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Changing rainfall patterns and their impact on cereal crops in the Szentes district

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Abstract— One of the most significant impacts of climate change on domestic agriculture is an adverse change in rainfall patterns and an increased frequency of droughts. In our study, we analyzed the daily rainfall data at the automatic hydro-meteorological measuring station of the Lower Tisza Water Directorate (ATIVIZIG) in Szentes from 1981 to 2000 and 2001 to 2020. The focus of our study was the change in precipitation patterns caused by climate change and the phenology-dependent water demand and related yield of field cereal crops (wheat, maize). The yields of wheat and maize grown on the two largest arable land areas in the Szentes District and its wider region, the Southern Great Plain, between 2003 and 2020 showed a moderately strong correlation with changes in annual rainfall for the farms studied. This points to a strong dependence on rainfall for yields, also taking into account the risk of rainfall extremes. We found that in the second period under study, the dispersion of both annual and monthly rainfall totals increased strongly but in an insignificant way. The number of days with high rainfall increased by 19.3% and the number of days with extreme rainfall increased by 40.9%. Even larger increases were observed for the highest five-day rainfall totals (62.1%).

Key-words: rainfall patterns, drought, global warming, Southern Great Plain region, *Triticum aestivum, Zea mays, Helianthus annuus*

1. Introduction

In a number of studies, the increasing frequency of extreme weather events has been consistently highlighted (*Hetesi et al.,* 2016; *Stott*, 2016), including extreme precipitation patterns in the Carpathian Basin (*Hetesi et al.,* 2023; *Jánosi et al.,* 2023). There is a typically strong correlation between precipitation patterns and crop yields, especially in areas where the only source of water is natural precipitation (*Varga-Haszonits* and *Varga*, 2005). The amount of water available for arable crops is not only a major determinant in their survival but also in their productivity. Their growth, development, and subsequent achievement of optimum yields require sufficient water (mainly through natural precipitation), which enhances the domestic application of water-saving agrotechnical solutions (*Hetesi et al.,* 2022).

In addition to the amount of precipitation, its optimal temporal distribution is also important. The critical periods in common wheat (*Triticum aestivum*) are the tillering stage (*Nyiri*, 1993) and the period of generative organ development. During this period, water shortage is particularly limiting for further development and subsequent yield. If the amount of available water is insufficient, the yield quality will deteriorate along with the amount of genetically available yield (*Alaei et al.,* 2010; *Xuemei et al.,* 2010; *Nouri et al.,* 2011; *Ragheid et al.,* 2011;). In maize (*Zea mays*), adequate water supply is important from the early growth period. While the plant is small, the rows are not closed, so there is a high loss of water through direct evaporation from the soil (*Lacolla et al.,* 2023). The entire reproductive (grain filling) period requires the most moisture; rain fed production requires its temporal alignment with the peak of seasonal rainfall. Continued warming may cause an asynchrony large enough to threaten yields, particularly from exposure of the silk-tasseling phase to hot, dry conditions (*Harrison et al.,* 2011). In Hungary, the irrigation effect of maize is significant, with the crop's water requirements almost always greater than the rainfall of the growing season (*Tamás et al.,* 2022).

Too little precipitation can lead to drought stress, which in combination with other abiotic stress factors (e.g., extreme heat) can have an accumulative effect, causing greater damage (*Keles* and *Oncel*, 2002; *Barnabás et al.,* 2008). In addition to the lack of precipitation, extreme precipitation also has a detrimental effect on the development of cereals. Excessive precipitation and the high humidity that often accompanies it can facilitate the growth and transmission of many hydrophilic plant pathogenic fungi (*Pál-Fám* and *Rudolf*, 2014). Moreover, high precipitation also favors weed infestation, which causes significant agricultural damage (*Varga et al.,* 2002; *Márton et al.,* 2013).

The Szentes District investigated in this study is located in Csongrád-Csanád County, part of the Southern Great Plain region of Hungary. The region has excellent agricultural endowments, the largest area under wheat production (209 706 ha) and the highest total harvested weight (1 107 162 t) in the country (KSH, 2020, 2022). Comparably, maize ranks second among the regions, after the Northern Great Plain region, in terms of area under cultivation (221 541 ha) and total harvested weight (1 821 828 t) (KSH, 2020, 2022).

Our objective was to investigate the precipitation patterns in the Szentes District of the region, and to show their becoming more extreme during the year. In addition, we analyzed the impact of varying rainfall on wheat and maize yield averages using the example of a large farm located on the outskirts of the village of Derekegyház. These two arable crops were therefore chosen, because they cover the largest share of the area under cultivation both in the region and on the farm under study.

2. Materials and methods

Our study was conducted in the Szentes District in the Southern Great Plain region (*Fig. 1*). Szentes is the third most populous settlement in the county, situated on the left bank of the River Tisza, and has been a Tisza crossing point since 1903. It has low-lying, inhabited suburban settlements, which are on flood plains exposed to floods and inland waterways. Both the water level of the river and the local measurement of precipitation are a priority for water management and disaster prevention. The Lower Tisza Water Management Directorate (ATIVIZIG, 2024) measures daily rainfall at the Felsőveker hydrometeorological station in the municipality. As it is standard, the rainfall totals are automatically read at exactly 07:00 every day with an accuracy of tenths of a millimeter.

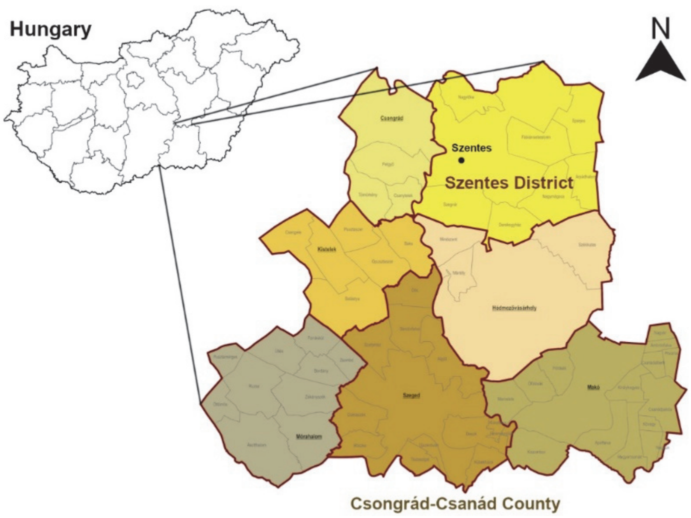

Fig. 1. Study area: the Szentes District in Csongrád-Csanád County, marked in yellow.

First, we looked at annual and monthly variations in precipitation. To this end, the period under study was divided into two equal time intervals (1981–2000; 2001–2020). The precipitation totals and their standard deviations were then compared. Our hypothesis was that the effect of climate change in weather extremes would be observed: in the second period, we would observe a larger variance in both annual and monthly precipitation totals; and that the second period would have a higher number of off-average values (weather records).

Precipitation extremes were investigated by calculating the main climatological indices for the period 1981–2000 and 2001–2020. *Table 1* summarizes the trends indices in Szentes, indicating the method of calculation. It is noted that the four parameters in the first four rows of the table are not extreme in nature, but rather refer to the variation in total precipitation. One of the most important of the indices is the standardized precipitation index, the calculation of which is recommended by the World Meteorological Organization (WMO) in order to characterize meteorological drought and for early warning systems for meteorological services of member countries (WMO, 2012).

To monitor droughts, the Standardized Precipitation Index (SPI) was determined for the two study periods. Computation of the SPI involves fitting a probability density function (PDF) to total precipitations for the stations of interest. In this study, the gamma distribution is applied, and defined by its frequency or PDF as:

$$G(x) = \int_0^x g(x)dx = \frac{1}{\beta^\alpha \Gamma(\alpha)} \int_0^x x^{(\alpha-1)} e^{(-x/\beta)} dx \quad for\ x > 0\,, \tag{1}$$

where x is the precipitation amount, α and β are shape and scale parameters, and $\Gamma(\alpha)$ is the Gamma function (*McKee et al.,* 1993). The α and β parameters have to be estimated, to each time scale of interest (1981–2020) and for each year. The maximum likelihood estimation was also employed. The resulting parameters were used to find the cumulative probability of an observed precipitation event for a timescale. This was then used in turn to obtain SPI values classified into different ranges of above and below normal values, in this way indicating the severity of the drought or non-drought event (*Table 2*). Several characteristics of droughts such as magnitude, duration or intensity can be derived based on the SPI values. In order to account for the probability q of zero rainfall to occur, the cumulative distribution function (CDF) for the Gamma distribution is modified as:

$$H(x) = q + (1 - q)\, G(x). \tag{2}$$

Table 1. Abbreviation and detailed method of calculation of the precipitation indices used in this study

Precipitation index	Meaning, definition	Calculation	Units of measurement
DD	Number of dry days, i.e., when precipitation does not exceed 1 mm	$n\ (R_{day} < 1\text{ mm})$	day
RR0.1	Number of days with a daily rainfall total of 0.1 mm or above	$n\ (R_{day} \geq 0.1\text{ mm})$	day
RR1	Number of days with a daily rainfall total of 1 mm or above	$n\ (R_{day} \geq 1\text{ mm})$	day
RR5	*Number of days with a daily rainfall total of 5 mm or above*	$n\ (R_{day} \geq 5\text{ mm})$	day
RR10	*Number of days with a daily rainfall total of 10 mm or above*	$n\ (R_{day} \geq 10\text{ mm})$	day
RR20	Number of days with a daily rainfall total of 20 mm or above	$n\ (R_{day} \geq 20\text{ mm})$	day
RX1	Maximum daily rainfall total		mm
RX5	Maximum rainfall total within 5 consecutive days	$\text{Max}(R_{day}i, i+1, i+2, i+3, i+4)$	mm
SPI	Standardized Precipitation Index	Eqs. 1 and 2.	–
SDII	Simple Day Intensity Index: the average rainfall rate on „wet days" (R≥1 mm) during the period of interest (here year)	$(\sum P)/RR1$ where Σp is the yearly precipitation	mm/day
CDD	The longest period without precipitation, when consecutive daily rainfall totals are less than 1 mm	$\text{Max}(R_{day}i, i+1, \dots, i+n)$ when $R_{day} < 1$ mm	day
CWD	The longest period of precipitation when consecutive daily rainfall totals reach at least 1 mm	$\text{Max}(R_{day}i, i+1, \dots)$ when $R_{day} \geq 1$ mm)	day
R75	Number of days with moderate precipitation	$R_{day} > R_{75\%}$ where $R_{75\%}$ is the upper quartile of daily precipitation in the period under consideration	day
R95	Number of very precipitation days	$R_{day} > R_{95\%}$ where $R_{95\%}$ is the 0.95 percentile of daily precipitation in the period under consideration	day
DS5	Number of dry periods longer than 5 days		1
DS10	Number of dry periods longer than 10 days		1
DS5N	Number of days during dry spells longer than 5 days		day/period

Table 2. Changes in the main climatological indices for the periods 1981–2000 and 2001–2020. (Source of data: ATIVIZIG, 2024).

	1981–2000	2001–2020	Change (%)
DD	1505 day	1590 day	+5.6
RR0.1	2340 day	2513 day	+7.4
RR1	1505 day	1590 day	+5.6
RR5	614 day	683 day	+11.2
RR10	285 day	340 day	+19.3
RR20	66 day	93 day	+40.9
RX1	52.3 mm	75 mm	+43.4
RX5	95.2 mm	154.3 mm	+62.1
SPI	–0.23	+0.24	–
CDD	44 day	46 day	+4.5
CWD	9 day	8 day	–11.1
SDII	6.38 mm/day	6.93 mm/day	+8.7
R75	1735 day	1776 day	+2.4
R95	351 day	364 day	+3.7
DS5	334	345	+3.3
DS10	155	154	–0.6
DS5N	4163	4150	–0.3

The calculated precipitation probabilities were transformed into the corresponding standard normal values, from which the SPI values were subsequently calculated. Additional descriptions can be found in *Edwards* and *McKee* (1997). The drought classification was based on the SPI (*McKee et al.,* 1993).

Finally, we tested whether there is a significant correlation between rainfall and yields in wheat, maize, and sunflower fields. The rainfall data were obtained from the ATIVIZIG measuring station in Szentes and the yields from a 300 ha farm on the outskirts of the village of Derekegyház. These three crops were chosen because they account for the largest share of the farm's production area. Likewise, these three crops are the most widely grown in the Southern Great Plain region. The dependence of wheat and maize yields on water availability is a well-known fact in the literature. Both crops are rain-fed. Maize prefers more humid conditions than wheat and is also drought-sensitive. Sunflowers (*Helianthus annuus*) are moderately drought tolerant compared to wheat and maize. The rainfall requirements of sunflowers are highly dependent on their phenological stage. As the plants grew during July, transpiration increased alongside the expanding leaf area; therefore, sunflower water use increased and reached its highest level in July or August. However, during the mowing period following pan maturation, precipitation in the pan may be conducive to fungal infections (*Gulya et al.,* 2018). Thus, the dependence of sunflower yield on precipitation was used as a control in our study, and no correlation between the two variables was expected. In contrast, for wheat and maize, we hypothesized that yields would be strongly dependent on rainfall.

In our research, the normality of the samples was checked using Shapiro-Wilk tests, which can also be applied to samples with a small number of elements. Where normality was met, we compared the standard deviations of the samples using an F-test. Where normality was not met, Levene's test was used to determine the homogeneity of variance. At several sites, a two-sample Kolmogorov-Smirnov test was used. This less well-known statistical test compares the continuous distribution of two samples. This does not specify the common distribution (e.g., normal or abnormal) (*Naaman*, 2021). The test's null hypothesis is that the two samples come from a population with the same distribution. The null hypothesis can be rejected if the value obtained is greater than the critical value from the table.

Statistical tests (linear trend estimates, F-tests, Shapiro-Wilk tests, correlation analyses) were performed at a significance level of $\alpha = 0.05$ in all cases not specifically indicated. In exceptional cases, different levels of significance were used to demonstrate the conclusiveness of the computational results. These are indicated in all cases. We used a significance level lower than the usual $\alpha = 0.05$, because the two-sample Kolmogorov-Smirnov tests are more robust, weaker statistical tests (*Marrozzi*, 2009, 2013).

3. Results and discussion

Looking at the development of the annual precipitation sum (*Fig. 2*), the year 2000 was a year of extreme drought, even at the national level, and one of the worst years for Hungarian agriculture due to the lack of precipitation. The annual rainfall at the Felsőveker station was less than 300 mm (299.6 mm), which was extremely low by national standards. Furthermore, it highlighted the meteorological drought vulnerability of the Southern Great Plain region due to the lack of precipitation. Szeged, located approximately 40 km south of Szentes as the crow flies, recorded the lowest annual precipitation in 2000 in national comparison, 203.3 mm (*Szentes*, 2023).

The year 2010 was exceptionally wet, with a national average of more than one and a half times the multi-year average (169%) (HungaroMet, 2024). At Felsőveker, a total rainfall of 848.4 mm was recorded. In May this year, unprecedented flooding occurred on smaller rivers, and a further flood wave was still flowing in June. The River Tisza, which borders Szentes, also experienced flooding. September and December were also extremely wet months. In Szentes, nine people were forced to leave their homes, which had become unsafe due to the flooding (*Nagy*, 2011).

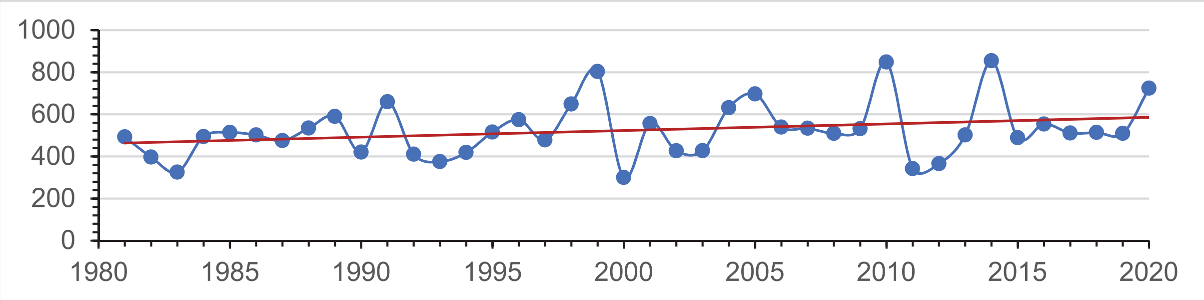

Fig. 2. Annual rainfall totals (mm) in Szentes between 1981 and 2020 (Source of data: ATIVIZIG, 2024).

The year 2011 brought a reversal of the trend, with prolonged periods of drought and precipitation levels of less than half the long-term average. The national precipitation total in 2011 was 404.4 mm, which is only 4.3 mm more than the second lowest annual value (year 2000) since measurements began to be taken (*Fekete* and *Keve*, 2020). The central region was the driest in the country (HungaroMet, 2024). At the Szentes station, 341.9 mm of precipitation was recorded in 2011, which is much lower than the national value.

Year 2014 (HungaroMet, 2024) was even wetter than 2010, when a total of 854.0 mm of precipitation was recorded at the hydrometeorological station. July 2014 was one of the five wettest Julys in the national statistics, which have been kept since 1901. Although this month is one of the wettest months of the year in a large part of the country, it is also often a period of severe drought (*Ambrózy et al.*, 1990). The highest July precipitation in 2014, 237.6 mm, was recorded very close to the station at Pankota near Szentes. The month of September 2014 was also very wet, with several properties in Szentes at risk of flooding, low-lying suburban houses and farms in particular. Two thousand sandbags were transported to the Szentes area by the disaster management team, whose units from Szeged and Hódmezővásárhely also took part in the clean-up. In Szentes, firefighters pumped rainwater from three locations. According to climate research studies, these record years are not clearly due to climate change, but they are an indication of the weather becoming more extreme.

At the national level, annual rainfall totals have shown a downward trend since 1901. In contrast, Szentes shows a small, but not significant ($R^2 = 0.0787$)

increase in annual precipitation totals between 1981 and 2020. The results of the Shapiro-Wilk tests $[\mathrm{W}(20) = 0.96;\ \mathrm{p} = 0.555;\ \mathrm{W}(20) = 0.9;\ \mathrm{p} = 0.039]$ indicate that the annual precipitation totals for the period 1981–2000 follow a normal distribution. The distribution of the data for 2001–2020 is very close to a normal distribution, but is not normally distributed at the 0.05 significance level. Nevertheless, an F-test was used to compare the dispersion of rainfall amounts over the two time intervals. Our hypothesis was that the extremes of precipitation would move in a wider range and occur more frequently. However, the results of the F-test $[SD_1 = 120.05, SD_2 = 137.70, \mathrm{F}(19{,}19) = 0.8, \mathrm{p} = 0.556]$ did not show that the precipitation extremes increased significantly.

We also examined how annual rainfall totals varied during the growing season relevant for crop water requirements (from March 1 to October 31) (*Fig. 3*). Similarly, the year 2000 was considered the driest year, while the highest rainfall was recorded in 2014. There is no significant increasing trend in rainfall amounts in this comparison ($R^2 = 0.0507$). Our two rainfall amount samples (1981–2000; 2001–2020) are normally distributed $[\mathrm{W}(20) = 0.93, \mathrm{p} = 0.163;\ \mathrm{W}(20) = 0.93, \mathrm{p} = 0.125]$, and therefore an F-test was used. Likewise, the F-test did not reveal any significant difference $[SD_1 = 99.31, SD_2 = 122.80, \mathrm{F}(19{,}19) = 0.7, \mathrm{p} = 0.363]$ between the sample variances. The variances within the growing season were lower than the variances in annual rainfall totals.

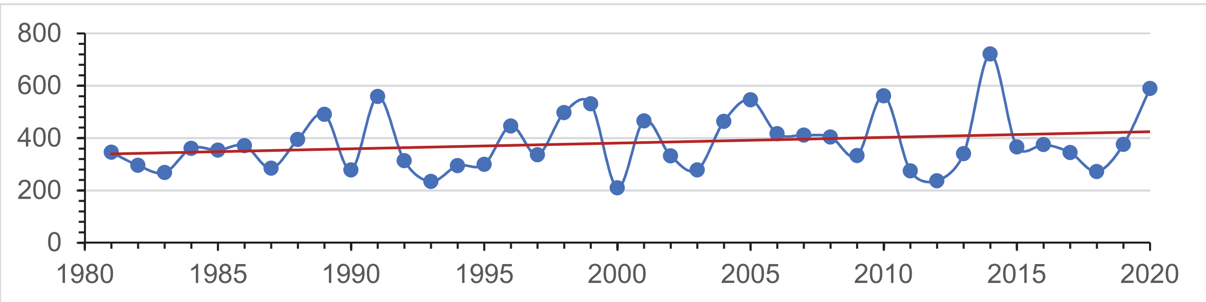

Fig. 3. Trends in rainfall (mm) per vegetation period (from March 1 to October 31) in Szentes between 1981 and 2020 (Source of data: ATIVIZIG, 2024).

Similarly, there is no significant trend (increase) in the number of precipitation days per year between 1981 and 2020 ($R_2 = 0.0015$). The record year of 2010 had an exceptionally high number of precipitation days 114, while the years 1983, 2000, and 2011 had much fewer than 60 precipitation days on average (*Fig. 4*).

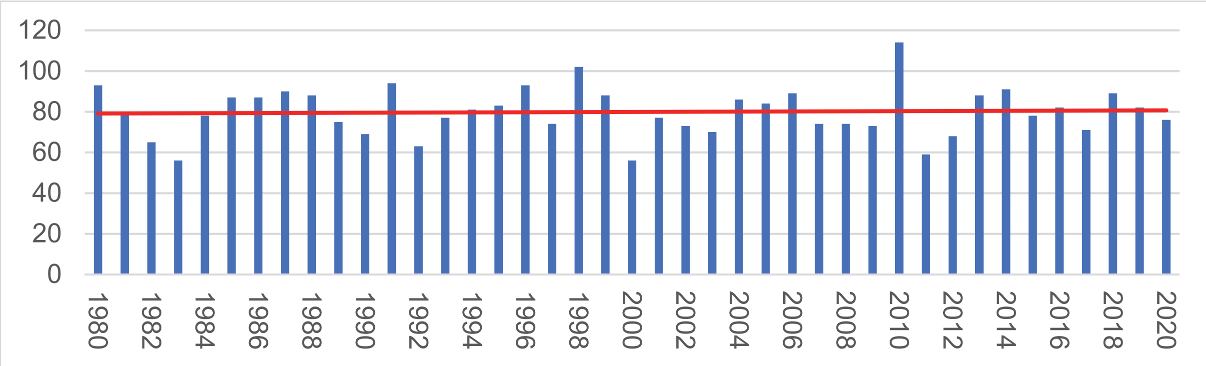

Fig. 4. Changes in the number of precipitation days between 1980–2020 (Source of data: ATIVIZIG, 2024).

The monthly number of days with precipitation (excluding outliers) follows a normal distribution between 1981 and 2020 (*Fig. 5*). Outliers, i.e., values exceeding one and a half times the width of the interquartile range from the lower to the upper limit of the range, are marked by circles in *Fig. 5*. Outlier days were: March 1988 (19 days), July 2014 (18 days), and October 2003 (20 days). In October 2003, the national rainfall was well above the multi-year average, at around 90 mm. The high precipitation was accompanied by cold weather, with snow falling in several municipalities across the country on October 23–24, with snow cover of more than 10 cm covering the surface for several days (HungaroMet, 2024). At the Felsőveker measuring station, 126.4 mm of precipitation was recorded in October.

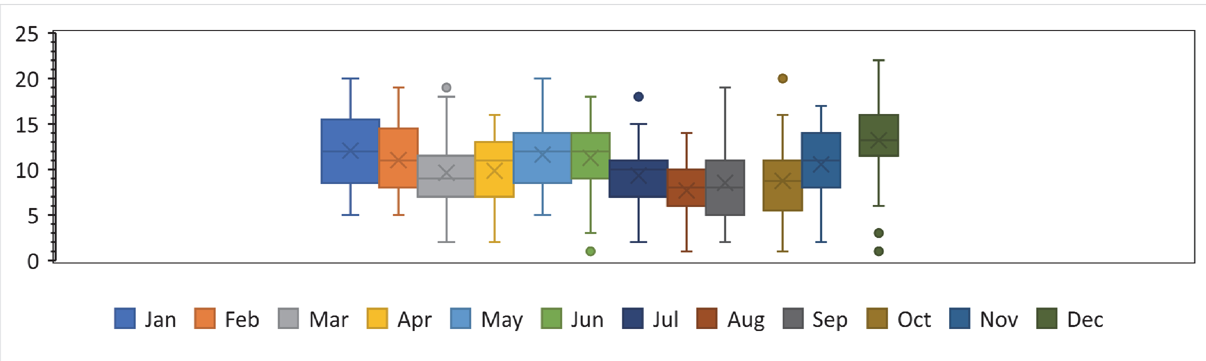

Fig. 5. Changes in the number of precipitation days per month between 1981 and 2020 (Source of data: ATIVIZIG, 2024).

Outlier days were recorded in June 2000 (1 day), December 2013 (1 day) and December 2016 (3 days). It is noteworthy that five of the six outlier months fell in the second half of the period under study (2001–2020).

Two-sample Kolmogorov-Smirnov tests show that there is no significant difference in the distribution of daily precipitation between 1981–2000 and 2001–2020. There is an increase in the number of days with low rainfall (maximum 10 mm per day) and an increase in the number of days with extreme rainfall, which merits further research.

For the extreme precipitation study, increases were observed for most climatological indices (*Table 2, Fig. 6*). This is in line with the spatial results from observed data on the change in annual precipitation totals (1981–2020) (HungaroMet, 2021a). The number of precipitation days (RR0.1) increased by 7.4%. A precipitation day is defined here as a daily precipitation sum reaching 0.1 mm. The number of days with high rainfall ($R_{day} \geq 10$ mm) increased by 19.3%. The number of extreme rainfall days (when the daily rainfall total reaches 20 mm) has increased even more (40.9%). Increases in RR10 and RR20 have been shown in several previous studies (*Bartholy* and *Pongrácz*, 2004; 2005a; 2005b) for several domestic stations (including Szeged, which is the closest to Szentes) in the period 1976–2001. However, a further study (No. T-049824 OTKA grant, final report) shows that RR10 and RR20 values are already showing diverging trends in the European region. In addition, climate models for long-term Hungarian projections highlight the seasonal variability of the RR1 and RR10 indices. They show an increase in RR1 in summer and a decrease in RR1 in winter for the period 2071–2100 compared to the reference period 1961–1990 (*Pongrácz et al.*, 2012).

The record for the highest daily rainfall (RX1) was 75 mm in the second period under study (September 13, 2014). The highest 5-day rainfall was also recorded between September 10 and 14, 2014, with a value of 154.3 mm. By comparison, this value is approximately twice the average monthly 30-day rainfall total for June 1991–2020, which is the highest average rainfall total for any of the months (HungaroMet, 2021b). This is a significant increase compared to the record 5-day rainfall total of 95.2 mm in 1981–2000.

The longest period without rainfall between 1981–2000 was 44 days, but this record was also broken between 2001–2020 with a 46-day period. The length of the rainfall-free and rainfall-rich periods is important for determining drought periods. Two-sample Kolmogorov-Smirnov tests show no significant difference in the distribution of the length of the rainy season ($D_{max} = 0.22$; $K_s = 0.47$; $\mathrm{p} = 0.98 > 0.05$) and the length of the dry season ($D_{max} = 0.11$; $K_s = 0.65$; $\mathrm{p} = 0.79 > 0.05$).

The simple daily rainfall intensity index (SDII) shows an increase of +8.7% in the second period. This means that the average amount of precipitation per day of precipitation has increased by this amount.

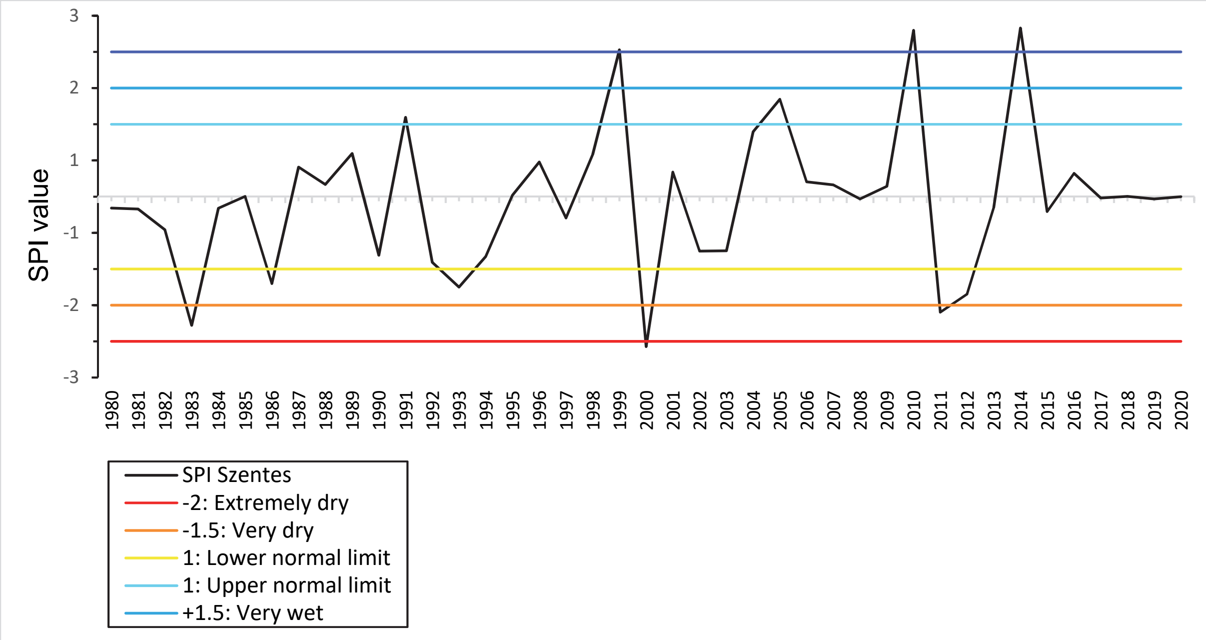

Fig. 6. Change of SPI values in Szentes between 1980–2020 (Source of data: ATIVIZIG, 2024).

In further examination of extreme precipitation events using the Kolmogorov-Smirnov test we found that the distribution of the precipitation amount neither for days with high precipitation ($D_{max} = 0.1231$; $K_s = 0.7016$; $p = 0.7085 > 0.05$) nor for days with extreme precipitation ($D_{max} = 0.1455$; $K_s = 0.7628$; $p = 0.6057 > 0.05$) differed significantly in the two periods (*Fig. 7*). It is noteworthy, however, that for nine of the ten days with the highest daily precipitation, totals fell in the period 2001–2020.

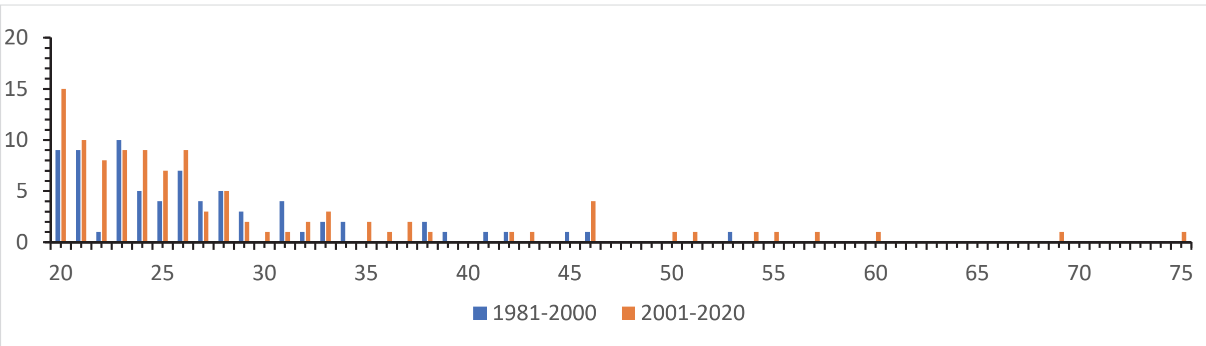

Fig. 7. Distribution (%) of rainfall totals on days with extreme precipitation (>20 mm) between 1981–2000 and 2001–2020 (Source of data: ATIVIZIG, 2024).

Since national laws only consider the effect of daily maximum temperatures and rainfall totals on drought development, drought statistics may be biased by days with intense rainfall, ignoring the rolling effect of precipitation. An increase in the frequency of dry days may result in a similar rolling effect, which can be explained by soil water resources, soil water holding capacity, and its finite nature.

In our study, we investigated whether there is a significant relationship (correlation) between annual precipitation and the yield of wheat and maize fields on the farm near the municipality of Derekegyháza, which share the two largest area shares. *Fig. 8* shows how sensitive the yield of different crops is to rainfall. A medium strong correlation ($R^2 = 0.32$) is observed for maize, which is considered a drought indicator crop, and a medium strong correlation ($R^2 = 0.20$) for wheat. As a control, the yields of the sunflower fields occupying the third largest area of the farm were also examined. Our original hypothesis was supported by the fact that sunflower yields did not show any correlation ($R^2 = 4 * 10^{-5}$) with rainfall.

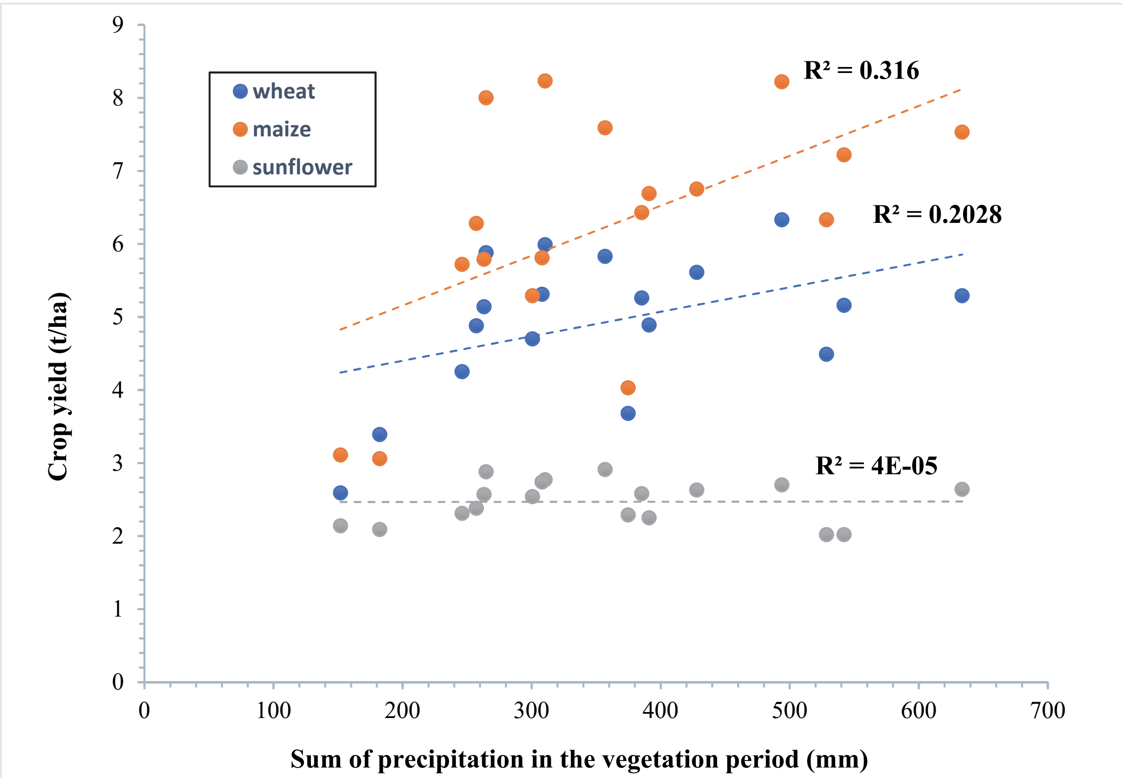

Fig. 8. Yields (t/ha) of maize, wheat, and sunflower on a farm near Derekegyház and annual precipitation data in Szentes between 1978 and 2020 (Source of data: ATIVIZIG, 2024; Derekegyház farm, 2023).

The lowest yields shown in *Figure 7* belong to the years 2003 and 2007, when the growing season rainfall did not even reach 200 mm. The year with the highest rainfall was 2014, when a total of 633.6 mm of rainfall was recorded during the growing season. Even so, this is not the year with the highest average yields, which points to the impact of the high rainfall not being clearly positive (+78% compared to the growing season average). The highest yield averages typically occurred in years close to the multi-year rainfall average (2016, 2018, 2020).

A similar positive correlation was found between maize yield (R^2=0.21) and wheat yield ($R^2 = 0.10$) and annual precipitation between 2006 and 2019 in a study in Poland, but Poland has a rainier climate than Hungary (*Wójcik-Gront* and *Gozdowski*, 2023).

The lack of a strong correlation can be explained by several factors, the most important of which is the phenological, phase-dependent water demand of plants, which varies during the growing season. The water requirements of plants are more or less constant and are a well-known varietal characteristic. Like many abiotic environmental factors, rainfall is optimal for crops within a range. Too much rainfall can lead to anaerobic soil conditions and soil erosion, as the soil has a finite capacity to absorb water. It can also increase the growth and spread of weeds, pests, and pathogens that require a wet and humid environment. Among pathogens, fungal diseases such as rust (*Puccinia sorghi, Puccinia striiformis, Puccinia triticina*) and fusarium (*Fusarium* sp.) are particularly susceptible to humid conditions. Among pests, aphids (*Aphidoidea*) and leafbeetles (*Oulema* sp.) are also important.

It is also worth comparing wheat and maize crop yields with buying-in prices (*Fig. 9*). It can be seen that the two driest years (2003, 2012) had the lowest yields, which drove up buying-in prices. In the years with better yields, prices fell.

Fig. 9. Trends in wheat and maize crop yields and average buying-in prices 2003–2020. (Source of data: KSH, 2024; Derekegyház farm, 2023).

An even more accurate relationship between crop yields and buying-in prices would be obtained by inflation-adjusted prices. However, the drought year of 2012 is still striking, with only 182.3 mm of rainfall in the vegetation period and prices at a record high (wheat: 60 425 HUF/10 000 kg, maize: 56 697 HUF/10 000 kg). The previous year, also dry, was also low, with 246.1 mm of rainfall. Thus, the high buying-in price in 2012 probably reflects the rolling effect of the drought, just as the fall in prices was delayed, the rise in yields appeared with a lag. Limited storage time also plays a role in this.

4. Conclusions

No clear upward trends in annual and monthly rainfall totals were observed over the period 1981–2020; we did, however, demonstrate a non-significant but still notable increase in the frequency of rainfall extremes. Dividing the period under study into two equally long periods, we found that the number of days with high precipitation increased by 19.3% and the number of days with extreme precipitation increased by 43.4%. The increase in the frequency of intense rainfall periods is even more significant. The highest five-day precipitation index was 62.1% higher in the second period (154.3 mm). There was also a change in the distribution of rainfall totals. The probability of the occurring two extreme conditions, the frequency of dry days and, in parallel, the frequency of extreme precipitation days increased.

It would also be worth looking at the number of days with precipitation over a longer time horizon. It is questionable whether the already significant decrease in the national average (17 days per 120 years between 1901 and 2020) can be observed here. It would also be worth knowing how the frequency of extreme precipitation events has changed.

The dependence of wheat and maize yields on the amount of precipitation is shown using the example of the average yields of a large farm from 2003 to 2020. The drought-sensitive nature of maize, which prefers humid conditions, was shown by the dependence of the yield average on higher precipitation. Wheat yield averages were found to be less dependent on precipitation than maize, which is consistent with the lower water requirement of the crop. This result confirms the role of intra- and inter-annual rainfall forecasting in crop protection.

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