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ESTIMATION OF PLANT WATER REQUIREMENTS DURING SEQUENCES OF DAYS WITHOUT PRECIPITATION IN 2011-2015

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Abstract

This paper presents data on daily precipitation totals from six meteorological stations and the climatic water balance for the stations located throughout Poland in 2011-2015. The following sequences of days without precipitation were distinguished: from 11 to 15 days, from 16 to 20 days, and of more than 20 days. The number of precipitation-free sequences during the growing season in 2011-2015 was highly variable. Over the studied period, there were from 1.0 rainless sequence in Wtelno to 2.4 such sequences in Gołębiów per one growing season. The most frequently occurring were sequences of 11-15 days, while those of 16-20 days were less frequent. In the years under analysis, all of the different sequences occurred most frequently in July, and the least frequently in April. The highest numbers of sequences without precipitation were recorded in the south-east of Poland (Zakalniki, Gołębiów).

Keywords: rainfall, evapotranspiration, growing season

INTRODUCTION

In the climatic conditions of Poland, the atmospheric precipitation is the primary source of water for plants. The Polish climate is characterized by very high variability in precipitation; we frequently observe large differences in the amounts of precipitation occurring even in a relatively small area. The long-term average amount of precipitation for central Poland is 550-600 mm, and in dry years this sum does not even reach 500 mm (Koźmiński and Michalska 1995). In a temperate climate, the lower limit of precipitation necessary for intensive agricultural production is 600 mm, and precipitation of less than 500 mm is considered to be below the minimum threshold (Banaszak 2003). Over the next several years, the climatic balance of Poland should be expected to deteriorate (Łabędzki 2009, Kuchar and Iwański 2011, 2013). Climate models for Europe suggest that due to global warming the amount of precipitation in Poland in the summer half-year will decrease. At the same time, as a result of the increasing mean temperature, evapotranspiration will increase, and the water balance will become significantly worse (Parry et al. 2007). A frequent phenomenon occurring in our climate zone are sequences of days without precipitation, which in conjunction with low amounts of rainfall during the growing season cause large losses in crop yields, and are therefore one of the main sources of risk in agricultural production (Radzka 2014). Some authors call the sequences of precipitation-free days atmospheric dry spells (Grabowska et al. 2004, Kossowska-Cezak 2000, Hurtowicz 1988, Łabędzki and Bąk 2014). The authors variously define the length of the sequence of rainless days and the amount of rainfall that breaks that sequence. Kasperska-Wołowicz et al. (2003) consider it very difficult to determine the amount of precipitation that breaks a dry spell. According to these authors, 2 mm of rain in one day (or in the next two days) in the summer is not enough to assume that the precipitation-free sequence has been broken. This amount will not even satisfy the daily water requirement of plants; it will only wet the top layer of soil and quickly evaporate (Klamkowski et al. 2014). According to Schmuck (1969), a sequence of 9 days without precipitation during the peak demand for water does not yet cause damage to crops. A dry spell lasting more than 15 days usually inhibits the development of crop plants or reduces the yield. Koźmiński (1986) worked on the assumption that during the growing season a day with the amount of rainfall equal to or greater than 1.5 mm, or two consecutive days with a total amount equal to or greater than 1.5 mm break the precipitation-free sequence lasting 11-15 days, and a day with the amount of rainfall equal to or greater than 2 mm, or two consecutive days with a total amount equal to or greater than 2 mm break the precipitation-free sequence lasting longer than 15 days. Czaplak (1996) distinguished rainless sequences lasting longer than 15 days during the growing season and made an assumption that a precipitation-free sequence is not broken by a single day or two consecutive days with precipitation of less than 1 mm; it is broken, however, by three consecutive days with precipitation (even in trace amounts of less than 0.05 mm). According to Konopko (1988), a dry spell is a period in which there are days without atmospheric precipitation or with a very small amount of precipitation not exceeding 0.5 mm per day. The author adopted rainless periods lasting 10-20 days, 20-30 days and over 30 days, and assumed that a day (or two consecutive days) in which the total rainfall is 5 mm or more is the last day of the dry spell because this amount of precipitation will wet the plants and topsoil, and reduce the deficiency in air humidity over the crop stand during one day or two consecutive days.

Defining the length of precipitation-free periods makes it possible to determine the beginning, end, and duration of each dry spell, but does not include evapotranspiration or soil moisture conditions in the period preceding the dry spell. The extent of the shortage of precipitation is dependent not on the length of the precipitation-free period but on the total evapotranspiration during that period. Doorenbos and Pruitt (1977) give a definition of reference evapotranspiration as the evaporation from a large green standing crop of grass (8-15 cm tall) completely shading the soil surface and having no difficulty in taking up water. The definition thus formulated allows us to calculate ET_0 on the basis of climatic parameters, i.e. solar radiation, temperature, air humidity and wind speed (Łabędzki et al. 2012). In practice, use is also made of simplified models which only need the time course of the changes in air temperature, or air temperature and humidity (Treder et al. 2010).

The aim of the study was to determine the extent of the shortage of precipitation on the basis of reference evapotranspiration during sequences of days without precipitation.

MATERIAL AND METHODS

Sequences of days without precipitation and climatic water balance for those sequences (for the years 2011-2015) were determined on the basis of data from six automatic weather stations (iMETOS – Pessl Instruments Austria) located in different parts of Poland. The stations were located in the following localities: Błędów, Wtelno, Zakalniki, Gołębiów, Biała Rządowa, Czerniec (Fig. 1, Tab. 1).

The adopted sequences of days without precipitation were defined according to the method proposed by Koźmiński (1986). This method was considered the most reliable for assessing the shortage of precipitation. The following durations of precipitation-free sequences were distinguished: from 11 to 15 days, from 16 to 20 days, and of more than 20 days. It was assumed that a precipitation-free period lasting for more than 11-20 days is broken by a day or two consecutive days with the combined total precipitation of more than 1.5 mm. According to this assumption, a precipitation-free period lasting for more than 20 days is broken by a day or two consecutive days with the combined total precipitation of more than 2 mm. A sequence of days without precipitation was assigned to a particular month when at least 60% of that sequence occurred during that month (Grabowska et al. 2004).

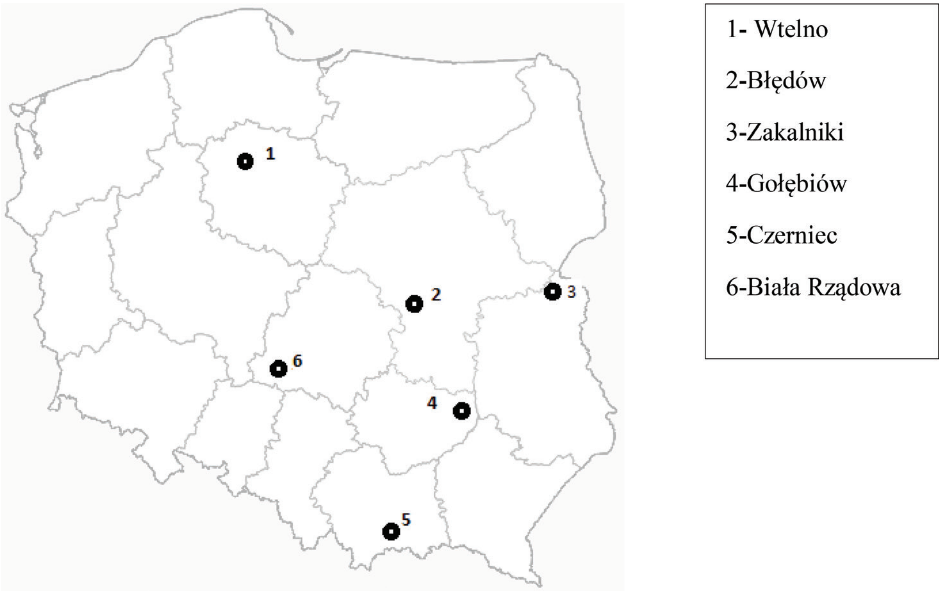

Figure 1. Location of the meteorological stations included in the study.

Table 1. Geographical coordinates of the meteorological stations included in the study.

Station	Geographical coordinates		Elevation above sea level (m)
	latitude	longitude	
1. Błędów	51°77’	20°69’	170
2. Wtelno	53°14’	17°53’	98
3. Zakalniki	52°22’	23°05’	161
4. Gołębiów	50°72’	21°52’	269
5. Biała Rządowa	51°15’	18°27’	186
6. Czerniec	49°56’	20°40’	112

Due to the lack of comprehensive meteorological data, the reference evapotranspiration was calculated using the Hargreaves model (Hargreaves and Samani 1985), which takes into account measurements of the maximum and minimum air temperatures, and data on the solar radiation reaching the Earth’s atmosphere. For the calculations, use was made of the application posted on the website www.nawadnianie.inhort.pl, which had been developed under the IO

Multi-Year Programme, Task 3.1 'Development of water – and energy-saving technologies of growing horticultural crops'.
The Hargreaves model:

$$ETo = HC\ Ra\ (Tmax-Tmin)^{HE}\ ((Tmax+Tmin/2))+HT$$

here:
HC – empirical factor = 0.00023
Ra – extraterrestrial radiation (mm per day)
Tmax – maximum air temperature (°C)
Tmin – minimum air temperature (°C)
HE – the author's empirical factor = 0.5
HT – the author's empirical factor = 17.8

RESULTS AND DISCUSSION

The values of average temperature and total precipitation for the period studied are presented in Tables 2 and 3. The average temperatures for the growing season in the years 2011-2015 do not differ substantially from the average temperatures for the multi-year period 1951-1990 (Bac and Rojek, 1999). The average temperature for the growing season ranged from 13.9°C in Zakalniki to 14.7°C in Gołębiów.

Table 2. Average temperature for the entire growing season (April-October) for individual stations in 2011-2015.

Year	Błędów	Wtelno	Zakalniki	Gołębiów	Biała Rządowa	Czerniec
	Average temperature					
2011	14,1	14,6	13,8	14,4	14,6	*
2012	14,3	14,4	13,8	14,8	14,5	14,6
2013	13,9	14,1	13,8	14,4	14	14,1
2014	14,2	14,5	14,2	15,6	14	14,1
2015	14	13,7	13,8	14,4	14,6	14,3
Multi-year average 2011-2015	14,1	14,3	13,9	14,7	14,3	14,3

U – lowest value for the year, U – highest value for the year, * – no data

The five-year study period was characterized by high spatial variability of precipitation. In 2011, relatively high precipitation occurred in Błędów (521 mm), but low in Biała Rządowa (335 mm) – the distance between the stations is

207 km. The difference between these amounts of rainfall was 186 mm, which made the amount in Biała Rządowa about 36% lower than in Błędów.

In 2012, the lowest total precipitation was recorded in Czerniec – 389 mm, and the highest in Wtelno – 558 mm. The difference here is 169 mm – the amount in Czerniec was 30% lower. These two stations are, however, very far from each other (about 560 km) – one of them is located in the north-west of Poland and the other in the south.

The year 2013 was characterized by low amounts of rainfall throughout the growing season. The lowest value was recorded by the station in Gołębiów – 316 mm, and the highest, 460 mm, in Czerniec. The difference here is 144 mm – the amount in Gołębiów was 31% lower. The levels of precipitation in the two consecutive years, 2012 and 2013, showed exceptional variability in distribution. The station in Czerniec recorded the lowest total rainfall in the growing season of 2012 and the highest in 2013 and 2014.

Interesting seems to be the fact that in 2014 the total precipitation recorded during the growing season by the station in Czerniec was 923 mm, while at the same time in the centre of Poland, in Biała Rządowa, the total rainfall reached only 320 mm, and was thus almost 3 times lower. In Czerniec in 2014, very high levels of precipitation were recorded in the months of April (111 mm), May (183 mm), July (242 mm) and August (149 mm). In this case, we can speak of a very high variation. The difference for these stations was as much as 603 mm, which represents 65% less precipitation recorded during the growing season in Biała Rządowa.

Table 3. Total precipitation for the entire growing season (April-October) for individual stations in 2011-2015

Year	Błędów	Wtelno	Zakalniki	Gołębiów	Biała Rządowa	Czerniec	Average
	Precipitation						
2011	521	405	449	511	335	*	444
2012	414	558	397	403	406	389	428
2013	422	371	417	316	437	460	404
2014	443	356	378	395	320	923	469
2015	359	269	312	508	210	430	348

U – lowest value for the year, U – highest value for the year, * – no data

During the entire growing season of 2015 the recorded levels of precipitation were very low. In Biała Rządowa they amounted to 210 mm, and in Gołębiów to as much as 508 mm. The difference between the two stations was 298 mm, which represents 59% less rainfall for Biała Rządowa. For most of the analyzed stations, the amount of total precipitation for the growing season in the individual years did not reach 500 mm. According to the criteria adopted by Banaszczak (2003), the stations except Błędów (2011), Wtelno (2012), Gołębiów (2015) and Czerniec (2014) were below the minimum precipitation threshold of 500 mm for intensive crop production.

In the years covered by the study, a total of 53 sequences of days without precipitation were recorded for all the locations and growing seasons (Tab. 4). The most frequent during the growing season were sequences of 11-15 days without rainfall. The highest number of such sequences (15) was recorded in 2013.

Table 4. Total number of sequences of days without precipitation for the stations in 2011-2015

Year	Class of a precipitation-free sequence	Months							Sum
		April	May	June	July	August	September	October	April-October
2011	11-15		1				1		2
	16-20	1				1			2
	>20						3		3
2012	11-15		4				3		7
	16-20								
	>20								
2013	11-15	2	1	1	6	2		3	15
	16-20	1						3	4
	>20				2	1			3
2014	11-15			1	1				2
	16-20								
	>20								
2015	11-15	1		2	3	2			8
	16-20			3		1	1	1	6
	>20					1			1
Sum		5	6	7	12	8	8	7	53

U – highest value

Collectively for the 6 locations, all of the different sequences of precipitation-free days were recorded most frequently in July (0.39 times per growing season), and the least often in April (0.16 times per growing season) (Tab. 5). Following the analysis of the duration of individual sequences of rainless days, it was found that the most frequently occurring (an average of 1.12 times per growing season) were the sequences of 11-15 days, less frequently those of 16-20 days (an average of 0.38 times per growing season), while the 20-day sequences without precipitation were the least likely to occur (an average of 0.22 times per growing season).

Table 5. Average frequency of occurrence of all the sequences of days without precipitation in the individual months of the growing season (April-September) in Poland in 2011-2015 (number of sequences per season).

Class of sequences od days without precipitation	April	May	June	July	August	September	October	April-October
11-15 days	0,1	0,2	0,13	0,33	0,13	0,13	0,1	1,12
16-20 days	0,06	0	0,1	0	0,06	0,03	0,13	0,38
>20 days	0	0	0	0,06	0,06	0,01	0	0,22
Sum	0,16	0,2	0,23	0,39	0,25	0,26	0,23	1,72

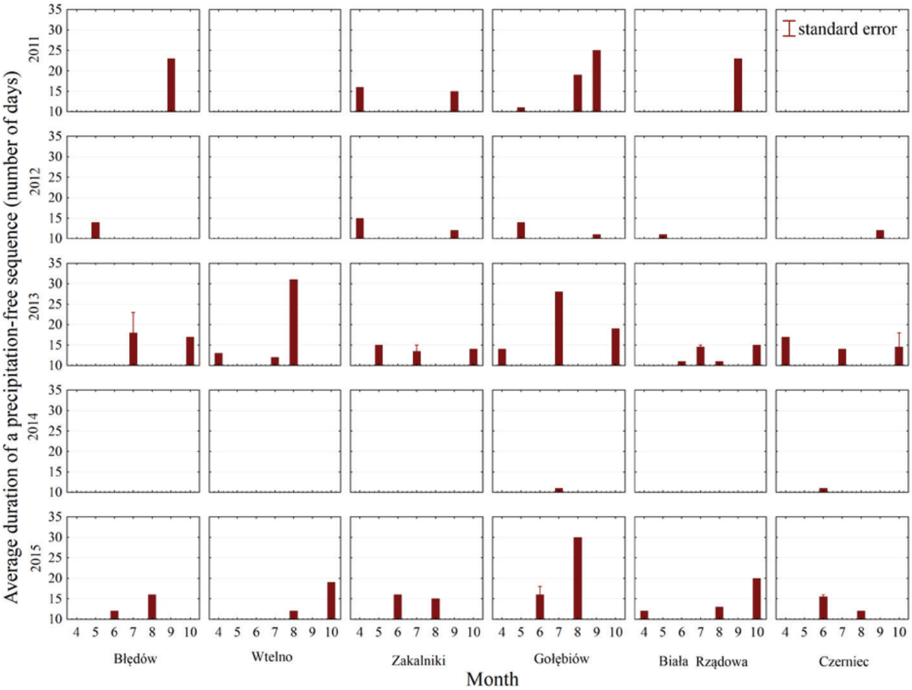

Figure 2. Average duration of a precipitation-free sequence (number of days) for the growing season in 2011-2015.

The average lengths of the sequences of days without precipitation during the growing season in 2011-2015 showed very high variability (Fig. 2). Of all the locations, the longest sequence, 32 days, occurred in Wtelno in 2013. An interesting fact is that in Wtelno in 2011, 2013, and 2014 none of the sequences was recorded at all. In Gołębiów also in 2013 and 2015 there was a sequence of approx. 30 days without precipitation.

Figure 3 shows, for each year and meteorological station, the average daily values of ET_0 during the occurrence of sequences of days without precipitation. With a total lack of rainfall, the determined values of evapotranspiration represent the average daily negative balance on the basis of which it is possible to estimate the water requirements of plants during periods without rain. Particularly high values of the average daily shortage of precipitation during rainless periods were recorded in 2013 and 2015. In the summer of 2013, in Wtelno, Biała Rządowa and Czerniec, the average daily ET_0 for a precipitation-free sequence exceeded 4 mm. Considering that each of the sequences lasted for more than 10 days, the water demand during that time for plants with a crop coefficient K > 1 was more than 40 mm. Similar values were recorded in Błędów, Biała Rządowa and Czerniec in 2015.

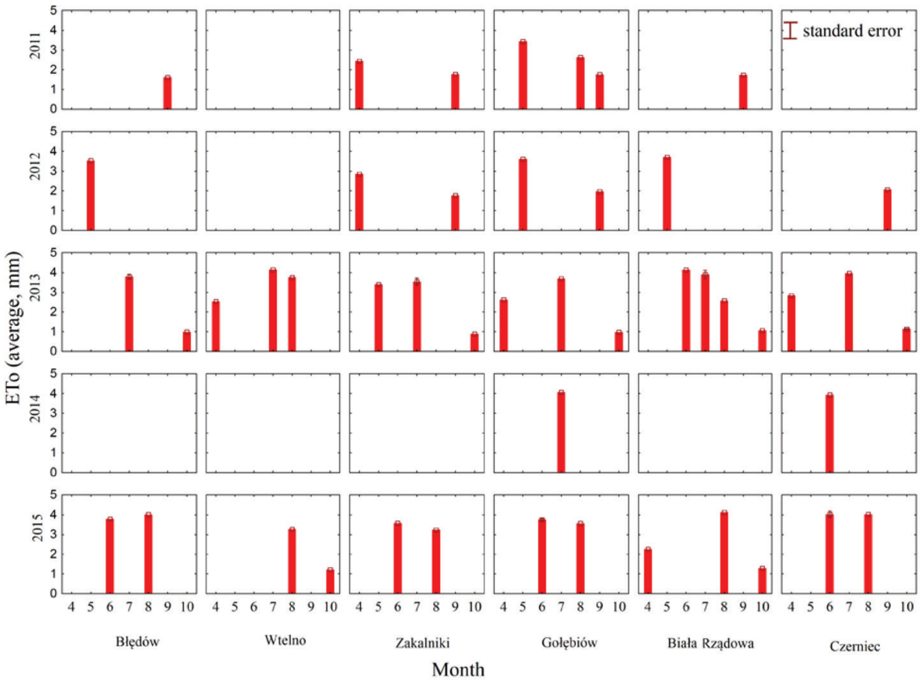

Figure 3. Average daily values of reference evapotranspiration during the occurrence of a precipitation-free period.

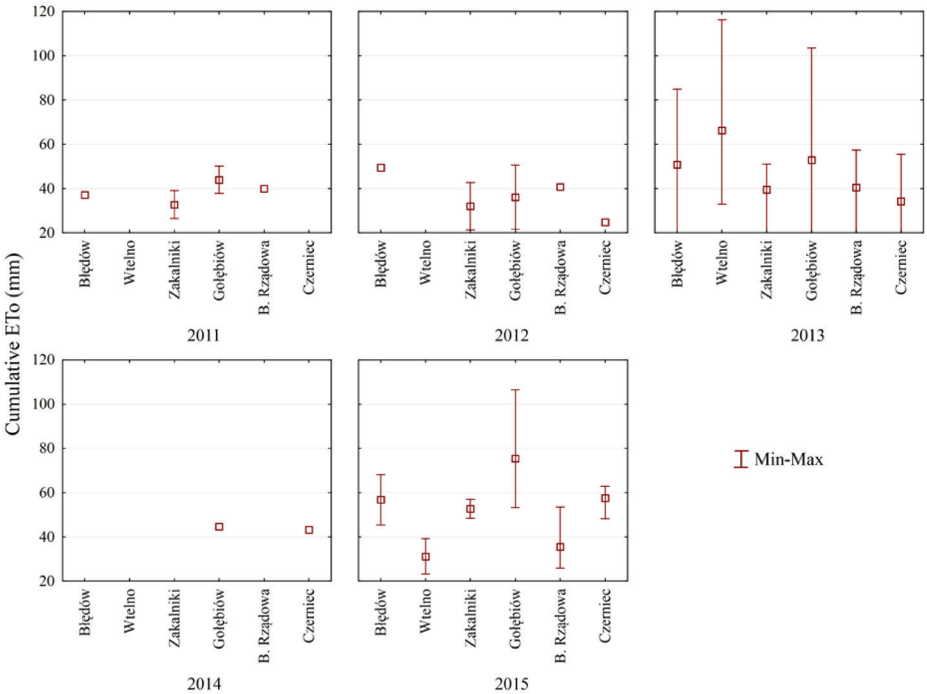

Figure 4. Cumulative ET_0 for the individual stations included in the study in 2011-2015.

Figure 4 shows the average values of cumulative evapotranspiration during the occurrence of sequences of days without precipitation. The lowest number of precipitation-free sequences occurred in 2014. Longer periods of the absence of rain (in 2014) were observed only in Gołębiów and Czerniec. Despite the fact that the total amount of precipitation was not significantly different from the average values from previous years, the shortage of precipitation was about 40 mm. It can be seen that in all the years of the study the average cumulative ET_0 for all the stations and years ranges from 40 to 60 mm. However, the largest periodic shortages may be much higher. In 2013, the largest shortage of precipitation was observed in Wtelno, where the deficit during the precipitation-free period was as high as 116 mm; a very large shortage of precipitation was also observed in Gołębiów in 2013 – 104 mm, and in 2015 – 107 mm. Insufficient quantity of water during the growing season significantly reduces crop yields, but above all it reduces the quality of agricultural produce, in particular of fruits and vegetables (Perez-Pastor et al 2007,Treder et al. 2009, Żarski et al. 2009). Słowik (1973), while analyzing the sensitivity of plants to drought, reports that the most sensitive among fruit trees are apple trees grafted onto dwarfing rootstocks, in which the bulk of the roots lies at a depth of 10-40 cm. Assuming, after Prochal (1986), that the amount of readily available water is 6 mm per 10 cm of soil for loose light loamy sands, and 8 mm for heavy clays and silty and loamy deposits, it can easily be seen that even in the case of heavy soils and deep-rooting plants the amount of water accumulated in the soil will not be sufficient to satisfy the water needs of plants during the occurrence of the described sequences of days without precipitation. For example, the amount of readily available water that can be accumulated in a 40-cm layer of a heavy soil is approx. 32 mm. This value is lower than the average cumulative evapotranspiration during the sequences of precipitation-free days shown in Figure 4. The estimated extent of the shortage of precipitation during sequences of days without precipitation can be helpful in determining the peak demand for water during the growing season and the size of water reservoirs for the irrigation of plants. When designing such a reservoir, one should bear in mind not only the seasonal shortages but also the maximum water uptake that occurs during the sequences of rainless days.

CONCLUSIONS

1. In the years analyzed, an average of 1.72 sequences of days without precipitation per growing season (April-October) were recorded in the areas covered by the study. The most frequently occurring were sequences of 11-15 days, and the least frequently those of 20 days.
2. In the areas studied, precipitation-free sequences lasting 16-20 days and more than 20 days occurred most frequently in August, and those lasting 11-15 days in July and May. Sequences of more than 20 days without precipitation did not occur at all in the months of April, May, June and October.
3. Cumulative evapotranspiration during the sequences of days without precipitation can greatly exceed the amounts of readily available water accumulated in the soil profile.

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