Precipitation pulses and intraseasonal drought in Northeast China

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Abstract. 30 years meteorological data were collected to analyze variations of precipitation amount, number of days, frequency and intervals using the Mann-Kendall (MK) and t test and relationships between rainfall patterns and climates over rainfed farmland. The results indicated that annual precipitation amount had a downward trend from 1989-2018. Whether in different years or months, small precipitation events($0<P \leq 5$ mm) are a dominating feature, significantly and positively related to annual total precipitation, which mainly occur in early or late growing seasons (May or September). The precipitation intervals decrease along with the category, and are longer in the drought years than in the humid years. Percent of intervals <6 days are more than 65%, the average dry days are 5. Short intervals(1-3 days) increase from May, get to the maximum in mid-growing season. Long intervals (>4 days) are opposite. While in growing seasons, the average dry days are <3 days.

Keywords: precipitation events; precipitation intensity; dry days; rainfed maize; climate change.

1. Introduction

Climate change is mainly manifested by rising temperature and changes in precipitation patterns(IPCC 2021). Increases in the temporal and spatial variability of precipitation patterns can change the intensity and frequency of extreme humid or drought events(Touma et al. 2015). Precipitation characteristics can have a greater impact on ecosystems than total rainfall(Zheng et al. 2019; Nazari et al. 2020). Lauenroth & Bradford(2012) indicated that event size and specifically the numerical importance of the smallest size (0-5 mm) was an important control on water loss over the U.S. Great Plains. Other researchers have found that large rainstorms (>30 mm) have more influence on ratio of transpiration to evapotranspiration than total precipitation(Raz-Yaseef et al. 2012). For these reasons, it is important to study changes in the spatial and temporal rainfall patterns to improve water management strategies(Fu et al. 2013).

The northeast China (94% is rainfed farmland) is one of the three major golden maize belts in the world. (Liu et al. 2016). In such areas, whether on temporal or spatial scales, the amount, timing, and intensity of precipitation events can be highly intermittent and unpredictable(Cheng et al. 2017). However, the majority of studies mainly focus on extreme rainfall(Zhang et al. 2015; Azizzadeh & Javan 2018), or variability of precipitation pulses over other ecosystems(Lauenroth & Bradford 2009; Song et al. 2019). Few studies have focused on the variability in precipitation pulses.

In this paper, we collected 30 years of meteorological data from two sites to analyze variability of precipitation amount, number of days with measurable precipitation, their timing, intensity, frequency, and intervals between precipitation events, during growing season and months.

2. Materials and methods

2.1. Site Description

Our analyses are based on 30 years of daily precipitation and air temperature data collected from the China Meteorological Administration (1989-2018). The two sites are located in Jinzhou

Agricultural Ecosystem Research Station (41°49′ N, 121°12′ E; elevation 17 m) and Chaoyang (41°33′ N, 120°27′ E; elevation 218 m) in southwestern northeastern China. They both have a continental monsoon climate with four distinct seasons. The mean annual temperature is 10.4 °C and 9.8 °C respectively. The 30 year mean annual precipitation is 549 mm and 472 mm. About 60% of the precipitation is received between July and September. The soil in Jinzhou is brown and slightly acidic (pH of 6.3), with organic matter, 15.24 $g \cdot kg^{-1}$; nitrogen, 1.04 $g \cdot kg^{-1}$; phosphorus, 0.50 $g \cdot kg^{-1}$; and potassium, 22.62 $g \cdot kg^{-1}$. The soil in Chaoyang is brown, with organic matter, 9.48 $g \cdot kg^{-1}$; nitrogen, 0.73 $g \cdot kg^{-1}$; available phosphorus, 4.44 $mg \cdot kg^{-1}$ and available potassium, 154.57 $mg \cdot kg^{-1}$.

2.2. Data Source and Methods

We sorted the daily precipitation data from each site into the following eight size categories after removing the zeros (dry days): 0<to ≤5 mm, 5< to ≤10 mm, 10< to ≤15 mm, 15< to ≤20 mm, 20<to ≤25 mm, 25< to≤30 mm, 30< to ≤50 mm, and >50mm. To determine the lengths of intervals between precipitation events, we counted the days without precipitation and sorted them into the following intervals: 1-3 days, 4-6 days, 7-10 days, 11-20 days, 21-30 days, and >30 days.

The trends of precipitation amount, number of days and intervals between precipitation events among years were analyzed using Mann-Kendall test (MK test) and t test. MK test is a robust trend detection method, does not require samples to fit a normal distribution and is not very sensitive to outliers, has been widely applied to diagnose the trends in hydrometeorological time series (Mann 1945; Kendall 1975; Zhang et al. 2021).

Standardized rainfall index (SPI), first proposed by Mckee et al.(1993), is used to define humid year(SPI≥1), drought year(SPI≤-1) and intraseasonal drought(SPI≤-1 at time scale of growing season, May to September).

3. Results

3.1. Variability of precipitation amount and number of days with precipitation

Average annual precipitation amounts at Jinzhou and Chaoyang over 30 years were 549 mm and 472 mm respectively. Average growing season (May to September) precipitation amount at Jinzhou and Chaoyang were 469 mm and 407 mm respectively (Figure 1a and 1b).

At Jinzhou station, the largest and smallest annual precipitation amount was 899 mm in 1998 and 338 mm in 2014. While in growing seasons, the largest and smallest precipitation amounts were 787 mm in 1994 and 280 mm in 2015. According to SPI classification, these years can be defined as humid (1990, 1991, 1994, 1998, 2004, 2010, 2012), drought (1989, 1992, 1999, 2003, 2014, 2015, 2017, 2018), and intraseasonal drought (1989, 1992, 1999, 2000, 2002, 2003, 2009, 2014, 2015, 2017, 2018).

At Chaoyang station, the largest and smallest annual precipitation amount was 725 mm in 1994 and 270 mm in 2018. During the growing season, the largest and smallest precipitation amounts were 725 mm in 1994 and 212 mm in 2009. These years can be defined as humid (1990, 1993, 1994, 1996, 1998, 2010, 2012, 2017), drought (1992, 1999, 2000, 2009, 2013, 2015, 2018) and intraseasonal drought (1992, 1999, 2000, 2004, 2008, 2009, 2013, 2015, 2018).

That is, 1990,1994, 1998, 2010 and 2012 are humid years, 1992, 1999, 2015 and 2018 are drought years, and 1992, 2000, 2009, 2015 and 2018 are intraseasonal drought years in both sites.

The differences in the number of days with precipitation between the two sites was small (Figure 1c and 1d). The average number of days with precipitation was 65 and 63 at Jinzhou and Chaoyang station respectively and both 45 in growing seasons. The most and least number of days with precipitation were 84 and 46 in Jinzhou and 83 and 47 in Chaoyang. For the growing seasons, the most and least number of days with precipitation were 60 and 35 in Jinzhou and 55 and 33 in Chaoyang.

The average precipitation for both sites was greatest in July and the number of days with precipitation peaked in June and July. Minimum precipitation occurred at the beginning and end of the growing season for both sites as did the number of days with precipitation.

There were small though not significant but discernable decreasing trend in annual total precipitation and the number of precipitation day from 1989-2018 at both sites suggested by Mann–Kendall test. As there were more than one changepoint (Figure omitted), t test was employed to examine changes in annual total precipitation and the number of precipitation day(Figure 1e and 1f).

There are two abrupt changes in precipitation both in yearly and growing season in Jinzhou, which are year 1999 and 2004 ($p \leq 0.01$). And one abrupt change in Chaoyang, which is year 1999 ($p \leq 0.05$). No abrupt changes are detected in number of days with precipitation in both sites.

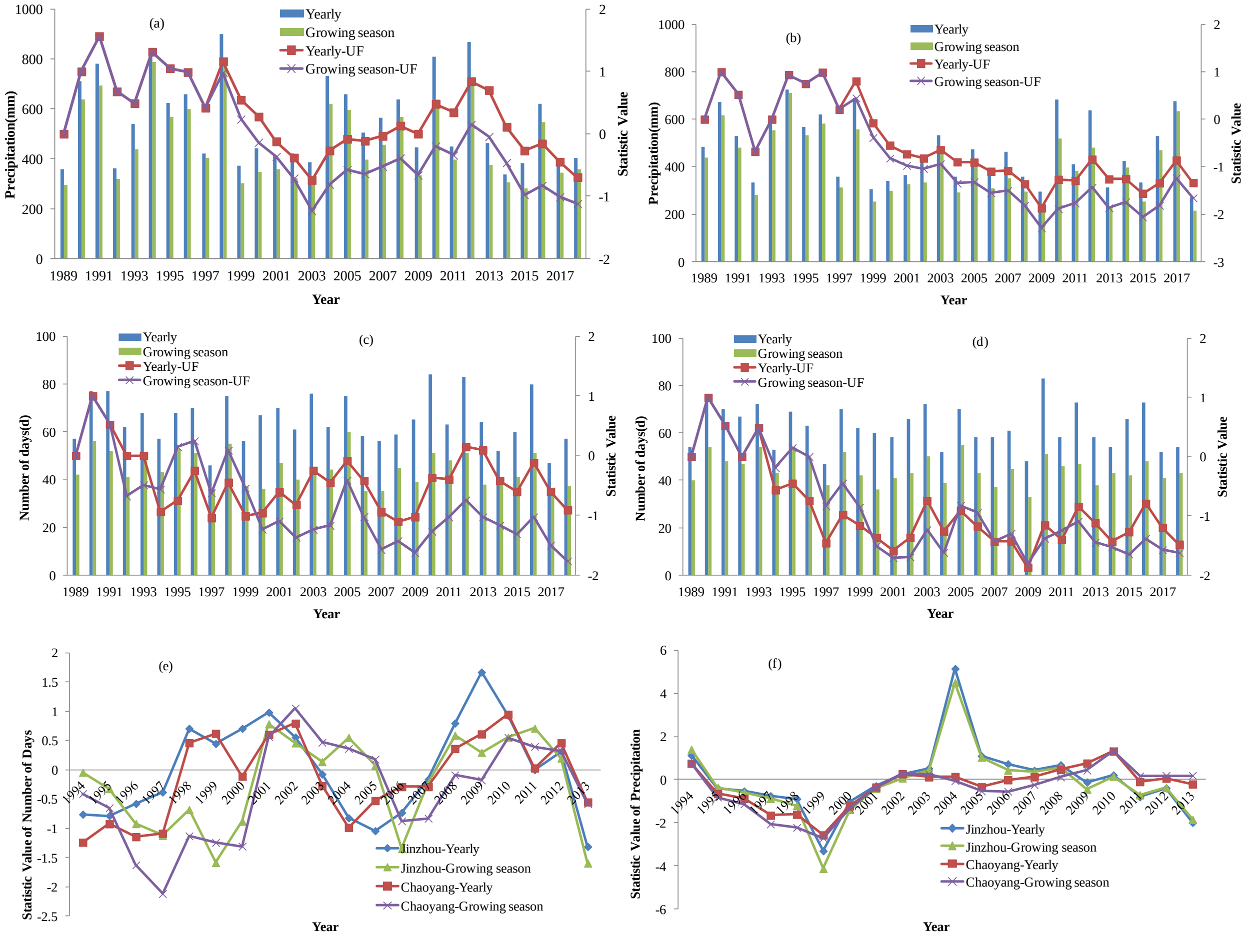

Fig. 1. MK test for precipitation amount (a) Jinzhou (b) Chaoyang and number of days with precipitation (c) Jinzhou (d) Chaoyang and t test for precipitation amount and number of days with precipitation (e) Jinzhou and (f) Chaoyang.

3.2. Characteristics of precipitation intensity and frequency

The number of precipitation events were dominated by the smallest category of events at both sites (Figure 2). The smallest events accounted for 62% and 63% at Jinzhou and Chaoyang respectively and the $25 < P \leq 30$ mm class accounted 2% at Jinzhou and the $50 < P$ mm class accounted for 2% at Chaoyang. Over the growing season, the contributions of the different event sizes were similar to the annual distribution and were similar between sites. The percentages decreased as the size category of events increased. However, percentages of the different event sizes differed in different months. Small events ($0 < P \leq 5$) mainly occurred early or late in the growing season (May or September) and large events ($10 < P$) mainly occurred in mid-growing seasons (July and August).

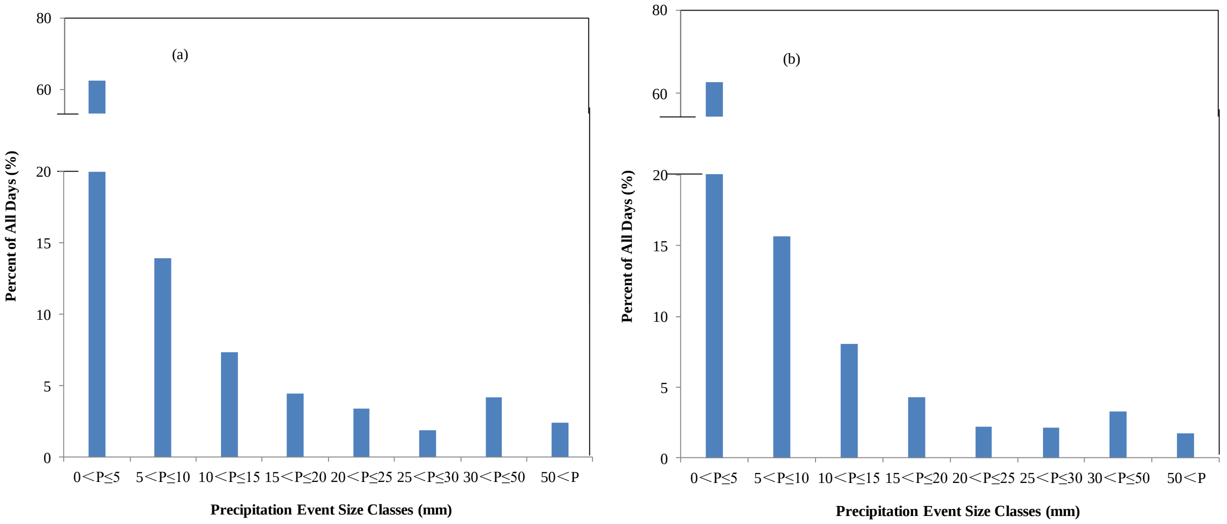

Fig. 2. Distribution of precipitation events among different size categories during 1989-2018 at (a) Jinzhou (b) Chaoyang.

The amounts of precipitation contributed by events >5 mm was significantly and positively related to annual total precipitation at both sites (Figure 3a and 3b). The relationship with annual precipitation for Jinzhou was y=0.99x-56.8, $R^2 = 0.99$, and for Chaoyang was y= 0.98x-50.9, $R^2 = 0.99$, where y was the amount of precipitation in mm and x was the amount of precipitation in each year in mm. The relationship with mean temperature was negative. The amount of precipitation in 0 to <5 mm events was small and similar among years with different annual precipitation and also among years with different annual temperature (Figure 3c and 3d).

The percentage of 0 to <5 mm precipitation events was also positively related to annual precipitation at both sites (Figure 3e and 3f). The relationship with annual precipitation for Jinzhou was y=0.018x+77.92, $R^2 = 0.58$, and for Chaoyang was y= 0.025x+74.49, $R^2 = 0.53$, where y was the percentage of events and x was annual precipitation in mm. Percentage of >5 mm precipitation events was negatively related to annual precipitation in both sites. The relationship with annual precipitation for Jinzhou was y=-0.018x+22.08, $R^2 = 0.58$, and for Chaoyang was y= -0.025x+25.51, $R^2 = 0.53$, where y was the percentage of events and x was annual temperature in °C. There was no relationship between the percentage of precipitation events and annual temperature (Figure 3g and 3h).

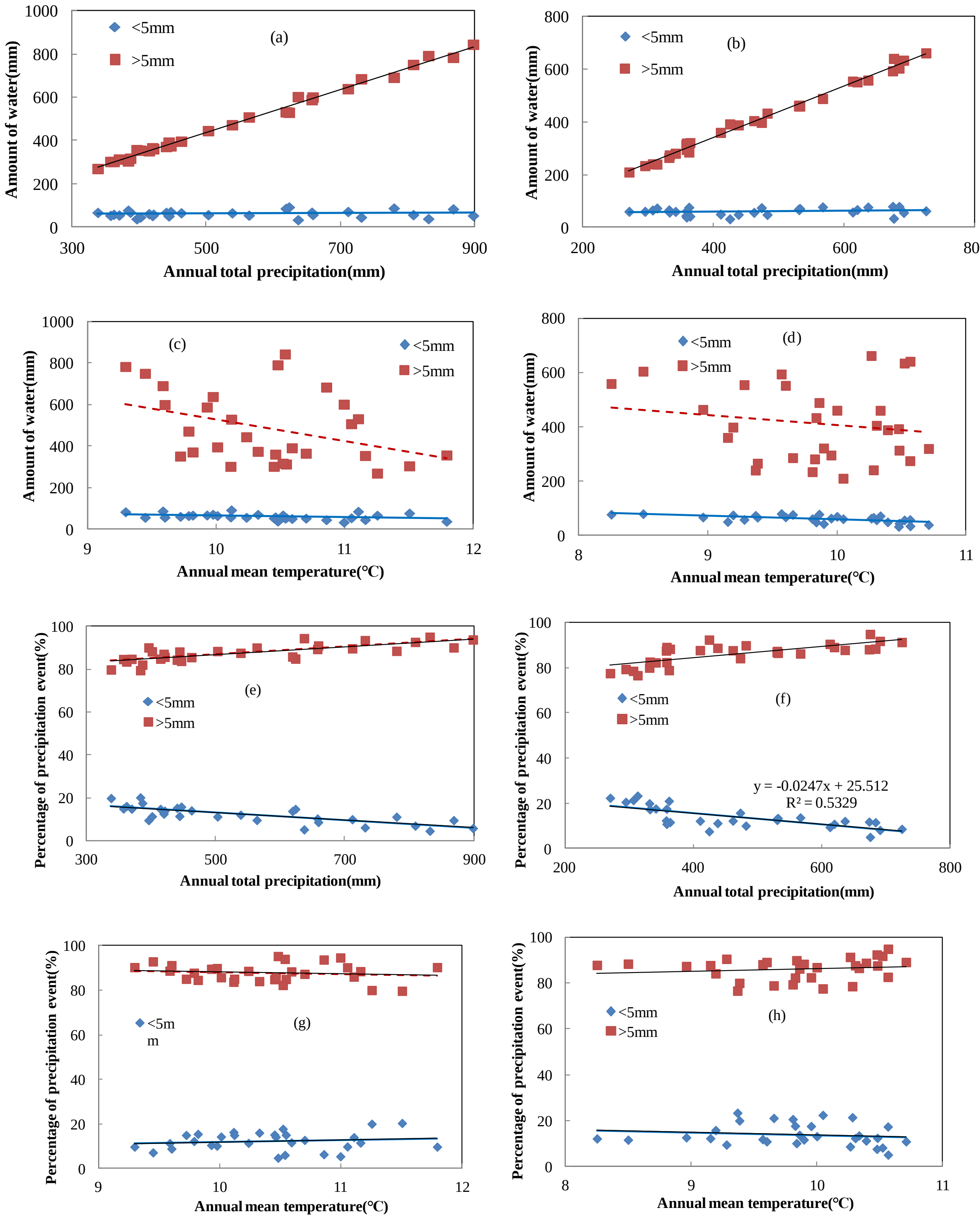

Fig. 3. Regression relationships between amount of water and percentage of precipitation event of 0 to <5 mm, >5 mm and annual precipitation (AP) and annual temperature (AT) for (a), (c), (e), (g) Jinzhou and (b), (d), (f), (h) Chaoyang.

3.3. Characteristics of intervals between precipitation events

Similar to the precipitation event size classes, annually the sizes of intervals between precipitation events decreased as the categories increased (Figure 4). The percentage of dry periods between 1 and 3 days was the most frequent accounting for 43% and 44% at Jinzhou and Chaoyang respectively. Intervals >30 days at Jinzhou were the least frequent accounting for 3%, while 21<intervals <30 days in Chaoyang accounted for the fewest at 3%. The percentage of intervals <6 days comprised more than 65% at both sites, which indicated that the mean dry period for all sites was 6 days or shorter. During in growing season, the average number of dry days was <3 days at both sites.

The number of days between precipitation events was variable among years. Similar to the precipitation amount among years, the shortest dry intervals had a slight decreasing trend over the study period. The yearly change in the other intervals was not obvious. The dry intervals were longer in the drought year (6 days) than in the humid year (4 days).

Percentage of dry intervals <10 days increased very slightly as annual precipitation increased and increasing annual temperature had a negative effect on the percentage of >10 dry days. However, the R^2 were small in both cases.

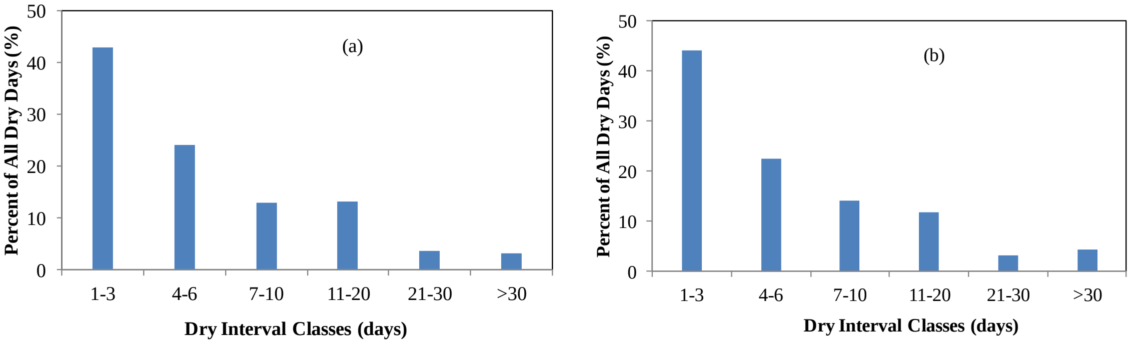

Fig. 4. Distribution of dry days among six size categories for study sites (a) Jinzhou (b) Chaoyang.

4. Discussion

We found that annual precipitation had a decreasing trend from 1989-2018 at both sites (Figure 1a and 1b). However, the number of days with measurable precipitation and the intervals between precipitation events did not change over the study period (Figure 1c and 1d). The effects of climate change are most related to changes in temperature and least related to changes in precipitation (IPCC 2021). Researchers have reported decreases in light precipitation, decreases in the number of long duration precipitation events (≥3 days), and decreases in the number of days with precipitation. There have also been reports of increases in precipitation intensity or of convective precipitation as a result of climate change in several regions of the world (Berg et al. 2013; Westra et al. 2014).

Whether in different years or months, small precipitation events (0<P ≤5 mm) are a dominating feature of the precipitation regime in semi-humid rainfed farmland of northeast China (Figure 2). Similar results have been reported for North American subtropical deserts (Huxman et al. 2004), arid and semi-arid regions of the United States (Lauenroth & Bradford 2009), and desert steppe in Inner Mongolia, China (Song et al. 2019). Additionally, we found that small events (0＜P≤5 mm) mainly occurred early or late in growing seasons (May or September) and large events (10＜P mm) mainly occurred in mid-growing seasons (July and August). This is similar to studies for desert steppe in Inner Mongolia, China (Song et al. 2019).The annual average number of small events comprised more than 60% of the total number of events at both sites, but only accounted for less than 13% of the total precipitation. Although large events (P>30 mm) accounted for fewer than 7% of total events, they comprised more than 35% of total precipitation. The number of 0 to <5 mm precipitation events was significantly and positively related to annual precipitation at both sites (Figure 4a and 4b).

The percentage of intervals between precipitation events of <6 days on average comprised more than 65% of the dry days at both sites. Similar to precipitation event size classes, the frequency of the intervals between precipitation events decreased as the length of the interval increased (Figure 4a and 4b). Intervals between precipitation events can range between a few to several days. Wythers et al. (1999) found that the average number of days between both growing season and non-growing season precipitation events was 7 days, and 90% of all dry periods were fewer than 15 days for the North American shortgrass steppe. Lauenroth & Bradford (2009) also working in North America found for

529 sites in the intermountain zone and the Great Plains that for 26 sites an average of 90% of all of the dry periods were 10 days or shorter, for 356 of sites 90% were 20 days or shorter and for 466 sites 90% were 30 days or shorter.

At our sites, dry intervals were longer in the drought years than in the humid years, which is similar for a desert steppe in Inner Mongolia during the growing season (Song et al. 2019). We found that short intervals (1-3 days) increased from May, reached the maximum in mid-growing season, then decreased. Long intervals (>4 days) had the opposite pattern. During the growing seasons, the average number of dry days was <3 at both sites. The percentage of <10 day intervals increased as annual precipitation increased and decreased as annual temperature increased.

Acknowledgements

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