Article

Multi-Site Evaluation of Accumulated Temperature and Rainfall for Maize Yield and Disease in Loess Plateau

Xiaoyue Wang [1,†], **Xinghua Zhang** [1,†], **Mingxian Yang** [1], **Xiaonan Gou** [1], **Binbin Liu** [1], **Yinchuan Hao** [1], **Shutu Xu** [1], **Jiquan Xue** [1,*], **Xiaoliang Qin** [1] **and Kadambot H. M. Siddique** [2]

1   College of Agronomy, Northwest A&F University, Yangling 712100, China; wxyue@nwafu.edu.cn (X.W.); zhxh4569@163.com (X.Z.); mxyang@nwafu.edu.cn (M.Y.); xiaonangou@nwafu.edu.cn (X.G.); liubinbin@nwafu.edu.cn (B.L.); h.ychuan@163.com (Y.H.); shutuxu@nwafu.edu.cn (S.X.); qinxiaoliang@nwsuaf.edu.cn (X.Q.)

2   The UWA Institute of Agriculture and School of Agriculture & Environment, The University of Western Australia, LB 5005, Perth, WA 6001, Australia; kadambot.siddique@uwa.edu.au

*   Correspondence: xjq2934@163.com; Tel.: +86-29-8708-2990

†   These authors contributed equally to this work.

Abstract: The Guanzhong region is a typical and important grain-producing area in China. The effect of accumulated temperature and rainfall on maize production is important in the face of global warming. Here, we collected meteorological data from six test sites in the Guanzhong region to study climate change from 1972 to 2018 in this area. A two-year study was conducted at multiple experimental sites to analyze the effect of climatic factors on maize yield and disease in the Guanzhong region. In the past 40 years, average temperatures have significantly increased at all sites, except for Hancheng. Rainfall varied significantly between years at each site, except for Huxian, with an overall declining trend. Accumulated temperature had a significant positive effect on yield ($R^2 = 0.28$, $p = 0.041 < 0.05$), but rainfall did not affect yield ($R^2 = 0.0971$, $p = 0.324 > 0.05$). During the growing period, total rainfall had a significant positive correlation with northern leaf blight disease in maize, and rainfall before silking had a significant positive correlation with ear length and row grain number. The demand for accumulated temperature by maize differed between sites. It is predicted that maize yield will increase with increasing temperature in the Guanzhong region. Greater attention should be paid to improve agronomic practices, such as adjustment of sowing dates, straw mulching, deep tillage, and pest control to adapt to future climate change.

Keywords: Guanzhong region; temperature; rainfall; yield; disease

1. Introduction

The IPCC's (The Intergovernmental Panel on Climate Change) fifth assessment report shows that greenhouse gas concentrations are increasing, and global warming is undeniable [1]. An analysis of China's meteorological data from the 1950s to 2010s revealed an overall warming trend of China's climate [2]. An analysis of climate simulation results showed that China's climate is following a warming trend in the 21st century [3]. Pan et al. predicted that surface air temperature warming significantly increased in northwest China and exceeded 6 °C, and that future precipitation will increase by 50 mm by the end of the 21st century [4]. Climate change has a significant impact on agricultural production [5]. With China's large population and huge food demand, it is important to study the impact of climate on agricultural production in China.

Climate warming has benefits for irrigated agriculture but not for rainfed agriculture. Increased rainfall can benefit both rainfed and irrigated agriculture but may be detrimental in the humid areas of southeast China [6]. Maize (*Zea mays* L.) is the largest grain crop in China in terms of area and production. Increased temperatures can have an adverse effect on maize yields in the long term, while the reverse is true in the short term. Long-term

temperature changes had a 20-fold greater impact on maize yield than annual temperature changes [7]. Wu and Xiao et al. believe that climate change will reduce maize yield [8,9]. When crop varieties and sowing date did not change, climate change had no significant effect on maize yield in a high latitude region of northeast China but had a significant negative effect on maize yield in a low latitude region [10]. Previously, the impact of climate change on maize yield was shown to affect all provinces of China, and rising average temperatures reduced maize yield in most of the study areas, and while rainfall changes affected maize yields differently in different regions, they had no significant effect on maize production nationwide [8,11].

The degree and range of disease occurrence will affect maize growth; severe disease greatly reduces maize production and even grain quality [12,13]. Big spot disease in maize, also known as northern leaf blight (*Exserohilum turcicum* (Pass.) Leonard et Suggs) [14], occurs under high humidity at temperatures between 20 °C and 28 °C [15]. It mainly affects the leaves, causing serious leaf drop, inhibiting photosynthesis [16]. The optimal temperature for southern leaf blight (*Helminthosporium maydis* Nisik & Miy) is around 27 °C, which is more likely to occur on rainy days [17]. Maize smut (*Ustilago maydis* (DC) Corda.) also mainly affects the leaves; it can rapidly generate many disease spots, consume plant nutrients, and reduce plants to empty stalks—once the disease breaks out, yield is seriously affected [18].

The Guanzhong region has a typical semi-arid and semi-humid environment and fertile soil. It is a large area located in the north of the Qinling Mountains, accounting for 19% of the total area of the Shaanxi Province. The Weihe River flows from east to west. The Guanzhong region was cultivated for thousands of years. It is currently engaged in a two-season farming mode, with winter wheat (*Triticum aestivum* L.) sown in winter and maize in summer. From 2000 to 2015, temperature in the Guanzhong Plain increased, while the mean precipitation increased first and then decreased [19]. This paper focuses on (1) rainfall and temperature changes in the Guanzhong region in the past 40 years, (2) the effect of temperature and accumulated temperature on maize yield and disease incidence in multi-site experiments in the Guanzhong region, and (3) the effect of climate change on maize planting and growth in this region.

2. Materials and Methods

2.1. Collection of Meteorological Data

Weather data from 1962–2018 were collated from weather stations at six experimental locations; historical temperature data for nine locations in 2017 and 2018 came from the 2345 Weather Forecast Network (http://tianqi.2345.com/wea_history/60446.htm (accessed on 9 January 2020)).

2.2. Field Experiment

Average annual rainfall in the Guanzhong region is 500–700 mm, concentrated from May to October, with more in the east than in the north, south, and west. North of the Weihe River, the rainfall isolines are sparsely distributed (520 mm average rainfall), while south of the Weihe River, the rainfall isolines are densely distributed (650 mm average rainfall). Rainfall shows strong interannual-decadal variability.

The field trials took place in 2017 and 2018 at seven sites: Fuping Dry Land Demonstration Park (Fuping; 109°11′ E, 34°42′ N; altitude: 445 m), Hancheng Seed Management Station (Hancheng; 110°25′ E, 35°28′ N; altitude: 457 m), Linwei District seed management Station (Linwei; 109°30′ E, 34°30′ N; altitude: 357 m), Sanyuan Seed Management Station (Sanyuan; 108°56′ E, 34°37′ N; altitude: 424 m), Shaanxi Seed Industry Group (Huxian; 108°32′ E, 34°06′ N; altitude: 414 m), Qishan Seed Management Station (Qishan; 107°37′ E, 34°26′ N; altitude: 682 m), Shaanxi Fufeng Farming Good Breeding Farm (Fufeng; 108°01′ E, 34°23′ N; altitude: 610 m) (Figure 1). Maize variety ZhengDan 958 was sown at 75,000 plants ha^{-1} in mid-June and harvested at the end of September in both years. The experiment was a randomized block design with six replicates. There were six plots

in each site; each plot was 20 m^2 (5 × 4 m) with five lines. The planting density was 7.5 × 10^4 plants ha^{-1}; the row width was 1 m, and the plant spacing was 0.13 m. The six plots were arranged in two rows with three replicates in each row. The sowing depth was about 5 cm. Fertilization at each site was comparable with local practices. The base fertilizer was applied with compound fertilizer, and the machine was used to spread evenly before plowing. The range of pure N application was 170–300 kg ha^{-1}; P application was 34–264 kg ha^{-1}; and the range of K application was 33–170 kg ha^{-1} at all experimental sites to ensure sufficient fertilizer during the maize growing season. Weeds in the field were controlled by spraying herbicide (Huanuo, Yang ling Lv bao nong lin Technology Limited company, Yanngling, China) in time.

2.2.1. Measurement Indicators and Methods

The growth stages at each test site were recorded and divided as follows: seeding-emergence, seedling-tasseling, tasseling-silking, and silking-maturity. Ten maize plants with normal growth were selected in each plot to measure plant height (ground to node of first panicle) and ear height (ground to top of young panicle) at the silking stage.

In the week before harvest, the lodging rate was calculated as the percentage of unbroken plants with a plant inclination > 45° to the total number of plants in the plot. The stem broken rate was calculated as the percentage of broken plants below the ear to the total number of plants in the plot. At harvest, the percentage of empty stalks was calculated as the ratio of unyielding panicles and panicles bearing fewer than 20 grains to the total number of panicles in the plot.

Figure 1. Geographical location of the experimental sites.

2.2.2. Yield and Yield Components

At maturity, three rows in the middle of each plot (12 m^2) were harvested for production measurements, with at least two protection rows surrounding the harvest rows. Plot yield was converted to a grain moisture content of 14%. Twenty ears per plot were sampled to determine ear length, row number per ear, kernel number per row, kernel number per ear, bald tip length, 100-grain weight, and other ear traits.

2.2.3. Disease Survey

Each plot was surveyed for five maize diseases: northern leaf blight, southern leaf blight, ear rot (*Fusarium gminearum* Schwabe, *Fusarium verticillioides* (Sac.) Nirenberg, *Penicillium oxalicum* Currie. et Thom., *Aspergillus flavus* Link), smut, and stem rot (*Pythium aphanidermatum* (Edson) Fitzp., *Fusarium moniliforme* (Sacc.) Nirenberg, *Colletotrichum graminicola* D.J. Politis, *Macrophomina phasecolina* (Tassi) Goid). Each survey assessed 100 plants that were randomly selected within each plot. The incidence grade of northern leaf blight and southern leaf blight was rated 10 to 15 days before harvest, and ear rot was rated at harvest. Smut was assessed at 30 days after silking and stem rot at three days before harvest.

2.3. Data Analysis

Growing degree days (GDD) is an index representing the heat accumulated during the growing period of plants. In this paper, GDD refers to the effective accumulated temperature by average daily temperatures $\geq 10\ °C$, and is calculated as follows [20].

$$GDD = \sum_{i=1}^{n} \frac{T_{max} + T_{min}}{2} - T_{base} \tag{1}$$

where *n* is number of days, T_{max} and T_{min} are daily maximum and minimum temperatures (°C), respectively, and T_{base} is the reference temperature for crop growth (10 °C used here). If the average daily temperature is less than 10 °C, then the day's effective accumulated temperature is 0 °C.

The experimental data were collated and plotted in Microsoft Excel 2007, with the significance difference test, variance analysis, and correlation analysis performed using SPSS 25.0 software ((SPSS Inc., Chicago, IL, USA). A two-factor analysis of variance was used to compare yields and traits in different regions within two years. Plant height, ear height, lodging rate, stem broken rate, and disease incidence at different locations were analyzed by single-factor analysis of variance (ANOVA). The relationships between disease incidence and effective accumulated temperature and rainfall were assessed by correlation analysis. The effect of effective accumulated temperature and rainfall on plant height, ear height, lodging rate, and fallback rate were evaluated by correlation analysis.

3. Results

3.1. Rainfall and Mean Temperature Trends—Annual and Growing Season

Annual rainfall from 1972 to 2018 was summarized for six test sites in Guanzhong. Annual rainfall in Guanzhong varied greatly between years but followed a similar trend at each site in a roughly four-year cycle (Figure 2a). Overall, Huxian, Qishan, and Fufeng had more annual rainfall than Hancheng, Fuping, and Sanyuan. Annual rainfall and growing season rainfall followed a significant downward trend from 1972 to 2018 at all sites, except for Huxian (Figure 2b).
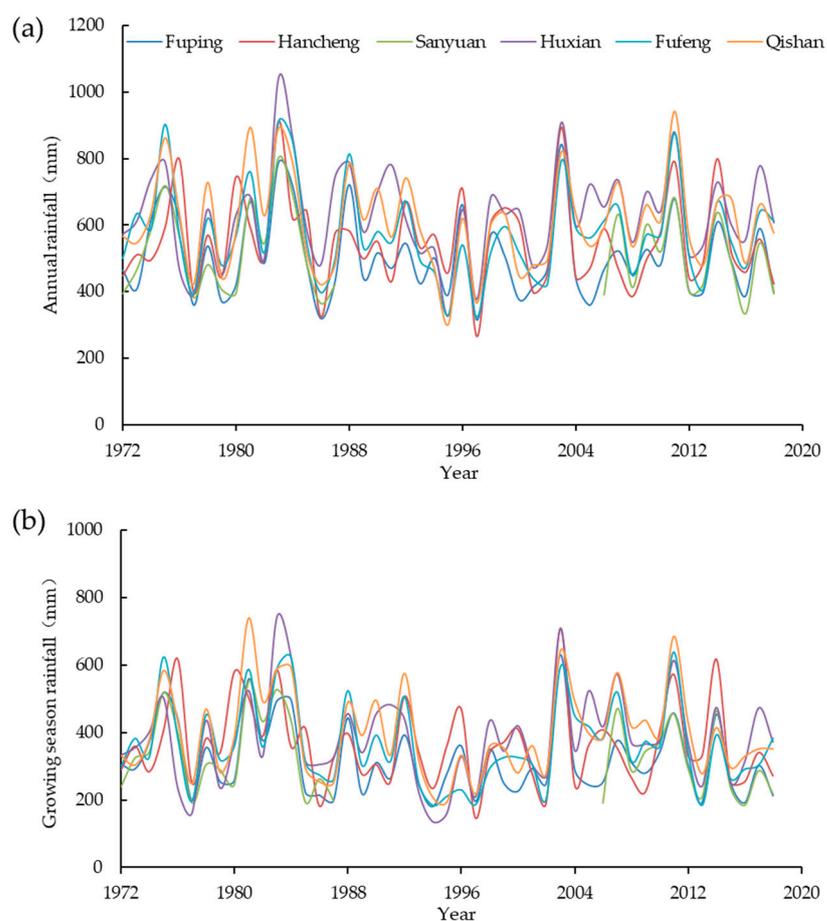
Figure 2. Changes in annual (**a**) and growing season rainfall (**b**) from 1972 to 2018 at different experimental sites.

The average annual temperature followed a significant upward trend at all sites, except for Hancheng (Figure 3a). Fufeng, Qishan, and Fuping had lower average annual temperatures than Huxian and Sanyuan. During the maize growing season, each test site had similar annual temperatures, fluctuating upwards from 1972 to 2018 (Figure 3b). Fufeng and Qishan had a lower average temperature of the growing season than the other four sites. Cumulative temperatures during the growing season ranged from 1200 °C·d to 2000 °C·d (Figure 4). The variation trend in cumulative temperatures during the growing season was similar to that of average temperature with a fluctuating upward trend from 1972 to 2018. Fufeng and Qishan also had a lower cumulative temperature during the growing season than the other four sites.
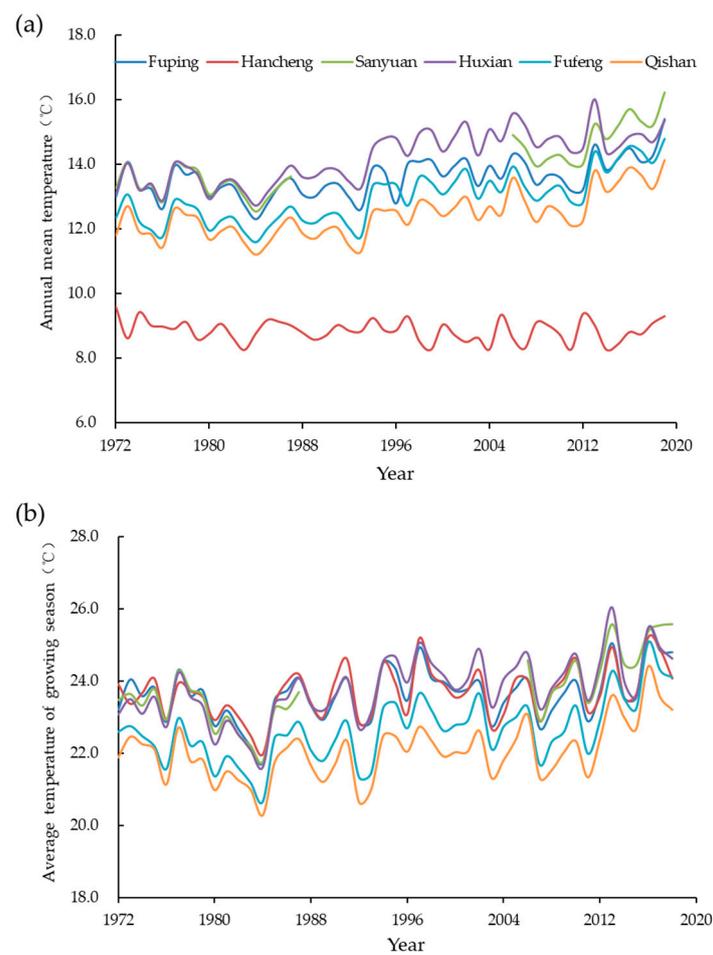
Figure 3. Variation in annual mean temperature (**a**) and average temperature during maize growing season (**b**) from 1972 to 2018 at different experimental sites.
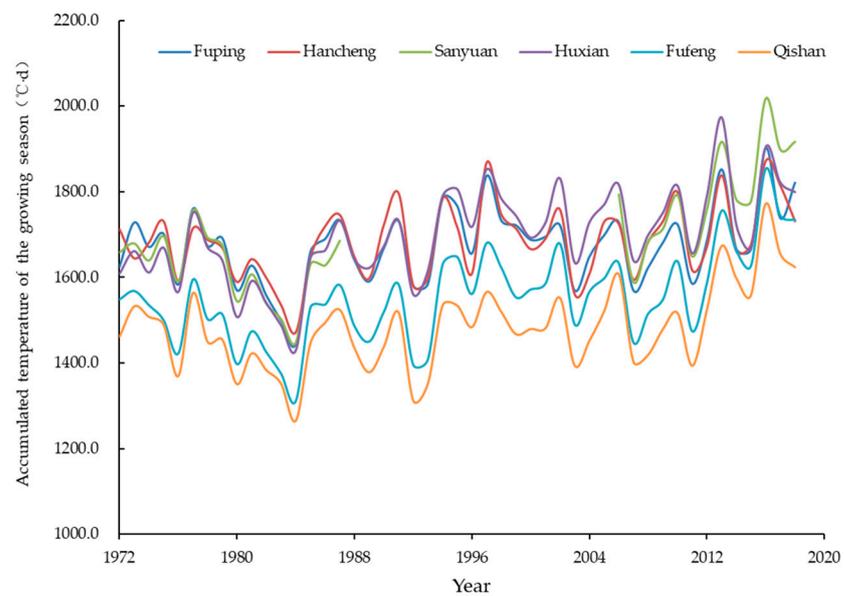
Figure 4. Change in mean effective accumulated temperature during the maize growing season from 1972 to 2018 at different experimental sites.

3.2. Fertility and Cumulative Processes in Different Regions

Fuping and Hancheng had longer growing periods than the other sites. All sites had a shorter growing period in 2018 than in 2017, except for Huxian. The growing period length varied between Qishan, Sanyuan, Fufeng, and Linwei in both years. In 2017, Huxian had the most days in the emergence–tasseling stage and the fewest days in the silking–maturing stage, and the reverse were true at Fuping. In 2018, Sanyuan, Linwei, and Qishan had shorter growing periods than the other sites (Figure 5). During the growing period, the accumulated temperature decreased at Hancheng, Fufeng, and Qishan in 2018, relative to 2017, but increased at Fuping, Linwei, Sanyuan, and Huxian. Qishan had the lowest accumulated temperature during the growing period in both years (Table 1).
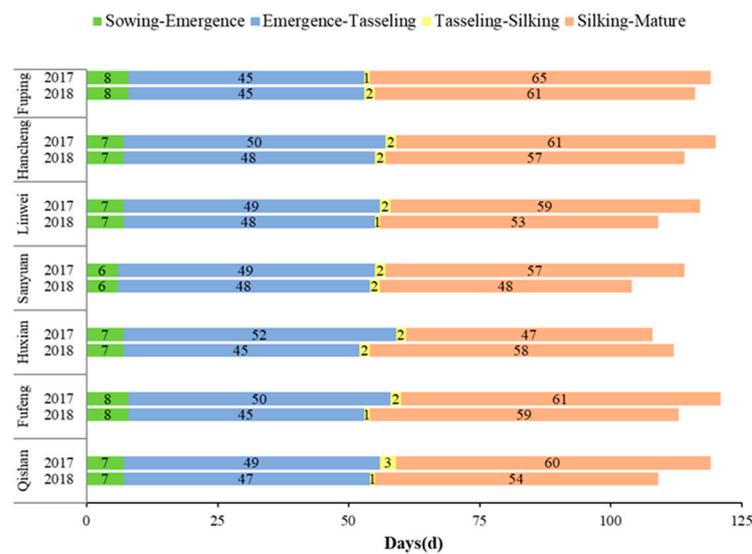
Figure 5. Maize growth duration of the sowing, emergence, tasseling, silking, and maturity stages at different experimental sites in 2017 and 2018. Values in figure were mean maize growth duration between two stages.

Table 1. Effective accumulated temperature at different growth stages of maize at different experimental sites in 2017 and 2018. Values were mean effective accumulated temperature duration between two stages.

Site	Sowing-Emergence (°C·d)	Emergence-Tasseling (°C·d)	Tasseling-Silking (°C·d)	Silking-Maturity (°C·d)	Emergence-Maturity (°C·d)	Total Effective Accumulated Temperature (°C·d)
2017						
Fuping	134.5	851.0	17.5	628.5	1497.0	1631.5
Hancheng	109.5	957.0	30.5	767.0	1754.5	1864.0
Linwei	115.0	874.5	36.5	662.0	1573.0	1688.0
Sanyuan	103.0	958.5	38.0	584.0	1580.5	1683.5
Huxian	109.0	997.0	38.0	570.0	1605.0	1714.0
Fufeng	122.0	915.5	31.5	612.5	1559.5	1681.5
Qishan	99.5	842.5	47.0	581.0	1470.5	1570.0
2018						
Fuping	129.5	804.5	39.5	815.5	1659.5	1789.0
Hancheng	117.0	846.5	39.5	742.0	1628.0	1745.0
Linwei	119.5	871.5	22.0	780.5	1674.0	1793.5
Sanyuan	103.0	849.5	44.0	744.0	1637.5	1740.5
Huxian	112.5	799.5	44.0	819.5	1663.0	1775.5
Fufeng	118.5	718.0	19.5	797.0	1534.5	1653.0
Qishan	88.0	715.0	18.5	662.0	1395.5	1483.5

3.3. Agronomy and Disease Performance at Each Site

In both years, Sanyuan produced the shortest maize plants, and Fufeng produced the tallest plants. All sites had shorter ear heights in 2018 than in 2017, except for Hancheng; Huxian had the tallest ear heights in both years. In 2017, Huxian and Hancheng had the highest lodging rate, while Fuping and Weinan had the lowest lodging and fallback rates (Table 2). Accumulated temperature and rainfall had negative correlations with ear height, but the correlation coefficient was small. Accumulated temperature had a negative correlation with plant height and a positive correlation with lodging and fallback rates. Rainfall had a positive correlation with plant height, lodging rate, and fallback rate. These results indicate that increasing temperatures will inhibit crop growth, while increasing rainfall will enhance crop growth, making them more prone to lodging (Table 3).

Table 2. Plant height, ear height, lodging rate, and fallback rate for maize at different experimental sites in 2017 and 2018. The statistical test used was the least significant difference (LSD) method. Data shown were means ± the standard deviation.

	Fuping	Hancheng	Linwei	Sanyuan	Huxian	Fufeng	Qishan
2017							
Plant height (cm)	254.7 ± 11.8 ab	248.2 ± 8.4 abc	252.1 ± 15.3 abc	223.4 ± 22.1 d	237.8 ± 6.4 cd	262.2 ± 6.8 a	244.5 ± 10.0 bc
Ear height (cm)	110.3 ± 2.6 a	106.1 ± 7.2 ab	102.2 ± 5.6 ab	97.4 ± 8.3 b	99.2 ± 8.0 b	111.2 ± 7.1 a	105.3 ± 10.2 ab
Lodging rate (%)	1.2 ± 1.9 b	1.1 ± 0.7 b	0.8 ± 1.1 b	0.0 ± 0.0 b	9.8 ± 3.4 a	0.0 ± 0.0 b	0.0 ± 0.0 b
Fallback rate (%)	1.9 ± 2.1 b	13.8 ± 7.2 a	0.9 ± 1.1 b	0.0 ± 0.0 b	0.5 ± 0.6 b	0.0 ± 0.0b	0.0 ± 0.0 b
2018							
Plant height (cm)	235.0 ± 6.4 b	252.0 ± 10.7 a	237.5 ± 12.8 b	215.0 ± 13.8 c	245.9 ± 8.1 ab	255.0 ± 15.2 a	246.0 ± 7.5 ab
Ear height (cm)	101.3 ± 3.1 b	116.6 ± 6.0 a	99.2 ± 10.1 b	96.2 ± 6.5 b	99.0 ± 6.7 b	96.0 ± 11.1 b	102.0 ± 6.4 b
Lodging rate (%)	0.0 ± 0.0 b	0.0 ± 0.0 b	0.0 ± 0.0 b	0.0 ± 0.0 b	13.4 ± 3.2 a	0.0 ± 0.0 b	0.0 ± 0.0 b
Fallback rate (%)	0.0 ± 0.0 b	0.0 ± 0.0 b	0.0 ± 0.0 b	0.0 ± 0.0 b	3.2 ± 0.9 a	0.0 ± 0.0 b	0.0 ± 0.0 b

Different letters within a row indicate significant differences between regions.

Table 3. Pearson correlation coefficients between effective accumulated temperature, rainfall and plant height, ear height, lodging rate, and fallback rate at different experimental sites in 2017 and 2018. Data shown were coefficients between two variables.

Correlation	Plant Height (cm)	Ear Height (cm)	Lodging Rate (%)	Fallback Rate (%)
Effective Accumulated Temperature (°C·d)	−0.201	−0.081	0.011	0.482
Rainfall (mm)	0.547	−0.078	0.434	0.141

In 2017, Qishan had significantly more northern leaf blight than the other sites. Fuping had the highest incidence of ear rot and stem rot, and Huxian had the highest smut incidence. In 2018, Huxian and Fufeng had a relatively high incidence of northern leaf blight and southern leaf blight. Hancheng had serious stem rot in Hancheng, while Qishan had none in both years (Table 4). The correlation coefficients for accumulated temperature and the occurrence of southern leaf blight, ear rot, and stem rot were low and had little influence on various diseases. There was a significant positive correlation between rainfall during the growing period and the occurrence of northern and southern leaf blight disease (Table 5).

Table 4. Disease incidence of maize at different experimental sites in 2017 and 2018. The statistical test used was the least significant difference (LSD) method. Data shown were means ± the standard deviation.

Site	Northern Leaf Blight (Grade)	Southern Leaf Blight (Grade)	Ear Rot (Grade)	Smut (%)	Stem Rot (%)
2017					
Fuping	1.0 ± 0.0 b	1.0 ± 0.0 a	4.0 ± 1.1 a	0.3 ± 0.3 b	4.3 ± 3.3 a
Hancheng	1.1 ± 0.4 b	1.0 ± 0.0 a	1.1 ± 0.4 b	0.3 ± 0.6 b	0.6 ± 1.0 b
Linwei	1.0 ± 0.0 b	1.0 ± 0.0 a	1.3 ± 0.8 b	0.1 ± 0.4 b	1.2 ± 1.2 b
Sanyuan	1.0 ± 0.0 b	1.0 ± 0.0 a	1.6 ± 1.0 b	0.6 ± 0.7 b	0.3 ± 0.8 b
Huxian	1.3 ± 0.8 b	1.0 ± 0.0 a	1.0 ± 0.0 bc	1.8 ± 0.8 a	0.2 ± 0.3 b
Fufeng	-	-	0.7 ± 1.4 b	-	-
Qishan	2.3 ± 1.0 a	1.3 ± 0.8 a	0.0 ± 0.0 c	0.0 ± 0.0 b	0.0 ± 0.0 b
2018					
Fuping	1.0 ± 0.0 b	1.0 ± 0.0 b	1.0 ± 0.0 a	0.30 ± 0.73 ab	0.00 ± 0.00 c
Hancheng	1.0 ± 0.0 b	1.0 ± 0.0 b	1.3 ± 0.8 a	0.00 ± 0.00 b	3.25 ± 1.04 a
Linwei	1.0 ± 0.0 b	1.0 ± 0.0 b	1.0 ± 0.0 a	0.00 ± 0.00 b	0.00 ± 0.00 c
Sanyuan	1.0 ± 0.0 b	1.0 ± 0.0 b	1.0 ± 0.0 a	0.73 ± 0.90 a	1.63 ± 1.15 b
Huxian	2.7 ± 0.8 a	2.0 ± 1.1 a	1.0 ± 0.0 a	0.63 ± 0.57 ab	0.32 ± 0.27 c
Fufeng	2.0 ± 1.1 a	1.3 ± 0.8 b	1.0 ± 0.0 a	0.17 ± 0.41 ab	0.00 ± 0.00 c
Qishan	2.0 ± 1.1 a	1.0 ± 0.0 b	1.0 ± 0.0 a	0.00 ± 0.00 b	0.00 ± 0.00 c

Different letters within a row indicate significant differences between regions.

Table 5. Pearson correlations between effective accumulated temperature, rainfall, and disease incidence of maize at different experimental sites in 2017 and 2018. Data shown were coefficients between two variables.

Correlation	Northern Leaf Blight (Grade)	Southern Leaf Blight (Grade)	Ear Rot (Grade)	Smut (%)	Stem Rot (%)
Effective Accumulated Temperature (°C·d)	−0.399	0.053	−0.050	0.203	−0.003
Rainfall (mm)	0.709 *	0.481	−0.094	0.092	−0.289

* significant at $p < 0.05$.

3.4. Production and Production Factors

Overall, the average production rank for both years was Fuping/Hancheng/Fufeng > Linwei/Sanyuan > Huxian > Qishan. The average output in 2018 increased at all sites, relative to 2017, except for Qishan (significant decline) and Fuping (small decline). At most sites, ear length, rows per ear, kernel numbers per row, and 100-grain weight increased in 2018, relative to 2017, while bare tip lengths decreased. In 2018, Hancheng produced the most spike rows. Hancheng, Linwei, Huxian, and Qishan produced the most grain, and Sanyuan produced the least grain. Linwei produced the highest 100-grain weight in both years, and Qishan produced the lowest. The bare plant rate at Fuping was zero in both years (Table S1). Ear length and row grain number had the most variation between years, while 100-grain weight did not significantly change. Some yield components significantly differed between sites, mainly ear length and 100-grain weight. There was a significant interaction effect of year and site for various yield components (Table S1).

3.5. Effect of Climatic Conditions on Yield and Yield Factors in Maize

Maize yield increased with increasing effective accumulated temperature during the growing period (R^2 = 0.28). During the growing period, rainfall did not affect maize yield in the Guanzhong region (Figure 6). Precipitation before the silking stage and effective accumulated temperature after the silking stage had a significant positive correlation with grain yield. Rainfall before silking had a significant positive correlation with ear length and row grain number (Table S2). The effective accumulated temperature after silking had a positive correlation with row grain number (Table S3).
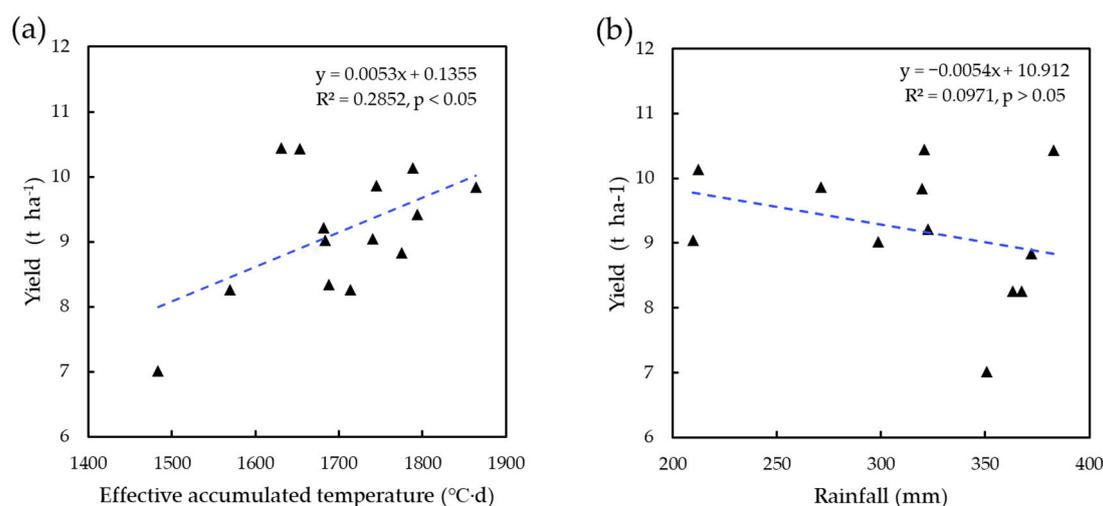
Figure 6. Variation trends in yield with mean effective accumulated temperature (**a**) and rainfall (**b**) at different locations in the Guanzhong region in 2017 and 2018.

4. Discussion

4.1. Relationship between Accumulated Temperature and Yield in the Guanzhong Region

Maize is a warm-loving crop, which matures when it reaches a specific effective accumulated temperature during the growing period [21]. The higher accumulated temperature during the emergence-silking and sowing-maturity stages indicates a higher maize demand for heat units than the sowing-emergence and silking-maturity stages [22]. Climatic conditions can affect maize yield and yield factors [23]. We found that the effective accumulated temperature from tasseling to maturity positively affected kernel numbers per row. The effective accumulated temperature differed at each test site, with maize yield increasing with increasing accumulated temperature at Guanzhong (Figure 6), as maize needs higher temperatures to mature in this high latitude area region.

In the past 50 years, the annual average temperature in China increased significantly [24]. The increased land production potential was mostly affected by rising temperature in Guanzhong [25]. Our study found that temperature followed a significant increasing trend at most sites, except for Hancheng. In northern China, maize yield increased significantly with increasing cumulative temperatures $\geq 10\ ^\circ$C throughout the year [26], consistent with the significant positive correlation between yield and cumulative temperature in our study. This may be because Guanzhong is located in the north of the Qinling Mountains, and crops are often affected by low temperature and frost damage, so higher temperature is beneficial to crop growth in Guanzhong. On the other hand, increasing temperatures will increase the effective cumulative temperature utilization of maize, thus increasing yield. With the impact of global climate change, temperatures in the Guanzhong region are likely to rise further, while the cumulative temperature needed for maize growth and maturity will differ between sites within the region (Figure 2). However, rising temperature would shorten the growth period of maize [27], while high temperature is not conducive to the growth and development of maize, and it increases soil evaporation, reduces the relative humidity in the environment, and increases drought. Therefore, it is also necessary to select late maturing varieties with high temperature tolerance and adjust cultivation practices to cope with the negative effects of climate change in the future.

4.2. Relationship between Rainfall and Yield in the Guanzhong Region

Rainfall is critical for maize production in arid regions [28]. Our study found that rainfall before silking had a significant positive correlation with ear length and row grain number (Table S2). Therefore, meeting the water demand of maize growth period has an important effect on yield. From 2000 to 2015, the rainfall in Guanzhong showed a downward trend [25]. Our study found that: The annual variation of rainfall in the

Guanzhong region is variable, and it showed different trends from 1972 to 2018. Except for Huxian County, other places showed a downward trend from 1972 to 2018. With the future rise in temperature in Guanzhong, maize in some areas may face drought. Wang et al. reported that the irrigation demand of maize in the Guanzhong area would be 300–400 mm/ha under future climate change [29]. The existing cultivation practices may lead to a decrease in maize yields. Therefore, it is necessary to delay the sowing date or increase the amount of irrigation to deal with the negative impact of climate change on maize in Guanzhong in the future [27]. For areas with increased rainfall or in years with above average rainfall, maize varieties with good lodging resistance should be selected, and various diseases and insect pests should be prevented.

4.3. Relationship between Climatic Factors, Incidence and Yield in the Guanzhong Region

Bacteria is an important factor affecting maize grain quality [30–32]. Ear rot directly affects yield and grain quality in maize; other diseases indirectly affect maize growth and reduce yield [30]. Climate change has an important impact on the occurrence and prevalence of pathogens, especially in extreme weather conditions such as high temperature and humidity, increasing the prevalence of various diseases and insect pests [30,32]. In the Guanzhong region, accumulated temperature and rainfall were not correlated with southern leaf blight or smut. However, rainfall had a significant positive correlation with northern leaf blight, and this is consistent with previous studies that rainfall was significantly positively correlated with the incidence of northern leaf blight and southern leaf blight in maize [33]. The increase in rainfall and the decrease in sunshine duration during the whole growth period of maize will provide a good environment for the outbreak rate of corn diseases and insect pests [33,34]. With the increasing temperature and decreasing rainfall in the Guanzhong region (Figures 2 and 3), maize may face drought stress and warming climate, which is conducive to insect pests' overwintering and reproduction [33–35]. Therefore, it is necessary to select suitable varieties to prevent various diseases and insect pests caused by rising temperatures.

5. Conclusions

With global warming, temperatures will continue to rise, while rainfall will decrease in most of the Guanzhong region. Cumulative temperature had a significant positive correlation with yield. Maize yield in the Guanzhong region is expected to increase further with the increasing average and cumulative temperatures during the growing period. Drought-resistant varieties are needed as well as disease management packages to reduce disease outbreaks, and improved agronomic management should be developed to reduce serious yield losses associated with adverse effects of high temperature and variable rainfall.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/agriculture11040373/s1, Table S1. Maize yield and yield components at different experimental sites in 2017 and 2018. The statistical test method was the least significant difference (LSD) method. Data shown were means ± the standard deviation; Table S2. Pearson correlation between yield components and rainfall(mm) at different growth stages of maize in 2017 and 2018. Data shown were coefficient between two variables; Table S3. Pearson correlation between maize yield components and effective accumulated temperature (°C·d) at different growth stages of maize in 2017 and 2018. Data shown were coefficient between two variables.

Author Contributions: Conceptualization, designed experiments, J.X. and X.Q.; analyzed data, writing—original draft preparation, X.W. and X.Z.; investigation, collected data, M.Y., X.G. and B.L.; field management, Y.H.; writing—review and editing, K.H.M.S. and S.X. All authors have read and agreed to the published version of the manuscript.

Institutional Review Board Statement: Not applicable.

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