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Effects of Sowing Date on Yield and Water Use Efficiency of Dryland Wheat in Southern Shanxi under Different Precipitation Year Types (Postprint)

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Abstract

Based on daily precipitation data from Linfen City, Shanxi Province over the past 54 years, seven experimental years were categorized into wet years, normal years, and dry years. This study investigated the effects of different year types and sowing dates on the duration of key growth stages, precipitation, accumulated temperature, sunshine hours, wheat yield, and grain water use efficiency of rainfed wheat, and conducted correlation analysis, multiple regression analysis, and path analysis to provide theoretical basis and technical support for stable and high yield of rainfed wheat. The results indicated that the influence of sowing date on wheat growth period duration was primarily manifested in the seedling, tillering, and erecting-jointing stages, while the difference in heading and maturity stages was at most 1 day. The entire growth period duration of rainfed wheat was significantly positively correlated with accumulated temperature. Precipitation year type significantly affected rainfed wheat yield and its components; even under the same precipitation year type, different precipitation distributions led to substantial yield differences. Rainfed wheat yield in wet years increased by 100.0% and 135.9% compared with normal years and dry years, respectively. Grain water use efficiency ranked as wet years > dry years > normal years. Under wet and dry year conditions, grain water use efficiency increased with delayed sowing date, whereas under normal year conditions, it initially increased and then decreased with delayed sowing date. During the jointing-heading period, wheat yield was significantly negatively correlated with accumulated temperature, extremely significantly negatively correlated with sunshine hours, and extremely significantly positively correlated with precipitation. During the heading-maturity period, yield was extremely significantly positively correlated with both accumulated temperature and sunshine hours. Annual precipitation and its distribution were the key factors affecting stable and high yield of rainfed wheat. The optimal sowing date for wet years was around October 4th, when yield components were well coordinated, enabling high yield attainment with minimal water consumption during the growth period and relatively high water use efficiency. For normal and dry years, the optimal sowing date should be around September 28th, resulting in the highest yield and relatively high water use efficiency. With delayed sowing date, the seeding rate should be appropriately increased.

Full Text

Impact of Sowing Date on Yield and Water Use Efficiency of Wheat in Different Precipitation Years in Dryland of South Shanxi

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Abstract

Sowing date significantly affects pre-winter individual development, population quality, and wheat yield. Wheat cultivation in the dryland areas of South Shanxi accounts for 60% of the province’ s total wheat area, and precipitation in this region plays a crucial role in ensuring agricultural production and food security in Shanxi Province. Under global warming conditions, research on optimal sowing dates for wheat in Shanxi is essential for sustainable agricultural development. Based on 54 years of daily precipitation data from Linfen, Shanxi Province, seven experimental years from 2008 to 2015 were classified into three precipitation year types: wet precipitation years (2012, 2014, and 2015, with 527.8-597.2 mm precipitation), normal precipitation years (2011 and 2013, with 450.7-483.3 mm precipitation), and dry precipitation years (2009 and 2010, with 293.4-385.4 mm precipitation). This study analyzed precipitation, accumulated temperature, sunshine duration during the wheat growing season, as well as wheat growth duration, yield, and water use efficiency (WUE) under three sowing dates (September 20, 30, and October 5 in 2008-2009; September 22, 28, and October 4 in 2009-2015). The relationships between yield, yield components, WUE, and meteorological factors were examined through correlation analysis, multiple regression, and path analysis to provide theoretical basis and technological support for high and stable yield production of dryland wheat. Results showed that sowing date significantly affected the duration of seedling, tillering, and jointing stages, while having no significant effect on booting and maturing stages. There was a significantly positive relationship between wheat growth duration and accumulated temperature. Precipitation year type and precipitation distribution during the wheat growth season significantly affected wheat yield and yield components. Yield in wet precipitation years was 100.0% and 135.9% higher than in normal and dry precipitation years, respectively. For different precipitation year types, grain WUE ranked as: wet precipitation year > dry precipitation year > normal precipitation year. In wet and dry precipitation years, grain WUE increased with delayed sowing date, while in normal precipitation years, WUE increased when sown before September 28 but decreased thereafter. From jointing to heading stage, wheat yield was negatively correlated with accumulated temperature and sunshine duration, but positively correlated with precipitation. From heading to maturity stage, yield was positively correlated with both accumulated temperature and sunshine duration. Annual precipitation and its distribution were the key factors determining high and stable wheat yield in dryland. In wet years, October 4 was identified as a suitable sowing date, which promoted coordinated yield components, high yield and WUE, and low water consumption. In normal and dry years, September 28 was more suitable for achieving higher yield and WUE.

Keywords: Dryland wheat; Precipitation year; Meteorological factors; Yield; Water use efficiency

Introduction

Shanxi Province has a warm temperate and temperate continental climate, located in the semi-arid region of the Loess Plateau, with annual precipitation of 400-600 mm. Influenced by the continental monsoon climate, precipitation shows uneven spatial and temporal distribution, with approximately 60% concentrated in the fallow period (July-September). Winter and spring are characterized by little rain and snow, frequent wind, and high evaporation in the 0-20 cm soil layer, making the saying "drought in nine out of ten years" an accurate description of the wheat growing season. Wheat is China' s most important staple food crop, and dryland wheat accounts for 60% of the total wheat area in Shanxi Province. Drought and water shortage are the key factors limiting yield. Developing dryland farming and studying optimal sowing dates and seeding rates under global warming conditions to ensure sustainable development of dryland agriculture represents a major challenge for China' s agricultural development. Different sowing dates result in varying ecological conditions such as temperature and light during the wheat growth period, significantly affecting yield components and water use efficiency. Zhang et al. demonstrated that delayed sowing increased wheat ear formation rate but significantly reduced spike number and grain yield, while increasing grain protein content and altering protein composition. Li et al. and Zhao et al. showed that sowing date affected the fitting degree of canopy spectral models for wheat chlorophyll content, and that sowing date and rate significantly impacted wheat grain yield. Pei et al. found that under warm winter conditions, early sowing with continuously high temperatures easily caused excessive pre-winter growth, advanced growth stages, weak individuals, reduced population quality, and lower yield; while late sowing with low temperatures resulted in weak pre-winter individuals, poor population quality, fewer spikes, and reduced yield. Xu and Bai studied suitable sowing dates for winter wheat and summer maize in double-cropping systems based on accumulated temperature changes. While numerous studies have examined the effects of sowing date on wheat growth and yield, research on critical sowing dates under different precipitation year types remains scarce. This study addresses the characteristic of South Shanxi hilly dryland where precipitation mainly occurs during the wheat fallow period with large inter-annual fluctuations. Through seven consecutive years (2008-2015) of research on the effects of different sowing dates on wheat growth and yield, and through analysis of accumulated temperature, precipitation, sunshine hours, yield, water use efficiency, and their correlations under different precipitation year types and sowing dates, this research aims to identify the key climatic parameters constraining grain yield and water use efficiency of dryland wheat, providing theoretical basis for stable and high yield production.

1.1 Experimental Site

The experiment was conducted from September 2008 to June 2015 in Yuebi Village, Dayang Town, Yaodu District, Linfen City, Shanxi Province, located in hilly dryland. The experimental site is located at 36°05.520 N, 111°45.727 E, at an altitude of 693.5 m, with an average annual temperature of 12.6°C and annual precipitation of 430-550 mm. There were no irrigation conditions, and the cropping system was annual wheat monoculture. The soil was loamy calcareous cinnamon soil. Before sowing in 2008, the 0-20 cm tillage layer contained organic matter 9.08 g · kg ^{1}, alkaline hydrolysis nitrogen 39.29 mg · kg ^{1}, available phosphorus 20.32 mg · kg ^{1}, and available potassium 128.64 mg · kg ^{1}. Precipitation conditions at the experimental site are shown in Table 1 .

1.2 Experimental Design

Three sowing date treatments were established. In 2008-2009: September 20 sowing with seeding rate 112.5 kg · hm ^{2}, September 30 sowing with 165.0 kg · hm ^{2}. In 2009-2015: September 22 sowing with 112.5 kg · hm ^{2}, September 28 sowing with 150.0 kg · hm ^{2}, and October 4 sowing with 187.5 kg · hm ^{2}. Each year, N 150 kg · hm ^{2}, P O 120 kg · hm ^{2}, and K O 60 kg · hm ^{2} were applied as basal fertilizer before sowing. The tested variety was the nationally certified wheat ‘Jinmai 92’ (new line ‘Lin Y8159’ in 2008-2012, nationally certified and named ‘Jinmai 92’ in 2013). Plot size was 7 m × 20 m = 140 m^2 with three replications.

1.3.1 Accumulated Temperature, Sunshine Duration, and Precipitation During Wheat Growth Period

Meteorological data were obtained from the National Meteorological Information Center (http://www.nmic.cn/) national benchmark station in Linfen City, Shanxi Province, from 2008-2015.

1.3.2 Wheat Yield Components and Grain Yield

At maturity, three 20-cm row sections were randomly sampled from each treatment. After removing plants with fewer than 6 grains per spike, the remaining stems with spikes were counted as effective spike number, and all grains were counted to calculate average kernels per spike. Five 1.0 m^2 quadrats were randomly harvested from each treatment, threshed, air-dried, and weighed to calculate grain yield. Five hundred grains were counted and weighed to calculate 1000-kernel weight, with two repetitions (difference between repetitions 0.5 g).

1.3.3 Grain Water Use Efficiency

Soil samples were collected with an auger at sowing and harvest from 0–200 cm depth (every 20 cm layer). Soil water content was determined by the aluminum box drying method. Calculations were as follows:

$$\text{Water storage capacity } W = w \times \rho_s \times h \times 0.1 \quad (1)$$

where: W is soil water storage capacity (mm), w is soil water content (%), is soil bulk density (g · cm ^{3}), h is soil layer thickness (cm), and 0.1 is the unit conversion coefficient.

Water consumption during growth period = pre-sowing 0–200 cm soil water storage+precipitation−post-harv

$$\text{Grain water use efficiency } (\text{WUE}_{\text{grain}}) = \text{grain yield/water consumption during growth period} \quad (3)$$

1.4 Data Processing

Microsoft Excel was used for statistical calculation of accumulated temperature, sunshine duration, and precipitation data during wheat growth period. DPS 15.10 software was used for variance analysis, correlation analysis, and stepwise regression analysis.

2.1 Duration, Accumulated Temperature, Sunshine Hours, and Precipitation of Wheat Growth Stages Under Different Sowing Dates

Tables 2 and 3 show that within the experimental sowing date range, the timing, duration, accumulated temperature, sunshine hours, and precipitation of each growth stage varied among different sowing dates. Early sowing resulted in longer growth duration, higher total accumulated temperature, longer sunshine hours, and more precipitation. The effect of sowing date on growth stage duration was mainly observed during the seedling, tillering, and jointing stages, with minimal effect on heading and maturity stages. With delayed sowing, the duration of sowing-seedling and seedling-tillering stages increased; accumulated temperature required for sowing-seedling stage increased significantly, while that for seedling-tillering stage showed little difference; tillering-jointing stage duration shortened significantly with reduced accumulated temperature and sunshine hours. Precipitation year type had minimal effect on the timing, duration, accumulated temperature, sunshine hours, and precipitation of each growth stage.

Correlation analysis between growth stage duration and accumulated temperature, sunshine hours, and precipitation showed that sowing-seedling duration was extremely significantly positively correlated with accumulated temperature during this stage ($r = 0.712$**). Tillering-jointing and jointing-heading durations were extremely significantly or significantly positively correlated with sunshine hours ($r = 0.659$** and $r = 0.440$*, respectively). Heading-maturity duration was extremely significantly positively correlated with accumulated temperature and sunshine hours during this stage (*r* = 0.883** and $r = 0.751$**, respectively). Total growth duration was significantly positively correlated with accumulated temperature ($r = 0.462$*), but correlations with precipitation were not significant.

2.2 Wheat Yield and Yield Components Under Different Precipitation Year Types and Sowing Dates

Table 4 shows that annual precipitation significantly affected dryland wheat yield and its components, following the trend: wet precipitation year > normal precipitation year > dry precipitation year, with wet precipitation year yield significantly higher than other year types. In terms of yield components, wet precipitation year had significantly higher spike number than normal and dry years, which was the main factor affecting dryland wheat yield. Kernels per spike were also higher than in normal and dry years, while 1000-kernel weight was similar to that in normal years.

In wet precipitation years (2012 and 2015), wheat spike number and yield increased with delayed sowing and corresponding increased seeding rate; in 2014, the September 28 sowing date produced the highest yield. In 2014 and 2015, kernels per spike decreased with delayed sowing, while the opposite occurred in 2012. The 1000-kernel weight increased with delayed sowing. In normal and dry precipitation years, wheat spike number and yield first increased then decreased with delayed sowing, peaking at September 28 sowing; except for 2011, early sowing produced the lowest spike number and yield. Kernels per spike increased with delayed sowing (except in 2010 when September 28 sowing was highest). The pattern of 1000-kernel weight change with delayed sowing was not consistent.

Annual precipitation distribution also significantly affected dryland wheat yield. In 2014 (a wet year), growing season precipitation was 199.2 mm, with substantial precipitation in April–May (136.6 mm), which promoted kernel development and grain filling, resulting in high kernels per spike and 1000-kernel weight and the highest yield. In 2013 (a normal year), growing season precipitation was only 130.8 mm, concentrated in late May (76.2 mm), representing ineffective precipitation that contributed little to yield, resulting in the lowest yield and grain water use efficiency.

2.3 Grain Water Use Efficiency Under Different Precipitation Year Types and Sowing Dates

Table 5 shows that water consumption during the growth period was closely related to annual precipitation. Overall, water consumption followed the trend: wet precipitation year > normal precipitation year > dry precipitation year, while water consumption decreased with delayed sowing. Grain water use efficiency ranked as: wet precipitation year > dry precipitation year > normal precipitation year. In wet and dry precipitation years, grain water use efficiency increased with delayed sowing, while in normal precipitation years, it first increased then decreased with delayed sowing.

Correlation analysis of precipitation, soil water storage, water consumption, and water use efficiency showed that water consumption during the growth period was extremely significantly positively correlated with precipitation during the fallow period, annual precipitation, and pre-sowing soil water storage ($r = 0.589$**,** **0.686**, and 0.843**, respectively). Correlations between grain water use efficiency and precipitation or soil water storage were not significant.

2.4 Correlations Between Accumulated Temperature, Sunshine Hours, Precipitation, and Yield and Yield Components

Table 6 shows that dryland wheat yield was significantly and extremely significantly negatively correlated with accumulated temperature and sunshine hours from jointing to heading stage, respectively, but extremely significantly positively correlated with precipitation during this stage. From heading to maturity stage, yield was extremely significantly positively correlated with both accumulated temperature and sunshine hours. Regarding yield components: spike number was extremely significantly positively correlated with accumulated temperature during tillering–jointing stage, but extremely significantly negatively correlated with accumulated temperature and sunshine hours during jointing–heading stage. Kernels per spike was extremely significantly negatively correlated with sunshine hours during jointing–heading stage, but extremely significantly positively correlated with accumulated temperature and sunshine hours during grain filling stage, and extremely significantly negatively correlated with precipitation during this period. The 1000-kernel weight was only significantly positively correlated with precipitation during jointing–heading stage. Water consumption during the growth period was significantly positively correlated with accumulated temperature during the growth period, significantly negatively correlated with accumulated temperature and sunshine hours during jointing-heading stage, significantly positively correlated with precipitation during tillering and jointing-heading stages, and extremely significantly positively correlated with accumulated temperature during grain filling stage. Yield was extremely significantly positively correlated with all three yield components and water consumption during the growth period, which was also extremely significantly positively correlated with spike number and kernels per spike.

Stepwise regression analysis showed that total sunshine hours and spike number had high direct path coefficients on grain yield (0.772 and 0.529, respectively). Spike number mainly affected yield indirectly through sunshine hours during jointing-heading stage (indirect path coefficient = 0.236). Grain yield, precipitation during jointing-heading stage, and precipitation during grain filling stage had high direct path coefficients on grain water use efficiency (2.788, 3.165, and 4.657, respectively). Yield mainly affected water use efficiency indirectly through precipitation and accumulated temperature during jointing-heading stage (indirect path coefficients = 2.108 and 1.706).

3 Discussion and Conclusion

As global "warming and drying" climate change characteristics become increasingly evident, the impact of sowing date on wheat growth and yield has attracted widespread attention. Xu et al. proposed that suitable wheat sowing dates in Jining, Shandong should be delayed to October 5–9 based on 0°C accumulated temperature during the wheat growth period and pre-winter period over the past 40 years, with an additional 5-day delay for warm winters and spring-type varieties. Bai et al. suggested that suitable wheat sowing dates in Yanzhou, Shandong should be about 5 days later than in the 1970s based on accumulated temperature above 0°C required for strong seedlings before winter. However, reports on changes in meteorological factors during the growth period remain limited. This study demonstrated that delayed sowing shortened the dryland wheat growth period, reduced total accumulated temperature, shortened sunshine hours, and decreased growing season precipitation. Sowing date significantly affected the growth process from emergence to heading, while differences in heading and maturity dates among different sowing dates were small, consistent with Pei et al.' s results on the effects of sowing date on growth of high-quality wheat under irrigated conditions.

Precipitation is the key to stable and high yield of dryland wheat, and sowing date significantly affects grain yield and water use efficiency. Studies by Zhang et al., Zhao et al., and Zhang et al. all showed that delayed sowing significantly reduced grain yield, requiring increased seeding rate to improve spike number for high yield. Previous research mainly focused on the effects of sowing date on grain yield in specific years, with few studies on sowing date under different precipitation year types. This study revealed that precipitation year type significantly affected dryland wheat yield, with wet precipitation years increasing yield by 100.0% and 135.9% compared to normal and dry years, respectively. Precipitation during key growth stages substantially promoted wheat yield. In the wet year of 2014, substantial precipitation in April–May (jointing–heading stage, 136.6 mm) resulted in moderate spike number but high kernels per spike and 1000-kernel weight, leading to the highest yield. In the normal year of 2013, low precipitation during the growing season concentrated in late May (grain filling stage, 76.2 mm) represented ineffective precipitation that contributed little to yield, resulting in the lowest yield and grain water use efficiency. Water consumption in wet precipitation years was 55.86% and 83.29% higher than in normal and dry years, respectively, mainly related to high precipitation during the late fallow period, as verified by pre-sowing soil water storage measurements. Optimal sowing dates differed among precipitation year types: in wet years, sowing around October 4 achieved high yield with coordinated yield components, minimum water consumption, and high water use efficiency; in normal and dry years, sowing around September 28 achieved the highest yield and water use efficiency.

Previous studies have extensively examined relationships between temperature changes during wheat growth periods and yield and its components, but few have investigated correlations between precipitation, sunshine hours, and dryland wheat yield, water consumption, and grain water use efficiency. Liu et al. reported that 0°C accumulated temperature from rising to jointing stage positively affected yield in the Huang-Huai dryland region, accounting for 26.17% of the determining factors. This study found that during jointing–heading stage, dryland wheat yield and water consumption were significantly negatively correlated with accumulated temperature and sunshine hours, but significantly positively correlated with precipitation. During heading–maturity stage, yield was significantly positively correlated with accumulated temperature and sunshine hours. Therefore, low temperature, low light, and high precipitation during jointing–heading stage were beneficial for coordinating the three yield components, while high temperature, high light, and low precipitation during heading-maturity stage facilitated photosynthate accumulation, ultimately increasing grain yield. These conclusions can enrich Chinese wheat cultivation theory but require verification and refinement through longer-term experiments.

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