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Effect of the Forecast Air Temperature Change on the Water Needs of Vines in the Region of Bydgoszcz, Northern Poland

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Abstract: The climatic changes observed in Poland are manifested by an increase in air temperature, but not an increase in rainfall, which causes an increase in the water needs of plants, and hence the necessity to develop irrigation systems for crops. The aim of this study was to assess the water needs of grapevines in 2021–2050 in the Bydgoszcz region (northern Poland), an area with high requirements for supplementary irrigation. The calculations were based on the expected changes in air temperature according to the climate change scenario for Poland: the 4th Intergovernmental Panel on Climate Change—Special Report on Emissions Scenarios: balanced scenario (A1B). The average monthly temperature in 1981–2010 was used in the calculations. The water needs of grapevines were estimated using the reference evapotranspiration calculated using the Blaney–Criddle equation, and then using the crop coefficient and potential (crop) evapotranspiration. It was found that in 2021–2050, the water needs of grapevines, both during the growing season (May–September) and during the irrigation period (June–August), will increase by 6%. The highest and significant increase in water needs, by 10%, should be expected in August. The estimated increase in water needs of grapevines indicates the need to development sustainable irrigation systems for vineyards in northern Poland.

Keywords: climate change; evapotranspiration; irrigation; precipitation; vineyard; *Vitis vinifera* L.

1. Introduction

In Poland, there has currently been a significant increase in interest in the cultivation of grapevines (*Vitis vinifera* L.) [1]. Undoubtedly, the progressive process of global warming observed in the last century has contributed to changes in the regionalization of crops of this thermophilic species [2]. New vineyards are often planted in areas where they already existed in the distant past. Viticulture in Poland has a very long tradition, as it came to our country along with Christianity [3]. About a thousand years ago, thermophilic plants such as grapevines were successfully cultivated in Poland [4]. The results of research in the field of climate history indicate that the air temperature and precipitation totals in the 10th century in Poland were comparable to those in recent years [5]. According to Woś [6], the air temperature in Europe in the 11th century was probably higher than the average temperature in the previous centuries, and the 12th and 13th centuries were considered the warmest period in the history of mankind. Between the 10th and 15th centuries, air temperature in the northern hemisphere rose by an average of half a degree compared to antiquity. Higher air temperature was responsible for the development of viticulture in countries remote from the Mediterranean [7]. The relatively high air temperature in the 11th, 12th, and 13th centuries was favorable for the cultivation of grapevines in Poland [8]. In the 11th century, most vineyards were located in the region of Silesia and Zielona Góra. Additionally, grapevines were grown in the area of Poznań, Płock, Włocławek and Toruń, and even in areas further north. These are lowland regions located in western and central Poland, in the Kuyavian–Pomeranian, Greater Poland, and Masovian provinces, i.e., in the zone of strong maritime climate influence with the lowest average annual rainfall and the highest average annual air temperature in Poland. These are the areas with the highest climatic irrigation requirements in Poland (high rainfall deficiencies, negative values of the climatic water balance), and at the same time, with very small hydrological possibilities (low flows in watercourses) [3].

Grapevine growing in Poland is currently of little economic importance. However, it is accompanied by a high level of public interest, which contributes to the rapid increase in the cultivation area of this species [9]. The reasons for the growing interest in viticulture in Poland are also the significant advances in the breeding program of new grapevine cultivars with low susceptibility to fungal pathogens and frost damage, as well as the gradual warming of the Polish climate, which is particularly conducive to the cultivation of grapevines [3,9,10].

According to Łabędzki [11,12], in accordance with the climate change scenario for Poland, the 4th Intergovernmental Panel on Climate Change—Special Report on Emissions Scenarios (IPCC—SRES: A1B) "balanced scenario" [13], at the end of the 21st century, it can be expected that air temperature in Poland will increase by approx. 2 °C to 4 °C. Compared to the years 1961–1990, the average annual air temperature in Poland in 2011–2020 increased from 7.6 °C to 9.1 °C, i.e., by 1.5 °C. In turn, the average air temperature of the summer season (June–August) in 2011–2020 was 18.5 °C and was by as much as 1.9 °C higher than in 1961–1990 [14]. Meanwhile, the average air temperature in summer 2021 was 19.1 °C and was 1.1 °C higher than the long-term average temperature value for the summer months in 1991–2020 [15]. According to the climate change scenario in the years 2011–2050, developed by the regional model of climate change for Poland RM5.1 with boundary conditions used from the global circulation model ARPEGE (Action de Recherche Petite Echelle Grande Echelle), a clear upward trend in air temperature is expected in April and June, as well as in August by 0.5–0.7 °C per decade^{-1} and generally throughout the growing season by 0.3 °C per decade^{-1} (compared to the reference years 1971–2000) [16]. Moreover, according to the same climate model, the amount of precipitation during the vegetation period is projected to decrease by about 55 mm. The increase in average rainfall will be visible in April and May, with a slight decrease in June. However, in the summer months (July–September), a significant drop in precipitation is expected [17]. The meteorological data cited above confirm a clear gradual increase in air temperature in Poland, which has been observed particularly over the last dozen years.

The enormous impact of climate change, mainly air temperature increase, on the development of vineyards in Europe was summarized by Droulia and Charalampopoulos [18]. Research published by Duchene and Schneider [19] and Duchene and Pieri [20] focused on the impact of climate warming on the advance of phenological stages of grapevines in France. They investigated the effect of climate change on earlier ripening of fruit that occurs under warmer climatic conditions. Climate changes have significantly contributed to the acceleration of the appearance of subsequent phenological stages of grapevines also in central Poland, which significantly affects the yield and fruit quality [21]. According to Neumann and Matzarakis [22], in Germany by the end of the 21st century, as a result of climate change, there is a chance to expand the regions suitable for wine-growing, as well as to expand the list of thermophilic grape cultivars that can be grown in this country. Then, the simulation by Eccel et al. [23] predicts that in Italy, as a result of global warming, grapevine growing will be extended to some regions of the Italian Alps where no vineyards have yet been planted. Finally, Bonfante et al. [24] carried out research on a new dynamic zone procedure for grapevine cultivation in Italy. The aim of his work was to integrate the impact of climate warming on the fruits' quality responses and evaluate land resilience.

Although the grapevine is a drought-resistant plant [25], the forecasted climate changes related to warming and falling rainfall will gradually increase the water needs of this species [26–29], indicating the necessity of expansion of irrigation systems. Therefore, in recent years, various irrigation techniques have been implemented in production vineyards all over the world, and especially in Europe, which significantly improve the quality of the fruits and increase the yield [30–38]. According to Intrigliolo et al. [39], vineyard irrigation treatments may increase fruit yield by up to 58%. Nevertheless, in the process of supplementary irrigation of the grapevine, it is necessary to take into account many biotic and abiotic factors that affect the yield and quality of fruit [40,41]. It was found that cultivar, exposure time to water limitations and rootstocks, as well as climate, leaf surface to yield ratio, and training systems also have a large influence on the composition of must and wine [41]. According to Cancela et al. [40], to successfully manage precision irrigation systems for grapevines, it is important to understand their effects on plant and soil physiology in vineyards, as well as on fruit yield and quality.

The objective of this research was to estimate the probable water needs of grapevines in the years 2021–2050 in the region of Bydgoszcz, located in northern Poland. The calculations were based on the predicted changes in air temperature in accordance with the climate change emission scenario for Poland: the 4th Intergovernmental Panel on Climate Change—Special Report on Emissions Scenarios: balanced scenario (IPCC—SRES: A1B) [13,16,17].

2. Materials and Methods

2.1. Experimental Site

The assessment of the water needs of the grapevines was carried out for the region of Bydgoszcz, located in northern Poland (Figure 1). This region has the highest requirements for supplementary irrigation in Poland during the growing season. In the region of Bydgoszcz, there is a clear differentiation between the flat and lowland southern part and the northern part, which is slightly more diversified in terms of terrain (the predominance of terrain elevations) [42–47].

The resources of surface water flowing in the region of Bydgoszcz are the lowest in Poland, and in 2019, amounted to 1,830,200,000 m^3. These resources cover an area of 17,320.9 km^2 with an annual rainfall of around 550 mm and no inflow of waters from outside this area. In the Kuyavian–Pomeranian Province, there are large exploitation resources of groundwater, which at the end of 2019, amounted to 1673.8 hm^3 per year and were higher by 25.3 hm^3 than in 2018 [48].

Most of the region of Bydgoszcz is suitable for vine planting and viticulture, as a large part of the region is located within the isoline of the sum of active temperatures (SATs) of 2500 °C, which define areas suitable for viticulture (Figure 2). In the case of grapevines, SATs are calculated as the sum of the average daily temperature above 10 °C, which is the basic climatic criterion for delimiting areas suitable for growing this species [49,50]. In the years 1981–2000, in central Poland, the average value of SAT reached almost 2500 °C; in 2003, the SAT exceeded 2700 °C, and in 2006, the SAT was as much as 2900 °C [21]. On the other hand, in north-eastern Poland, the SAT value was around 2200 °C, in the highlands of the central part of the country the SAT was 2600 °C, and in the south-west and west Poland, the SAT was 2700 °C [3,51].

Figure 1. Geographical location of the Bydgoszcz region in Poland and Europe.

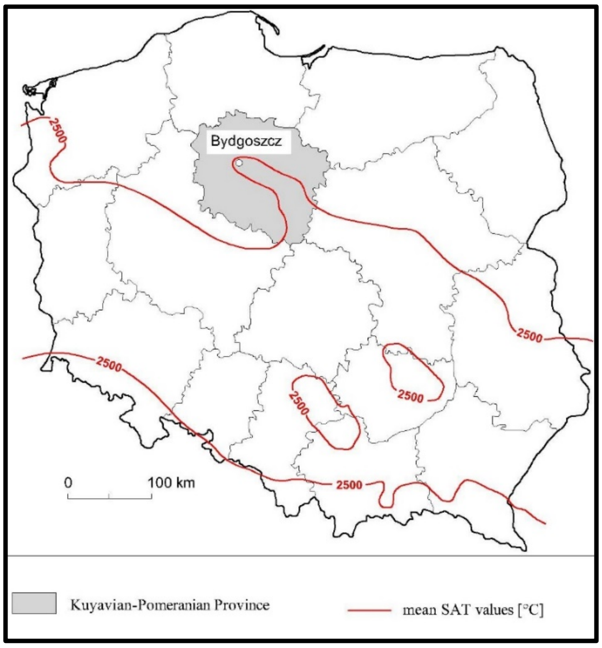

Figure 2. The borders of the Kuyavian–Pomeranian Province against the background of areas suitable for viticulture in Poland, which are limited by the isoline of the sum of active temperatures (SAT) 2500 °C.

2.2. Grapevine Water Needs Calculation

The calculations performed to determine the water needs of the grapevines (*Vitis vinifera* L.) were made on the basis of reference evapotranspiration. Then, using the crop coefficient, the potential (crop) evapotranspiration was assessed. Reference evapotranspiration is an agrometeorological parameter commonly used in irrigation planning and management [52,53]. The reference evapotranspiration was determined according to the Blaney–Criddle formula that was modified by Żakowicz [54] in order to adjust the calculations to the conditions of Poland. According to FAO (Food and Agriculture Organization), the Blaney–Criddle formula is recommended for use in calculating water needs when only temperature data are available [55,56], as in this study. Thus, the Blaney–Criddle formula is widely used to calculate reference evapotranspiration in studies with limited meteorological data [57–59]. In this study, the reference evapotranspiration was calculated using the following Formula (1):

$$\mathrm{ETo} = \mathrm{n} \times [\mathrm{p} \times (0.437 \times \mathrm{t} + 7.6)–1.5] \quad (1)$$

where:

ETo = reference evapotranspiration (mm);
n = number of days in the month;
p = coefficients of evaporation according to Doorenbos and Pruitt [55] for the individual months of the grapevine growing season;
t = monthly average air temperature (°C).

Using the reference evapotranspiration and crop coefficient, the potential (crop) evapotranspiration of the grapevines was calculated using the following Formula (2):

$$\mathrm{ETp} = \mathrm{ETo} \times \mathrm{kc} \quad (2)$$

where:

ETp = potential (crop) evapotranspiration (mm);
ETo = reference evapotranspiration (mm);
kc = crop coefficient being the ratio of evapotranspiration measured in conditions of sufficient soil humidity to reference evapotranspiration according to Łabędzki [60].

When calculating the reference evapotranspiration, the crop coefficient (kc) was used for the subsequent months of the vegetation period (May–September) [55]. Crop coefficient values are adjusted to the reference evapotranspiration calculated by the Blaney–Criddle equation. Plant coefficient expresses the intensity of the influence of a group of plant factors related to the plant development stage on evapotranspiration in the conditions of absence of soil moisture (Table 1).

Table 1. Values of crop coefficients for grapevines [55].

Characteristic	Months of Grapevine Growing Season				
	May	**June**	**July**	**August**	**September**
Crop coefficient	0.45	0.70	0.85	0.90	0.85

Formula (2) has been used to evaluate the crop evapotranspiration in many scientific studies published, inter alia, by Łabędzki [60], Doorenbos and Kassam [61], Mendez-Costabel et al. [62], and Ewaid et al. [63]. However, this equation is also used to assess crop transpiration in the AquaCrop model developed by the Land and Water Division of Food and Agriculture Organization of the United Nations [64].

The 30-year period from 1981 to 2010 was used as a reference, using the values of the average monthly air temperature for Bydgoszcz according to measurements carried out at the station of the Institute for Land Reclamation and Grassland Farming at Falenty. The period from 1 May to 30 September was assumed to be the growing season of the grapevine, while the irrigation period was assumed to be from 1 June to 31 August, and August was considered the month when the grapevines' water needs are the highest. In the calculations carried out in this study, the forecast values of the average monthly air temperature for the region of Bydgoszcz in the years 2021–2050 (forecast years) were used according to the climate change emission scenario for Poland, i.e., 4th IPCC—SRES: A1B [13,16,17]. The Special Report on Emissions Scenarios has defined possible emission scenarios, where the climate change scenario for Poland is "balanced scenario" (SRES: A1B). A1 emission scenarios cover three (A1FI, A1T, A1B) different ways of technological changes in the energy system, differing in terms of technological emphasis. In the A1B scenario, a "balance" is projected between all energy sources. This is a situation with little reliance on one particular energy source [13].

2.3. Statistical Analysis

The study uses statistical methods and statistical indicators, and results in presentation methods commonly used in agroclimatology [65,66]. The results of the grapevines' water needs calculations were statistically developed by determining the mean, normal (median), maximum and minimum, as well as the standard deviation and mean coefficient of variation. The calculations were made in Microsoft Excel 2013 software. Using the linear regression equations, the potential trends in changes in the value of the grapevines' water needs in both compared periods, i.e., in the reference years (1981–2010) and the forecast years (2021–2050), were also determined. The calculations were completed with a linear regression analysis. According to Łabędzki et al. [67], the reference evapotranspiration in the forecast years was calculated using simple linear regression equations between air temperature and the Penman–Monteith reference evapotranspiration. Linear regression equations were based on data from reference years. The correlation and determination coefficient were also assessed. The significance of the correlation coefficients, with a sample size of $n = 30$, was determined at the significance level of $p = 0.05$ [68].

3. Results and Discussion

In the light of the progressive climate change, mainly related to warming and the lack of an increase in the amount of rainfall, the question arises how these phenomena will affect the water needs in plant production. This study is an attempt to analyze the impact of temperature rise on the cultivation of grapevines in the years 2021–2050 in the northern part of Poland. The research was carried out on the basis of the current climate and the expected changes in air temperature forecasted by the emission scenario for Poland SRES: A1B [13,16,17].

Table 2 presents the basic statistical indicators of grapevine evapotranspiration, such as mean, minimum, maximum, and median. It was found that the values of these indicators in the reference years (1981–2010) were lower than in the forecast years. Finally, it was also found that the values of the studied indicators for grapevines in northern Poland in the years 1981–2010 were lower compared to the corresponding indicators for grapevines in western (1981–2010) and central Poland (1981–2020) [28,29], which proves a higher water deficit in the region of Bydgoszcz.

The standard deviation calculated in these studies is a measure of the variability of the individual monthly totals of the grapevines' water needs. The value of standard deviation ranged between 3.4 mm and 7.4 mm in the reference years and from 4.5 mm to 7.2 mm in the forecast years (Table 2). In the reference years, the lowest values of standard deviation occurred in May, and the highest in July. In the forecast years, the lowest variation in the individual monthly totals of the grapevines' water needs was calculated in September, and the highest in June. For comparison, in western (1981–2010) and central (1981–2020) Poland, the highest values of variability of individual monthly totals of grapevine water needs were also recorded in July [28,29].

Table 2. Statistical indicators of grapevine evapotranspiration in individual months of the growing season (May–September) as well as during the irrigation period (June–August) and growing season in the reference years (1981–2010) and in the forecast years (2021–2050).

Indicator	Months					Irrigation Period	Growing Season
	May	June	July	August	September		
1981–2010							
Mean (mm)	47.8	87.4	115.5	104.0	59.6	354.7	414.3
Minimum (mm)	39.0	80.2	102.6	91.3	50.5	328.0	385.8
Maximum (mm)	54.7	96.3	132.6	114.6	69.9	381.0	440.2
Median (mm)	48.4	88.2	115.9	104.4	59.8	356.6	414.4
Standard Deviation	3.4	4.1	7.4	5.3	4.5	12.3	14.6
Coefficient of Variation (%)	6.9	4.7	6.4	5.0	7.6	3.5	3.5
2021–2050							
Mean (mm)	45.3	88.4	120.6	113.6	68.6	367.9	436.6
Minimum (mm)	35.5	74.8	104.2	96.9	60.0	327.7	396.3
Maximum (mm)	58.3	102.3	133.6	128.3	76.2	403.6	479.8
Median (mm)	44.7	88.4	120.6	113.6	68.0	370.0	437.6
Standard Deviation	5.6	7.2	7.1	7.0	4.5	19.8	22.2
Coefficient of Variation (%)	12.4	8.2	5.9	6.2	6.5	5.4	5.1

The mean coefficient of variation assessed in this study is a measure of the relative variability of the grapevines' water needs. It was noticed that the values of the coefficient of variation did not show large differences between individual months of the grapevine growing season, both in the reference and the forecast years (Table 2). The variability coefficient ranged from 4.7% to 7.6% in the reference years and from 5.9% to 12.4% in the forecast years. The highest value of the relative variability of the grapevines' water needs in the reference years was calculated in September, while in the forecast years in May. Additionally, in western (1981–2010) and central Poland (1981–2020), the highest values of the relative variation of grapevines' water needs were calculated in September [28,29].

Both the standard deviation and the coefficient of variation of the grapevines' water needs calculated in this study clearly show that higher values of the analyzed indicators occurred in the forecast years than in the reference years (Table 2). This dependence is visible both during the growing season, i.e., from 1 May to 30 September, and during the irrigation period, i.e., from 1 June to 31 August. Standard deviation values estimated for both the growing season and the irrigation period were over one third higher in the forecast years than in the reference years. Additionally, the coefficient of variation, both during the growing season and during the irrigation period, was about one third higher in the forecast years than in the reference years.

Table 3 and Figure 3 show the results of the correlation between the reference and forecast evapotranspiration of crops and the reference and forecast years. It was found that in the years 2021–2050, the trend of temporal variability of grapevines' water needs was significant only in August. According to the predicted increase in air temperature in Poland [16,17], in August, the grapevines' water needs will increase by 3.17 mm in each decade. It can be expected that in the period from May to July, the water needs of grapevines will increase to a much smaller and insignificant degree from 0.39 mm decade^{-1} to 1.73 mm decade^{-1}, and in September, the downward trend of -0.52 mm decade^{-1} can even be observed. The significant increase in the water needs of grapevines in August, estimated in this study, results from a significant increase in air temperature in this month (0.7 °C decade^{-1}) predicted by Bąk and Łabędzki [16,17].

Table 3. The significance of the equations of trends in water needs of grapevines and their tendencies in the reference years (1981–2010) and forecast years (2021–2050).

Month/Period	Reference Years	Forecast Years
	Linear correlation coefficient (r)	
May	0.116 ns	0.151 ns
June	0.230 ns	0.207 ns
July	0.237 ns	0.047 ns
August	0.174 ns	0.392 *
September	0.123 ns	0.100 ns
May–September	0.263 ns	0.224 ns
May–August	0.261 ns	0.274 ns
June–August	0.299 ns	0.287 ns
July–August	0.259 ns	0.251 ns
	Tendency of water needs (mm decade^{-1})	
May	0.45	0.98
June	1.09	1.73
July	2.02	0.39
August	1.06	3.17
September	0.65	–0.52
May–September	4.37	5.70
May–August	3.72	6.27
June–August	4.17	5.29
July–August	3.08	3.56

*—significant at $p = 0.05$; ns—not significant

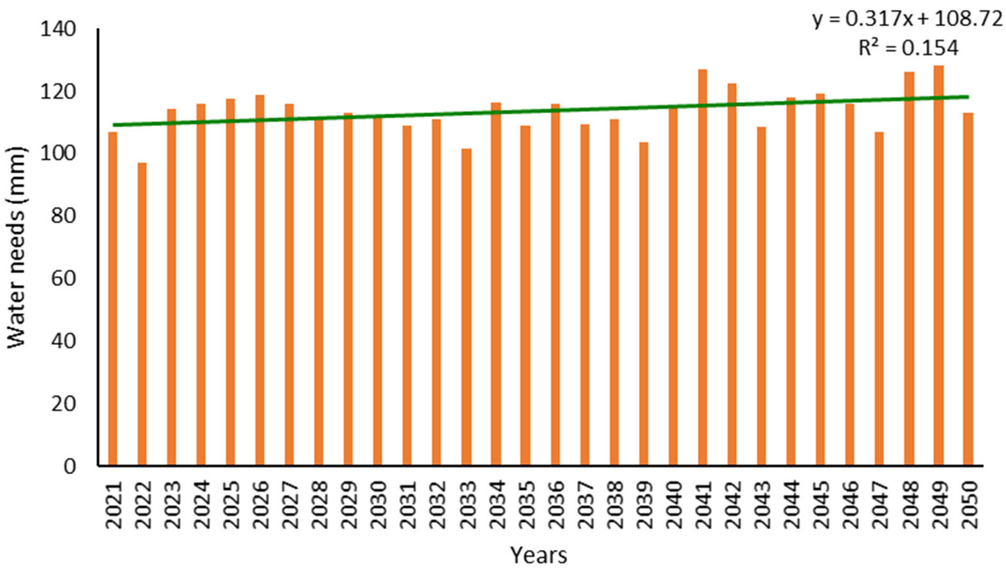

Figure 3. Time trend of grapevines' water needs in August in the forecast years (2021–2050).

Figures 4 and 5 show the grapevines' daily and monthly water needs during the growing season in the reference and forecast years, respectively. The highest water needs of grapevines, both in the reference years and in the forecast years, were calculated in July. Slightly lower values of water needs were recorded in August, and even lower in June. The lowest water needs of grapevines were calculated in May and September. With the exception of May, both the daily and monthly water needs of grapevines in the forecast years were higher than in the reference years. In western (1981–2010) and central (1981–2020) Poland, the highest daily and monthly water needs of grapevines were also recorded in July [28,29].

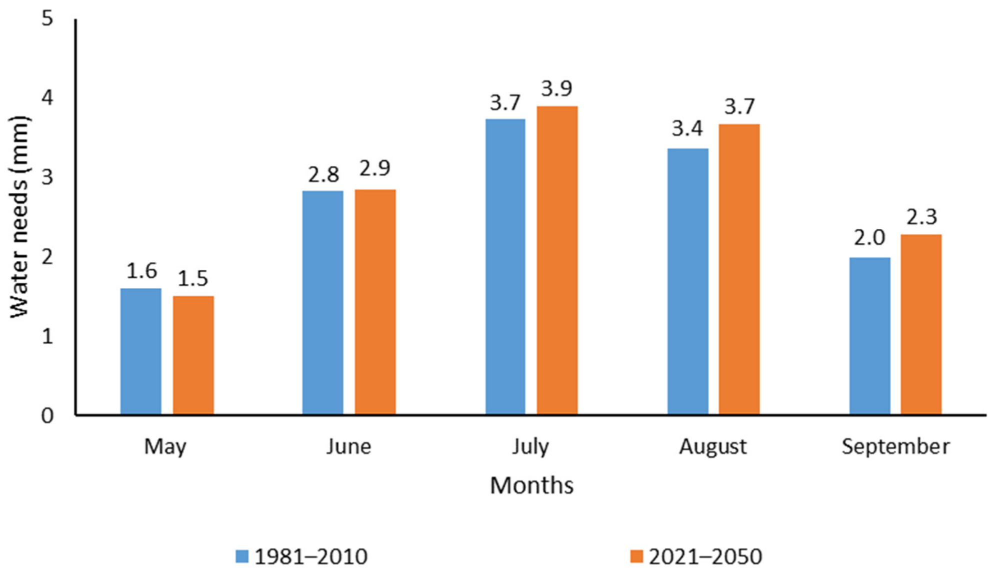

Figure 4. Daily water needs of grapevines during the growing season in the reference years (1981–2010) and in the forecast years (2021–2050).

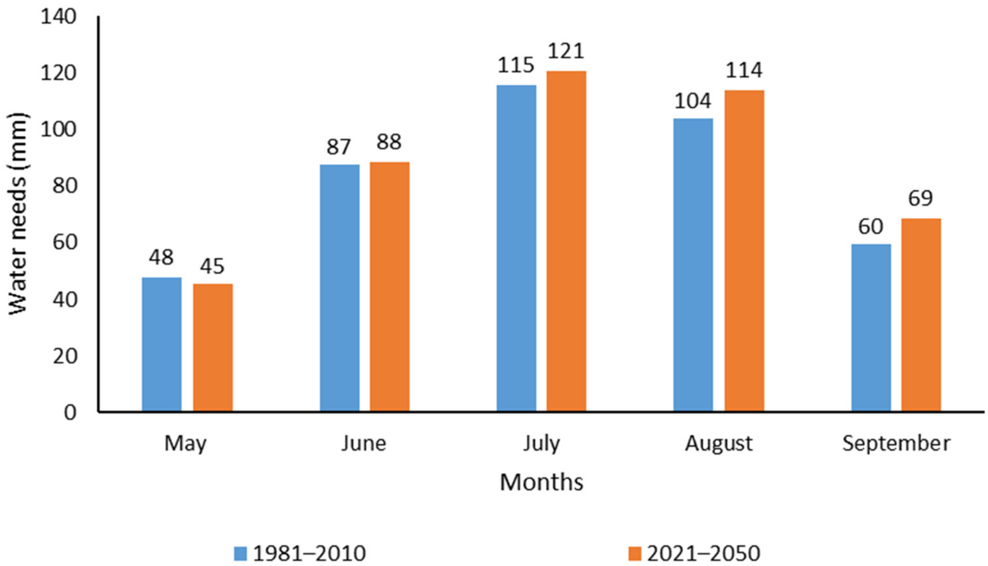

Figure 5. Monthly water needs of grapevines during the growing season in the reference years (1981–2010) and in the forecast years (2021–2050).

In the light of the anticipated climate changes, the total water needs of grapevines during the growing season in the region of Bydgoszcz will increase from 414 mm (average for the years 1981–2010) to 437 mm (average for the years 2021–2050) (Table 4 and Figure 6). For comparison, the average water needs of grapevines in western Poland in the years 1981–2010 was 438 mm [29]. In the present study, ultimately, the predicted increase in the water needs of grapevines will be 23 mm, i.e., 6%. Therefore, it is predicted that during the irrigation period, in the forecasted years, the grapevine water needs will increase from 306 mm to 323 mm, i.e., by 17 mm and by 6%. Among the considered months of the growing season, the greatest increase in grapevines' water needs by 10 mm, i.e., by 10%, will take place in August.

Table 4. Comparison of the water needs of grapevines (mm) in the reference years (1981–2010) and in the forecast years (2021–2050).

Years	Period		
	May–September	**June–August**	**August**
1981–2010	414	306	104
2021–2050	437	323	114
(2021–2050)–(1981–2010)	+23	+17	+10
Change (%)	+6	+6	+10

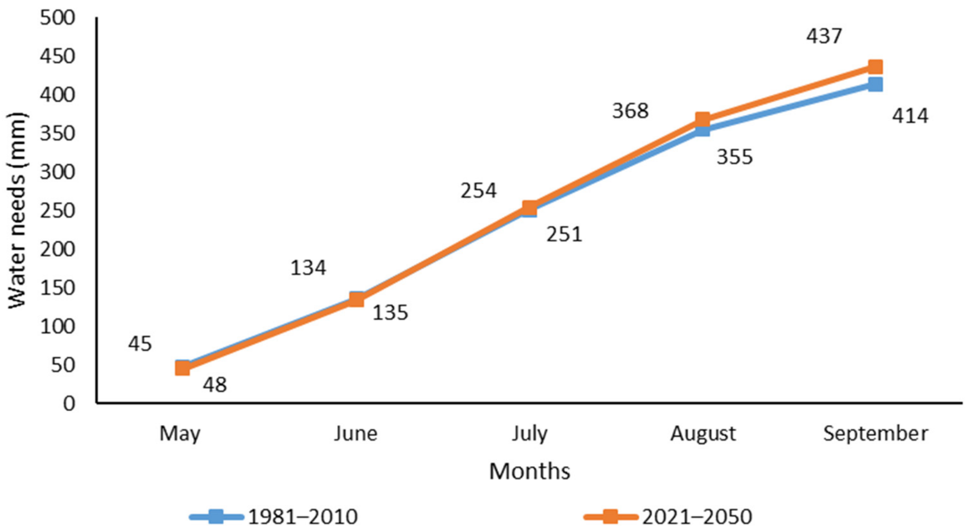

Figure 6. Cumulative sums of grapevines' water needs during the growing season (May–September) in the reference years (1981–2010) and in the forecast years (2021–2050).

In the light of the expected increase in air temperature in the region of Bydgoszcz [16,17], the rise in the water needs of grapevines in the summer (May–September) until 2050, as published by Rolbiecki and Piszczek [69], will reach the value of 68 mm. The difference between the results of previous studies [69], and the present research is that different methods were used to assess the water needs of grapevines. Additionally, in the studies reported by Rolbiecki and Piszczek [69], the calculations were carried out for a longer period (2016–2050). Rolbiecki and Piszczek [69] calculated the water needs of grapevines on the basis of the so-called optimal precipitation according to Kemmer and Schulz [70,71]. This indicator of water needs is still quite commonly used in determining the water needs of fruit plants [72–74]. In the present research, the grapevines' water needs were calculated using the plant coefficient, which is more accurate than the Kemmer and Schulz method [70,71]. Calculation of plant evapotranspiration in conditions of optimal soil moisture (i.e., water needs of irrigated crops) using plant coefficients based on reference evapotranspiration is considered to be the optimal method for determining the water needs of plants and, consequently, the irrigation requirements [52,60,69,73].

Undeniably, due to global warming, with the simultaneous lack of additional rainfall, the water needs of plants will gradually increase in the coming years. Water is one of the main atmospheric factors influencing the grapevine growing process. In general, the grapevine is dry-loving and thermophilic, but a deficit of rainfall at any stage of development may harm plants, ultimately affecting the size and quality of the fruit yield [75]. Water deficit during budburst and shoot/inflorescence development can inhibit shoot growth as well as poor flower-clustering development and fruit set [76]. Water stress can lead to a reduction in the leaf area and photosynthesis, and it is also conducive to the flower abortion and cluster abscission [77]. It has also been found that water deficit affects the composition of grapes and wine [78,79]. Therefore, in order to improve the quality of fruit and wine, deficit irrigation was applied.

Potential effects of the projected climate change on grapevines include changes in the plant phenological time, changes in grape and wine composition, heterogeneous impacts on yields and expansion into areas that were previously unsuitable for viticulture, and above all, significant geographical changes in traditional cultivation areas [18]. The changes we are seeing in the climate will require the implementation of appropriate and cost-effective adaptation strategies. These adaptation measures should be carefully planned and adapted to local conditions. Undoubtedly, one of the adaptation measures is the introduction of irrigation systems to supplement rainfall deficiencies [80].

Nowadays, irrigation of grapevines is already common practice in vineyards all over the world. Vineyard irrigation is mainly based on the so-called in deficit irrigation, which includes regulated deficit irrigation, sustained deficit irrigation, and partial root drying. According to this strategy, drip irrigation is the most effective method of irrigating vineyards [81]. Drip irrigation has the advantage of saving water, which is important in terms of climate change [82]. However, a huge challenge is the appropriate design and programming of the irrigation system so that the amount of water supplied to plants is adequate to the water needs of the plant [56,83–87]. Therefore, one of the factors in the implementation of irrigation systems in vineyards is research leading to the estimation of the water needs of grapevines.

4. Conclusions

Due to the forecasted changes in air temperature, it is expected that the water needs of grapevines in the years 2021–2050 in the region of Bydgoszcz, located in northern Poland, will increase by 6%. In August, a significant increase in water needs, even by 10%, should be expected. The equation of the temporal variability of the grapevines' water needs determined for August shows an increase by as much as 3.17 mm in each decade. The results obtained in this study are the first scientific research on the impact of climate change on the water needs of vineyards in northern Poland. The forecasted increase in the water needs of grapevines in the years 2021–2050 confirms the necessity to undertake activities aimed at the development of irrigation techniques in vineyards located in the region of Bydgoszcz. The results of these studies will be helpful in the process of designing irrigation systems and in programming of irrigation treatments for grapevines in northern Poland.

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