JEE Journal of Ecological Engineering
Volume 20, Issue 7, July 2019, pages 222–232
https://doi.org/10.12911/22998993/109859

Received: 2019.05.07
Revised: 2019.05.25
Accepted: 2019.06.05
Available online: 2019.06.27

The Water Needs of Grapevines in the Different Regions of Poland

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ABSTRACT

The aim of this study was to estimate the water needs of grapevines (*Vitis vinifera* L.) in the different regions of Poland. The requirements of grapevines water, considered as the crop evapotranspiration, were determined using the plant coefficient method. The grapevine plants crop evapotranspiration was measured using the reference evapotranspiration and plant coefficients. The plant coefficients were adapted to the reference evapotranspiration that was calculated using the Blaney-Criddle's formula, modified for Polish conditions by Żakowicz. The water needs of grapevines were determined for five agro-climatic regions of Poland with the representative meteorological stations. The calculations of grapevines water requirements were carried out for the thirty-year period determined from 1981 to 2010. The study was based on the six-month growing season established from May 1 to October 31. Four months, including May, June, July and August, were considered as the irrigation period. The highest grapevines water requirements (440 mm) during the growing season, were observed in the north-west and central-east region of Poland. In turn, the lowest water requirements were revealed in the south-east (414 mm) and north-east (415 mm) region of the country. During the irrigation period, the highest grapevines water needs occurred in the central-north-west (355 mm) and central-east (353 mm) region of Poland, while the lowest (329 mm) – in the south-east region of the country. The upward time trend of the grapevines water requirements was observed both in the growing season and in the irrigation period. With the exception of the central-north-west region, this time trend was significant throughout Poland. The highest increase in the water needs of grapevines during the growing season (by 6.9 mm in each subsequent ten-year period) occurred in the central-east and south-east region of Poland. In the irrigation period, the highest rise of grapevines water requirements was noted in the south-west (7.4 mm decade^{-1}) and south-east (7.6 mm decade^{-1}) region of the country. The highest rainfall deficit was observed in the central-north-west region of Poland; 125 mm during the growing season, and 117 mm in the irrigation period.

Keywords: evapotranspiration, irrigation, rainfall deficit, *Vitis vinifera* L., water requirements

INTRODUCTION

Poland has never been, and is still not perceived as a grapevine country. From May 1, 2004, our country was incorporated in the A zone of viticulture, which includes the regions with less favorable conditions for the grapevine cultivation [Lisek 2011, Kapłan 2013]. The A zone of viticulture, also includes such countries as Great Britain and Denmark, as well as the north-eastern region of Germany. Nowadays, according to Pink [2015], there is a significant increase in the interest pertaining to the viticulture in Poland. On the one hand, the reason for the rising popularity of the viticulture is the progress in breeding programs aimed at creating new cultivars of this species, which have better tolerance to the pathogens and frost damage; on the other hand, the warming of climate in Poland favors the cultivation of grapevine plants [Woś 1999, Szymanowski and Smaza 2007, Kopeć 2009, Łabędzki 2009a, 2009b, Lisek 2011, Kapłan 2013, Myśliwiec 2013, Bąk and Łabędzki 2014, Rolbiecki and Piszczek 2016].

In Poland, most of the vineyards are located in the south-eastern, south-western and southern regions, where the most favorable climate conditions for the viticulture occur [Bokwa and Klimek 2009, Kopeć 2009, Myśliwiec 2013, Adamczewska-Sowińska et al. 2016]. Despite the less favorable climate conditions, new vineyards are also found in the eastern and central Poland. During the last ten years, the number of vineyards in our country has been rising systematically. According to the Agricultural Market Agency, in Poland, marketing year only 26 vineyards with the right to introduce the wine to the market were registered in the 2009/2010. In the 2015/2016 marketing year, 103 vineyards were registered. Thus, the number of vineyards increased almost four times during this time. At the same time, the area of grapevine cultivation increased from 37.1 to 194.2 ha, i.e. raised more than five times [Adamczewska-Sowińska et al. 2016]. It is estimated that currently there are nearly 500 vineyards currently in Poland; however, only about 20% of them are officially registered as vineyards with the right to introduce the wine to the market. Currently, according to the www.winoogrodnicy.pl website, where vineyard owners can independently submit their farms, there are 440 vineyards in Poland with a total area of over 506 ha.

In our country, precipitation is the basic source of water for the grapevine plants [Myśliwiec 2013]. The average amount of rainfall in the regions with favorable conditions for the grapevine cultivation ranged from 500 to 800 mm [Myśliwiec 2013, Adamczewska-Sowińska et al. 2016]. According to Dzieżyc [1988], the water requirements of grapevine plants varied between 380 and 500 mm.

The purpose of this research was to estimate the water requirements of grapevine plants (*Vitis vinifera* L.) in the different regions of Poland.

MATERIAL AND METHODS

The water needs of grapevines (*Vitis vinifera* L.) were determined using the plant coefficients method. The water requirements of grapevine plants were considered as the crop evapotranspiration (Etp) that was measured using the reference evapotranspiration (Eto) and plant coefficients (kc). The plant coefficients were adapted to the reference evapotranspiration that was calculated using the Blaney-Criddle's formula, modified for the Polish conditions by Żakowicz [Żakowicz 2010, Rolbiecki 2018]. The plant coefficients for the grapevine plants were applied according to Doorenbos and Pruitt [1977] for fully developed vineyards, where the vegetation cover of the soil in the middle of the growing season is between 40 and 50%.

The grapevines water needs were determined according to Łabędzki et al. [2013] for five agro-climatic regions of Poland with the representative meteorological stations located in Olsztyn, Bydgoszcz, Warsaw, Wrocław and Kraków (Table 1, Fig. 1). The study on the water requirements of the grapevine plants were performed for the thirty-year period in the years 1981-2010. According to Rolbiecki [2018], usually, in the case of grapevine plants cultivated in the regions with a cold winter, the first leaves develop in the early May, and the fruit harvest can be carried out in the mid-September. Consequently, in the presented studies, the calculations of grapevines water requirements were based on the six-month growing season established from May 1 to October 31. Four months, including May, June, July and August, were considered as the irrigation period.

Table 1. Geographical location of the considered meteorological stations in Poland

No.	Region of Poland	Meteorological station	Altitude m a.s.l.*	Longitude	Latitude
1.	North-east (N-E)	Olsztyn	133	20°25′	53°46′
2.	Central-north-west (C-N-W)	Bydgoszcz	46	18°01′	53°08′
3.	Central-east (C-E)	Warszawa	106	20°59′	52°09′
4.	South-west (S-W)	Wrocław	116	17°05′	51°06′
5.	South-east (S-E)	Kraków	209	19°57′	50°04′

Explanations: * m a.s.l. meters above mean sea level.

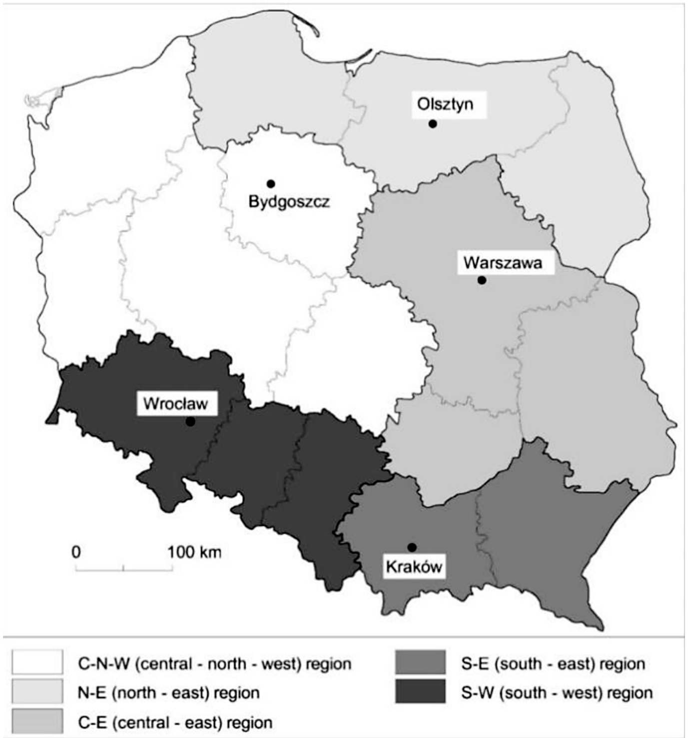

Figure 1. Agro-climatic regions of Poland with the representative meteorological stations [according to Łabędzki et al. 2013]

RESULTS AND DISCUSSION

During the considered six-month period of the growing season, the highest value of standard deviation, which is the measure of monthly amount of the grapevines water needs variation, was calculated in July (5.8-7.4 mm), while the lowest standard deviation was noted in May (2.8-3.4 mm) (Table 2). Generally, among the five studied agro-climatic regions in the C-N-W part of Poland, the highest value of standard deviation, revealed for the grapevines water requirements, was observed.

In all the considered regions of our country, the variability coefficient, which is the measure of relative diversity of grapevines water needs, was at a relatively low level (Table 2). The highest values of the variability coefficient of water requirements of grapevines were estimated in October (from 12.8 to 15.1%), while the lowest value of this coefficient was calculated in June (from 4.5 to 5.3%) and August (from 4.6 to 5.0%).

The crop evapotranspiration (Etp) is a measure of plant water requirements [Łabędzki et al. 1996]. In the present study, the evapotranspiration of grapevines crop was determined using the Blaney-Criddle's formula that was modified for the Polish conditions. The calculation was based on the reference evapotranspiration (Eto) and plant coefficients (kc) reported by Doorenbos and Pruitt [1977].

In the years 1981-2010, during the considered growing season from May 1 to October 31, the highest grapevines water needs (440 mm) in the C-N-W and C-E region of Poland were estimated (Fig. 2). In turn, the lowest grapevines

Table 2. Statistical characteristic of the grapevines water needs in the particular months and regions of Poland

Specification	Region of Poland	Months					
		May	June	July	August	September	October
Minimum (mm)	N-E*	37.0	75.8	98.6	86.5	47.3	16.7
	C-N-W	39.0	80.2	102.6	91.3	50.5	18.8
	C-E	41.4	79.4	100.5	91.7	51.8	21.2
	S-W	37.0	74.9	96.5	89.1	49.0	20.5
	S-E	37.1	72.2	93.4	86.5	48.5	19.1
Maximum (mm)	N-E	53.2	90.4	123.7	109.1	63.8	30.0
	C-N-W	54.7	96.3	132.6	114.6	69.9	33.5
	C-E	54.4	93.4	131.6	118.7	67.9	33.8
	S-W	51.2	92.1	126.4	113.4	70.1	35.9
	S-E	50.6	89.1	117.6	111.8	66.9	35.5
Median (mm)	N-E	45.0	83.9	110.7	97.9	56.0	23.5
	C-N-W	48.4	88.2	115.9	104.4	59.8	26.6
	C-E	47.6	87.6	114.3	103.0	59.2	27.4
	S-W	45.2	83.4	110.0	100.7	58.7	28.3
	S-E	43.7	81.5	107.1	95.5	58.3	26.8
Standard deviation (mm)	N-E	3.3	3.7	6.7	4.9	4.3	3.4
	C-N-W	3.4	4.1	7.4	5.3	4.5	4.0
	C-E	3.0	4.1	7.0	4.7	4.2	3.6
	S-W	2.8	4.4	6.7	4.6	4.5	3.6
	S-E	2.8	3.9	5.8	4.6	4.1	3.5
Variability coefficient (%)	N-E	7.4	4.5	6.1	5.0	7.7	14.7
	C-N-W	6.9	4.7	6.4	5.0	7.6	15.1
	C-E	6.4	4.7	6.1	4.6	7.1	13.2
	S-W	6.2	5.3	6.1	4.6	7.7	12.8
	S-E	6.4	4.8	5.5	4.9	7.1	13.2

Explanations: * N-E – north-east region, station Olsztyn; C-N-W – central-north-west region, station Bydgoszcz; C-E – central-east region, station Warszawa; S-W – southwest region, station Wrocław; S-E – southeast region, station Kraków.

water requirements in the S-E (414 mm) and N-E (415 mm) region of the country were found. At the same time, the lowest amount of atmospheric precipitation (315 mm) was observed in the C-N-W region of Poland, while the highest rainfall (439 mm) was noted in the S-E region of the country.

According to Myśliwiec [2013] and Adamczewska-Sowińska et al. [2016], in the regions with favorable conditions for the viticulture, the yearly precipitation ranged from 500 to 800 mm. On the other hand, Słowik [1973] suggested that much lower yearly precipitation, varied between 400 and 500 mm, are enough to get

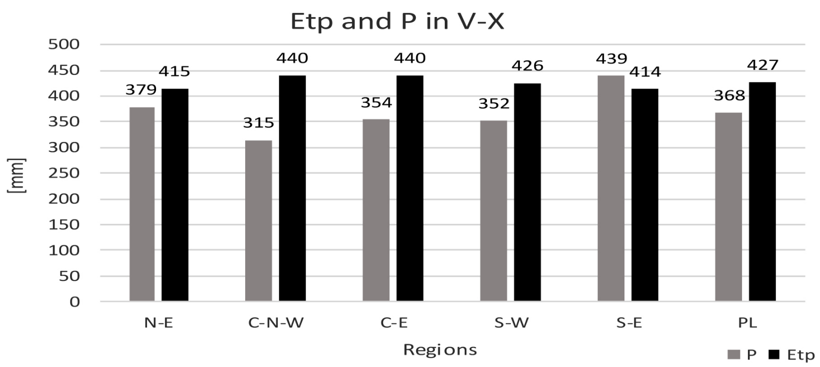

Figure 2. Water needs (Etp) of grapevines in the growing season (from May 1 to October 31) compared to the precipitation (P) in the different regions of Poland

a high yield of grapes. Finally, Dzieżyc [1988] reported that the yearly water needs of grapevine plants ranged from 380 and 500 mm. However, the calculations presented by both Słowik [1973] and Dzieżyc [1988] are based on the assumption that 50% of precipitation total occurs during the growing season [Treder and Pacholak 2006]. For comparison, in the climatic conditions of the Iberian Peninsula (in Requena, Spain), the rain-fed vines received a yearly average rainfall of 368 mm, of which 169 mm occurred from April to harvest [Intrigliolo and Castel 2008].

The highest rainfall deficit (125 mm) in the growing season from May 1 to October 31 occurred in the C-N-W region of Poland (Fig. 3). The precipitation deficiencies were not detected in the S-E region of the country. Rzekanowski and Rolbiecki [2000a, 2000b], Rolbiecki et al. [2002a, 2002b], Stachowski and Markiewicz [2011] and Żarski et al. [2013] observed the highest water needs of the studied plants also in the central regions of Poland.

During the studied thirty-year period established from 1981 to 2010, in all studied regions of Poland, a noticeable tendency towards increase in the grapevines water requirements was observed in the growing season (from May 1 to October 31) (Fig. 4). With the exception of the C-N-W region of our country, the upward time trend of water needs was significant throughout Poland (Table 3).

The time trend equations created for the considered six-month growing seasons in the years 1981-2010, presented the increase of grapevines water requirements in the range from 4 mm in the C-N-W region to 6.9 mm in the C-E and S-E regions of Poland that were observed in each subsequent decade (Table 3).

In the studied thirty-year period from 1981 to 2010, a noticeable tendency to increase the grapevines water requirements during the irrigation period was observed throughout Poland from May 1 to August 31 (Fig. 5). At the same time, very high significant relationships ($p = 0.01$, i.e. $P = 99\%$) were revealed in the C-E, S-W and S-E region of the country (Table 4).

The time trend equations, created for the irrigation period (from May 1 to August 31), showed the highest increase of the grapevines water needs – by 7.4 and 7.6 mm in the S-W and S-E region of Poland, respectively – in each subsequent decade of the considered thirty-year period (from 1981 to 2010) (Table 4). The lowest and also insignificant time trend of the grapevines water requirements (3.7 mm decade^{-1}) was calculated in the C-N-W region of the country.

Throughout Poland, in the years 1981-2010, during the period of increased water needs from May 1 to August 31, the average crop evapotranspiration of grapevine plants was 342 mm (Fig. 6). The highest water requirements in the C-N-W (355 mm) and C-E (353 mm) region of Poland were observed. The lowest water requirements (329 mm) were found in the S-E region of the country.

On average, the rainfall deficit in the grapevine cultivation during the period of increased water needs in Poland was noted from May to August and amounted to 64 mm (Fig. 7). At this time, the highest precipitation deficiencies (117 mm) in the C-N-W region of our country were recorded. At the same time, no rainfall deficit was revealed in the S-E region of Poland.

According to the reports from Myśliwiec [2013] and Adamczewska-Sowińska et al. [2016], the highest water needs of grapevines in Poland

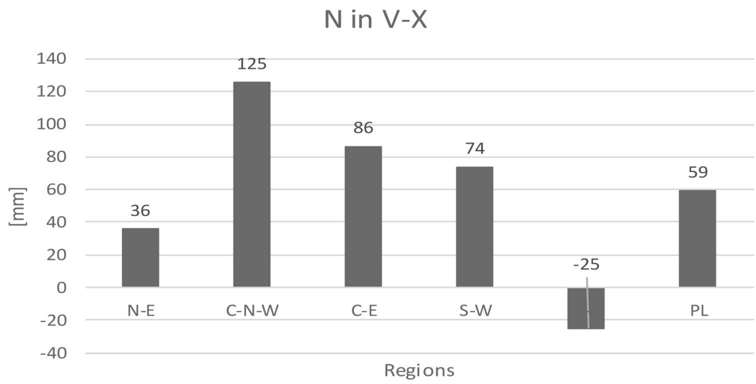

Figure 3. Rainfall deficit (N) in the grapevines cultivation during the growing season (from May 1 to October 31) in the different regions of Poland, on average in the years 1981-2010

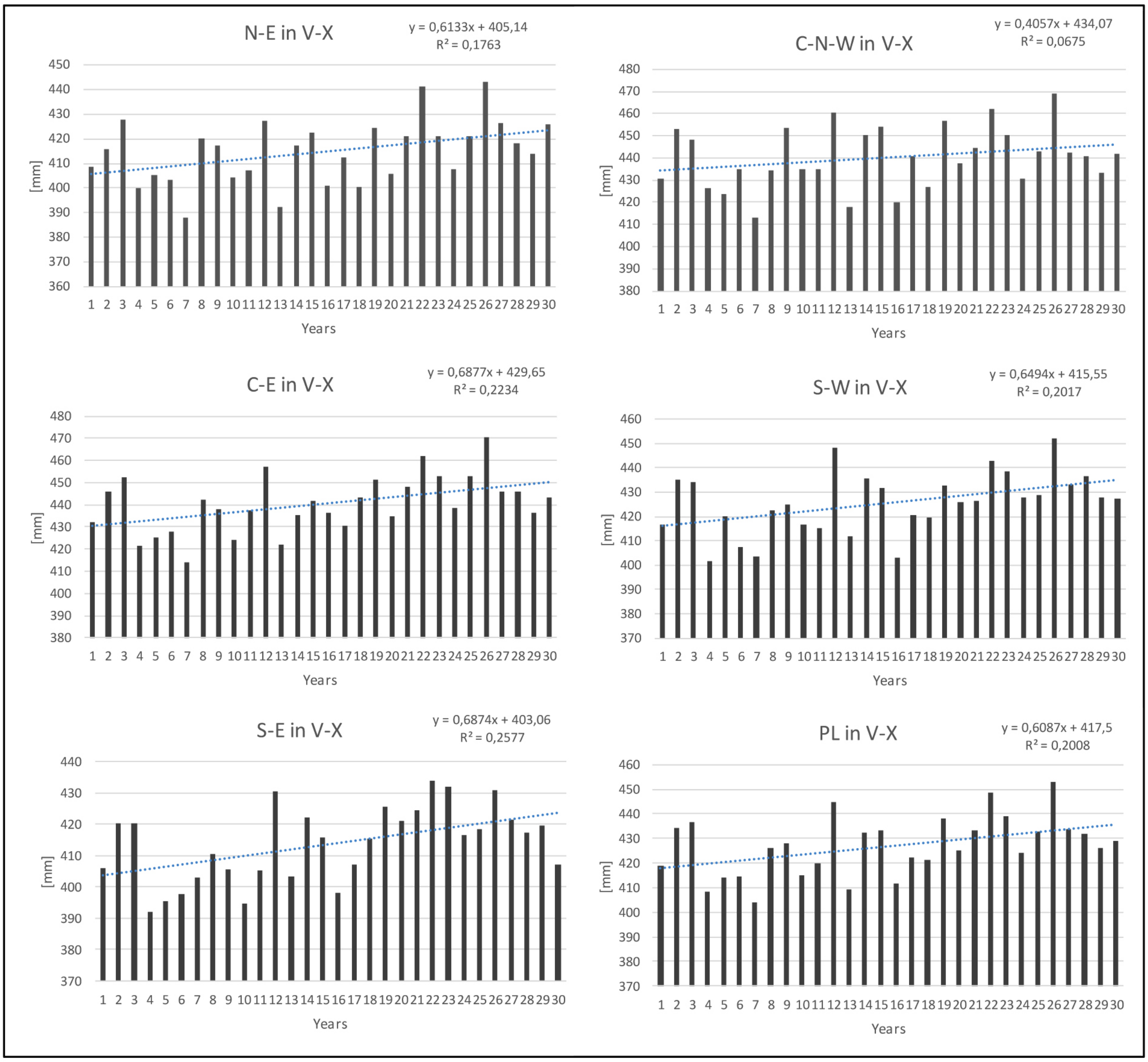

Figure 4. Time trend of grapevines water needs (Etp) in the period from May 1 to October 31 in the different regions of Poland

Table 3. Equations of the time trends of grapevines water needs in the growing season (from May 1 to October 31), in the years 1981-2010

Region of Poland	Time trend equation	r	Tendency of water needs ($mm \cdot decade^{-1}$)
North-east (N-E)	y = 0.6133x + 405.14	0.42**	6.1
Central-north-west (C-N-W)	y = 0.4057x + 434.07	0.26 ns	4.0
Central-east (C-E)	y = 0.6877x + 429.65	0.47***	6.9
South-west (S-W)	y = 0.6494x + 415.55	0.45**	6.5
South-east (S-E)	y = 0.6874x + 403.06	0.51***	6.9
Poland (PL)	y = 0.6087x + 417.5	0.45**	6.1

Explanations: *** significance at p = 0.01 (P = 99%); ** significance at p = 0.05 (P = 95%); ns – not significant.

occur during the period of intensive growth of plants and fruits, which is from May to August. Consequently, the four-month period, including May, June, July and August, was considered in the present study. The water deficit, occurring during a drought, contributes to the poor growth of the plants and fruits, drying of shoots and yellowing of leaves. In the blooming stage that occurs in June, the grapevine plants require moderate soil moisture and minimal air humidity, because both the deficit and the excess rainfall reduce the efficiency of flowering. On the other hand, rainless

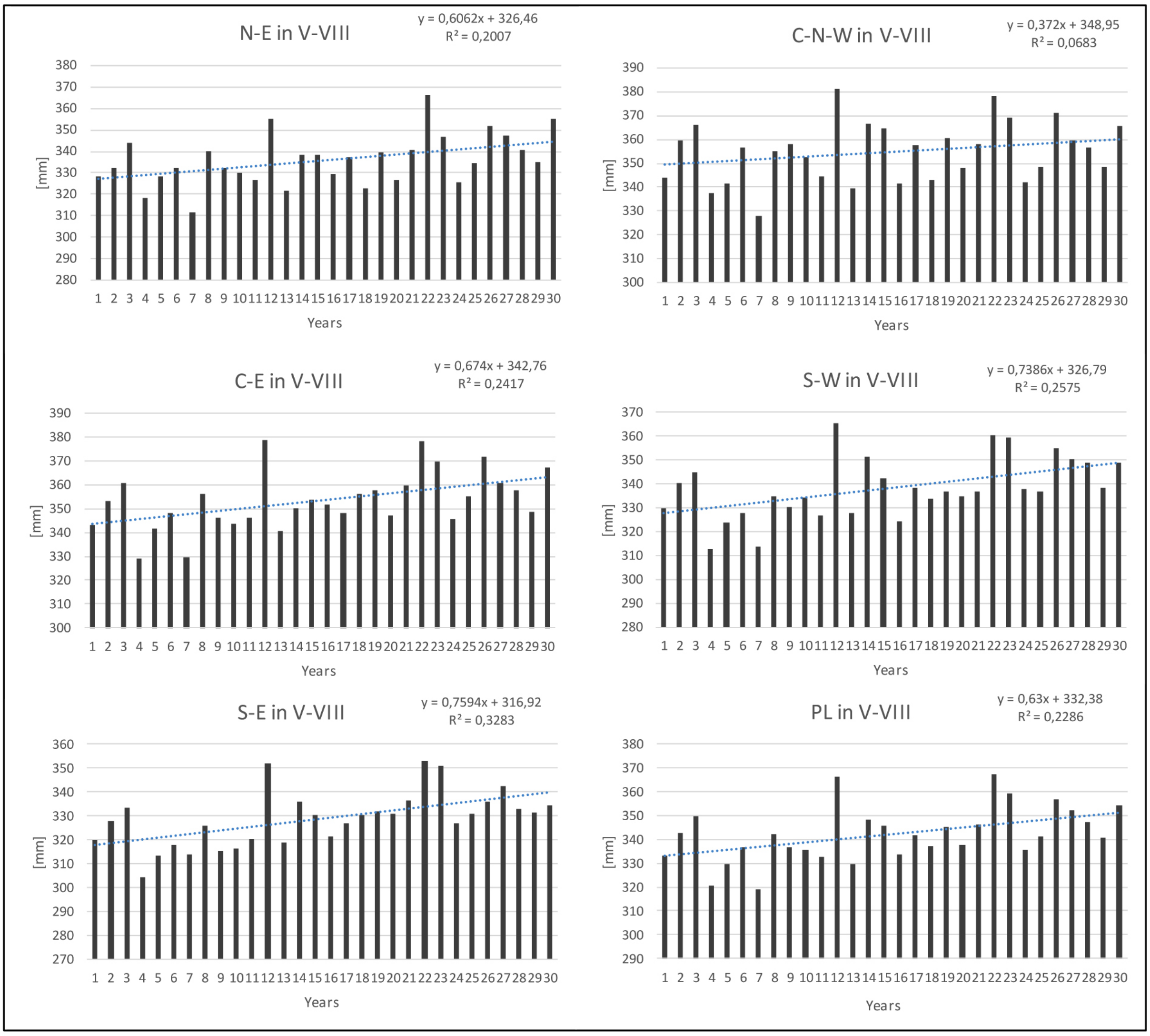

Figure 5. Time trend of the grapevines water needs (Etp) during the irrigation period (from May 1 to August 31) in the different regions of Poland

Table 4. Equations of the time trends of grapevines water needs in the irrigation period (from May 1 to August 31), in the years 1981-2010

Region of Poland	Time trend equation	r	Tendency of water needs ($mm \cdot decade^{-1}$)
North-east (N-E)	y = 0.6062x + 326.46	0.45**	6.1
Central-north-west (C-N-W)	y = 0.372x + 348.95	0.26 ns	3.7
Central-east (C-E)	y = 0.674x + 342.76	0.49***	6.7
South-west (S-W)	y = 0.7386x + 326.79	0.51***	7.4
South-east (S-E)	y = 0.7594x + 316.92	0.57***	7.6
Poland (PL)	y = 0.63x + 332.38	0.48***	6.3

Explanations: *** significance at p = 0.01 (P = 99%); ** significance at p = 0.05 (P = 95%); ns – not significant.

weather is conducive to the ripening of fruits and wooding of shoots of grapevine plants. However, heavy rainfall during the fruit ripening stage that occurs in September causes the fruit cracking and rotting.

According to Lisek [2008], because of climate fluctuations the grapevine cultivation in central regions of Poland is at present more successful than twenty years ago. The most important is an increase of air temperature in the period from May to September. As a result of climate changes, the phenological stages of plants occur earlier, subsequently the quality of grapes grown in central regions of Poland is higher.

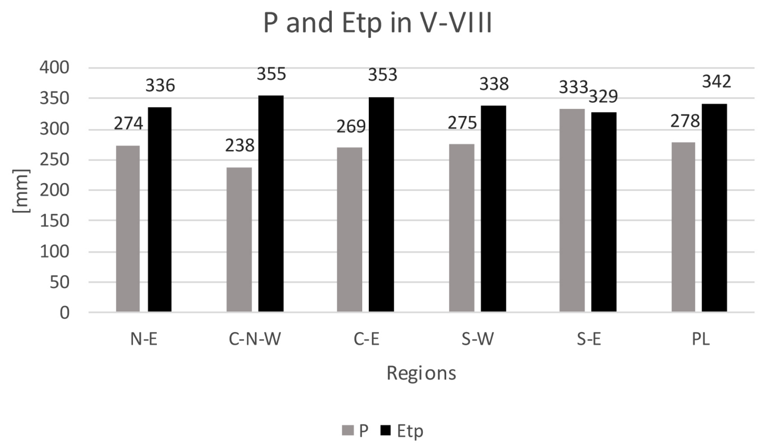

Figure 6. Water needs (Etp) of grapevines during the irrigation period (from May 1 to August 31) compared to the atmospheric precipitation (P) in the different regions of Poland

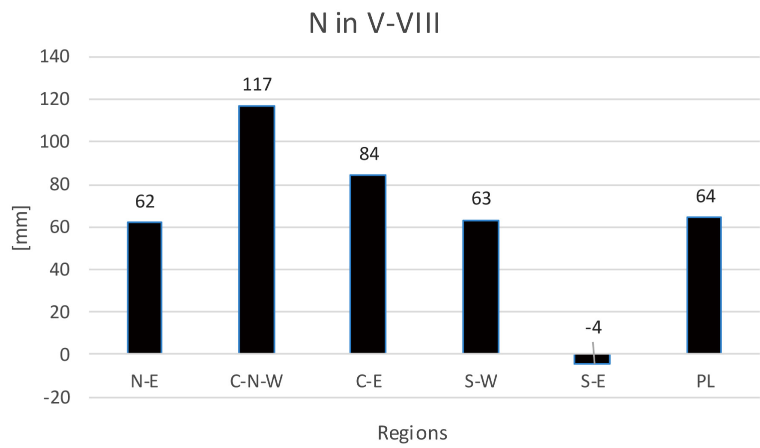

Figure 7. Rainfall deficit (N) in the grapevine cultivation during the irrigation period (from May 1 to August 31) in the different regions of Poland, on average in the years 1981-2010

Undoubtedly, the north-east region of Poland is the least suitable for the viticulture [Anonim 2001, Grabowski and Kopytowski 2009]. The number of days and sum of temperature in the north-east region of Poland are too low in relation to the minimum required values that are necessary for the large-scale viticulture of the medium-late and late cultivars [Grabowski and Kopytowski 2009].

During the growing seasons, in the years 1981-2010, the results revealed the increase of grapevines water requirements in all five considered regions, and in four of them this upward time trend was statistically significant. The reason for the demonstrated increase in the grapevines water needs is the raise of air temperature in Poland observed during last years, the value of which in the Blaney-Criddle's formula largely determines the level of reference evapotranspiration [Doorenbos and Pruitt 1977, Rolbiecki 2018]. According to Łabędzki [2009a, 2009b], the climate changes observed presently, will certainly increase the water requirements of the vegetation in the near future. The A2 scenario, defined by the Special Report on Emissions Scenarios (SRES), forecasts the increase of global temperature about 4°C at the end of the 21st century. In Poland, as expected, the temperature will raise in the range of 2-4°C. Moreover, in most of the climate change scenarios for Poland, no increase in the amount of precipitation is expected [Łabędzki et al. 2013]. Consequently, the predicted climate changes will increase the water needs of vegetation, also including the grapevine plants [Rolbiecki and Piszczek 2016, Rolbiecki et al. 2017]. Therefore, it is necessary to undertake certain adaptation activities, such as the irrigation techniques development, including the deficit irrigation, the importance of which will grow with the progress of the observed climate changes [Łabędzki 2009a, 2009b, Kuchar and Iwanski 2011, Stachowski and Markiewicz 2011, Kuchar and Iwanski 2013, Żarski et al. 2013, Kuchar et al. 2015, Kuchar et al. 2017]. Irrigation is a common cultural practice in the viticulture [Ruiz-Sanchez et al. 2010]. Many studies have already demonstrated the positive impact of modern micro-irrigation methods, including the deficit irrigation, on the growth and yielding of grapevines [Yunusa et al. 2000, Cifre et al. 2005, Chaves et al. 2007, Burg 2008, Acevedo-Opazoa et al. 2010, Chaves et al. 2010, Ruiz-Sanchez et al. 2010, Intrigliolo et al. 2012, Nolz et al. 2016, Nolz and Loiskandl 2017]. Under the Spanish climate conditions, all irrigation regimes increased vine yield up to 58% with respect to the rain-fed treatment, and no differences in yield among the irrigated treatments occurred [Intrigliolo et al. 2012]. In Poland, the irrigation of grapevine plantings using a drip-system is recommended among others by Treder and Pacholak [2006] as well as by Myśliwiec (2013).

CONCLUSIONS

1. In Poland, in the considered thirty-year period from 1981 to 2010, during the growing season from May 1 to October 31, the highest grapevines water needs (440 mm) were noted in the north-west and central-east region of Poland. The lowest water requirements were revealed in the south-east (414 mm) and north-east (415 mm) region of our country.
2. In the irrigation period, including May, June, July and August, the highest grapevines water needs occurred in the central-north-west (355 mm) and central-east (353 mm) regions of Poland, while the lowest (329 mm) was observed in the south-east region.
3. In the studied thirty-year period, during the growing season, as well as in the irrigation period, an upward time trend of the grapevines water requirements was observed. With the exception of the central-north-west region of Poland, the time trend was significant throughout the country. The highest increase of grapevines water needs in the growing season (by 6.9 mm in each subsequent ten-year period) in the central-east and south-east region of Poland was noted. In the irrigation period the highest rise of water requirements in the south-west (7.4 mm decade^{-1}) and south-east (7.6 mm decade^{-1}) region of the country was revealed.
4. The highest rainfall deficit was observed in the central-north-west region of Poland, amounting to 125 mm during the growing season, and 117 mm in the irrigation period. However, precipitation deficit did not occur in the south-east region of our country.

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