2006).

Within this context, referring to viticulture, Laget *et al.* (2008) recommend deepening knowledge on how the viticultural ecosystem will be affected by the global climate change, considering that in the future, some vine-growers may abandon certain varieties and replace them with others, more resistant to the new climate conditions. The researchers noticed a shift in temperatures in the early 1980, with an average increase of +0.2 °C recorded for the period 1950-1980, compared to +1.3 °C recorded for the period 1980-2006.

The warming trend registered in recent years in most of Western Europe, especially in France, indicates a 1-2 weeks advancement in vegetation phenophases and almost one month in harvesting, accompanied by changes in sugar and acidity levels (Seguin and De Cortazar, 2005).

In our country, research has been carried out on the general trend of climate change over the recent decades, implicitly on the variation of air temperature, atmospheric precipitation and thermo-pluviometric indices, but also on their effects on agriculture (Sandu *et al.*, 2010; Piticar *et al.*, 2012; Dumitrescu *et al.*, 2015; Busuioc *et al.*, 2015). An increase of 0.5 °C in the average annual temperature has been recorded in the country, more pronounced in the south and east, as well as a downward trend in annual rainfall and a change in precipitation distribution, especially in the seasons of winter and summer.

Studies on the influence of climate change on vine cultivation have been conducted mainly in the vineyards in Dobrogea, south-eastern Moldova and in the south of the country (Cichi *et al.*, *2007*; Dejeu *et al.*, 2008; Ranca, 2008; Iliescu *et al.,* 2009; Bucur *et al.,* 2014; Pîrcălabu *et al.,* 2014; Dobrei *et al.*, 2015; Irimia *et al.*, 2018 a, Bucur *et al.,* 2019; Iliescu, 2019; Nistor *et al.,* 2019; Onache *et al.,* 2020 etc). Research has highlighted changes in the development and duration of the main vegetation phenophases, respectively 1-2 weeks outrun in buds bursting and blooming, and 2-3 weeks in grape ripening and maturation, as well as changes in the productive potential of the varieties. An increase in the frequency of the drought phenomenon has equally been noticed, which can have destructive effects on the vineyards, when precipitations are low in the previous autumn and winter, and the quantities recorded in the spring are insufficient to restore the water supply in the deep layers of the soil feeding the vine stems (Zaldea *et al.*, 2017). Moreover, a displacement of the area favourable for vine cultivation towards the north of the country and a tendency to increase the suitability of red varieties cultivation were highlighted, sometimes to the detriment of the white ones (Chiriac, 2007; Vasile *et al.*, 2010; Irimia *et al.*, 2014, Irimia *et al.*, 2018 b).

The development and constant updating of climate and phenological databases is an important stage in optimising the zoning of the vines, as well as a starting point in issuing possible scenarios in the context of climate change. Within this context, our paper aims to highlight climate change over the last 30 years in the Copou wine ecosystem, Iasi vineyard, respectively the increase in the average annual temperature, decreasing rainfall, increasing frequency of dry years and their impact on the productive potential of varieties. The study provides information on the evolution of the main climatic factors (1991-2020), the development of vegetation phenophases (2000-2020), the main vine-specific bioclimatic indicators, the distribution of accessible soil moisture (2000-2020), the frequency of drought and average grape production obtained (1991-2020). Knowledge of the viticultural potential of a vineyard allows the correct placement of the vine varieties in relation to the climatic factors and the capitalisation of their qualitative potential, the optimisation of the cultivation technologies, the knowledge of the types of wine that can be obtained in their perimeter and, implicitly, the duration of exploitation of the plantations.

Materials and Methods

Climate data analysis

The study was based on a series of daily meteorological parameters (temperature, precipitation) recorded at the SCDVV Iaşi weather station, located in the northern part of the municipality of Iaşi, at 191 m altitude, 47°12`18`` north latitude and 27°32`04`` east longitude. The analysed period covered a series of homogeneous data for the last 30 years (1991-2020), based on which a series of multiannual bioclimatic coefficients and indicators used in winegrowing were calculated: thermal coefficient, precipitation coefficient, hydrothermal coefficient, Martonne aridity index, real heliothermal index, vine bioclimatic index, oenoclimatic aptitude index and Huglin heliothermal index (Table 1). Bioclimatic indicators were selected due to their use in viticultural zoning works, their efficiency in characterising wine-growing areas in temperate climates, and their marked spatial variation, which allows an overall analysis of the climate of the vineyard (Irimia and Patriche, 2019).

Table 1. Bioclimatic indices, equations and sources

Index and Abbreviation	Equation	Source
Thermal coefficient (TC)	TC=∑ta °C/Ndg	Constantinescu, 1945
The precipitation coefficient (PC)	PC=Pg /Ndg	Constantinescu *et al.,* 1964
Hydrothermal coefficient (HC)	HC=Pg /∑ta °C x 10	Selyanianov, 1928
De Martonne aridity index (IDM)	IDM=Pa /(T + 10)	De Martonne, 1926
The real heliothermal index (IHr)	IHr = I x ∑tu °C x 10^{-6}	Branas, 1974
The vine bioclimatic index (Ibcv)	Ibcv= [(I x ∑ta °C)/(Pg x Ndg)]/10	Constantinescu *et al.*, 1964
The oenoclimate aptitude index (IAOe)	IAOe = I + ∑ta °C – (Pg-250)	Teodorescu *et al.*, 1987
The Huglin heliothermal index (IH)	IH =∑[(Tmj-10) + (Txj-10)]/2 x k	Huglin, 1986

∑t°a – active heat balance (sum of average temperatures >10 °C); ∑t°u – useful heat balance (sum of the average temperatures from which the value of the biological threshold of 10 °C decreases); Ndg - number of days in the growing season with average temperatures >10 °C between 1 April and 30 September (the growing season); Pg - precipitation during the growing season; Pa – annual precipitation; T – average annual temperature; Tmj – average temperature in the growing season; Txj - maximum temperature in the growing season; I- real insolation; k = day length coefficient, varying from 1,02 to 1,06 between 40° and 50° latitude.

Determination of soil moisture

In order to establish soil moisture, the oven drying method was used (Canarache, 1964). Thus, for each month in the growing season, sampling by layers was performed every 10 cm, up to a depth of 150 cm; the results were first expressed in percentage compared to the weight of dry soil, then in volume percentage. Based on the hydrophysical indices values, the soil moisture available at a given time (Macc), expressed in mm and %, was calculated:

$$\text{Macc} = \text{M\% vol} - \text{WC} \quad (1)$$

where WC is the wilting coefficient and M% is the volumetric moisture content.

In order to establish the degree of available plant water supply, the available moisture (Macc) was compared to the useful water capacity (UWC), previously calculated for the Copou Iaşi wine centre. The following formula was used for calculation of UWC:

$$\text{UWC} = \text{FC} - \text{WC} \quad (2)$$

where FC is the field water capacity for the soil

Productive parameters

The climate study is completed by observations regarding the development of vegetation phenophases from 2000 to 2020: budding, blooming, entering in ripening and grape maturation (Lorenz *et al.*, 1995) and productivity determinations (actual average production, kg/ha) of vine varieties that make up the Iaşi vineyard assortment.

Results and Discussion

Temperature evolution

Temperature is the climate factor that determines the grapevine spread area, the start and development of growth phenophases, setting the cultivation system and, last but not least, the quantity and quality of grape production. During the period 1991-2020, there was an average multiannual temperature of 10.3 °C with an amplitude of 3.4 °C determined by the difference between the maximum average of 12.0 °C recorded in 2020 and the minimum average of 8.6 °C recorded in 1996. The graphic representation highlights an alternation between periods, a colder one during the time span 1991-2006, and a warmer one for the period 2007-2020 (Figure 1).

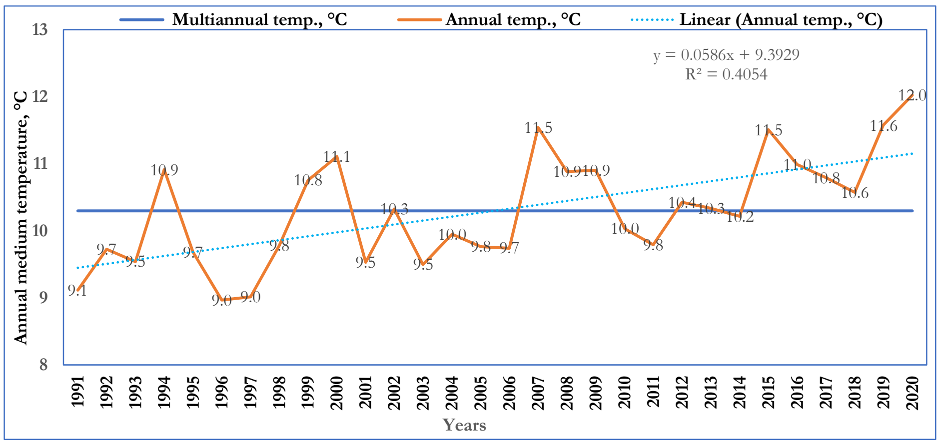

Figure 1. Evolution of average annual temperatures recorded in the Copou – Iaşi wine centre

The temperature-increasing trend indicates a marked warming of the vineyard climate, likely to change the conditions for the development of vegetation phenophases in vines, including much earlier ripening of grapes.

For the analysed period, the deviations of the average annual temperatures were calculated, noting a balanced distribution of the years. Thus, in 50% of the years, positive values of temperature deviations were registered, reaching a maximum of 1.7 °C in 2020. The difference of 50% is represented by the years with negative deviations, with a maximum value of – 1.3 °C in 1996 (Figure 2).

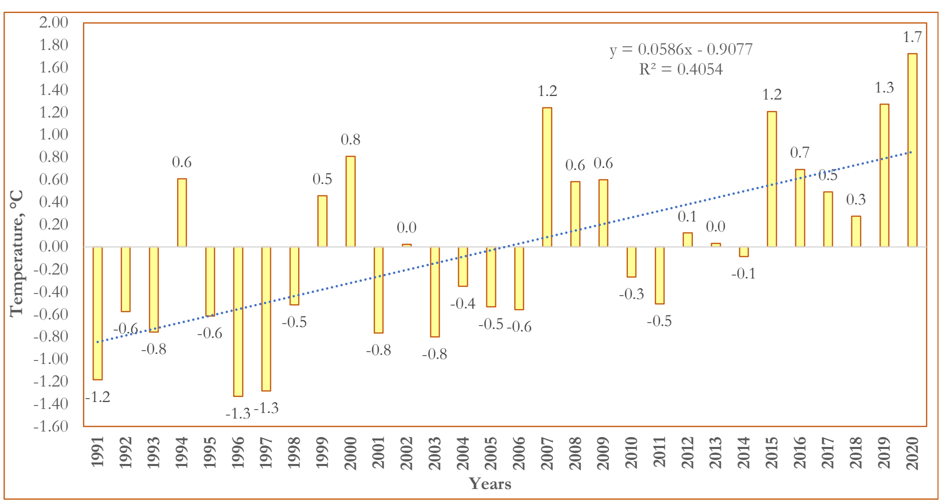

Figure 2. Deviation of thermal values compared to the multiannual thermal average

According to the Hellman criterion, the thermal characteristics of the analysed period highlight four years with positive deviations above 1.0 °C (2007, 2015, 2019, and 2020), which are considered the warmest, and three years with negative deviations greater than -1.0 °C (1991, 1996 and 1997), the coolest (Table 2).

Table 2. Classification of the thermal regime according to the Hellmann criterion

Deviation against average, °C	Hellman criterion	No. of cases	Years
1.9 ....1.0	warm	4	2007, 2015, 2019 and 2020
0.9 ....-0.9	normal	23	1992, 1993, 1994, 1995, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2016, 2017, 2018.
-1.0....-1.9	cool	3	1991, 1996, 1997

Evolution of precipitation

The climate area in our country is characterised by periods (years) of normal rainfall; however, during certain intervals, deviations from the normal are also recorded, with precipitation excess or deficit. In the Copou-Iaşi wine centre, the precipitation multiannual average (1981-2010) is 579.6 mm, with 398.1 mm during the growing season (April-September). In recent years, we have seen a decrease in the precipitation regime and an increase in the frequency of dry years.

The analysis of annual precipitations for the interval 1991-2020 highlights a wetter period between 1991 and 2005, with values above average, followed by a period of pluviometric deficit, between 2006 and 2020, with values below the period average (Figure 3). The lowest amount of annual precipitation (365.5 mm) was recorded in 2015, and the highest in 1991, with 829.5 mm.

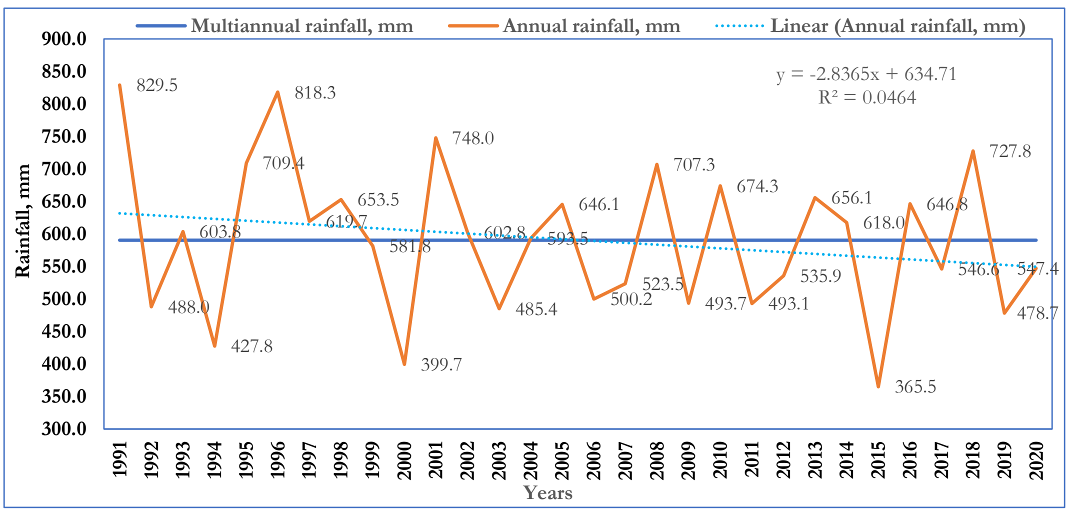

Figure 3. Evolution of annual precipitations recorded in the Copou-Iaşi wine centre

In order to highlight the variations in annual precipitations, the deviations from the average were calculated; this allowed for their characterisation according to the Hellman criterion (Figure 4). The graphical representation shows a decrease in quantities towards the end of the analysed interval.

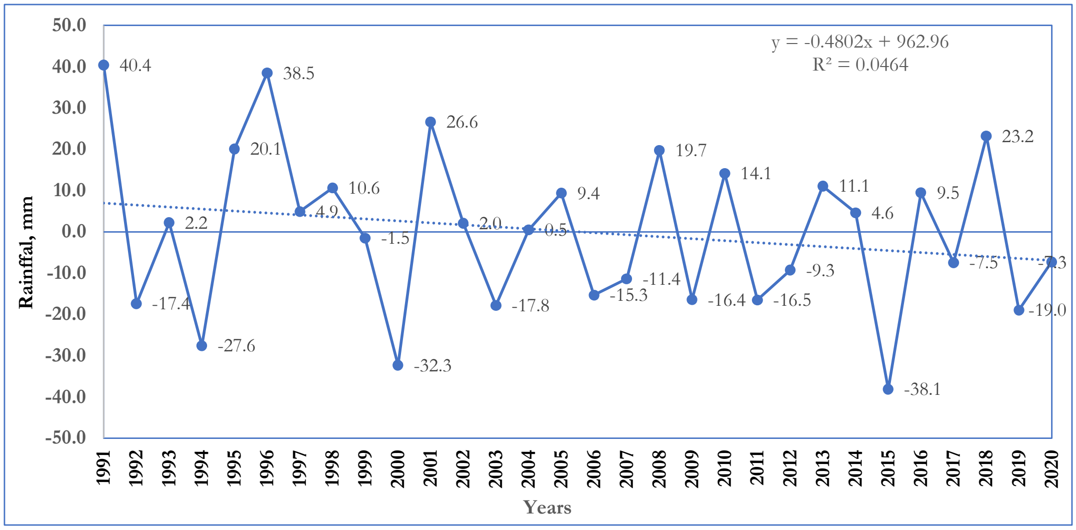

Figure 4. Deviations of annual precipitations compared to the multiannual average

As regards the annual deviations from the average, it can be noticed that in 46.7% of the analysed years, the total precipitation was below average, while in 53.3% the values were higher than the multiannual average.

By calculating the frequency of annual precipitations recorded in the Copou-Iaşi wine centre, their probability was established (Table 3). Thus, it was observed that the probability of annual precipitation with values between 601-650 mm is 20%, and between 401-450 mm of 3.33%.

Table 3. Frequency of annual precipitation and its probability for the period 1991-2020

Precipitation, mm	No. of years	Probability, %
351-400	2	6.67
401-450	1	3.33
451-500	5	16.67
501-550	5	16.67
551-600	2	6.67
601-650	6	20.00
651-700	3	10.00
701-750	4	13.33
751-800	0	0.00
801-850	2	6.67
Total number of years	30	

Depending on the deviations from the average rainfall, it was noted that of the 30 years included in the study (1991-2020), only six are considered normal in terms of rainfall, and most of them - 13 years - had little precipitation, characterised from “moderately dry” (3 years), to “dry” (1 year), “very dry” (6 years) and 3 “extremely dry” years (Table 4).

High temperatures and drought caused by climate change also led to significant changes in multiannual bioclimatic coefficients and indicators, directly correlated with the average annual temperature, the active heat balance (Σ t°a), the useful heat balance (Σt°u), the real insolation, the amount of annual precipitations and precipitation in the growing season (Table 5).

Table 4. Precipitation's regime and characterisation of the analysed interval

Deviation against average %	Hellman criterion	No. of cases	Years
<-20.0	Exceedingly droughty	3	1994, 2000, 2015
-20.0….-15.1	Very droughty	6	1992, 2003, 2006, 2009, 2011, 2019
-15.0….-10.1	Droughty	1	2007
-10.0….-5.1	Moderately droughty	3	2012, 2017, 2020
-5.0….5.0	Normal	6	1993, 1997, 1999, 2002, 2004, 2014
5.1….10.0	Moderately rainy	2	2005, 2016
10.1….15.0	Rainy	3	1998, 2010, 2013
15.1….20.0	Very rainy	1	2008
>20.0	Exceedingly rainy	5	1991, 1995, 1996, 2001, 2018

Table 5. The values of the main synthetic bioclimatic indicators from in the Copou Iaşi wine centre

Year	TC	HC	IDM	PC	IHr	Ibcv	IAOe	IH
1991	17.2	2.5	43	4.3	1.4	3.0	3581.9	1713.2
1992	18.1	1.2	25	2.1	1.9	7.7	4337.8	1950.5
1993	16.4	1.4	31	2.3	1.8	6.2	4191.9	1831.0
1994	18.5	1.2	20	1.6	2.5	7.8	4841.8	2254.5
1995	17.4	1.8	36	3.2	2.2	4.9	4230.5	2010.9
1996	17.6	1.9	43	3.4	2.0	4.5	4072.6	1904.5
1997	17.4	1.5	33	2.6	1.8	5.8	4090.9	1809.2
1998	18.4	1.1	33	2.0	2.1	7.5	4605.4	2047.5
1999	18.9	1.0	28	2.0	2.3	8.5	4635.9	2081.6
2000	18.8	0.8	19	1.5	2.4	11.1	4842.3	2298.3
2001	16.0	1.8	38	2.9	2.0	4.5	4231.8	2006.9
2002	16.9	1.4	30	2.3	2.1	5.6	4367.0	2017.4
2003	18.5	0.9	25	1.7	2.5	10.1	4828.4	2215.7
2004	17.5	1.3	30	2.2	1.9	6.6	4369.3	1900.4
2005	18.0	1.4	33	2.6	2.0	6.1	4340.7	1998.6
2006	17.5	1.1	25	1.9	2.1	7.6	4508.5	2018.3
2007	20.3	0.8	24	1.7	2.5	10.6	4799.9	2406.1
2008	18.2	1.7	34	3.2	1.8	4.6	4107.8	1994.0
2009	18.2	0.6	24	1.2	2.4	12.9	4863.6	2229.3
2010	19.5	1.3	34	2.5	2.0	6.2	4454.5	2113.7
2011	18.1	1.2	25	2.3	2.2	6.8	4462.4	2098.3
2012	20.6	0.8	26	1.6	2.8	10.7	5058.2	2541.0
2013	18.8	1.6	32	3.0	2.1	5.4	4322.1	2059.0
2014	16.3	1.2	31	2.0	2.0	7.0	4354.8	2103.0
2015	19.4	0.5	17	1.0	2.6	16.3	4960.8	2406.0
2016	19.4	1.0	31	1.9	2.5	8.8	4819.9	2322.0
2017	17.9	0.9	26	1.6	2.5	9.6	4753.9	2237.0
2018	19.3	1.3	35	2.6	2.6	6.4	4768.8	2408.4
2019	19.6	1.0	22	2.0	2.3	8.9	4638.4	2247.7
2020	19.6	0.9	25	1.8	2.5	9.9	4786.1	2323.2

The thermal coefficient (TC), which represents the ratio between the active heat balance (Σ t°a) and the number of days in the growth period, has shown an increasing trend in recent years (from 16.0 in 2001 to 20.6 in 2012). The values of the thermal coefficient increase directly proportional to the sum of the active temperature degrees.

The hydrothermal coefficient (HC), which represents the ratio between the sum of precipitations during the growing season and the active heat balance, reached minimum values of 0.5 in 2015 and maximum values of 2.5 in 1991. The trend of this coefficient is decreasing, as a result of the decreasing amounts of precipitations during the growing season. Values of the hydrothermal coefficient below 0.8 substantiate the need for vineyards irrigation.

The "de Martonne" aridity index (IDM), which expresses the ratio between the sum of annual precipitation and the useful temperature, registered a minimum value of 17 in 2015 and a maximum of 43 in 1991 and 1996. These values indicate that during 1991-2020, in the Copou – Iaşi wine centre there were both years that were part of a semi-arid climate, and years with a semi-humid and humid climate.

The precipitation coefficient (PC), established by the ratio between the amount of precipitation during the growing season and the duration of the bioactive period, registered lower values in the dry years and higher values in the rainy years (from 1.0 in 2015 and 4.3 in 1991).

The real heliothermal index (IHr) represents the product between the sum of the hours of real insolation during the vegetation period and the useful heat balance. On the territory of our country, characterised by a temperate continental climate, this index ranges between 1.35 and 2.70. As regards the Iaşi vineyard for the analysed period, the index shows an increasing trend from a minimum of 1.4 in 1991 to a maximum value of 2.8 in 2012. The increase in its values reflects an increase in the heliothermal resources (light and temperature), which creates the possibility of grape ripening in late varieties.

The vine bioclimatic index (Ibcv) in the vineyards of our country displays a pronounced variation from the value of 4.0 in the vineyards in the north of the country to the value of 15.0 in the south. During the analysed period, it registered the most favourable values in 2000 (11.1), 2007 (10.6), 2009 (12.9), 2012 (10.7) and 2015 (16.3), and the lowest values in 1991 (3.0), 1996 and 2001 (4.5), 2008 (4.6) and 2013 (5.4).

The oenoclimate aptitude index (IAOe) represents the sum between the real insolation and the active thermal balance, less the difference of precipitations besides 250 mm, which is considered to be an ecological optimum. On the territory of our country, the values of this index range between 3,700 and 5,200. In the areas with values below 4,300, only white wines can be obtained; areas with values ranging between 4,300 and 4,600 present an average favourability for obtaining red wines. Values above 4,600 indicate favourable conditions for obtaining red wines. Equally, the red varieties can be cultivated in a warmer climate, in which the oenoclimate aptitude index exceeds the value of 5,100. Over the last three decades, the oenoclimatic aptitude index (IAOe) registered an average value of 4,507.6, including the Iaşi vineyard in the area favouring white wines, and, in certain years, in the areas with an average degree of favourability for the production of red wines.

The Huglin heliothermal index provides the necessary information about the level of thermal potential, which is extremely important for the cultivation of table and wine grape varieties, with different ripening times. During the analysed period in the Copou Iaşi wine centre area, the Huglin heliothermal index registered an average value of 2,118.2, falling into the "warm temperate climate category", comprised within the range of values above 2,100 and lower than or equal to 2,400.

The small amounts of precipitation corroborated with the high temperatures, led to a marked decrease in the values of the soil accessible moisture (Macc) during certain periods, far below the optimal ones for the vineyard culture. It is known that the optimal soil moisture for vineyard culture is between 50-80% of the useful water capacity (UWC), higher values being favourable for growing shoots, and the lowest for grain maturation. In addition, during the long periods of drought (lasting for 2-3 years), the water reserve in the deep layers of the soil of 100-150 cm decreases (Alexandrescu *et al.,* 1998).

Monitoring the monthly distribution of accessible soil moisture during 2000-2020 has highlighted the low values in the dry and very dry years: 2000, 2007, 2009, 2011, 2012, 2015, 2017, 2019 and 2020 (Table 6). Among these, the years 2015 and 2020 stand out with extremely low values registered in almost all the months of the growing season – between 23-39%, on the whole depth of the soil profile (0-150 cm). During the years when the drought caused significant damage, the precipitation deficit started from the previous year (summer or autumn), continued during the winter, as well as in the spring and summer of the following year. Such situations were recorded for the years 2006-2007, 2011-2012, and 2019-2020, and had negative effects on the growth of the stocks.

Table 6. Monthly distribution of available soil moisture, average values by layers

Year	Depth, cm	Available moisture (%) from the vegetation period						Year	Depth, cm	Available moisture (%) from the vegetation period					
		IV	V	VI	VII	VIII	IX			IV	V	VI	VII	VIII	IX
2000	0-20	8	18	10	2	36	35	2011	0-20	59	40	70	52	29	32
	20-50	55	61	53	45	55	48		20-50	72	66	84	64	33	36
	50-100	79	71	67	63	61	45		50-100	88	73	88	84	38	39
	100-150	108	100	92	85	96	54		100-150	135	110	116	116	50	63
2001	0-20	26	48	62	20	27	42	2012	0-20	43	60	14	11	18	24
	20-50	57	62	72	39	32	67		20-50	82	55	19	14	15	22
	50-100	40	68	86	58	42	63		50-100	94	81	43	23	20	24
	100-150	50	61	114	87	65	42		100-150	88	125	74	41	45	46
2002	0-20	48	45	34	55	59	74	2013	0-20	39	58	62	33	24	39
	20-50	61	61	42	80	68	71		20-50	67	69	78	53	17	41
	50-100	74	67	48	77	70	51		50-100	74	76	83	71	46	48
	100-150	114	107	92	92	105	71		100-150	121	127	135	112	94	65
2003	0-20	56	32	32	58	42	35	2014	0-20	49	63	36	43	26	21
	20-50	69	60	52	53	53	42		20-50	62	72	57	49	28	31
	50-100	77	66	50	57	49	48		50-100	80	85	67	48	32	38
	100-150	117	103	84	83	76	74		100-150	141	118	100	70	41	54
2004	0-20	40	32	45	55	73	71	2015	0-20	53	33	33	10	9	66
	20-50	77	67	60	56	63	70		20-50	65	46	48	36	25	34
	50-100	80	76	67	54	64	65		50-100	93	75	56	37	30	28
	100-150	126	120	101	82	76	56		100-150	111	119	81	46	63	54
2005	0-20	64	66	49	65	62	42	2016	0-20	61	59	53	23	14	9
	20-50	77	83	60	65	66	59		20-50	71	77	63	30	24	26
	50-100	85	99	72	68	69	63		50-100	82	73	53	35	32	22
	100-150	126	134	117	113	95	90		100-150	63	57	76	40	33	42
2006	0-20	64	62	59	52	52	45	2017	0-20	62	32	39	30	17	8
	20-50	77	76	71	49	54	53		20-50	71	60	45	34	32	23
	50-100	85	75	76	57	55	55		50-100	82	79	55	32	36	23
	100-150	126	126	117	87	79	70		100-150	122	134	82	71	55	45
2007	0-20	35	32	4	29	65	36	2018	0-20	27	23	67	39	24	17
	20-50	69	61	43	26	56	54		20-50	61	36	73	55	35	38
	50-100	58	54	40	30	33	52		50-100	100	70	79	73	58	37
	100-150	72	67	56	38	37	55		100-150	156	104	87	93	97	56
2008	0-20	65	61	58	63	50	23	2019	0-20	51	72	61	31	32	1
	20-50	75	66	65	67	51	69		20-50	63	67	70	46	22	7
	50-100	101	93	66	87	57	62		50-100	88	86	89	68	41	26
	100-150	148	117	70	124	68	64		100-150	119	124	152	122	82	37
2009	0-20	35	70	49	11	9	6	2020	0-20	40	59	57	21	12	-22
	20-50	70	69	63	34	26	9		20-50	28	24	35	34	22	24
	50-100	83	73	72	33	22	18		50-100	29	32	37	32	18	28
	100-150	118	100	91	75	42	38		100-150	28	46	39	43	38	36
2010	0-20	72	47	48	56	59	61								
	20-50	64	65	75	77	75	70								
	50-100	90	77	85	86	85	74								
	100-150	145	126	128	128	120	89								

The observations made for the period 2000-2020, regarding the evolution of the vegetation phenophases crossed by the main varieties in the assortment, in direct relation with the climate factors, pointed to the fact that they were conditioned by the level and action of climate factors and the hereditary specifics of the varieties.

For the varieties from the Iaşi vineyard assortment (Aligoté, Fetească albă, Fetească regală, Sauvignon blanc, Chardonnay, Muscat Ottonel şi Chasselas doré), the debudding started in the second decade of April and lasted until the first decade of May. The useful heat balance conditioning the debudding phenophase varied from one year to another, with values ranging between 15.0 °C for the early varieties and 63.2 °C for the late ones (Table 7).

Table 7. Evolution of vegetation phenophases

Year	Debudding		Blooming		Ripening		Maturation	
	Date	Σ t°u	Date	Σ t°u	Date	Σ t°u	Date	Σ t°u
2000	17-April	47.4	27-May	279.9	5-August	744.1	17-September	433.5
2001	21-April	25.4	9-June	230.0	6-August	627.7	17-September	386.6
2002	24-April	32.1	2-June	282.9	1-August	697.8	10-September	388.7
2003	29-April	30.9	3-June	374.7	27-July	608.5	14-September	455.8
2004	23-April	26.8	10-June	263.0	28-July	519.0	20-September	450.5
2005	23-April	30.3	15-June	304.8	10-August	618.4	10-September	289.3
2006	25-April	39.9	13-June	249.5	5-August	628.1	20-September	403.5
2007	12-April	18.4	2-June	330.3	23-July	708.9	3-September	512.7
2008	14-April	25.5	7-June	253.3	2-August	611.7	15-September	458.7
2009	21-April	40.8	2-June	242.7	29-July	691.2	9-September	446.9
2010	25-April	19.5	6-June	278.9	25-July	589.7	9-September	523.6
2011	28-April	34.5	5-June	270.6	2-August	631.7	20-September	497.1
2012	25-April	63.2	25-May	257.6	23-July	752.3	2-September	546.7
2013	22-April	23.9	21-May	283.4	20-july	564.7	10-September	528.7
2014	20-April	18.6	4-June	248.9	3-August	633.3	22-September	513.3
2015	21-April	27.7	3-June	299.5	4-August	768.4	12-September	483.5
2016	10-April	42.9	2-June	255.4	5-August	792.1	10-September	419.1
2017	12-April	19.0	2-June	250.8	31-July	686.2	11-September	500.5
2018	14-April	60.1	21-May	267.4	21-July	665.2	13-September	628.3
2019	22-April	15.0	7-June	292.2	2-August	683.3	13-September	500.5
2020	13-April	18.7	8-June	243.0	27-July	552.4	03-September	409.7

In recent years, following the increase in air temperature values, we have noticed a tendency towards a delayed debudding and a shortening of the period of its development. Thus, in the dry years, implicitly in years characterised by milder winters, debudding took place in the first and second decade of April (2000, 2007, 2008, 2016, 2017, 2018, 2020).

Climate change has made it increasingly difficult to accurately predict the beginning of the flowering phenophase. The increase in the amount of average useful temperatures hastened its onset, especially in the period 2007-2019, when flowering took place starting with the last decade of May. The multiannual phenological observations regarding the varieties in the assortment confirm that the earliest flowering started at the end of May in the years 2000, 2012, 2013 and 2018, and in the other years in the first and second decade of June. It was noticed that even in the case of this phenophase, there is an outrun tendency due to the increasing values of air temperatures and a shortening of its development.

Due to the high values of air temperature, the large number of days with maximum temperatures above 30 °C in July and August and the soil water deficit, there was an obvious outrun tendency in the ripening phenosis. Thus, for the analysed period, grape ripening occurred between 20 July and 10 August and lasted between 5 and 19 days, depending on the variety and year. In the dry years, the ripening started faster, respectively in the last decade of July (2003, 2004, 2007, 2009, 2010, 2012, 2013, 2017, 2018 and 2020), and it lasted for a shorter time; in rainy years (2001, 2005), it started in the second decade of August. The useful heat balance conditioning the ripening phenophase ranges between 519.0 °C and 792.1 °C (Table 7).

The full maturity of the grapes has evolved depending on the variety and climate conditions of the year. For the analysed period, the varieties from the Iaşi vineyard assortment reached full maturity at the earliest in the first decade of September. The useful heat balance that conditioned the maturation phenophase ranges between 289.3 °C and 628.2 °C.

In the dry years, the high values of the temperatures, corroborated with the soil water deficit, deepened the atmospheric and pedological drought with unfavourable effects on the vegetation condition of the stumps and, implicitly, on grape productions, which fluctuated from one year to another (Figure 5).

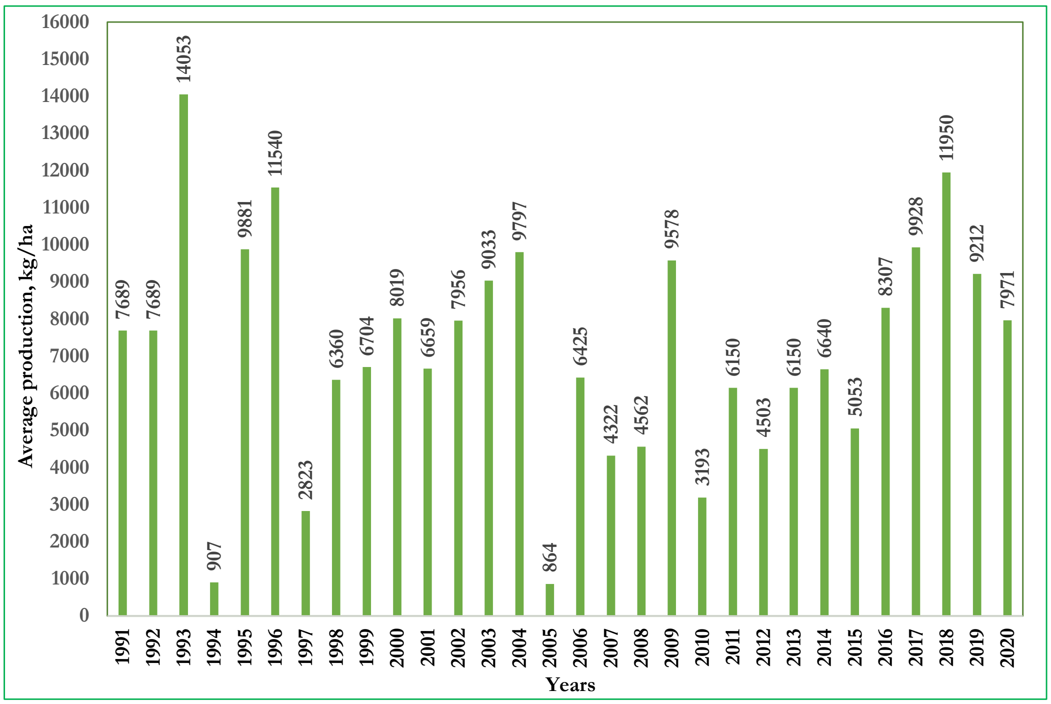

Figure 5. Average grape production (kg/ha)

It was found that its effect is felt especially in the second or third year of the drought period, and the restoration of the productive potential of the vineyard lasted for two to three years; thus, in the following years, no grape production was obtained to cover the expenses incurred. The varieties from the assortment registered productions below their productive potential in the years: 1994, 1997, 2005, 2007, 2008, 2010, 2012, and 2015.

Conclusions

The analysis of the ecoclimate conditions specific to the Iaşi vineyard between 1991 and 2020, compared to the multiannual values, pointed to an increase in the thermal regime and a decrease in the hydric one, which is often unevenly distributed, represented by torrential rains alternating with long periods of drought. The average annual temperature between 1991 and 2020 showed an obvious upward trend, from 8.6 °C in 1996 to 12.0 °C in 2020, with an amplitude of 3.4 °C. During the analysed interval, an alternation of periods was noticed, a colder one between 1991 and 2006, and a warmer one between 2007 and 2020. The evolution of precipitations shows deviations from the average with different meanings and values, pointing to a decreasing trend at the end of the analysed interval. Thus, of the 30 years studied, only 6 were normal; most of the years (13) they were dry, very dry and extremely dry. The small amounts of precipitation, corroborated with the high temperatures, led to the marked decrease in the values of the soil available moisture in certain periods, far below the optimal ones for vineyard culture. The years 2015 and 2020 were marked by extremely low values, in all months of the growing season and throughout the depth of the soil profile (0-150 cm). The values of the synthetic ecological indicators from the Copou-Iaşi wine centre indicate a favourable, balanced area for the vine culture, very suitable for quality white wine varieties, and moderately suitable for red wine varieties. The multiannual phenological observations regarding the varieties in the assortment show that, in the dry years, implicitly in those with milder winters, debudding occurred in the first and second decade of April, blooming took place at the end of May at the earliest and, in the other years, in the first and second decades of June; ripening started in the last decade of July, and full maturity in the first decade of September at the earliest. The influence of climate factors was directly reflected in grape production during the dry years, which were below the biological potential of the varieties cultivated in the Copou Iaşi wine centre.

Authors' Contributions

Conceptualization, G.Z., V.C. and A.N.; methodology, G.Z. and A.N.; validation, G.Z., D.D. and A.N.; formal analysis, G.Z..; investigation, A.N and A.D.G.; writing—original draft preparation, G.Z.; project administration, D.D.; funding acquisition, D.D. All authors read and approved the final manuscript.

Acknowledgements

This work was supported by the Ministry of Agriculture and Rural Development – Romania, under the Sectorial Plan the ADER 2022, PS 7.3.3 "Research on the classification of vine varieties for table grapes and wine in the context of climate change in wine-growing areas"

Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

References

Branas J (1974). Viticulture. Imprimérie Dehan, Montpellier.

Bucur GM, Cojocaru GA, Antoce AO (2019). The climate change influences and trends on the grapevine growing in Southern Romania: A long-term study. In: BIO Web of Conferences 15:01008. *https://doi.org/10.1051/bioconf/20191501008*

Bucur GM, Dejeu L (2014). Influence of climate variability on growth, yield and quality of grapes in the south part of Romania. Agriculture for Life, Life for Agriculture 58(2):133-138.

Busuioc A, Dobrinescu A, Bîrsan MV, Orzan A (2015). Spatial and temporal variability of climate extremes in Romania and associated large - scale mechanisms. International Journal of Climatology 35:1278-1300. *https://doi.org/10.1002/joc.4054*

Canarache A (1964). Metode de cercetare a solului [Soil research methods]. Editura Academiei PRP, Bucuresti.

Chiriac C (2007). Influența schimbărilor climatice asupra mediului în zona podgoriei Cotnari. [The influence of climate change on the environment in the Cotnari vineyard area]. Analele Universității „Ştefan cel Mare" Suceava, Secțiunea Geografică, Anul XVI:215-222.

Cichi D, Costea DC, Olteanu I, Mărăcineanu LC, Capruciu R (2007). Modifications climatiques - effets sur la vigne cultivee au sud-ouest de la Roumanie, colloque Réchauffement climatique, quels impacts probables sur les vignobles? [Climate change - effects on vines grown in southwestern Romania, Global Warming conference, what are the likely impacts on vineyards?] Dijon.

Constantinescu Gh (1945). Criterii noi în stabilirea epocilor de coacere la struguri [New criteria in establishing the grape ripening times]. România Viticolă 7-9.

Constantinescu Gh, Donaud A, Dragomir E (1964). Determination de la valeur de l'indice bioclimatique de la vigne pour les principaux vignobles de la R.P. Roumanie [Determination of the value of the vine bioclimatic index for the main vineyards of the R.P. Roumanie]. Revue Roumaine de Biologie, série de Botanique 9:35-40.

De Martonne E (1926). Une nouvelle fonction climatologique: L'indice d'aridité [A new climatological function: The aridity index]. La Meteorologie 449-458.

Dejeu L, Patic M, Mereanu D, Savu (Bucur) GM, Gutue C (2008). Impact of climate change on grapevine culture durability. 31st World Congress of Vine and Wine, Verona, Italia. Volume: 6th General Assembly of the OIV, published on CD-ROM.

Dobrei AG, Dobrei A, Nistor E, Sala F, Mălăescu M, Drăgunescu A, Camen D (2015). Research concerning the qualitative potential of the wines obtained from different grape-growing ecosystems. Journal of Horticulture, Forestry and Biotechnology 19:103-107.

Dumitrescu A, Bojariu R, Birsan MV, Marin L, Manea A (2015). Recent climatic changes in Romania from observational data (1961-2013). Theoretical and Applied Climatology 122:111-119. *https://doi.org/10.1007/s00704-014-1290-0*

Emadodin I, Corral DEF, Reinsch T, Kluß C, Taube F (2011). Climate Change effects on temperate grassland and its implication for forage production: a case study from Northern Germany. Agriculture 11:232. *https://doi.org/10.3390/agriculture11030232*

Georgakopoulos P, Travlos IS, Kakabouki I, Kontopoulou CK, Pantelia A, Bilalis DJ (2016). Climate change and chances for the cultivation of new crops. Notulae Botanicae Horti Agrobotanici Cluj-Napoca 44(2):347-353. *https://doi.org/10.15835/nbha44210533*

Huglin P (1986). Biologie et écologie de la vigne. Edition Payot, Lausanne.

Iliescu M, Tomoiagă L, Chedea VS, Pop EA, Sîrbu A, Popa M, Călugăr A, Babeş AC (2019). Evaluation of climate changes on the vine agrosystem in Tarnave vineyard. Journal of Environmental Protection and Ecology 20(4):1754-1760.

Iliescu M, Farago M, Comșa M, Ranca A, Boloș P, Babeș A (2009). Evaluation of the climate changes in Târnave and Murfatlar vineyards. Bulletin of University of Agricultural Sciences and Veterinary Medicine, Horticulture 66(1):662.

Irimia LM, Patriche CV (2019). Potențialul viticol al podgoriilor și evoluția acestuia în contextul schimbărilor climatice [The viticultural potential of vineyards and its evolution in the context of climate change]. Ion Ionescu de la Brad, Iași, Romania.

Irimia LM, Patriche CV, Murariu OC (2018b). The impact of climate change on viticultural potential and wine grape varieties of a temperate wine growing region. Applied Ecology and Environmental Research 16:2663-2680. *http://dx.doi.org/10.15666/aeer/1603_26632680*

Irimia LM, Patriche CV, Quenol H (2014). Analysis of viticultural potential and delineation of homogeneous viticultural zones in a temperate climate region of Romania. Journal International des Sciences de la Vigne et du Vin 48:145-167. *https://doi.org/10.20870/oeno-one.2014.48.3.1576*

Irimia LM, Patriche CV, Roșca B (2018a). Climate change impact on climate suitability for wine production in Romania. Theoretical and Applied Climatology 133:1-14. *https://doi.org/10.1007/s00704-017-2156-z*

Jones GV, Webb LB (2010). Climate change, viticulture, and wine: Challenges and opportunities. Journal of Wine Research, 21(2):103-106. *https://doi.org/10.1080/09571264.2010.530091*

Jones GV, White MA, Cooper OR, Storchmann K (2005). Climate change and global wine quality. Climatic Change 73:319-343. *https://doi.org/10.1007/s10584-005-4704-2*

Laget F, Tondut JL Deloire A, Kelly TM (2008). Climate trend in a specific Mediterranean viticultural area between 1950 and 2006. Journal International des Sciences de la Vigne et du Vin 42(3):113-123. *https://doi.org/10.20870/oeno-one.2008.42.3.817*

Lorenz DH, Eichhorn KW, Bleiholder H, Klose R, Meier U, Weber E (1995). Growth stages of the grapevine: Phenological growth stages of the grapevine (*Vitis vinifera* L. ssp. *vinifera*)-Codes and descriptions according to the extended BBHC scale. Australian Journal of Grape and Wine Research 1:100-103. *https://doi.org/10.1111/j.1755-0238.1995.tb00085.x*

Nistor E, Dobrei AG, Dobrei A, Camen D (2019). Growing season climate variability and its influence on Sauvignon blanc and Pinot gris berries and wine quality: study case in Romania (2005-2015). South African Journal for Enology and Viticulture 39(2):196-207. *https://doi.org/10.21548/39-2-2730*

Onache PA, Sumedrea DI, Florea A, Tănase A (2020). The influence of climatic conditions on oenological parameters of some wine cultivars from different Romanian vineyard. Romanian Journal of Horticulture 1:103. https://doi.org/10.51258/RJH.2020.14

Piña-Rey A, González-Fernández E, Fernández-González M, Lorenzo MN, Rodríguez-Rajo FJ (2020). Climate Change Impacts Assessment on Wine-Growing Bioclimatic Transition Areas. Agriculture 10(12):605. *https://doi.org/10.3390/agriculture10120605*

Pircalabu L, Tudorache A (2014). The identification of the climatic profiles in the viticultural area Doc Dealu Mare-Valea Calugareasca. The database associated to the climatic profile; Scientific Papers, Series B, Horticulture 58:195-200.

Piticar A, Ristoiu D (2012). Analysis of air temperature evolution in north-eastern Romania and evidence of warming trend. Carpathian Journal of Earth and Environmental Sciences 7 (4):91-106.

Ranca A, Boloș P, Guluță E (2008). Climate changes of the last 10 years in the Murfatlar vineyard and their influence on the behaviour of the specific grapevine varieties of this vineyard. 31st World Congress of Vine and Wine, Verona, Italy. Volume: 6th General Assembly of the OIV, published on CD-ROM.

Sandu I, Mateescu E, Vatamanu VV (2010). Schimbari climatice in Romania si efectele asupra agriculturii [Climate change in Romania and the effects on agriculture], Editura SITECH, Craiova.

Seguin B., De Cortazar IG (2005). Climate warming: Consequences for viticulture and the notion of 'terroirs' in Europe. Acta Horticulturae 689(689):61-70. *https://doi.org/10.17660/ActaHortic.2005.689.3*

Selyaninov G (1928). About the agricultural evaluation of the climate. Proceedings on Agricultural Meteorology 20:177–185.

Teodorescu St, Popa AI, Sandu GHN (1987). Oenoclimatul României [The oenoclimate of Romania],. Editura Ştiinţifică şi Enciclopedică, Bucureşti.

Van Leeuwen C, Darriet P (2016). The impact of climate change on viticulture and wine quality. Journal of Wine Economics 11(1):150-167. *https://doi.org/10.1017/jwe.2015.21*

Vasile A, Zaldea G, Damian D (2010). The influence of climatic changes on the dynamics of the vegetation phenophases in the vine varieties cultivated in Copou vine growing center of Iaşi. Lucrări Ştiinţifice Seria Horticultură U.S.A.M.V. Iaşi, Editura "Ion Ionescu de la Brad" 53(2):407-412.

White MA, Diffenbaugh NS, Jones GV, Pal JS, Giorgi F (2006). Extreme heat reduces and shifts United States premium wine production in the 21 st century. Proceedings of the National Academy of Sciences 103(30):11217-22. *https://doi.org/10.1073/pnas.0603230103*

Zaldea G, Nechita A, Damian D, Alexandru LC (2017). Dynamics of soil moisture in vineyards under water and thermal stress conditions. Lucrări Ştiinţifice Seria Horticultură U.S.A.M.V. Iaşi, Editura "Ion Ionescu de la Brad" 60 (2):197-202.