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The Impact of Climatic Factors on the Development Stages of Maize Crop in the Transylvanian Plain

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Abstract: Climate change has become the biggest global challenge, being a real danger especially for crops and an inevitable threat to food security. This paper presents the results of a study conducted in the Transylvanian Plain during 2012–2021, regarding the influence of climatic factors, such as temperature, rainfall, water reserve in the soil and hours of sunshine, on the development stages and yield of maize. During 2012–2021, the soil water reserve determined for maize cultivation was above the minimum requirements (1734.8 m^3 ha^{-1}) in the spring months, but fell below this limit in the months when the water consumption for maize was the highest, but without reaching the withering index (1202.8 m^3 ha^{-1}). The hours of sunshine in the maize vegetation period have been significantly reduced from 1655.5 h (2012) to values between 1174.6 and 1296.7 h, with a significant decrease in this parameter being observed. The coefficient of determination (R_2 = 0.51) shows the importance of rainfall during the period of emergence of reproductive organs in maize production. During 2019–2021, there was a decreasing trend of temperatures in May compared to the multiannual average of this month, and therefore the processes of emergence and growth of plants in the early stages were affected. During the period of the study, all parameters analyzed (temperature, rainfall, water reserve in the soil, hours of sunshine) deviated from the multiannual average, with negative variations compared to the requirements of maize. Climatic conditions, especially during the growing season, have a significant influence on the yield of a crop, especially when the interaction between several parameters is manifested.

Keywords: climatic conditions; water reserve in the soil; maize; crop development

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1. Introduction

It is unanimously accepted that current climate change is the result of direct or indirect human intervention in the composition of the global atmosphere [1]. Climate change has become the biggest global challenge, raising issues in terms of crop development and yield [2,3], through rising temperatures and uneven rainfall, leading to threats regarding food security for the growing population [4,5]. The problem of fluctuating climate has become more certain in the last two decades, when yield variability has become greater [6].

Maize (*Zea mays* L.) is a cereal with a large yield capacity [7] and with a widespread area being influenced by climate change [8]. Medium early maize genotypes are characterized by a lower sensitivity to higher temperatures and drought during the grain-filling period and could contribute to the ability of new hybrids to counteract the effects of climate change, having a high resistance to diseases and pests, and thus agricultural and harvesting works can be fully mechanized. Currently, maize is one of the most important crops due to its high productivity and its multiple uses in human food, animal feed and also as a raw material in various industries [6].

In Romania, maize is the most widespread crop, and it is used in human and animal nutrition [9]. The cultivation of maize in the Transylvanian Plateau is totally dependent on the amount of water from rainfall and groundwater supply [10]; thus, in order to have satisfactory results in terms of harvest and quality, the monitoring of climatic parameters and soil water supply is of real importance.

The yield potential of hybrids and the quality of yield are correlated and strongly influenced by environmental factors such as temperature, total rainfall and water storage in the soil [11,12], but also by solar radiation [13,14]. As yield is influenced by weather effects and agrotechnical conditions, its variability can be difficult to predict [6,15].

Temperature is one of the three primary environmental variables influencing plant phenology and physiology alongside solar radiation and soil moisture [16,17]; therefore, low temperatures delay seed germination and reduce growth rates. Insufficient soil water availability weakens the metabolic activity of maize, reduces its biomass accumulation and decreases its photosynthetic rate, eventually leading to a decrease in maize yield [18]

Temperature changes, especially during the growing season, have the ability to shorten the growing period and ultimately reduce yield [19,20]; additionally, a high temperature in the critical stages of development can deteriorate the quality of maize grains [21].

Certain authors consider maize as being moisture-demanding [22], but thanks to its low transpiration rate, strong root system and the possibility of reducing the area of perspiration by twisting the leaves in the case of drought, it is considered a drought-resistant plant. However, it responds differently to the lack of water depending on its development stage [23], the duration of drought and its severity [24]. Even if the amount of rainfall during the vegetation period of a crop corresponds to the value necessary for a good development of the plants, the non-uniformity of rainfall during important times can lead to a significant decrease in yield [21,25]. After the formation of the stem and the advancement in vegetation, the maize plant's requirements for water increase considerably [26], reaching a maximum level during the blooming period and in the formation of grains [27,28], in July–August. The critical phases and high water demand also occur 7–10 days before blooming, 10–20 days after blooming, as well as during the blister and milk stages [29]. For the conditions in Romania, the minimum amount of rainfall for the entire vegetation period of maize is 250–300 mm, and the best amount is between 300–380 mm, with the following distribution across the months: 60–80 mm in May, 100–120 mm in June, 100–120 mm in July and 40–60 mm in August [30].

Crop productivity and yields can be greatly diminished by abiotic stress events including drought, extreme temperatures, excess moisture and salinity [31,32]. Many researchers [33–35] have conducted very detailed research in the field of molecular biology in order to identify the genes in the inbred lines of maize that can contribute to increasing the tolerance of plants to drought and, inclusively, the development of plants and obtainment of superior yields.

The aim of this study is to identify the main climatic parameters that influence the development of the maize crop, and how these parameters affect the stages of development and the stability of maize yield.

2. Materials and Methods

2.1. Biological Materials

The experiment was designed and carried out at the Agricultural Research and Development Station Turda (ARDS Turda), located on a Chernozem soil [36]. The properties of the soil from the experimental site, at a depth of 0–20 cm, are as follows: clay content (<0.002 mm) 56.07%, fine dust (0.002–0.05 mm) 19.15%, dust (0.05–0.02 mm) 9.15%, fine sand (0.02–0.2 mm) 14.9%, coarse sand (0.2–2.0 mm) 0.73%, texture clayey loam, bulk density 1.13 g cm^{-3}, total porosity 58%, humus content 3.73%, pH of 6.81, total nitrogen content 0.205 mg kg^{-1}, mobile phosphorus 35 mg kg^{-1} and mobile potassium 320 mg kg^{-1}.

The potentiometric method was used to establish pH, and the Walkley–Black method was used for humus; total nitrogen was established using the Kjeldhal method; phosphorous and the content of potassium were established through the Egner–Riehm–Domingo extraction method.

The biological material used in this experiment was two hybrids of maize from the FAO 300–380 maturity group. The Turda Star hybrid was grown between 2012 and 2016 and the Turda 332 hybrid was grown between 2017 and 2021. Basic fertilization was carried out with phosphorus-based fertilizer at a rate of 40 kg ha^{-1} (P_2O_5), which was subsequently incorporated in autumn when ploughing was completed. Supplementary fertilization was carried out in spring, before the preparation of seedbed, with a nitrogen-based fertilizer at a rate of 100 kg ha^{-1}. The experiment was included in a 3-year crop rotation: soybean–winter wheat–maize.

2.2. Methods of Analysis

The gravimetric method was used to determine the momentary water supply, based on the property of the soil to lose the entire amount of water, physically bound, when subjected to oven drying at temperatures >105 °C. Soil sampling was carried out using the drill type Theta probe on the 10th of every month throughout the growing season of the crop, taking samples at a depth of 0–50 cm. After that, the soil was put in an oven for drying for 8 h at 105 °C.

The determination of the active temperature units was made by summing all the average temperature degrees that exceeded the threshold of 10 °C for a given period of time, and the hours of sunshine were calculated as the sum of hours of actual sunshine for the period monitored.

The rather accelerated pace of replacement of maize cultivars as well as their special ability to capitalize on different climatic conditions, depending on genetic and morpho-physiological properties, led us to test the behavior of new maize hybrids in a cycle of five years.

The climatic data presented come from the Turda Meteorological Station, which is part of the administrative structure of the Northern Transylvania Regional Meteorological Center under the Romanian National Meteorological Administration. The Weather Station is located at the ARDS Turda perimeter (located in the Transylvanian Plain, Romania), with longitude coordinates 23°47′; latitude 46°35′; altitude 427 m.

2.3. Statistics

The interpretation of the experimental results was carried out by calculating the linear regressions expressed by the degree equation I y = a + bx. The correlation coefficients were established by using the correlation coefficient "r". For the interpretation of the experimental data, the statistical parameters, mean ($\bar{x}$), variability coefficient (CV%), regression coefficient (R) and correlation coefficient (r) [37], were calculated:

$$\bar{x} = \frac{x_1 + x_2 + \cdots + x_n}{n} = \frac{\sum x}{n}$$

where $x_1 + x_2 + \cdots + x_n$—set of observations, ($\sum x$—sum of observations), n—number of observations.

The coefficient of variation (CV%) was calculated as the ratio between the standard deviation and the arithmetic mean [38].

$$CV\% = \frac{s}{\bar{x}}$$

where s—the standard deviation of the data set; $\bar{x}$—average value of the data set.

The correlation coefficient *r* was calculated with the formula [37]:

$$r = \frac{s_{xy}}{s_x s_y}$$

where s_{xy}—covariance of x,y; $s_x s_y$—variance x, y.

3. Results

In the case of maize, the water supply of the soil in spring is of particular practical importance. The reserve is formed by the accumulation of the rainfall in the soil during winter and the beginning of spring and can ensure the living conditions of maize in the first two months (May–June). During 2012–2021, the soil water reserve determined for the maize crop in our study was above the minimum requirements (1734.8 m^3 ha^{-1}) in the spring months, but fell below this limit in the months when the water consumption for maize is the highest, but without reaching the withering index (1202.8 m^3 ha^{-1}) (Figure 1).

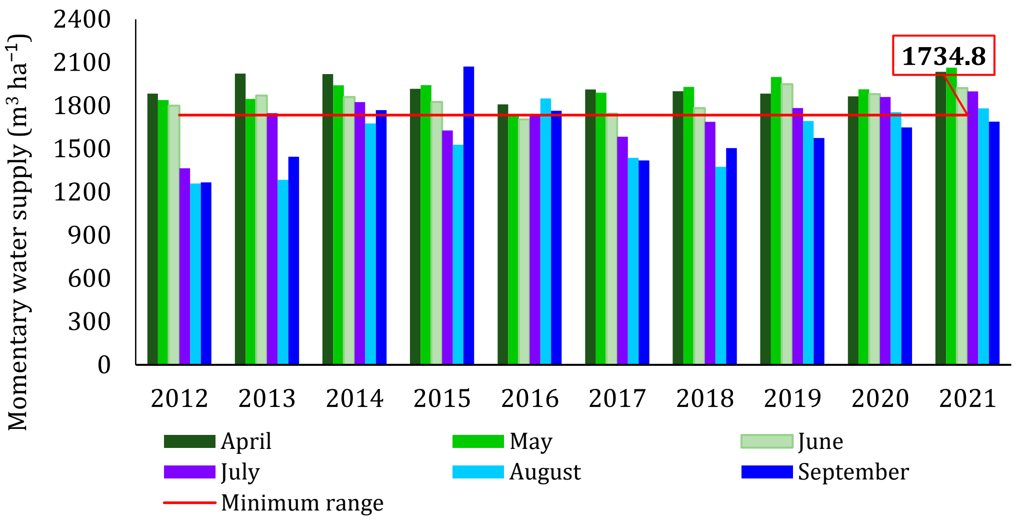

Figure 1. Momentary water supply 0–50 cm deep (m^3 ha^{-1}) in different growth stages of maize during 2012–2021 at the experimental site.

Even if the water in the soil is within normal limits for the development of the crop, it must also be considered that the water supply in the soil is not fully available to the plants, as a large part of it is closely related to soil particles.

Significant decreases in maize yield are recorded if water is lacking in the critical period between the first and second week before harvesting and the milk-wax maturity, during which the maize has the highest water consumption, 50% of the total consumption during the vegetation period [10,39]. This phenomenon is encountered in half of the period analyzed and it is reflected in the yield achieved in the studied period.

In the early stages of vegetation, when plants do not cover the soil well, 45% of the water is lost through evaporation and 55% through perspiration [40]. As the available water supply from the soil is very important from this development phase onwards, we can say that due to the reserve accumulated in soil until the sowing of the crop, it does not register decreases below the limit necessary for the optimal development of the crop. Therefore, in the conditions of the Transylvanian Plateau, there are no problems with the water reserve in the soil that is necessary for the emergence and the first phases of growth [41].

The determinations carried out reflect a good water supply in the first part of the growing season and up to June (growing period) and a decrease in the water supply in the soil in certain years during the formation of yield. An adequate supply of soil with water can compensate for the impact of extreme temperatures that may occur during the growing season.

From the 5-year period studied (2012, 2013, 2015, 2017, 2018), the soil water reserve in July and August was below the minimum requirements (1734.8 m^3 ha^{-1}) (Figure 1).

The effects of water stress in subsequent growing periods were the main causes of the reduction in yield [23,42]. Meteorological factors are one of the important factors that determine maize kernel weight and grain nutritional quality [43], because during the dry years, the phenomenon of grain drying occurs, and thus the grains have less weight than those obtained in normal climatic years, and there is an inverse relationship between production and protein content.

Even though the average air temperature has been rising in recent years, the hours of sunshine in the maize vegetation period have decreased significantly from 1655.5 h (2012) to values between 1174.6 h (2021) and 1296.7 h (2017) recorded in the last period. One can observe a decreasing trend of this parameter and the physiological processes of maize may be affected by this phenomenon if this trend is maintained (Figure 2).

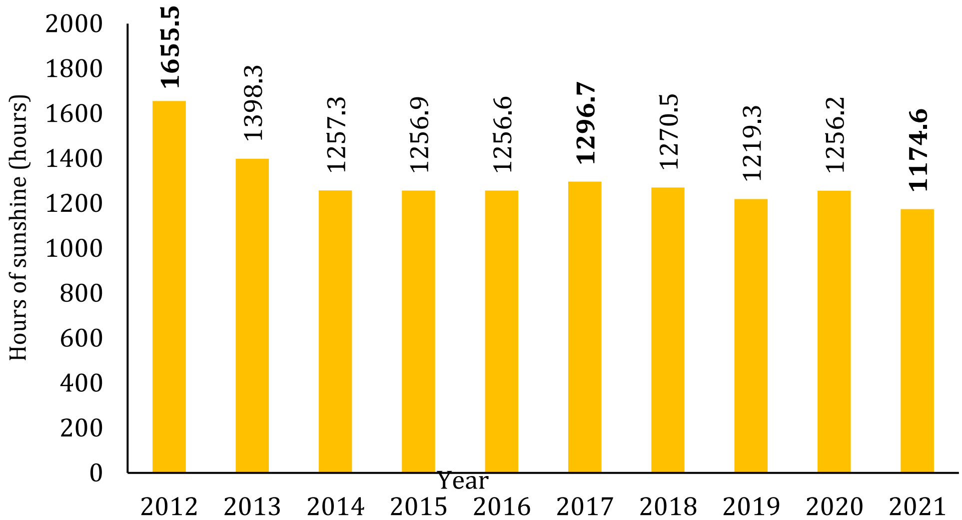

Figure 2. The hours of sunshine from May to September (hours) in different growth stages of maize during 2012–2021 at the experimental site.

The reduction in the hours of sunshine can have a negative impact on production, given the fact that maize is a short-day plant adapted to high-light conditions.

The decrease in the hours of sunshine is an important problem because during the pre-blooming period, maize is quite sensitive to insufficient light, a fact that can lead to disturbances in the formation of its reproductive organs.

The temperature requirements of maize are different depending on the vegetation stage of the plant [27,44]. In May, when maize plants have up to eight leaves, lower temperatures can cause damage to the leaves, which can lead to the well-known phenomenon of blocking the absorption of phosphorus, an important element in maize nutrition with a direct effect on the normal growth of plant. This phenomenon has been quite present especially in recent years, during which temperatures in May were lower than the multiannual average of this month (Figure 3).

The result of the analysis of the thermal regime (from sowing to plant emergence) is that in the conditions of the Transylvanian Plateau, some climatic phenomena from this period are quite frequent, such as frosts or late frosts.

According to the data in Table 1, (in the case of sowing to plant emergence) it happens that a greater number of days was recorded in the years when maize was sown in April than in the years when sowing was carried out in May. The variation in the number of days from sowing to plant emergence is between 10 days (in 2014 and 2015) and 22 days (2013).

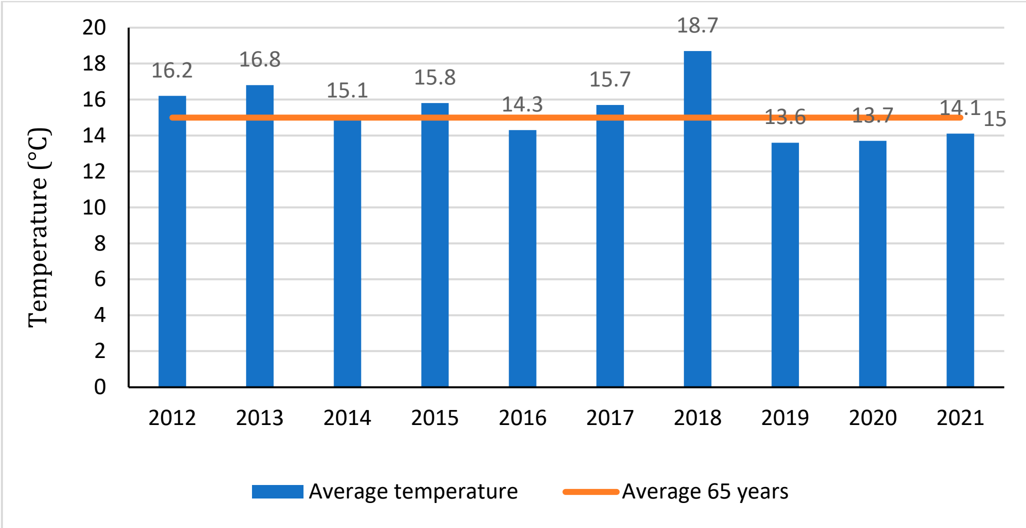

Figure 3. Average temperature in May (°C) registered when maize plants have up to 8 leaves. Notes: the differences compared to the multiannual average.

Table 1. Number of days from sowing to plant emergence and the sum of useful thermal degrees registered during 2012–2021 in Turda.

Year	Sowing Date	Plant Emergence Date	No. of Days from Sowing to Plants Emergence	The Sum of Useful Thermal Degrees (Σt > 10 °C) (°C)	Minimum Temperature of the Period (°C)	The Amount of Rainfall from Sowing to Plant Emergence (mm)
2012	08.05	25.05	17	83.0	6.3	48.6
2013	30.04	22.05	22	179.1	11.2	29.3
2014	12.05	22.05	10	51.0	5.5	26.8
2015	06.05	16.05	10	57.1	6.9	24.2
2016	19.04	05.05	16	29.0	−0.9	36.2
2017	27.04	10.05	13	65.3	−0.7	46.0
2018	03.05	15.05	12	118.4	11.3	25.2
2019	19.04	06.05	17	44.3	3.3	43.0
2020	27.04	12.05	15	47.4	3.6	29.2
2021	11.05	23.05	12	58.6	6.2	33.2
Amplitude	19.04–12.05	05.05–23.05	10–22	29.0–179.1	(−0.9)–(+11.3)	24.2–48.6

Source of climate data: Turda Meteorological Station.

In 2013, although the minimum temperature of the period did not fall below 11.2 °C, and the sum of useful temperatures was 179.1 °C, the fact that 29.3 mm of rainfall fell only in the second half of May led to a delay in crop emergence, and the number of days from sowing to emergence was 22 days.

The delay in the emergence of maize has been observed throughout several years, during which at least one of the factors of temperature and rainfall deviated from the requirements of maize for this stage, as it needs to meet all factors to germinate and develop normally.

Studying the temperature data over 10 years, we noticed that in 2016 and 2017, minimum temperatures with a value below the freezing limit were recorded during the crop germination period. The minimum temperatures had positive values in all other years.

The evolution of average temperatures in the pre-blooming period during the entire study interval can be seen as an upward trend compared to the average, as the analysis performed on the evolution of useful thermal units throughout the vegetation period does not show a significant increase in annual value. The sum of the thermal units varies from one year to another, without significant deviations from the average of the ten years analyzed. The amplitude of the recorded data, expressed by the coefficient of variability (c.v.%), indicates a high variability in terms of the amount of rainfall from sowing to maize silk, the amount of rainfall throughout the vegetation period, as well as yield. From these high values of the coefficients of variation regarding the pluviometric regime, we can deduce the very uneven distribution of rainfall from the vegetation period of the maize and from the 10 years studied. A small variability was determined in the sum of the useful thermal units from the sowing period to the appearance of stigmas, and from sowing to maturity (Table 2).

Table 2. The sum of the useful thermal units above the threshold of 10 °C and the amount of rainfall registered in Turda during 2012–2021.

Year	Sowing Date	Through Sowing Date to Maize Silk Appearance			Through Sowing Date to Physiological Maturity			Yield (kg ha^{-1})
		Date	Σt > 10 °C (°C)	Σpp (mm)	Date	Σt > 10 °C (°C)	Σpp (mm)	
2012	08.05	03.07	496.2	155.2	11.09	1369.0	263.6	4714
2013	30.04	10.07	594.3	192.5	17.09	1299.8	268.5	5937
2014	12.05	15.07	515.8	163.2	30.09	1144.1	331.4	9371
2015	06.05	07.07	517.7	171.7	15.09	1291.3	357.9	6885
2016	19.04	05.07	597.2	265.2	04.10	1391.6	499.7	10,105
2017	27.04	11.07	631.2	162.2	12.09	1314.3	279.1	8855
2018	03.05	16.07	666.9	228.4	24.09	1420.3	307.2	9320
2019	19.04	08.07	598.9	266.2	16.09	1367.9	358.6	8893
2020	27.04	20.07	590.5	279.4	07.09	1132.6	378.2	8642
2021	11.05	19.07	641.2	205.5	27.09	1228.8	313.3	10,137
Average ($\bar{x}$)	01.05	11.07	585.0	209.0	19.09	1296.0	335.8	8286
Amplitude	19.04–12.05	03.07–20.07	496.2–666.9	155.2–279.4	07.09–04.10	1132.6–1420.3	263.6–499.7	4714–10,137
cv%	-	-	9.8	22.9	-	7.7	20.8	22.0

Source of climate data: Turda Meteorological Station.

From the data presented, it can be noticed that the amplitude of the sowing date is much higher than the appearance of the maize silk. This demonstrates that the appearance of the maize silk is a genetically controlled trait and that regardless of the date of sowing, there are no significant differences in the time of the maize silk appearing. During the sowing season, we do not control the moment of blooming, as it is controlled mostly by the genotype and the sum of the useful degrees of temperature. It has been discovered that in just one year, the sum of the useful degrees from sowing to the appearance of stigmas was below 500 °C in 2012.

Temperature and rainfall conditions were best met in 2016 and 2021, when grain yield exceeded 10,105 kg ha^{-1} (2016) and 10,137 kg ha^{-1} (2021).

The average temperature of the period from sowing to physiological maturity has an annual variation from 15.8 °C to 19.4 °C. In 2016, the lowest average temperature of the vegetation period was recorded and the lowest temperature difference between the average maximum temperatures and the average minimum temperatures from sowing to physiological maturity was also determined (10.6 °C). In three of the years analyzed, higher values of the difference between maximum and minimum temperatures were recorded, namely in 2012, 2019 and 2021, with values between 10.6 °C and 12.9 °C. The amplitude of the average maximum temperatures recorded during the ten years had values between 21.9 °C and 26.0 °C in the same years in which the average temperatures had extreme values, namely 2016 and 2012, respectively (Table 3).

The reduced amount of rainfall from the sowing period to the appearance of stigmas made 2012 the year with a grain yield of only 4714 kg ha^{-1}, which represented about half of the average yield obtained during 2012–2021. This was also the year with the lowest sum of useful thermal units from the sowing period to the appearance of maize silk (496.2 °C), but among the highest during the vegetation period (1369 °C). The years 2014, 2016, 2018 and 2021, during which the maize reached physiological maturity later, were the years during which the most significant harvest increases were registered for the reference period 2012–2021.

Table 3. Variation in mean temperatures from sowing to physiological maturity.

Year	Mean Temperature from Sowing to Physiological Maturity (°C)	Mean of Maximum Temperatures from Sowing to Physiological Maturity (°C)		Mean of Minimum Temperatures from Sowing to Physiological Maturity (°C)	
		Average	Limits of Variation	Average	Limits of Variation
2012	19.4	26.0	10.0–38.1	13.3	6.3–20.5
2013	18.4	24.7	13.4–35.8	13.7	7.1–20.6
2014	17.8	24.2	14.3–34.5	12.8	2.5–19.4
2015	18.2	24.6	14.0–34.8	13.1	6.9–19.3
2016	15.8	21.9	10.5–33.4	11.3	−0.9–19.1
2017	18.9	24.8	14.7–36.8	13.1	1.1–20.2
2018	19.0	25.6	17.2–32.3	13.5	7.3–18.8
2019	17.5	24.3	6.4–34.9	11.4	2.7–18.8
2020	17.7	24.5	11.2–33.5	12.5	0.9–20.2
2021	17.0	24.1	11.8–34.7	11.5	4.7–19.8
Amplitude	15.8–19.4	21.9–26.0	6.4–38.1	11.3–13.7	−0.9–20.6

Source of climate data: Turda Meteorological Station.

The variations in the average monthly temperature during the vegetation period, as well as the increase in their value, have negatively influenced the maize yield, and an inverse relationship was determined between temperature and yield (Figure 4).

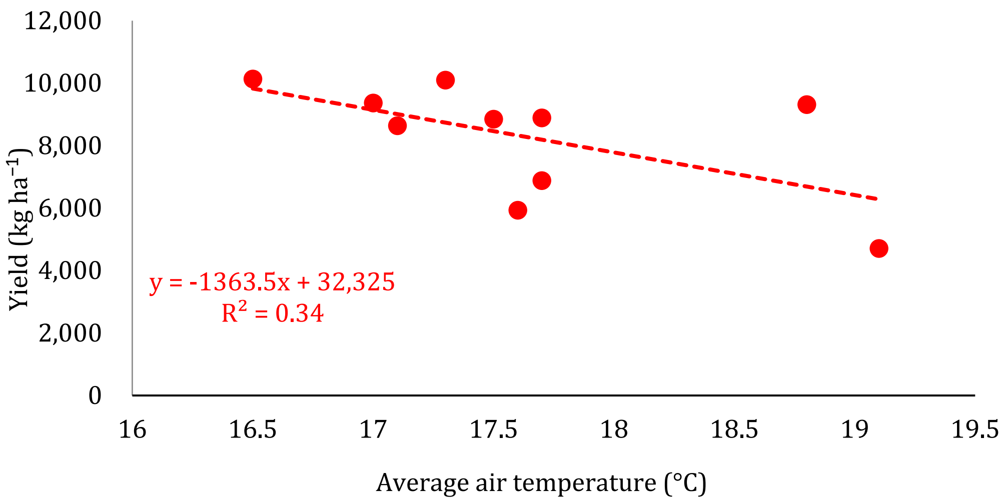

Figure 4. The relationship between the average temperature of the vegetation period and yield.

An increase of only 1 °C in the average seasonal temperature can reduce the economic yield of maize by 3–13% [45,46]. Temperatures between 33 and 36 °C, during the pre-blooming and post-blooming periods of maize, reduce the CO_2 exchange rate by ≈17%, the growth rate of the crop (17–29%), the number of grains (7–45%) and yield by 10–45% [47].

4. Discussion

A variation in climatic conditions is one of the most important factors involved in crop development and can directly affect production. Deb et al. [48] reported that changing the sowing date can increase the yield from 5 to 22.5% due to the extension of the growing and filling periods of the grains, but the climatic conditions from the beginning of the vegetation period are decisive in the normal evolution of the culture, and low temperatures and a lack of rainfall slow down the normal growth processes [49]. The positive or negative variations compared to the optimal values are reflected in the evolution of the vegetation state of the crops and also in the harvest [50,51], depending on the intensity and duration of the stress.

Iqbal et al. [52] stated that maize was particularly susceptible to drought stress during pollination and grain filling. However, besides the amount of water, the distribution of rainfall during critical phenological stages is also important for maize [53].

Rainfall in the summer months has a decisive influence on yield [54,55] and it is important both in terms of quantity and distribution. The relationship between the amount of rainfall in July and the yield is shown in Figure 5. As presented, there is a significant direct relationship between the two variables. The regression coefficient (33.10) expresses a strong correlation between the amount of rainfall recorded in July and the yield of maize, and a dependence on the values of the coefficient of determination (R_2 = 0.51). However, from the distribution of the points around the regression line, we notice the fact that even under the conditions when rainfall has lower values, the maize yields were high, and at about 40 mm, 8800 kg ha^{-1} was achieved. This indicates that the water supply in the soil in July managed to sustain this yield, without a substantial contribution of rainfall.

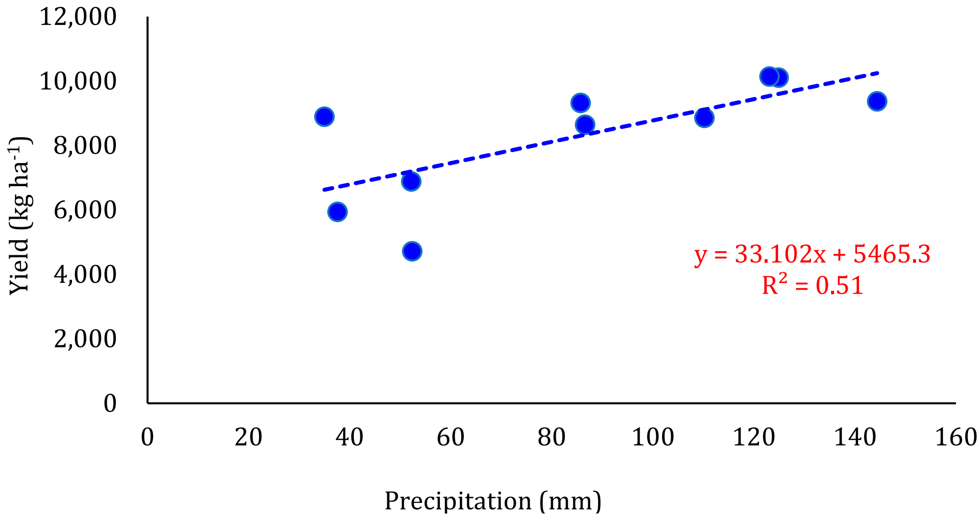

Figure 5. The relationship between the amount of rainfall in July and the maize yield.

For maize, summer rainfall has a decisive influence on yield [56,57], and its uniform distribution is more important than the total rainfall [58,59]. The decrease in soil moisture below the minimum range limit from the formation of the eighth leaf has a negative effect on the grain yield [60,61], depending more or less on the duration of the drought period. Undoubtedly, the rainfall factor is a major element in the cultivation of maize [62,63], especially if the rainfall level is defective during certain years or during certain stages of the vegetation period [64]. Moderate moisture from the appearance of the eighth leaf to tillering and from drought to tillering cuts maize yield in half [65]. The production also drops by half when the plants grow in drought conditions until the formation of the first eight leaves, and in moderate humidity conditions until sprouting [66,67], even if they continue to benefit from optimal humidity. It can be concluded that the maize harvest is ensured not so much by the annual amount of precipitation [57], but more so by its distribution during the vegetation period of the plants [68,69].

5. Conclusions

Climatic conditions, especially during the growing season, have a significant influence on the crop yield, especially when the interaction between several parameters is manifested. Changing the sowing date cannot avoid high temperatures during the blooming period. This can be solved, or even controlled, by choosing appropriate maize hybrids with a different vegetation period or that are improved in order to face less favorable environmental conditions. Average monthly temperatures in May decreased compared to the multiannual average, causing a negative effect on the optimal development of maize plants, especially in the first part of the vegetation period when a slow growth rate was observed. A direct positive relationship between the amount of rainfall recorded in July and the maize yield (R_2 = 0.51) was observed. The distribution of rainfall during the vegetation period was found to be more significant for yield compared to the annual amount of rainfall. The sum of the useful thermal units above the 10 °C threshold does not register a continuous growth throughout the entire vegetation period, and the growth trend is observed only in the pre-blooming period. In the light of present study, it can be concluded that climate has proven to be the most important factor in maize production. This means that in the years ahead, a significant contribution to maize production will be achieved by selecting appropriate hybrids, followed by appropriate production technologies.

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