Effects of Sowing Date and Rate on Growth and Development, Yield, and Water Use of Dryland Wheat 'Xiaoyan 60' Postprint

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Abstract

Under dryland conditions, investigating the effects of sowing date and seeding rate on population traits, yield, and water use of the new wheat line 'Xiaoyan 60' can provide a technical basis for rainfed wheat cultivation. The experiment was conducted at the Nanpi Eco-agricultural Experimental Station, Chinese Academy of Sciences, from 2014 to 2015. From October 15 to November 14, a sowing date was established every 6 days, comprising six sowing dates (T1–T6). Two seeding rate treatments were implemented: a constant rate (B1) and a progressively increased rate (B2). Treatment B1 was 300 kg · ha^{1}, applied uniformly across T1 to T6. Treatment B2 involved progressively increasing the seeding rate with delayed sowing, with an increment of 7.5 kg · ha^{1} per day of delay. The seeding rates for each sowing date were 300 kg · ha^{1} (T1), 345 kg · ha^{1} (T2), 390 kg · ha^{1} (T3), 435 kg · ha^{1} (T4), 480 kg · ha^{1} (T5), and 525 kg · ha^{1} (T6). The study examined the variation patterns of population traits, yield, and water use of 'Xiaoyan 60' under different sowing dates and seeding rates. The results indicated: 1) With delayed sowing, emergence time was prolonged, growth stages were delayed, and the entire growth period was shortened; seeding rate had no significant effect on the growth period. 2) With delayed sowing, emergence rate and spikes per plant gradually decreased; increased seeding rate enhanced the basic seedling population and spike number. 3) With delayed sowing, plant height and biomass decreased; increased seeding rate improved biomass, while plant height showed no significant change. 4) With delayed sowing, grain yield decreased; however, with progressively increased seeding rate, grain yield could exceed 6600 kg · ha^{1} before November 2 without significant differences. 5) When seeding rate was increased with delayed sowing, the first four sowing dates showed no significant changes in yield or water use efficiency, all exceeding 29 kg · ha^{1} · mm^{1}. The results demonstrate that 'Xiaoyan 60' is a variety with a wide sowing window. Although yield declines with delayed

sowing, within a certain range of sowing dates, increasing seeding rate to enhance population (spike number) can achieve yields comparable to timely sowing. The theoretical relationship between seeding rate and delayed sowing days is $y = 0.3682x^2 + 1.1939x + 316.7$ ($R^2 = 0.9839$).

Full Text

Effects of Sowing Date and Seeding Density on Growth, Yield, and Water Use Efficiency of 'Xiaoyan 60' Wheat Under Rainfed Conditions

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Abstract

Under rainfed conditions, investigating the effects of sowing date and seeding density on population characteristics, yield, and water use efficiency of the new wheat line 'Xiaoyan 60' can provide a technical basis for rain-adapted cultivation. The experiment was conducted at the Nanpi Eco-Agricultural Experimental Station of the Chinese Academy of Sciences during the 2014–2015 growing season. Six sowing dates were established at 6-day intervals from October 15 to November 14 (T1–T6). Two seeding density treatments were implemented: constant density (B1) and progressively increased density (B2). In B1, the seeding rate was 300 kg · hm ^{2} for all dates. In B2, the rate started at 300 kg · hm ^{2} and increased by 7.5 kg · hm ^{2} · day ^{1} with delayed sowing, resulting in densities of 300, 345, 390, 435, 480, and 525 kg · hm ^{2} for T1–T6, respectively. The study examined changes in population characteristics, yield, and water use efficiency under different treatments.

The results showed: (1) Delayed sowing prolonged emergence time and postponed growth stages, shortening the total growth period; seeding density had no significant effect on growth duration. (2) Delayed sowing gradually reduced emergence rate and spikes per plant; increased seeding density improved both basic seedlings and spike numbers. (3) Plant height and biomass decreased with delayed sowing; increased seeding density enhanced biomass but did not significantly affect plant height. (4) Grain yield declined with delayed sowing; however, with progressively increased seeding density, yields above 6,600 kg · hm ^{2} were achieved for sowing dates before November 2 with no significant differences. (5) When seeding density increased with delayed sowing, the first four

sowing dates showed no significant differences in yield or water use efficiency, all exceeding 29 kg · hm ² · mm ¹.

These results indicate that 'Xiaoyan 60' is a cultivar with wide sowing adaptability. While yield decreases with delayed sowing, increasing seeding density to boost population (spike number) within a certain range can achieve yields comparable to timely sowing. The theoretical relationship between seeding density (y) and delayed sowing days (x) is described by the regression equation $y = 0.3682x^2 + 1.1939x + 316.7$ ($R^2 = 0.9839$).

Keywords: Winter wheat; 'Xiaoyan 60' ; Sowing date; Sowing density; Wheat yield; Water use efficiency

Introduction

The coastal region of Bohai Bay in Hebei Province faces severe freshwater shortages and soil salinization that constrain agricultural development, making efficient water utilization in crop production critically important. The North China Plain represents a major grain-producing region, accounting for 26% of national wheat production. However, during the winter wheat growing season, average precipitation in this region is approximately 120 mm, far below the total water consumption requirement of winter wheat. Natural factors such as climate warming (affecting pre-winter development) and low temperature with limited sunlight in autumn (delaying maize maturity) have created a trend toward delayed wheat sowing dates. Adjusting sowing dates can delay development before winter dormancy, preventing excessive vegetative growth and reducing frost damage risk, thereby influencing wheat yield and quality. Therefore, under rainfed conditions, effectively utilizing rainfall during October to early November for wheat sowing is crucial for improving precipitation use efficiency and achieving high yields.

Optimal sowing date and density are key cultivation techniques for high wheat yields, directly affecting population quality and grain production. Previous research has shown that planting density affects tiller numbers at all growth stages, with smaller differences in total stem numbers throughout the growth period for early sowing, but larger differences for late sowing. Studies have demonstrated that density significantly affects yield and all three yield components. Sowing date significantly impacts spikes per unit area, thousand-grain weight, and yield, while having a regulatory effect on grains per spike. Within a certain range, spikes per unit area decrease with delayed sowing, grains per spike increase with delayed sowing, and thousand-grain weight initially increases then decreases with delayed sowing. Research in the North China Plain indicated that wheat sown before October 10 produced similar yields, after which yield decreased significantly with further sowing delays. Sowing date also affects growth progression and population characteristics, with the entire growth period shortening as sowing is delayed, though the reduction in days is less than the sowing delay itself.

'Xiaoyan 60' is a new line identified by Academician Li Zhensheng from a cross between 'Xiaoyan 54' and 'Lumai 13', showing yield increases compared to 'Jing 9428', 'Shi 4185', and 'Jimai 32'. It possesses desirable traits including salt tolerance, stress resistance, and high yield, making it suitable for saline-alkali soils. Large-scale promotion of 'Xiaoyan 60' requires supporting high-yield and water-saving cultivation techniques. However, few reports exist on the optimal sowing date and density for this cultivar under rainfed conditions, its growth and development characteristics, yield formation, and efficient water utilization. This study investigates the effects of sowing date and density on population characteristics, yield, and water use efficiency of 'Xiaoyan 60' under rainfed conditions to provide theoretical and technical support for drought-resistant, rain-adapted cultivation and popularization of this cultivar.

Materials and Methods

1.1 Experimental Site and Materials

The experiment was conducted during the 2014–2015 growing season at the Nanpi Eco-Agricultural Experimental Station of the Chinese Academy of Sciences (116°40 E, 38°00 N, elevation 11 m). The site features a warm temperate semi-humid monsoon climate with average annual precipitation of 480 mm, mean annual temperature of 12.3°C, total annual sunshine hours of 2,938.6 h, and total annual radiation of 133.6 kJ · cm ². The soil is desalinated fluvo-aquic with some saline soil, and shallow groundwater is brackish to slightly saline, representing the water-deficient salinized low plain characteristic of the Bohai Rim region. The topsoil layer (0–30 cm) contained 44.79 mg · kg ¹ available nitrogen, 4.94 mg · kg ¹ available phosphorus, and 149.97 mg · kg ¹ available potassium, with an average bulk density of 1.40 g · cm ³.

shows meteorological data for the 2014–2015 winter wheat growing season. The average temperature was 9.4°C, representing a normal year (average temperature during wheat growth period from 2011–2015 was 9.3°C). Using commonly employed precipitation year-type classification standards, the experimental area' s precipitation over the past 20 years (1996–2015) approximated the annual average, classifying it as a normal precipitation year.

1.2 Experimental Design

The experiment employed two factors: sowing date and seeding density. Six sowing dates were established: T1 (October 15), T2 (October 21), T3 (October 27), T4 (November 2), T5 (November 8), and T6 (November 14). Two seeding density treatments were implemented: constant density (B1) and progressively increased density (B2). B1 maintained 300 kg · hm ² across all sowing dates, while B2 increased by 7.5 kg · hm ² for each day of delay, resulting in densities of 300, 345, 390, 435, 480, and 525 kg · hm ² for T1–T6, respectively. Plot size was 3.3 m × 3.5 m (11.55 m^2) with four replications per treatment. Row spacing was 15 cm. Basal fertilizer application was 202 kg · hm ² nitrogen and 172.5 kg ·

hm ² P O , with 135 kg · hm ² nitrogen applied as topdressing in spring. Field management followed local practices.

1.3 Measurement Items and Methods

1.3.1 Soil Volumetric Water Content Soil water content in the 0–200 cm profile was measured by the oven-drying method at sowing and harvest. Measurements were taken every 10 cm in the 0–20 cm layer and every 20 cm in the 20–200 cm layer. Gravimetric water content (, %) was calculated as: = 100 × (wet soil weight - dry soil weight) / dry soil weight. Water depth equivalent was calculated using: Q = dh , where Q is water content in a soil layer (mm), d is dry bulk density (g · cm ³), h is layer thickness (mm), and is gravimetric water content.

1.3.2 Growth Stage Investigation Dates were recorded for emergence, re-greening, jointing, heading, anthesis, and maturity stages.

1.3.3 Tiller Number Measurement Starting from basic seedling establishment, tiller numbers were periodically measured within a fixed area of 1 m double rows.

1.3.4 Photosynthetic Parameter Measurement On May 15 during the grain-filling stage, between 9:00–11:00 AM on clear, windless days, three plants per treatment were selected for measurement of flag leaf photosynthetic rate (Pn) and transpiration rate (Tr) using a Li-Cor 6400 portable photosynthesis system (LI-COR Biosciences, USA).

1.3.5 Yield and Yield Component Measurement At maturity (June 6), 20 spikes were randomly selected from each plot for indoor measurement of plant height, spike length, grains per spike, and thousand-grain weight. Total biomass and grain yield were determined from 1 m double rows after threshing and air-drying, and harvest index was calculated.

1.3.6 Calculation Formulas Evapotranspiration (ET) was calculated using the soil water balance equation:

$$ET = P + I - R - D - \Delta W$$

where ET is evapotranspiration, P is precipitation (obtained from the meteorological station), I is irrigation (zero in this experiment), R is surface runoff, D is deep percolation, and ΔW is the change in soil water storage. Surface runoff and deep percolation were negligible in this experimental area, so total water consumption was approximated by precipitation plus change in soil water storage.

Biomass water use efficiency (WUEbm) was calculated as:

$$WUE_{bm} = \frac{BM}{ET}$$

where BM is total dry matter accumulation and ET is total evapotranspiration.

Yield water use efficiency (WUEy) was calculated as:

$$WUE_{y} = \frac{Y}{ET}$$

where Y is grain yield and ET is total evapotranspiration.

Leaf water use efficiency (WUEleaf) was calculated as:

$$WUE_{leaf} = \frac{Pn}{Tr}$$

where Pn is photosynthetic rate and Tr is transpiration rate.

Harvest index (HI) was calculated as:

$$HI = \frac{Y}{BM}$$

where Y is grain yield and BM is total dry matter accumulation.

1.4 Data Processing

Figures were prepared using Microsoft Excel 2007. Statistical analysis was performed using Microsoft Excel 2007 and IBM SPSS Statistics 20. Treatment comparisons were conducted using the least significant difference (LSD) method at = 0.05.

Results

2.1 Changes in Wheat Growth Progress Under Different Sowing Dates and Densities

Delayed sowing progressively increased the days from sowing to emergence. Emergence required 7 days for October 15 sowing, 10 days for October 21 sowing, and over 20 days thereafter, with the longest reaching 31 days. Growth stages including jointing, booting, and anthesis were postponed with delayed sowing, with T6 jointing delayed by 12 days. The gap narrowed at maturity, with differences of only 1–4 days . Within the same sowing date, seeding density had no significant effect on growth duration.

2.2 Effects of Sowing Date and Density on Wheat Population

As shown in , delayed sowing consistently reduced basic seedlings, emergence rate, spike number, and spikes per plant for 'Xiaoyan 60' . Within the same sowing date, increased seeding density substantially improved basic seedlings and spike numbers, but did not significantly affect emergence rate or spikes per plant. Under B1, compared with T1, other treatments showed reductions of 2.4-23.2% in basic seedlings, 2.3–18.9% in emergence rate, 14.6–56.6% in spike number, and 0.17-0.60 spikes per plant. Under B2, changes in emergence rate and spikes per plant were similar to those under B1.

The B2 density increase was determined based on local production experience (7.50 kg · hm ^{2} increase per day of delay). However, data in revealed that spike numbers for T4, T5, and T6 under increased density were still 7.1-16.2% lower than T1, with T6 showing a significant decrease. This suggests that the empirically derived density increase was insufficient to achieve the same population (spike number) as timely sowing for this cultivar under late-sowing conditions.

Based on spike number and yield data from the density increase experiment, the relationship between spike number and yield followed a quadratic polynomial: $y = -0.147x^2 + 226.8x - 80{,}471$ ($R^2 = 0.965$) [Figure 1: see original paper]. From this relationship, the optimal spike number for high yield was determined to be 770.66×10 · hm ^{2}. Theoretical seeding densities for each sowing date to achieve this optimal spike number were calculated based on changes in emergence rate and spikes per plant [Figure 2: see original paper], establishing the correlation equation between theoretical seeding density (y) and delayed sowing days (x) as $y = 0.3682x^2 + 1.1939x + 316.7$ ($R^2 = 0.9839$), indicating that later sowing requires progressively greater density increases.

Delayed sowing decreased wheat population biomass. Under B1, biomass significantly decreased from T3 onward; under B2, no significant differences were observed among treatments sown before November 8 (T5). Compared with T1, T6 biomass decreased by 50.2% under B1 and 29.0% under B2. Within the same sowing date, increased seeding density significantly improved biomass, with increases of 17.6%, 32.4%, 40.6%, and 42.4% for T3, T4, T5, and T6, respectively [Figure 3B: see original paper].

2.3 Effects of Sowing Date and Density on Plant Height and Biomass

Delayed sowing significantly reduced plant height [Figure 3A: see original paper]. Under B1, plant height decreased by 3.4–9.9 cm compared with T1; under B2, height decreased by 4.3–11.2 cm. Within the same sowing date, seeding density had no significant effect on plant height.

2.4 Effects of Sowing Date and Density on Yield and Components

shows that delayed sowing reduced spikes per unit area, particularly under constant density (B1). Grains per spike showed a decreasing trend but with no significant changes, with only T6 showing significant reduction compared with T1. No significant differences in thousand-grain weight were observed among treatments. The first four sowing dates (T1–T4) showed no significant differences in harvest index (HI), while the last two dates decreased to significantly lower levels.

Grain yield significantly decreased with delayed sowing under B1. Under B2, no significant differences were observed among the first four sowing dates, while the last two dates showed significant yield reductions. Within the same sowing date, increased seeding density significantly improved yield. Correlation analysis revealed that grain yield was extremely significantly positively correlated with spike number and significantly positively correlated with grains per spike .

Yield reduction under late sowing was primarily caused by decreases in spike number and grains per spike. Under B2, grain yields before November 2 exceeded 6,600 kg · hm ^{2} with no significant differences, demonstrating that yield loss from delayed sowing could be compensated by increasing seeding density.

2.5 Effects of Sowing Date on Water Use

Delayed sowing decreased wheat yield. indicates that water consumption showed a decreasing trend with delayed sowing, though differences among treatments were not significant (except for B1T6). Both biomass water use efficiency (WUEbm) and yield water use efficiency (WUEy) decreased with delayed sowing. Under B1, no significant differences were observed among the first three sowing dates for WUEbm and WUEy, but the last three dates showed significant reductions. Under B2, WUEbm significantly decreased only for T6, while WUEy significantly decreased for T5 and T6. Compared with T1, WUEy decreased by 9.5–45.9% for B1T4, B1T5, B1T6, B2T5, and B2T6. No significant differences were observed in leaf water use efficiency (WUEleaf) among treatments.

2.6 Correlation Analysis Between Water Use Efficiency and Physiological Indices

Correlation analysis among water use efficiency, harvest index, and yield for 'Xiaoyan 60' showed that grain yield was extremely significantly positively correlated with WUEbm, WUEy, and HI. WUEy was extremely significantly positively correlated with HI, indicating that higher harvest index leads to higher WUEy. Therefore, in water-saving cultivation, WUEy can be improved by increasing harvest index to achieve both water conservation and high yield.

Discussion and Conclusion

This study demonstrates that sowing date and density significantly affect wheat growth progression, population characteristics, and yield. Delayed sowing extended emergence time from 7 to 31 days, postponed growth stages, shortened the total growth period (though the reduction was less than the delay duration), and narrowed differences at maturity. These results are consistent with previous studies. Sowing date significantly affected field emergence rate and spikes per plant, while seeding density had minimal impact. Late sowing markedly reduced emergence rate and spikes per plant, whereas increased seeding density within the same sowing date increased basic seedlings and spikes per unit area. Therefore, in production practice, seeding density must be increased when the optimal sowing window is missed.

Plant height, an important morphological indicator, decreased with delayed sowing, while seeding density showed no significant effect on height. Population biomass decreased with delayed sowing, but increased seeding density significantly improved biomass within the same sowing date. This indicates that individual plant growth is primarily affected by sowing date, while population growth is influenced by both sowing date and basic seedling number, consistent with previous research.

This study showed that spikes per unit area decreased with delayed sowing, particularly under constant density (B1), aligning with previous findings. Grains per spike showed a decreasing trend but with minimal change, and no significant differences in thousand-grain weight were observed among treatments, consistent with other studies. During the one-month sowing window from October 15 to November 14, 'Xiaoyan 60' maintained thousand-grain weight within 40–44 g, indicating it is a cultivar with high and stable grain weight. Within the same sowing date, increased seeding density raised spikes per unit area while reducing grains per spike and thousand-grain weight, consistent with related research.

Grain yield decreased with delayed sowing, with the highest yield (6,970.75 kg · hm ^{2}) achieved in the October 21 sowing at 345 kg · hm ^{2} density. Under constant density (B1), yield decreased significantly with delay, with maximum reduction reaching 53.9%. Under progressively increased density (B2), no significant differences were observed among the first four sowing dates, with only T5 and T6 showing significant reductions. The saline soil in Cangzhou' s dryland farmland is relatively fertile, with typical rainfed winter wheat yields of 4,500–5,250 kg · hm ^{2}. In this study, under increased density treatment, sowing as late as November 8 (T5) still achieved 5,982.50 kg · hm ^{2}, exceeding local yield levels. This demonstrates that 'Xiaoyan 60' has a wide sowing window and good drought tolerance, but appropriate density matching according to production conditions is necessary for high yields.

This study calculated theoretical seeding densities for each sowing date to achieve high-yield spike numbers, establishing the regression equation $y = 0.3682x^2 + 1.1939x + 316.7$ ($R^2 = 0.9839$), which can be used to determine optimal seeding densities for different sowing dates within a certain range. Grain yield was extremely significantly positively correlated with WUEbm and WUEy, but not significantly correlated with WUEleaf, indicating that leaf-level water use efficiency does not reflect actual production performance, while WUEbm and WUEy better represent final average yield.

In conclusion: (1) Delayed sowing significantly reduced emergence rate and spikes per plant in 'Xiaoyan 60' , while seeding density had no significant effect on these parameters. (2) The theoretical relationship between seeding density (y) and delayed sowing days (x) is $y = 0.3682x^2 + 1.1939x + 316.7$ ($R^2 = 0.9839$), indicating that later sowing requires progressively greater density increases. (3) Under B2 density treatment, sowing 'Xiaoyan 60' from October 15 to November 2 produced no significant yield differences and exceeded local yield levels, demonstrating that this cultivar has wide sowing adaptability. Under late-sowing conditions, reasonable density increases can achieve both high yield and high WUEy.

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Note: Figure translations are in progress. See original paper for figures.