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The Water Requirements of Grapevines (*Vitis vinifera* L.) Under Climatic Conditions of Central Poland

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Abstract: The purpose of this study was to estimate the water needs of grapevines in central Poland in 1981-2010. Water needs were calculated by the plant coefficients, which were assumed according to the Doorenbos and Pruitt method. Reference evapotranspiration was assessed by the Blaney-Criddle's equation, modified for Polish conditions. Rainfall deficit with the occurrence probability of normal, medium dry and very dry years was determined by the Ostromęcki's method. Water needs of grapevines during the growing season was 434 mm. Upward time trend in the water needs both in the periods May-October and June-August was estimated. Temporal variability in the water needs was significant for most of the provinces. The rainfall deficit was recorded with the occurrence probability of normal as well as medium or very dry years in the entire study area. Due to climate changes, vineyards will require irrigation in the near future. This research significantly broadens and refines the knowledge about the water needs of grapevines in central Poland, which will allow the design of resource-efficient irrigation programs for grapevines in the studied region of Poland.

Keywords: climate changes, evapotranspiration, irrigation, precipitation, rainfall deficit

1. Introduction

The tradition of viticulture in Poland dates back to the Middle Ages. Nowadays, the largest number of vineyards in Poland is located in the south-eastern, south-western and southern provinces of the country, where are the most favourable climatic conditions for viticulture (Bokwa & Klimek 2009, Kopeć 2009, Myśliwiec 2013, Adamczewska-Sowińska et al. 2016). However, many new vineyards are also created in eastern and central Poland, despite the fact that there are much less satisfactory climatic environments for viticulture (Adamczewska-Sowińska et al. 2016, Koźmiński & Michalska 2001). The development of new vineyards in Poland is the effect of people's enrichment and changes in consumer preferences, as well the increase of ecological agro-tourism, including oeno-tourism activities. A large rise in interest in viticulture in Poland is also the result of the great progress in breeding program aimed to obtain new cultivars with low susceptibility to fungal diseases and frost damage, as well the gradual warming of the climate (Szymanowski & Smaza 2007, Kopeć 2009, Łabędzki 2009a, Łabędzki 2009b, Lisek 2011, Kapłan 2013, Myśliwiec 2013, Bąk & Łabędzki 2014, Pink 2015, Rolbiecki & Piszczek 2016).

Orchard plantations in central Poland are exposed to the largest deficit of atmospheric precipitation in the growing season (Rojek 2006, Rzekanowski 2009). According to Rzekanowski (2009) in the case of fruit plants, the highest water deficit occur in the great valleys area, i.e. the central Poland, while more favourable water conditions are in the southern and northern region of the country. The most important factors that limiting the development of vineyards in central Poland is minimum winter temperature (-30°C occurring at least once in 10 years), as well spring and autumn frosts (Lisek 2008). The sum of active temperatures (SAT) above 10°C is considered to be the most important climatic criterion, which is particularly useful for assessing the conditions of viticulture (Myśliwiec 2006, Lisek 2008, Grabowski & Kopytowski 2009). In the last few decades climate change that is favourable for viticulture has been observed in Poland. As reported Lisek (2008), in central Poland in the years 1981-2000 the average SAT was almost 2500°C, while in 2003 the SAT was over 2700°C, and in 2006 the SAT was up to 2900°C. For comparison, the SAT in the north-eastern Poland is about 2200°C, in the highlands of central Poland 2600°C and 2700°C in the south-west and west part of the country (Myśliwiec 2006, Grabowski & Kopytowski 2009). According to Lisek (2008), as the result of climate change, especially due to the increase in temperature in the period from May 1 to September 30, viticulture in central Poland is today much more effective than twenty years ago. On the one hand, due to climate warming, the subsequent phenological stages of the plant development occur earlier, what increases the quality of fruit of the grapevines. On the other hand, an increase in the average summer (May-September) temperature of 1°C rises the water needs of grapevines by 50 mm of

annual precipitation, assuming that at least 50% of annual precipitation occurs during the growing season (Słowik 1973, Dzieżyc 1988).

The purpose of the present study was to calculate the water needs of grapevine plants grown in central Poland. The results of the research will help to develop a program of resource-efficient irrigation of vineyards in central provinces of the country.

2. Materials and methods

In the present study, as a measure of water needs of grapevine (*Vitis vinifera* L.) was a crop evapotranspiration (Łabędzki et al. 1996). The water needs of grapevines were determined by the plant coefficients method. The reference evapotranspiration was calculated by the Blaney-Criddle's equation that was modified for Polish conditions (Żakowicz 2010, Rolbiecki 2018). The plant coefficients for grapevines (adjusted to the reference evapotranspiration that was considered by the Blaney-Criddle's method) were assumed according to Doorenbos and Pruitt (1977). It was supposed that vineyards are in the stage of full development, and the soil in the middle of the growing season is covered with plants at the level of 40-50%. It was also assumed that the grapevines are grown in the region with cold winter and severe spring, and autumn frosts; the first leaves appear in early May, while the harvest begins in mid-September.

The water needs of the grapevines were calculated on the basis of measurement data collected from five meteorological stations located in Bydgoszcz, Warszawa, Poznań and Łódź, which were representative for considered provinces situated in central Poland: Kuyavian-Pomeranian Province (K-P), Masovian Province (M), Greater Poland Province (G-P) and Lodz Province (L), respectively (Fig. 1). The calculations were carried out for the groving period of grapevines in Poland, considered from May 1 to October 31 in the years 1981-2010 (Doorenbos and Pruitt 1977, Rolbiecki 2018).

The precipitation deficit with the occurrence probability of the normal ($N_{50\%}$), medium dry ($N_{25\%}$) and very dry years ($N_{10\%}$) was determined for the six-month of intensive development of vines (May-October) by the Ostromęcki's method (Żakowicz & Hewelke 1995, Żakowicz & Hewelke 2009).

Among the studied provinces, in each month of the growing period, the lowest standard deviation of the grapevines water needs, which is a measure of the diversity of monthly sums of the water requirements, was estimated in the Masovian Province (Table 1). During the vegetation period, the highest standard deviation of the water needs, ranged from 7.0 to 8.0 mm depending on the province, was noted in July and the lowest standard deviation of the water needs, ranged from 3.0 to 3.4 mm depending on the province, was assessed in May.

Fig. 1. Provinces of central Poland

Table 1. Characteristics of the water requirements of grapevine plants

Characteristic	Province	Months of the growing season					
		May	Jun	Jul	Aug	Sep	Oct
Minimum (mm)	K-P	39	80	103	91	50	19
	M	41	79	100	91	52	21
	G-P	37	76	98	90	50	20
	L	38	75	96	88	49	19
Maximum (mm)	K-P	55	96	133	115	70	33
	M	54	93	132	119	68	34
	G-P	52	93	133	114	86	35
	L	52	90	127	115	67	35
Median (mm)	K-P	48	88	116	104	60	27
	M	48	88	114	103	59	27
	G-P	47	83	112	102	59	27
	L	45	83	110	101	57	27
Standard deviation (mm)	K-P	3.4	4.1	7.4	5.3	4.5	4.0
	M	3.0	4.1	7.0	4.7	4.2	3.6
	G-P	3.3	4.8	8.0	5.3	6.7	3.8
	L	3.1	4.2	7.6	5.0	4.7	3.9
Variability coefficient (%)	K-P	6.9	4.7	6.4	5.0	7.6	15.1
	M	6.4	4.7	6.1	4.6	7.1	13.2
	G-P	7.1	5.6	7.2	5.2	11.3	13.8
	L	6.8	5.0	6.9	4.9	8.2	14.6

K-P – Kuyavian-Pomeranian Province; M – Masovian Province; G-P – Greater Poland Province; L – Lodz Province

3. Results

The average water needs of grapevine plants during the vegetation period, i.e., from May 1 to October 31, in 1981-2010, in central Poland were 434 mm (Fig. 2a). The highest daily water needs of grapevines (over 3.64 mm) were calculated in July (Fig. 2b). A little lower values of daily water needs (3.31 mm) were estimated in August, as well in June (2.84 mm). The lowest water requirements were assessed in May (1.51 mm) and in October (0.87 mm).

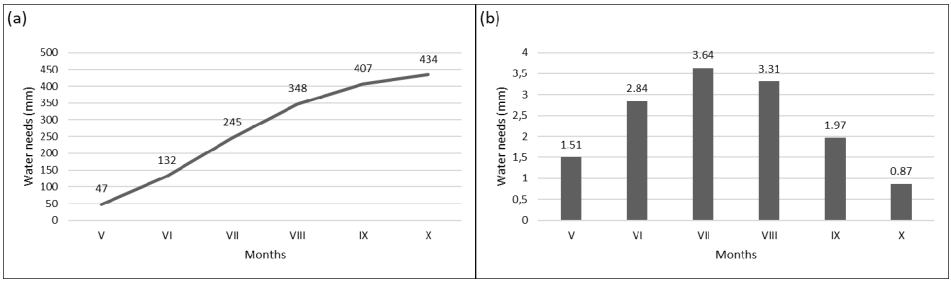

Fig. 2. Water needs (determined by the crop evapotranspiration) of grapevines in central Poland during the period of May-October (V-X) in the years 1981-2010 presented as the sum curve (a) and daily values in the particular months (b)

The highest water needs of grapevine plants in central Poland, in 1981-2010, both in the growing season (from May 1 to October 31) and during the period of increasing water needs by plants (from June 1 to August 31) occurred in the Kuyavian-Pomeranian and Masovian provinces (Fig. 3 a, b). In the above mentioned provinces, the value of crop evapotranspiration was 440 mm in the growing season and 307 mm (K-P), and 306 mm (M) in the period of increasing water needs by plants. The lowest water needs of grapevines, 423 mm in May-October and 293 mm in June-August, were noted in the Lodz Province.

In the studied thirty-year period, in each considered province of central Poland, was observed a visible tendency to increase the water needs of the grapevine plants both in the growing season (May-October), and during the period of increasing water needs by plants (June-August), as well as in the month with the highest water needs, i.e. in July (Table 2).

With the except of the Kuyavian-Pomeranian Province, a significant temporal variability in the grapevine water needs was noted in the entire studied area. The temporal variability in grapevine water needs during the growing season (May-October) indicate that in 1981-2010 the water requirements increased in each decade from 11.2 mm in Greater Poland Province to 4.1 mm in Kuyavian-Pomeranian Province. In June-August, during the period of increasing water needs by plants, the crop evapotranspiration rose in each following decade from

8.4 mm in Greater Poland Province to 4.2 mm in Kuyavian-Pomeranian Province. In July, the month when the water needs of the grapevines are the highest, the crop evapotranspiration increased in the range from 3.7 mm in Greater Poland Province to 2.0 mm in Kuyavian-Pomeranian Province.

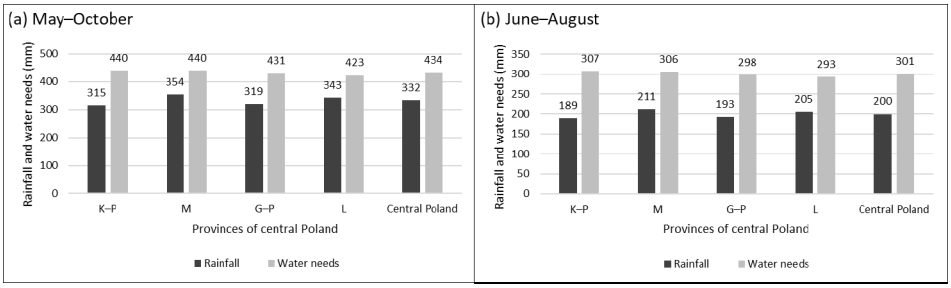

Fig. 3. Water needs (determined by the crop evapotranspiration) of grapevines and the average precipitation in the growing season (a) and in the period of increasing water needs by plants (b) in the considered provinces of central Poland (K-P – Kuyavian-Pomeranian, M – Masovian, G-P – Greater Poland and L – Lodz)

Table 2. Time trend equations of the grapevines water needs in the years 1981-2010

Period	Provinces			
	Kuyavian-Pomeranian	Masovian	Greater Poland	Lodz
Linear correlation coefficient (r)				
May-October	0.260 n.s.	0.473***	0.552***	0.421***
June-August	0.299 n.s.	0.521***	0.520***	0.476***
July	0.237 n.s.	0.422**	0.398**	0.409**
Tendency of water needs (mm decade^{-1})				
May-October	4.1	6.9	11.2	6.6
June-August	4.2	6.8	8.4	6.8
July	2.0	3.4	3.7	3.6

n.s. – not significant; *** – significant at $p \leq 0.01$; ** – significant at $p = 0.05$

The highest rainfall deficit in the studied six-month period of the intensive development of grapevines (from May 1 to October 31) with the occurrence probability of the normal years ($N_{50\%}$) and medium dry years ($N_{25\%}$) was noted in the Kuyavian-Pomeranian Province and amounted to 132 mm and 258 mm, respectively (Table 3). The highest rainfall deficit with the occurrence probability of the very dry years ($N_{10\%}$) were found in the Masovian Province (370 mm). In the three-month period (June-August), during the increasing of water needs by

plants, the highest rainfall deficit in the normal years ($N_{50\%}$) and medium dry years ($N_{25\%}$) were observed in the Kuyavian-Pomeranian Province (117 mm and 200 mm, respectively) and the highest rainfall deficit in the very dry years ($N_{10\%}$) was noted in the Masovian Province (302 mm). In July, the rainfall deficits $N_{50\%}$, $N_{25\%}$ and $N_{10\%}$ were evenly balanced. Generally, with the exception of the very dry years ($N_{10\%}$) the lowest rainfall deficit in the normal years ($N_{50\%}$) and medium dry years ($N_{25\%}$) was found in the Lodz Province.

4. Discussion

In Poland, atmospheric precipitations are the primary source of water for viticulture (Myśliwiec 2013). In areas suitable for the grapevines cultivation the annual precipitation ranged between 500 and 800 mm (Myśliwiec 2013, Adamczewska-Sowińska et al. 2016). Rzekanowski (2009), studying the water deficit during the growing season in Poland, on the basis of data from 27 meteorological stations, stated that the highest water deficit in the fruit plants cultivation occurs in central Poland. More favourable water conditions Rzekanowski (2009) noted in the southern and northern region of the country. Rolbiecki and Rzekanowski (1997), Rzekanowski and Rolbiecki (2000a, 2000b), Rolbiecki et al. (2002a, 2002b), Stachowski and Markiewicz (2011) observed also the highest need for irrigation supplementing atmospheric precipitation just in central Poland. A clearly negative effect of drought periods on the yielding of grapevine plants grown in Poland was published by Treder and Pacholak (2006). The water deficit occurring during the drought period contribute to the weak growth of shoots and fruits, drying of shoots growing from the buds in the corners of leafstalks and yellowing of leaves (Myśliwiec 2013). Consequently, the vineyards located in central Poland should be irrigated, especially during the periods of drought. Drip irrigation of the grapevine plantings in Poland was recommended previously by Treder and Pacholak (2006), and Myśliwiec (2013).

In general, in many countries and around the world the irrigation is a common cultivation treatment in vineyards (Ruiz-Sanchez et al. 2010). Much research work highlights the beneficial effects of micro-irrigation, including deficit irrigation, on the development and yielding of grapevines (Yunusa et al. 2000, Yunusa et al. 2005, 2007, Burg 2008, Intrigliolo & Castel 2008, Acevedo-Opazoa et al. 2010, Chaves et al. 2010, Ruiz-Sanchez et al. 2010, Intrigliolo et al. 2012, Nolz et al. 2016, Nolz & Loiskandl 2017). In the studies carried out in Spain, comparing to the rain-fed treatment, all applied irrigation methods increased the yield of grapevine fruit, even by 58% (Intrigliolo et al. 2012).

Table 3. Rainfall deficit (mm) in grapevines cultivation in central Poland

Probability of rainfall deficit occurrence	Provinces			
	Kuyavian-Pomeranian	Masovian	Greater Poland	Lodz
May-October				
$N_{50\%}$ = normal years	132	104	122	98
$N_{25\%}$ = medium dry years	258	250	256	218
$N_{10\%}$ = very dry years	335	370	305	309
June-August				
$N_{50\%}$ = normal years	117	95	104	88
$N_{25\%}$ = medium dry years	200	196	190	169
$N_{10\%}$ = very dry years	259	302	219	237
July				
$N_{50\%}$ = normal years	37	38	36	26
$N_{25\%}$ = medium dry years	94	89	83	86
$N_{10\%}$ = very dry years	128	123	100	131

The expected further climate changes may cause an increase in water needs of the plants, including also grapevines (Rolbiecki & Piszczek 2016, Rolbiecki et al. 2017, Jagosz et al. 2020, Piña-Rey et al. 2020). Therefore, some adaptation measures should be taken already today to protect plant crops against the effects of rising air temperature. These adaptation activities include the irrigation treatments, particularly the resource-efficient drip irrigation systems. The results of the research presented in this paper will allow for precise programming of irrigation treatments for vineyards located in central Poland. It was found that the water needs of grapevines during the growing season in the study area amounted to 434 mm, and this value was not covered by rainfalls.

In the presented research, the observations of the temporal variability analyzed on the basis of the 30-year period showed a significant gradual increase in the water needs of grapevine plants in most of the studied provinces. According to Łabędzki (2009a, 2009b), Kuchar and Iwański (2011), Stachowski and Markiewicz (2011), Kuchar and Iwański (2013), Łabędzki et al. (2013), and Kuchar, et al. (2015, 2017), the importance of the irrigation treatments will gradually increase along with the intensification of adverse climate changes. Łabędzki (2009a, 2009b) reports that in Poland a temperature will rise in the range of 2°C to 4°C. It should be noted that individual scenarios for temperature and precipitation changes, developed for Poland in the coming (2020) and following (2050 and 2080) years, differ significantly, especially in the summer

months (from June to August). On the one hand, all scenarios, in fact, assume an increase in air temperature. It is expected that the average monthly air temperature in July and August may exceed even 25°C. On the other hand, only some scenarios predict an increase in precipitation, while others assume a decrease in precipitation. This research has shown that in vineyards located in central Poland, there is already a significant deficit in precipitation.

5. Conclusions

It was found that during the growing season, i.e. from May 1 to October 31, the average water needs of grapevines grown in vineyards located in central Poland amounted 434 mm and it is not covered by rainfall. Both in the growing season and during the period of increasing water needs by plants, i.e. from June 1 to August 31, an upward time trend in the water needs of grapevines was noted. Except the Kuyavian-Pomeranian Province the significant temporal variability in water needs was significant for each provinces. Regardless of the occurrence probability of the normal, medium or dry years, the rainfall deficit in the growing season in grapevine cultivation was recorded in the entire studied area of central Poland. The presented research results constitute the basis for designing resource-efficient irrigation programs necessary in agricultural and horticultural crops in the light of the observed global warming of the climate.

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