Effects of Single-Seed Precision Sowing on Growth, Physiological Characteristics, and Yield of Summer Direct-Seeded Peanut (Postprint)

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Abstract

To clarify the effects of single-seed precision planting on individual development, population structure, and yield of summer direct-seeded peanuts, 'Huayu 22' peanut variety was used as experimental material to investigate differences in plant development dynamics, leaf physiological characteristics, and yield components between single-seed precision planting (SS) and double-seed hole planting (DS) under the same density conditions in wheat stubble summer direct-seeded peanut systems. The results showed that: during the early growth stage, main stem height and lateral branch length of single-seed precision planted peanuts were higher than those of double-seed hole planted peanuts, whereas during the late growth stage they were lower, though differences were not significant. Single-seed precision planting exhibited higher main stem node number, main stem green leaf number, branch number, and leaf area index at all growth stages compared with double-seed hole planting, with particularly significant differences in branch number. For summer direct-seeded peanuts, single-seed precision planting showed higher leaf SOD, POD, CAT activities, chlorophyll content, and net photosynthetic rate at the full fruit stage and maturity stage compared with double-seed hole planting, while its MDA content was lower; at the maturity stage, all indices showed significant differences except for CAT activity. Single-seed precision planting increased full pod number per plant and pod weight per plant, with pod yield being significantly higher than that of double-seed hole planting. Pod yield of summer direct-seeded peanuts was extremely significantly positively correlated with pod weight per plant and leaf net photosynthetic rate, and significantly positively correlated with economic coefficient, main stem green leaf number, leaf area index, and chlorophyll content.

Full Text

Preamble

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Effect of Single-Seed Sowing on Growth, Physiology and Yield of Summer Peanut*

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Abstract

Summer-sowing peanut has developed rapidly under a peanut-wheat relay cropping system. However, studies on individual development and population structure of summer-sown peanut remain inadequate. To address this knowledge gap, a field experiment was conducted in 2014 and 2015 to investigate differences in plant development, leaf physiological characteristics, and yield components between single-seed (SS) and double-seed (DS) sowing of summer peanut. The previous wheat crop was harvested on June 15, and the peanut cultivar 'HY22' was sown on ridges with plastic film mulching on June 20. Ridge spacing was 50 cm with a furrow width of 30 cm. Plant spacing was 10 cm for SS and 20 cm for DS, with both treatments maintaining the same plant density of 2.5 × 10 plants · hm ^{2}.

The results showed that main stem height and lateral branch length in the SS treatment were greater than those in the DS treatment during early growth stages, but became lower at later stages. Throughout the entire growth period, the numbers of nodes and leaves on the main stem, leaf area index, and especially branch numbers in SS were all higher than those in DS. At the pod-filling and maturity stages, the activities of superoxide dismutase (SOD), peroxidase (POD), and catalase (CAT), chlorophyll content, and net photosynthetic rate increased, while malondialdehyde (MDA) content decreased in SS treatment. Although no significant differences in these leaf physiological indices were observed between SS and DS at the pod-filling stage, remarkable differences emerged at maturity. Pod yield in SS increased significantly compared with DS due to a substantial increase in full pod number per plant. Yield was positively correlated with both pod weight per plant and photosynthetic rate, and also showed

significant positive correlations with economic coefficient, leaf number per main stem, leaf area index, and chlorophyll content.

Keywords: Peanut; Summer sowing; Single-seed sowing; Plant character; Physiological characteristics; Yield

Introduction

Summer-sown peanut (*Arachis hypogaea*) primarily rotates with wheat (*Triticum aestivum*), enabling two crops per year. Compared with wheat-intercropped peanut, summer-sown peanut offers simpler operations, better suitability for large-scale mechanized production, and avoids competition for land with grain crops (mainly wheat). Consequently, its cultivation area has expanded rapidly, exceeding that of wheat-intercropped peanut. In major peanut-producing regions such as Henan, Jiangsu, and Shandong, summer-sown peanut now accounts for over 50% of total peanut acreage. Previous research on summer-sown peanut has focused primarily on stubble management, planting methods, sowing dates, water stress, and fertilizer effects on growth and yield, with limited investigation of individual development and population structure. Studies have demonstrated that rational planting patterns and densities can effectively improve population structure and reduce conflicts between population and individual plants, making them crucial for delaying peanut senescence and increasing summer peanut yield.

Research on the three major crops—wheat, maize, and rice—has established that ideal plant architecture and population structure are essential for achieving high yields. Zhao et al. proposed that for super-high-yield summer maize, "population structural acquisition" represents the primary breakthrough pathway, while further 挖掘 "individual functional acquisition" in high-density populations constitutes the main target for super-high-yield cultivation. Mu et al. found that high-yield wheat populations under the "stable leaves, controlled plants, increased spikes" approach exhibit clear advantages in source expansion, sink enhancement, and flow facilitation. High biological yield represents an important characteristic of rice (*Oryza sativa*) super-high yield, though relationships among dry matter accumulation at various growth stages, economic coefficient, and yield vary depending on ecological region, cultivar type, and cultivation system. Peanut yield components, individual development, and population structure follow trade-off patterns, and whether their balance is reasonable serves as an important indicator of high-yielding populations. Under high-yield conditions, traditional double-seed hill sowing creates prominent conflicts between population and individual plants, leading to uneven plant size, declining population quality, and reduced yield. Single-seed precision sowing can alleviate these conflicts and achieve high yield and efficiency. However, few studies have compared yield differences between single-seed and double-seed sowing for wheat-stubble summer-sown peanut. Therefore, investigating developmental dynamics under these two methods and clarifying their effects on individual development, population structure, and yield can provide theoretical basis and technical support for further improving summer peanut yield levels.

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1. Materials and Methods

1.1 Experimental Materials and Design

The experiment used peanut cultivar 'Huayu 22' (HY22) and was conducted in high-yield fields in Liangtang Township, Guanxian County, Shandong Province from 2014 to 2015. In 2014, the 0–20 cm soil layer contained 11.85 g · kg ^{1} organic matter, 49.3 mg · kg ^{1} alkali-hydrolyzable nitrogen, 62.6 mg · kg ^{1} available phosphorus, and 92.8 mg · kg ^{1} available potassium. In 2015, the same soil layer contained 16.45 g · kg ^{1} organic matter, 68.5 mg · kg ^{1} alkali-hydrolyzable nitrogen, 92.1 mg · kg ^{1} available phosphorus, and 110.7 mg · kg ^{1} available potassium.

The previous wheat crop was harvested on June 15, with all straw returned to the field after crushing. Compound fertilizer (15-15-15) was applied at 1,125 kg · hm ^{2}, followed by rotary tillage after soil moisture preparation. Peanut was sown on June 20 and harvested on October 5, with a total growth period of approximately 110 days. Ridge-film mulching cultivation was employed with 80 cm ridge spacing, 50 cm ridge surface width, two rows per ridge, and 30 cm row spacing.

The experiment comprised two treatments: single-seed precision sowing (SS) and double-seed hill sowing (DS). SS used 10 cm plant spacing with one seed per hole at a density of 250,000 plants · hm ^{2}, while DS used 20 cm hill spacing with two seeds per hole at a density of 125,000 hills · hm ^{2}. Both treatments had three replications in a randomized block design, totaling six plots of 100 m^2 each. Other field management practices followed conventional high-yield protocols.

1.2 Measurement Items and Methods

1.2.1 Plant Character Investigation At flowering stage (around July 15), pod-setting stage (around July 30), pod-filling stage (around August 25), and maturity stage (around September 30), ten representative plants were continuously sampled from each plot to investigate main stem height, lateral branch length, branch number, main stem node number, and main stem green leaf number. For leaf area index determination, ten leaves per plant (two lower, five middle, and three upper leaves) were stacked with aligned veins, and small discs were punched along the midrib. After calculating hole area and oven-drying to constant weight, leaf area index was calculated as: single plant leaf area (cm^2) = single plant leaf weight (g) × total disc area (cm^2) / total disc leaf weight (g).

1.2.2 Leaf Net Photosynthetic Rate, Chlorophyll Content, and Protective Enzyme Activities At pod-filling and maturity stages, the third leaf from the top of the main stem with consistent light exposure was selected from each plot. Net photosynthetic rate was measured using a LI-6400 portable photosynthesis system (LI-COR, USA) on sunny days between 9:00–11:00 AM. The same leaves were collected in ice boxes for laboratory analysis of chlorophyll content and protective enzyme activities. For chlorophyll measurement, fresh leaf samples were de-veined, cut into pieces, extracted with 95% ethanol for 48 hours, and analyzed using a UV-2450 spectrophotometer. For enzyme assays, 0.5 g of fresh leaf tissue was ground in pH 7.8 phosphate buffer in an ice bath, centrifuged at 4,000 r · min ^{1} for 20 minutes at 4°C, and the supernatant was used to determine superoxide dismutase (SOD), peroxidase (POD), catalase (CAT) activities, and malondialdehyde (MDA) content. SOD activity was defined as the amount inhibiting 50% NBT photochemical reduction; POD activity was expressed as A change per minute; CAT activity was expressed as H O change per minute.

1.2.3 Yield Component Investigation At harvest, 20 consecutive plants were sampled from each plot to investigate pod number per plant, full pod number, and shriveled pod number. Pods were air-dried to determine pod weight per plant. After removing border rows and ends, 8 m^2 from each plot was harvested, podded, cleaned, and air-dried to calculate pod yield. Above-ground plant parts (including fallen leaves) were air-weighed to calculate economic coefficient as: economic coefficient = pod weight / (pod weight + above-ground plant weight).

1.3 Data Processing

DPS 7.05 software was used for least significant difference (LSD) tests of means, SPSS 16.0 for correlation analysis, and Origin Pro 8.0 for figure preparation.

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2. Results

2.1 Differences in Plant Characters Between Single-Seed and Double-Seed Sowing at Various Growth Stages

2.1.1 Main Stem Height and Lateral Branch Length As shown in [Figure 1: see original paper], main stem height and lateral branch length of summer-sown peanut grew rapidly during early stages, with growth slowing after the pod-filling stage. Compared with double-seed sowing (DS), single-seed sowing (SS) showed greater main stem height and lateral branch length during early growth, though differences were not significant. At the pod-setting stage, SS main stem height was 1.44 cm greater (two-year average) and lateral branch length was 1.30 cm greater than DS, indicating that SS promoted early vigorous growth and facilitated earlier ridge closure. However, DS showed faster growth in main stem height and lateral branch length during later stages. In 2014, SS had significantly lower main stem height at maturity and lower lateral branch length at both pod-filling and maturity stages compared with DS, while differences were smaller in 2015. At maturity, DS main stem height averaged 2.22 cm greater and lateral branch length 2.94 cm greater than SS across both years.

2.1.2 Main Stem Node Number and Main Stem Green Leaf Number The dynamic changes in main stem node number were generally consistent with main stem height and lateral branch length development, showing rapid early growth followed by slower later growth ([Figure 2: see original paper]A, B). SS maintained greater main stem node numbers than DS throughout the growth period, with smaller differences in 2014 but significant differences in 2015. Combined with main stem height dynamics, this indicates that DS growth during later stages occurred through increased internode length rather than increased node number. Main stem green leaf number in both treatments followed a single-peak curve, increasing rapidly during early stages, reaching maximum at pod-filling stage, then decreasing due to senescence and shedding of lower leaves ([Figure 2: see original paper]C, D). SS showed greater main stem green leaf numbers than DS at all growth stages, with 1.01 more leaves at pod-filling stage in 2014, 1.33 more at pod-filling stage in 2015, and 1.58 more at maturity stage in 2015.

2.1.3 Branch Number and Leaf Area Index Branch numbers differed significantly between SS and DS at all growth stages, with SS showing significantly higher values ([Figure 3: see original paper]A, B). Differences were small before flowering but increased after pod-setting. In 2014, SS had 11.25 branches at maturity, 2 more than DS; in 2015, SS also had 11.25 branches, 1.5 more than DS. The greater branch number in SS could support more lower-position pegs, facilitating earlier pegging and increasing full pod numbers. Leaf area index (LAI) dynamics in SS and DS were consistent with main stem green leaf number trends, increasing rapidly during early stages, peaking at pod-filling stage, then declining with leaf fall ([Figure 3: see original paper]C, D). In 2014, SS LAI at pod-filling stage (4.57) was significantly higher than DS (4.15). In 2015, SS LAI was significantly higher than DS at both pod-filling (4.81 vs. 4.38) and maturity stages (3.27 vs. 2.85), indicating better plant greenness retention and prolonged maintenance of larger leaf area for photosynthate accumulation.

2.2 Differences in Leaf Physiological Characteristics Between Single-Seed and Double-Seed Sowing

As shown in , differences in leaf SOD, POD, and CAT activities, MDA content, chlorophyll content, and net photosynthetic rate between the two treatments were small at pod-filling stage but became significant at maturity. In 2014, SS showed significantly higher SOD activity and net photosynthetic rate than DS at both pod-filling and maturity stages, significantly lower MDA content at both stages, and significantly higher POD activity and chlorophyll content at maturity. In 2015, SS exhibited significantly higher POD activity at both stages and significantly lower MDA content, while SOD activity, chlorophyll content, and net photosynthetic rate were significantly higher at maturity. The greater differences in protective enzyme activities, chlorophyll content, and net photosynthetic rate at maturity compared with pod-filling stage indicate that leaf physiological characteristics diverged more substantially during later growth, with SS delaying plant senescence and maintaining higher photosynthetic capacity.

2.3 Differences in Yield and Yield Components Between Single-Seed and Double-Seed Sowing

shows that SS produced higher pod yield per unit area, plant number per unit area, pod weight per plant, full pod number per plant, and economic coefficient than DS. In 2014, SS pod yield was 6.89% higher and pod weight per plant was 6.06% higher than DS. In 2015, SS pod yield was 8.74% higher and pod weight per plant was 5.86% higher than DS, with all differences reaching significance. SS also had higher plant numbers per unit area in both years, indicating better plant establishment. While total pod number per plant did not differ significantly between treatments, SS showed significantly higher full pod numbers (17.71% higher in 2014 and 45.16% higher in 2015), whereas DS had more shriveled and immature pods. This demonstrates that full pod number rather than total pod number per plant is the key factor affecting summer peanut pod yield. Economic coefficient was 4.55% higher in SS than DS in 2014 and 8.51% higher in 2015.

2.4 Correlation Analysis Between Yield Components and Plant Characters and Photosynthetic Capacity

Correlation analysis between pod yield, pod weight per plant, total pod number per plant, economic coefficient, main stem height, branch number, main stem green leaf number, leaf area index, chlorophyll content, and net photosynthetic rate at harvest revealed several significant relationships (). Pod yield per unit area was extremely significantly positively correlated with pod weight per plant and leaf net photosynthetic rate, and significantly positively correlated with economic coefficient, main stem green leaf number, leaf area index, and chlorophyll content. Pod weight per plant was significantly positively correlated with economic coefficient, main stem green leaf number, leaf area index, and net photosynthetic rate. Economic coefficient was significantly positively correlated with net photosynthetic rate and extremely significantly positively correlated with chlorophyll content. Leaf area index was extremely significantly positively correlated with main stem green leaf number. Net photosynthetic rate was significantly positively correlated with leaf area index and extremely significantly positively correlated with chlorophyll content.

3. Discussion and Conclusion

Due to its short growth period and low individual plant productivity, summer-sown peanut often relies on increased density for high yield. The key to high yield in dense populations lies in constructing a rational population structure. Studies have shown that as peanut density increases, main stem height and lateral branch length gradually decrease while branch number declines, leading to reduced pod number per plant, hundred-pod weight, double-kernel rate, and full pod rate, with yield following a parabolic trend. Single-seed sowing creates uniform individual plant distribution in the field, reducing or eliminating competition for light, water, and nutrients among individuals and promoting vegetative growth and dry matter accumulation for robust seedling establishment. Our results demonstrate that summer peanut under SS exhibited faster vegetative growth during early stages than DS, with greater main stem height, lateral branch length, branch number, main stem node number, main stem green leaf number, and leaf area index. These findings align with our previous research on spring peanut single-seed sowing, indicating that SS favors robust seedling development and rational population structure construction. In this study, SS showed lower main stem height and lateral branch length but significantly higher main stem node number and branch number at maturity, suggesting that DS exhibited faster internode elongation and a tendency for excessive late-stage growth.

Previous research has established that leaf area development is most critical for rational population structure construction, with leaf area index magnitude and duration of peak LAI directly affecting dry matter production capacity. The primary challenge for high peanut yield is improving light use efficiency, which first requires expanding effective leaf area. Extended peak LAI duration is a distinctive feature of high-yielding peanut. Zheng et al. reported that for high-yielding peanut populations in Shandong, spring peanut LAI peaked at the pod-filling stage with values above 5. Our results show that summer-sown peanut LAI also peaked at pod-filling stage, with SS reaching a maximum of 4.81, significantly higher than DS' s maximum of 4.38. DS suffered heavier leaf fall during later stages, resulting in lower LAI than SS. Feng et al. demonstrated that single-seed sowing delays plant senescence by affecting active oxygen metabolism, improving dry matter accumulation dynamics in both canopy and pods, and maintaining slower root senescence rates to ensure nutrient supply and assimilation. Our findings are consistent: SS showed higher leaf SOD, POD, and CAT activities and significantly lower MDA content than DS at pod-filling and maturity stages, indicating that SS improves plant senescence resistance. Studies have also reported higher photosynthetic pigment content and photosynthetic rates under single-seed sowing. In our experiment, chlorophyll content and net photosynthetic rate differences between SS and DS were small at pod-filling stage but became significant at maturity due to higher protective enzyme activities and slower leaf senescence in SS.

Shen et al. investigated reduced-seed increased-hole planting methods for summer peanut based on the AnM (controlled pegging) technique, achieving 23% fewer seeds and 54.1% more holes per hectare, resulting in 52.8% more pods per plant and approximately 18% yield increase. Their rationale was that single-seed sowing facilitates robust seedling development, leading to significantly higher pod number and yield per plant. However, these results were based on significantly lower planting density for single-seed sowing. Our study compared yield components under the same density conditions, better controlling experimental variables and eliminating environmental and resource utilization effects. The results showed that DS had more immature pods per plant, while total pod number per plant did not differ significantly between treatments. The key factor determining per-plant yield difference was full pod number. The higher pod yield in summer peanut under SS resulted from increased full pod number and reduced immature pod number, thereby increasing pod weight per plant. Previous research on spring peanut single-seed sowing indicated that pod weight per plant was significantly positively correlated with branch number and leaf area index but negatively correlated with main stem height and lateral branch length. Under our experimental conditions, summer peanut pod weight per plant was positively correlated with total pod number per plant, main stem height, and branch number. The factors significantly affecting pod weight per plant were economic coefficient, leaf area index, chlorophyll content, and net photosynthetic rate. This suggests that higher economic coefficient and photosynthetic capacity are crucial for improving summer peanut pod yield.

In summary, single-seed precision sowing of summer-sown peanut produces superior individual development and population structure, with significantly higher branch number, main stem node number, and leaf area index than double-seed sowing, facilitating earlier vegetative body construction and faster dry matter accumulation. During later growth stages, SS maintains significantly higher leaf protective enzyme activities, chlorophyll content, and net photosynthetic rate than DS, resulting in slower plant senescence, higher photosynthetic rates, and extended photosynthetic duration. The significantly higher pod yield under SS is attributed to significantly increased full pod number per plant, which enhances pod weight per plant. Higher plant establishment rate and economic coefficient under SS also contribute to yield increase.

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