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

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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 ecoclimatic 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
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; Busuioceanu 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; Pircălabu 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 x 6 | Branas, 1974 |
| The vine bioclimatic index (Ibcv) | Ibcv= [(I x ∑ta °C)/(Pg x Ndg)]/10 | Constantinescu et al., 1964 |
| The oenoclimatic 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 |

∑ta – active heat balance (sum of average temperatures >10 °C); ∑tu – 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:

\[ \text{Macc} = \text{M% vol} - \text{WC} \]  

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:

\[ \text{UWC} = \text{FC} - \text{WC} \]  

where FC is the field water capacity for the soil

**Productive parameters**

The climate study is completed by observations regarding the development of vegetation phenophses 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.
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 ($\Sigma t°a$), the useful heat balance ($\Sigma t°u$), 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  | lbcv | lAOe | 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  | 4554.5 | 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 oenoclimatic 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.

| Year | Depth, cm | Available moisture (%) from the vegetation period | Year | Depth, cm | Available moisture (%) from the vegetation period |
|------|-----------|--------------------------------------------------|------|-----------|--------------------------------------------------|
| 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 și 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).

| Year | Debudding | Blooming | Ripening | Maturation |
|------|-----------|----------|----------|------------|
|      | Date      | Σ t'υ    | Date      | Σ t'υ     | Date       | Σ t'υ    | Date       | Σ t'υ    |
| 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     | 20-September| 403.5   |
| 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)](image)

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.

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Conflict of Interests

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

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