Effect of Sowing Date on Dry Matter Accumulation and Yield of Maize in the Hilly Region of Central Sichuan (Postprint)

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Abstract

Using the major recommended maize varieties 'Zhenghong 505' and 'Chengdan 30' in the hilly region of central Sichuan as experimental materials, five sowing dates were established at 15-day intervals from March 26 to May 25 to investigate the effects of sowing date on dry matter accumulation and yield of maize in this region, aiming to provide a theoretical basis for determining appropriate sowing time. The results indicated that delayed sowing date shortened the maize growth period, particularly the duration from sowing to silking, reduced post-silking dry matter accumulation and its contribution to yield, and decreased harvest index. Early sowing facilitated increased post-anthesis dry matter accumulation, whereas yield formation under late sowing required greater mobilization of photosynthates accumulated pre-anthesis. The yield of 'Zhenghong 505' decreased progressively with delayed sowing date, whereas that of 'Chengdan 30' initially increased slightly before declining. The yield difference between early summer sowing (sown on May 10) and spring sowing (sown on April 10) was not significant; however, summer sowing (sown on May 25) significantly reduced yield compared with spring sowing, similar to 'Zhenghong 505', due to shortened growth period, reduced dry matter accumulation, and lower harvest index. Early spring-sown 'Zhenghong 505' outyielded 'Chengdan 30', whereas summer-sown 'Chengdan 30' produced higher yield than 'Zhenghong 505', demonstrating that 'Chengdan 30' possessed stronger tolerance to summer sowing conditions. Sowing date exerted a greater influence on dry matter accumulation, yield, and yield components of 'Zhenghong 505' than on those of 'Chengdan 30', necessitating greater attention to timely sowing for the former in production practice. The suitable window for spring sowing in this region is relatively wide; however, the conflict between cropping system and mechanized production must be addressed. For summer sowing, selection

of varieties tolerant to summer sowing conditions should be prioritized, with sowing completed by early-to-mid May.

Full Text

Effect of Sowing Date on Dry Matter Accumulation and Yield of Maize in Hilly Regions of Sichuan Province, China

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Abstract

Using the main maize varieties 'Zhenghong 505' and 'Chengdan 30' in the hilly regions of central Sichuan, five sowing dates were established at 15-day intervals from March 26 to May 25 to investigate the effects of sowing date on dry matter accumulation and yield of maize, aiming to provide a theoretical basis for optimal sowing time selection in this region. The results showed that delayed sowing shortened the growth period, particularly from sowing to silking, reduced post-silking dry matter accumulation and its contribution to yield, and decreased harvest index. Early sowing favored increased post-anthesis dry matter accumulation, while late sowing required greater mobilization of pre-anthesis assimilates for yield formation. The yield of 'Zhenghong 505' decreased with delayed sowing, whereas that of 'Chengdan 30' initially increased slightly before decreasing. Early summer sowing (May 10) showed no significant yield difference from spring sowing (April 10), but summer sowing (May 25) caused significant yield reduction in both varieties due to shortened growth period, reduced dry matter accumulation, and lower harvest index. 'Zhenghong 505' out-yielded 'Chengdan 30' under early spring sowing, while 'Chengdan 30' produced higher yields under summer sowing, indicating stronger tolerance to summer sowing conditions. Sowing date had a greater impact on dry matter accumulation, yield, and yield components of 'Zhenghong 505' than on 'Chengdan 30', suggesting that proper sowing time is more critical for the former. The suitable sowing window for spring maize in this region is relatively wide, though production systems must address the conflict between farming practices and mechanization. For summer sowing, emphasis should be placed on selecting tolerant varieties and completing sowing by mid-to-late May.

Keywords: Maize; Sowing date; Growth stage; Dry matter accumulation and distribution; Transport; Yield

Introduction

Sowing date is one of the most critical cultivation factors affecting crop production, with appropriate timing being essential for achieving high yields. The influence of sowing date on maize (*Zea mays*) results from comprehensive interactions with ecological factors including light, temperature, water, and soil during the growth period, leading to significant differences in maize development and yield formation under different sowing dates. Previous studies have shown that delayed sowing significantly shortens the maize growth period, though yield responses vary by ecological conditions—some showing yield reduction with delayed sowing, while others exhibit initial yield increases followed by decreases. This indicates that optimal sowing dates are region- and variety-specific. Since grain yield is determined by biological yield (i.e., dry matter accumulation), with higher dry matter accumulation leading to higher grain yield, investigating differences in maize dry matter accumulation and distribution under various sowing dates helps elucidate the material basis for sowing date effects on yield.

The hilly region of central Sichuan represents the main maize production area in Sichuan Province, where sowing dates range from March to June due to diverse cropping systems. Traditional intercropping spring sowing (March–April) has dominated, but recent demonstrations of summer maize sown after wheat (*Triticum aestivum*) or rapeseed (*Brassica campestris*) harvest (May sowing) are being promoted to adapt to new agricultural management models and mechanization needs. Zhao et al. suggested that sowing dates in this region should schedule the critical water demand period after summer drought but before autumn drought, making late March to mid-April most suitable. However, few studies have examined optimal sowing dates for summer maize or compared dry matter accumulation and yield component differences between spring and summer maize in this region. Using 'Zhenghong 505' and 'Chengdan 30' as test materials, this study established five sowing dates at 15-day intervals from March 26 to May 25 to investigate sowing date effects on maize dry matter production and yield formation, providing a theoretical basis for determining appropriate sowing times.

1.1 Study Area Description

The experiment was conducted at Xinjian Village, Hexing Township, Zhongjiang County, Sichuan Province (104°37 E, 30°35 N). The average daily temperature from March to August during 2010–2014 was 21.8°C, with total precipitation of 714.7 mm. In 2015, the average daily temperature from March to August was 22.4°C, with precipitation of 565.3 mm, representing drier conditions than normal. Specific daily mean temperatures and precipitation during the experimental period are shown in [Figure 1: see original paper]. Pre-planting soil nutrient contents in the plow layer were: organic matter 11.77 $g \cdot kg^{-1}$, total nitrogen 1.47 $mg \cdot kg^{-1}$, alkali-hydrolyzable nitrogen 42.93 $mg \cdot kg^{-1}$, available phosphorus 5.9 $mg \cdot kg^{-1}$, and available potassium 117.56 $g \cdot kg^{-1}$.

1.2 Experimental Design

Test varieties were the leading cultivars recommended by Sichuan Provincial Department of Agriculture: 'Zhenghong 505' (provided by Sichuan Agricultural University Zhenghong Biotechnology Co., Ltd.) and 'Chengdan 30' (provided by Beijing Origin Seed Technology Co., Ltd.), both having similar growth progressions (Table 1). Five sowing dates were established: March 26 (early spring sowing, A1), April 10 (spring sowing, A2), April 25 (late spring sowing, A3), May 10 (early summer sowing, A4), and May 25 (summer sowing, A5). A split-plot design was used with sowing date as the main plot and variety as the subplot, with three replications, totaling 30 plots. Each plot covered 17.6 m^2 (5.5 m × 3.2 m) with row spacing of (110+50) cm × 25 cm and planting density of 49,500 plants · ha^{-2} using direct seeding with plastic film mulching. All treatments received compound fertilizer (40% active ingredient, N:P:K = 25:7:8) as base fertilizer applied in narrow-row furrows. Total nitrogen application was 225 kg · ha^{-2}, applied as base fertilizer:ear fertilizer at a 1:1 ratio. Other cultivation management practices followed standard high-yield maize field protocols.

1.3 Measurement Items and Methods

At jointing, large trumpet, silking, 15 days after silking, and maturity stages (specific sampling times in Table 1), five representative plants were sampled per plot, separated by organ, killed at 105°C for 30 minutes, dried at 80°C to constant weight, and weighed for dry matter determination. Before harvest, effective ear number, barren stalk rate, and double ear rate were recorded per plot, followed by actual yield measurement. Twenty ears were selected based on average ear weight for yield component analysis, examining ear length, ear diameter, bare tip length, row number per ear, grain number per row, single ear weight, grain weight per ear, and thousand-grain weight. Related parameters were calculated following methods by Yang et al. and Dai et al.:

Silking-stage dry matter accumulation rate (%) = (Dry matter accumulation at silking / Dry matter accumulation at harvest) × 100 (1)
Post-silking dry matter accumulation = Dry matter accumulation at harvest - Dry matter accumulation at silking (2)
Post-silking dry matter accumulation rate (%) = (Post-silking dry matter accumulation / Dry matter accumulation at harvest) × 100 (3)
Dry matter translocation amount = Dry matter accumulation in each organ at silking - Dry matter accumulation in corresponding organ at harvest (4)
Dry matter translocation efficiency (%) = (Dry matter translocation amount / Dry matter accumulation in vegetative organs at silking) × 100 (5)
Contribution rate of pre-silking accumulation to yield (%) = (Dry matter translocation amount / Grain yield) × 100 (6)
Contribution rate of post-silking accumulation to yield (%) = 100 - Contribution rate of pre-silking accumulation to yield (7)

1.4 Data Processing and Statistical Analysis

Microsoft Excel and SPSS 19.0 software were used for chart production and statistical analysis.

2 Results

2.1 Effects of Sowing Date on Maize Growth Progress

Sowing date significantly affected maize growth progression (Table 2). Delayed sowing shortened the duration of each growth stage and the entire growth period. A negative correlation existed between delayed sowing days (X) and total growth period duration (Y), described by the regression equation Y = 122.15 - 0.35X (R^2 = 0.9660), indicating that each day of sowing delay shortened the growth period by an average of 0.35 days. In this experiment, the A5 sowing date shortened the maize growth period by 21 days compared to A1. Regarding individual growth stages, delayed sowing shortened all phases to varying degrees, primarily during the vegetative growth period after emergence and the vegetative-reproductive overlapping period (range: 0–10 days), while the reproductive growth period remained relatively stable, with only the A5 treatment shortening by approximately 6 days.

2.2 Effects of Sowing Date on Dry Matter Accumulation

2.2.1 Individual Plant Dry Matter Accumulation Dynamics Maize dry matter accumulation constitutes the material basis for grain yield formation. As shown in Figures 2a and 2b, significant differences in dry matter accumulation per plant existed among sowing dates for both varieties, though the overall accumulation pattern followed a consistent logistic growth curve characterized by slow-fast-slow dynamics (Figures 2c and 2d). For 'Zhenghong 505' , dry matter accumulation before the large trumpet stage increased with delayed sowing, while after the large trumpet stage, the opposite trend occurred—accumulation decreased with delayed sowing, with the reduction magnitude increasing progressively. For 'Chengdan 30' , dry matter accumulation per plant after the large trumpet stage initially increased then decreased with delayed sowing, peaking at A4 for the large trumpet and silking stages, and at A2 for 15 days post-silking, with A5 showing the lowest values. Maturity-stage dry matter accumulation decreased with delayed sowing for both varieties. Accumulation rates increased gradually before silking, peaked at silking, then decreased post-silking. Both varieties showed similar trends in accumulation rate changes with delayed sowing, though 'Zhenghong 505' exhibited slightly higher rates than 'Chengdan 30' .

2.2.2 Dry Matter Distribution Maize dry matter distribution among organs showed different trends across growth stages (Table 3). At silking, distribution followed: stem > leaf > cob + bract; at maturity, grain had the highest proportion while leaf had the lowest, with grain accounting for 36.17%–58.49% of aboveground dry matter. Stem-sheath, leaf, and cob + bract distributions were greater at silking than at maturity, indicating that post-silking dry matter accumulation was primarily allocated to grain.

As shown in Table 3, stem-sheath dry matter distribution at maturity for both varieties initially decreased then increased with delayed sowing, while leaf and cob + bract proportions increased progressively. Grain distribution proportions at maturity varied between varieties with delayed sowing: 'Zhenghong 505' showed decreasing grain distribution rates with delays, with reductions of 9.3%, 9.8%, 30.4%, and 43.4% for A2–A5 compared to A1. 'Chengdan 30' showed an initial increase then decrease, with summer sowing (A4 and A5 average) lower than spring sowing (A1 and A2 average, representing the main spring sowing period in this region). Averaged across varieties, summer sowing grain distribution rate was 14.4% lower than normal spring sowing, representing a 26.6% reduction. Early sowing (A1) gave 'Zhenghong 505' a higher harvest index than 'Chengdan 30', while late sowing (A4, A5) showed the opposite, indicating 'Chengdan 30' had stronger dry matter translocation to grain under late sowing conditions. Across both varieties, summer sowing reduced grain distribution compared to normal spring sowing.

2.2.3 Dry Matter Accumulation and Contribution to Grain Before and After Silking Table 4 shows that except for A1 of 'Zhenghong 505', dry matter accumulation and accumulation rates before silking were greater than after silking for both varieties across all sowing dates, while contribution rates to grain were higher after silking. 'Zhenghong 505' had comparable pre-silking dry matter accumulation to 'Chengdan 30', but higher post-silking accumulation for A1–A3 and lower for A4 and A5. Pre-silking accumulation rates and contribution rates were slightly higher for 'Chengdan 30' than 'Zhenghong 505' for A1–A4, but reversed for A5.

Sowing date significantly affected both pre- and post-silking dry matter accumulation, with greater impact on post-silking accumulation. Coefficients of variation across five sowing dates were 4.4% and 8.2% for pre-silking, and 46.5% and 31.2% for post-silking accumulation for 'Zhenghong 505' and 'Chengdan 30', respectively. Pre-silking accumulation initially decreased then increased with delayed sowing, while post-silking accumulation (Y) decreased progressively with sowing delay (X), following regression equations $Y_{ZH505} = 207.4 - 2.5171X$ ($R^2 = 0.9497^{**}$) and $Y_{CD30} = 158.3 - 1.4399X$ ($R^2 = 0.8598^{*}$). Consequently, pre-silking accumulation rates and contribution rates increased with delayed sowing, while post-silking rates and contributions decreased. This indicates early sowing favors post-anthesis accumulation, whereas late sowing requires greater mobilization of pre-anthesis dry matter for grain filling, particularly for A4. 'Zhenghong 505' showed greater rates of reduction in post-silking accumulation, accumulation rate, and contribution to grain with delayed sowing than 'Chengdan 30', necessitating enhanced post-anthesis management to prevent premature senescence and increase post-anthesis accumulation under late sowing.

2.2.4 Effects on Maize Dry Matter Translocation Sowing date significantly affected the redistribution and utilization of vegetative organ materials, though the magnitude and trend differed between varieties with significant variety × sowing date interactions (Table 5). For 'Zhenghong 505' , stem and leaf translocation amount, translocation rate, and contribution to grain initially increased, then decreased, then increased again with delayed sowing, with A5 showing maximum values for most indices. For 'Chengdan 30' , stem and leaf translocation showed irregular changes, with total translocation amount and rate peaking at A2 and contribution rate peaking at A4. Since grain is supplied by post-silking assimilates and vegetative organ material transfer, analysis revealed that 'Chengdan 30' had higher translocation amount, rate, and contribution than 'Zhenghong 505' , indicating 'Chengdan 30' relied more on vegetative organ material transfer, while 'Zhenghong 505' depended more on post-silking assimilates.

2.3 Effects of Sowing Date on Yield and Yield Components

Sowing date significantly affected both varieties' yields, though the trends and magnitudes differed substantially (Table 6). 'Zhenghong 505' showed greater sowing date sensitivity, with yield coefficients of variation of 38.2% versus 20.9% for 'Chengdan 30' across five sowing dates. 'Zhenghong 505' yield (Y) decreased significantly with delayed sowing (X), following Y = 7,815.3 - 83.96X (R^2 = 0.9704**), with each day' s delay reducing yield by approximately 84 kg·ha^{-2}. 'Chengdan 30'yield initially increased then decreased, peaking at April 10 sowing (A2), with smaller reductions before May 10 (A4) but substantial decreases thereafter, indicating suitability for summer sowing but preferably around May 10.

Sowing date effects on yield components varied by variety. Both varieties showed decreasing effective ear numbers with delayed sowing. For 'Zhenghong 505' , ear length, rows per ear, grains per row, and thousand-grain weight decreased with delayed sowing, reducing yield accordingly. For 'Chengdan 30' , thousand-grain weight decreased with delayed sowing, while ear length and grains per row initially increased then decreased (except A3 grains per row), with rows per ear less affected, indicating sowing date primarily influenced 'Chengdan 30' yield through ear length and grain weight.

Discussion

Crop yield is directly related to population dry matter accumulation, with higher accumulation generally leading to higher grain yield. Studies have shown that delayed sowing reduces dry matter accumulation sequentially, and early spring sowing produces higher accumulation than late sowing. This study found that population dry matter accumulation decreased overall with delayed sowing. Early-sown maize had longer accumulation duration, accelerated late-season accumulation rates, and maintained them longer, achieving greater dry matter accumulation. Late-sown maize had shortened growth periods, accelerated development, and reduced accumulation. Variety differences existed in sowing date effects on pre- and post-silking accumulation: 'Zhenghong 505' post-silking accumulation was far more sensitive to sowing date than pre-silking accumulation, with early sowing favoring post-silking accumulation; 'Chengdan 30' showed smaller sowing date effects on both pre- and post-silking accumulation, though late sowing was still detrimental.

Grain filling materials originate from two sources: post-anthesis assimilates (including direct photosynthate transfer and temporary storage remobilization) and pre-anthesis assimilates temporarily stored in vegetative organs and transferred during grain filling. Studies indicate that maize grain yield primarily derives from late-season photosynthates, contributing 78%–84% to grain yield. This study found post-silking photosynthate contributions of 62.22%–86.09%, decreasing with delayed sowing, indicating that late sowing relies more on pre-anthesis stored dry matter, especially for 'Zhenghong 505' . Therefore, late sowing requires enhanced post-anthesis management to delay senescence and increase post-anthesis photosynthate accumulation and contribution to grain.

Timely sowing provides more suitable rainfall and temperature conditions during growth stages to optimize yield, which is closely tied to dry matter accumulation. This experiment demonstrated significant sowing date effects on both varieties, with 'Zhenghong 505' showing greater sensitivity. Its yield decreased with delayed sowing, peaking at the first sowing date (March 25), with severe summer sowing reductions (A4 and A5 average) of 49.99% compared to spring sowing (A1, A2, and A3 average), indicating poor summer sowing tolerance. 'Chengdan 30' yield peaked at the second sowing date (April 10), with early summer sowing (May 10) showing no significant difference from spring sowing, though later summer sowing caused significant reductions, indicating broader suitable sowing windows and stronger summer sowing tolerance.

These results demonstrate that sowing date significantly affects pre- and post-silking dry matter accumulation, contribution to grain, and yield in the hilly regions of central Sichuan, making appropriate sowing date selection essential for high yields. Spring maize yields are higher with relatively wide suitable sowing windows, though production systems must resolve conflicts between intercropping practices (common for spring maize) and mechanization, requiring varieties with faster grain dehydration and stronger stalk lodging resistance at maturity. Summer sowing offers more favorable growing conditions but faces more yield constraints with greater reduction magnitude than spring sowing. For areas requiring summer sowing (after wheat or rapeseed harvest for mechanization convenience), two issues require attention: variety selection should favor summer-sowing tolerant cultivars like 'Chengdan 30' , and sowing should occur promptly after the preceding crop harvest, preferably by mid-to-late May, to ensure adequate post-silking dry matter accumulation.

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