ChinaRxiv 中X

AI translation · View original & related papers at
chinarxiv.org/items/chinaxiv-201711.01723

Effects of Planting Density and Sowing Method on Growth and Development, Yield, and Quality of Peanut in Saline-Alkali Soil Postprint

Authors: Zhang Zhimeng, Dai Liangxiang, Ci Dunwei, Yang Jishun, Ding Hong, Qin Feifei, Mu Guojun

Date: 2017-11-07T00:00:00+00:00

Abstract

Using the salt-tolerant variety 'Huayu 25' as experimental material, a field plot experiment was conducted with five planting densities under single-seed precision sowing: 18.0$×10^{4}$ holes · hm^{-2} (M1), 19.6$×10^{4}$ holes · hm^{-2} (M2), 21.4$×10^{4}$ holes · hm^{-2} (M3), 23.5$×10^{4}$ holes · hm^{-2} (M4), and 26.0$×10^{4}$ holes · hm^{-2} (M5), and three planting densities under double-seed hole sowing: 11.6$×10^{4}$ holes · hm^{-2} (M6), 13.0$×10^{4}$ holes · hm^{-2} (M7), and 14.7$×10^{4}$ holes · hm^{-2} (M8), to investigate the effects of planting density and sowing method on main agronomic traits, yield, and quality of peanut in saline-alkali soil, and to determine the optimal planting density and sowing method for peanut cultivation in such conditions. The results showed that: 1) Soil saline-alkali stress substantially inhibited peanut plant growth and development. Compared with peanuts grown in non-saline-alkali soil, main stem height and lateral branch length of peanuts in saline-alkali soil were significantly reduced, averaging only 25.6 cm and 29.0 cm, respectively. 2) Under single-seed precision sowing, main stem height and lateral branch length decreased significantly with increasing planting density within the range of 19.6–26.0$×10^{4}$ holes · hm^{-2} before the pod-filling stage. Before pod swelling and after the pod-filling stage, the numbers of primary and secondary branches under single-seed precision sowing were significantly higher than those under double-seed hole sowing, and within the M2–M4 density range, basal stem length decreased with increasing density, though differences were not significant. Changes in basal stem length and stem diameter occurred primarily before the pod-setting stage, with stem elongation proceeding faster than cross-sectional area expansion, and both basal stem length and stem diameter stabilized during later growth stages. 3) The rapid accumulation period of photosynthates in leaves and stems+petioles of peanuts in saline-alkali soil occurred mainly during the flowering and pegging stage and pod swelling stage. The maximum growth rate

(Vm) of leaves was only half that of stems+petioles, with rapid leaf growth occurring approximately 5 days earlier than that of stems+petioles, and the time to reach maximum growth rate (Tm) for leaves and stems+petioles under double-seed hole sowing was significantly delayed compared with single-seed precision sowing. Under single-seed precision sowing, Vm of aboveground vegetative organs of peanuts in saline-alkali soil exhibited a “parabolic” trend with increasing planting density, with the maximum Vm for leaves and stems+petioles under the M4 treatment being 0.492 5 g · plant^{-1} and 0.878 3 g · plant^{-1}, respectively. 4) Planting density significantly affected photosynthate accumulation at various growth stages of peanuts in saline-alkali soil, but had relatively minor effects on distribution ratios among organs at each stage. The photosynthate distribution pattern in peanuts in saline-alkali soil was essentially consistent with that in non-saline-alkali soil, with photosynthates being allocated mainly to vegetative organs such as stems and leaves during early growth stages, and more than one-third being allocated to pods by the pod-filling stage. 5) Planting density significantly affected pod yield under single-seed precision sowing, but had little influence on kernel soluble sugar, protein, fat, and oleic acid/linoleic acid ratio (O/L) across treatments. In moderate to slight saline-alkali soil areas, the suitable planting density for single-seed precision sowing is 19.0–23.5$×10^{4}$ plants · hm^{-2}.

Full Text

Effects of Planting Density and Sowing Method on Growth, Development, Yield and Quality of Peanut in Saline-Alkali Land

ZHANG Zhimeng[1], **DAI Liangxiang**[1], **CI Dunwei**[1], **YANG Jishun**[1], **DING Hong**[1], **QIN Feifei**[1], **MU Guojun**[2]

(1. Peanut Research Institute of Shandong Province, Qingdao 266100, China; 2. Hebei Agricultural University, Baoding 071001, China)

Abstract: Using the salt-tolerant peanut cultivar ‘Huayu 25’ as experimental material, a field plot experiment was conducted to investigate the effects of planting density and sowing method on key agronomic traits, yield, and quality of peanut in saline soils, and to determine optimal cultivation practices. Five planting densities were established under single-seed precision sowing: 180,000 holes · hm^{-2} (M1), 196,000 holes · hm^{-2} (M2), 214,000 holes · hm^{-2} (M3), 235,000 holes · hm^{-2} (M4), and 260,000 holes · hm^{-2} (M5). Three planting densities were established under double-seed hole sowing: 116,000 holes · hm^{-2} (M6), 130,000 holes · hm^{-2} (M7), and 147,000 holes · hm^{-2} (M8). The results demonstrated that soil salinity stress substantially inhibited peanut growth and development. Compared with peanuts grown in non-saline soils, plant height and branch length in saline soils were significantly reduced to approximately 25.6 cm and 29.0 cm, respectively. Under single-seed precision sowing within the density range of 196,000–260,000 holes · hm^{-2}, main stem height and branch length decreased significantly with increasing density before the pod-filling stage. Before pod swelling and after the pod-filling stage, the numbers of primary and secondary branches under single-seed sowing were significantly higher than those under double-seed sowing, and within the M2–M4 density range, basal stem length decreased with increasing density, though differences were not statistically significant. Changes in basal stem length and diameter occurred primarily before the pod-setting stage, with elongation rate exceeding the rate of cross-sectional area increase; both parameters stabilized during later growth stages. The rapid accumulation of photosynthetic products in leaves and stems+petioles of peanuts in saline soils occurred mainly during the flowering-pegging and pod-swelling stages. The maximum growth rate (Vm) of leaves was only half that of stems+petioles, with leaf rapid growth occurring approximately 5 days earlier than that of stems+petioles. Under double-seed sowing, the timing of maximum growth rate (Tm) for both leaves and stems+petioles lagged significantly behind that under single-seed precision sowing. Under single-seed precision sowing, Vm of aboveground vegetative organs in saline soils exhibited a parabolic response to planting density, with the M4 treatment producing the maximum Vm values of 0.4925 g $\cdot$ plant^{-1} for leaves and 0.8783 g $\cdot$ plant^{-1} for stems+petioles. Planting density significantly affected photosynthetic product accumulation at various growth stages but had minimal impact on distribution ratios among organs. The pattern of photosynthetic product allocation in saline soils was generally consistent with that in non-saline soils: products were allocated primarily to stems and leaves during early growth stages, with over one-third allocated to pods by the pod-filling stage. Planting density significantly affected pod yield under single-seed precision sowing but had little influence on kernel soluble sugar, protein, fat content, or the oleic/linoleic acid (O/L) ratio. For single-seed precision sowing in moderately saline soils, the optimal planting density was 190,000–235,000 plants $\cdot$ hm^{-2}.

Keywords: Saline-alkali soil; Peanut; Single-seed precision sowing; Planting density; Agronomic trait; Yield; Quality

---

Introduction

Soil salinization has become a global environmental and resource challenge. According to statistics, the worldwide area of saline soils has reached 9.55\$×10^{8}\$ hm^2, with soil salinization in China becoming increasingly severe. UNESCO and FAO estimate that China’ s saline-alkali land area is approximately 9.91\$×10^{7}\$ hm^2, most of which remains undeveloped. The Yellow River Delta region contains 4.43\$×10^{5}\$ hm^2 of saline-alkali land, accounting for about 70% of the total land area and representing the primary constraint on sustainable agricultural development in the region. Currently, cotton (Gossypium sp.), a relatively salt-tolerant crop, is the main crop grown in moderately saline soils of this region. However, due to continuous cropping, declining soil productivity, severe pest and disease pressure, and high labor requirements with decreasing economic returns, there is an urgent need to identify alternative crops with comparable growth periods and benefits and good salt tolerance.

Peanut (Arachis hypogaea) is a moderately salt-tolerant crop and an important oil and economic crop with drought resistance and tolerance to poor soil conditions, making it a potential alternative to cotton in saline soil regions. Developing peanut production in saline-alkali land is significant for improving agricultural planting structures, increasing farmer income, and ensuring food and oil security.

Optimizing planting patterns and density to increase peanut yield represents an important approach for high-yield cultivation. However, due to variations in climate, resource endowments, cultivation practices, and agricultural technology awareness, peanut cultivation patterns are diverse. Previous studies have shown that planting density affects peanut canopy structure and function more than other cultivation measures, and rational close planting is a trend for future super-high-yield cultivation. However, increasing planting density raises light interception within the canopy, causing mutual shading, field closure, poor light penetration, premature senescence of lower leaves, and reduced canopy photosynthetic capacity. Numerous studies have reported on high-yield and efficient peanut cultivation techniques, particularly regarding optimal configurations between peanut-wheat (Triticum aestivum) intercropping timing, fertilizer types and amounts, yield levels, and variety characteristics with planting density. These studies have clarified differences in ventilation, light penetration, canopy characteristics, and economic coefficients under different planting methods and densities, establishing appropriate density ranges for different yield levels and varieties in specific regions.

However, research on peanut adaptation to saline soils and high-yield cultivation techniques and theories for saline-alkali regions is still in its infancy, particularly regarding the effects of planting density on aboveground agronomic traits and photosynthetic product accumulation and distribution. This study was conducted in the coastal moderately saline-alkali soil region of Dongying City, Shandong Province, using screened salt-tolerant peanut varieties to investigate high-yield and efficient cultivation techniques. The objective was to provide theoretical and technical support for addressing declining cotton cultivation benefits and area, rationally adjusting agricultural planting structures, optimizing socio-ecological benefits, expanding peanut cultivation area, reducing conflicts between grain and oil crops for land, maintaining balanced development of cotton, grain, and oil production, and ensuring national food and oil security.

1.1 Experimental Materials

The experiment was conducted from April to October 2014 in Maotuo Village, Tingluo Town, Lijin County, Dongying City, Shandong Province. The test soil was sandy loam with salt content of 2.5 $g \cdot kg^{-1}$ in the 0–20 cm layer and 1.9 $g \cdot kg^{-1}$ in the 20–40 cm layer before peanut sowing. Basic soil physicochemical properties were: organic matter 6.2 $g \cdot kg^{-1}$, total nitrogen 0.81 $g \cdot kg^{-1}$, total phosphorus 0.81 $g \cdot kg^{-1}$, total potassium 10.53 $g \cdot kg^{-1}$, hydrolyzable nitrogen 49.3 $mg \cdot kg^{-1}$, available phosphorus (P_2O_5) 29.6 $mg \cdot kg^{-1}$, available potassium (K_2O) 93.6 $mg \cdot kg^{-1}$, and soil pH 7.6. The peanut variety used was the salt-tolerant cultivar 'Huayu 25'.

1.2 Experimental Design

A randomized block design was employed with two sowing methods: double-seed hole sowing and single-seed precision sowing. Single-seed precision sowing included five planting densities: hole spacing of 13 cm (180,000 holes $\cdot hm^{-2}$, M1), 12 cm (196,000 holes $\cdot hm^{-2}$, M2), 11 cm (214,000 holes $\cdot hm^{-2}$, M3), 10 cm (235,000 holes $\cdot hm^{-2}$, M4), and 9 cm (260,000 holes $\cdot hm^{-2}$, M5). Double-seed hole sowing included three densities: hole spacing of 20 cm (116,000 holes $\cdot hm^{-2}$, M6), 18 cm (130,000 holes $\cdot hm^{-2}$, M7), and 16 cm (147,000 holes $\cdot hm^{-2}$, M8). All treatments used flat planting with plastic film mulching in wide-narrow row patterns, with wide row spacing of 55 cm, narrow row spacing of 30 cm, row length of 10 m, and plot area of 42.5 m^2, with three replications. Sowing occurred on May 8 and harvest on September 22. The experimental field was irrigated with Yellow River water 13 days before sowing (April 25) to leach salts.

1.3 Plant Sampling and Preparation

Plant samples were collected at 19, 32, 56, 76, 85, and 106 days after emergence. At each sampling, 12 plants were randomly selected from each plot, brought to the laboratory, washed, and dried with filter paper. Plants were separated into leaves, stems (stem + petiole + pegs), and pods for measurement of main stem height, branch length, basal stem diameter, and basal internode length. At harvest, a uniform 4.5 m^2 area was harvested from each plot to calculate yield. Basal stem referred to the first internode (distance from cotyledon node to first true leaf), characterized by basal stem length and diameter measured with vernier calipers. Branch numbers were counted when branch length exceeded 3 cm.

1.4 Measurement Items and Methods

Plant dry weight was determined by oven-drying samples at 105°C for 30 minutes, then at 70°C to constant weight. Leaf area index (LAI) was measured using the punch-weight method. Kernel quality traits were determined as follows: soluble sugar content by anthrone colorimetry, soluble protein content by Coomassie brilliant blue method, fat content by Soxhlet extraction, and fatty acid composition by MPA Fourier transform near-infrared spectroscopy (Bruker Optics, Germany).

1.5 Data Analysis

Data were organized and graphed using Microsoft Excel 2003. Statistical analysis was performed using DPS v7.05 software, with significance testing by LSD method and data fitting.

2.1.1 Effects on Main Stem Height and Branch Length

Main stem height and branch length are important indicators of peanut plant traits and internal physiological-biochemical status, as well as easily observable morphological parameters. As shown in [Figure 1: see original paper], under different planting densities and sowing methods, both parameters exhibited slow growth from seedling to early flowering (19–32 days after emergence), rapid growth to maximum values from flowering-pegging to podding stage (56–85 days after emergence), and minimal changes in main stem height thereafter, while branch length continued to elongate noticeably until maturity.

Planting density and sowing method significantly affected main stem height and branch length after flowering (56 days after emergence). During rapid growth (56–85 days after emergence), main stem height and branch length under double-seed sowing were significantly lower than under single-seed precision sowing. Under single-seed precision sowing, main stem height and branch length increased significantly with density in the M1–M4 range at 56 days after emergence; however, from 76–85 days after emergence, they generally decreased or significantly decreased with increasing density from M2 to M5. Under double-seed sowing, main stem height and branch length at 56 days after emergence showed the trend M8 > M7 > M6, while at 76–85 days after emergence, all three treatments were significantly lower than single-seed sowing, with no significant differences among themselves. At maturity (106 days after emergence), planting density had no significant effect on main stem height and branch length, but single-seed precision sowing was significantly higher than double-seed sowing. At equivalent plant populations per unit area, comparisons of M4 vs. M6 and M5 vs. M7 showed significantly higher values for M4 and M5, respectively, at 56–85 days after emergence. In non-saline soils, peanut main stem height typically ranges 35–50 cm; in this study, maximum values were only 25.6 cm for main stem height and 29.0 cm for branch length, indicating that soil salinity stress substantially inhibited vegetative growth.

2.1.2 Effects on Branch Numbers

As shown in [Figure 2: see original paper], primary and secondary branch numbers across all treatments increased initially then decreased with plant development, though the timing of peak values differed with planting density and sowing method. Primary branches peaked at 76 days after emergence, while secondary branches peaked at 85 days, with the secondary branch peak under single-seed precision sowing lagging by approximately 10 days. At the 85-day peak, primary branch numbers under single-seed sowing were significantly higher than under double-seed sowing, reaching 6.0–6.3 and 5.0–5.7 branches per plant, respectively.

Before 56 days after emergence (pre-pod swelling), planting density and sowing method significantly affected branch numbers: under single-seed sowing, M1 and M5 were significantly lower than M2, M3, and M4 at seedling stage, while under double-seed sowing, no significant differences existed among treatments. At 32 days after emergence, M1 remained significantly lower than M2, M3, and M4, while all double-seed treatments were significantly lower than single-seed treatments. Between 56–76 days after emergence, primary branch numbers were unaffected by density or sowing method; after 85 days, both primary and secondary branch numbers under single-seed sowing were significantly higher than under double-seed sowing. The effects of planting density and method on total branch numbers were most evident before 56 days and after 85 days after emergence, corresponding to differentiation between vegetative and reproductive growth before flowering-pegging and during pod-filling. Between 56–76 days after emergence, total branch numbers were similar across densities and methods, with primary and secondary branches numbering 5.0–5.8 and 3.3–5.0, respectively, for total branch numbers of 9.2–10.3. Under single-seed sowing, maximum total branch numbers occurred at 85 days, with M2 reaching 12.3 branches, while under double-seed sowing, the maximum occurred approximately 10 days earlier at 76 days, with M2 reaching 10.0 branches. The influence of planting method and density on branch numbers related to periods of redundant growth, particularly the dynamics of secondary branches throughout the growing season.

2.1.3 Effects on Basal Stem Characteristics

Basal stem characteristics (length, diameter, and length/diameter ratio) indicate plant vigor, with robust plants having well-developed conductive and storage tissues that efficiently transport and store nutrients, providing a foundation for high yield. [Figure 3A: see original paper] shows that basal stem length was greatest at 19 days after emergence across all treatments, then stabilized with development, decreasing rapidly between 19–32 days after emergence, with a greater reduction under double-seed sowing. After 56 days until maturity, basal stem length stabilized at 0.65–1.22 cm; the initial maximum likely reflected the embryonic axis length during seedling emergence. Under single-seed precision sowing, basal stem length generally decreased with increasing density in the M2–M4 range at 19 days, though differences were not significant. From this stage to maturity, M2 basal stem length was significantly higher than M1, while under double-seed sowing, basal stem length varied with density.

Basal stem diameter changed little throughout the season, with the most rapid increase in cross-sectional area occurring between 32–56 days after emergence, tending to be greater under single-seed than double-seed sowing. The M2 treatment produced the thickest basal stems. The basal stem length/diameter ratio decreased gradually throughout the growing season, from 5.0–7.2 at seedling stage to 1.71–2.96 at 76 days after emergence, stabilizing at 1.13–2.63 by maturity. From 56 days after emergence to maturity, M4, M3, and M2 had lower length/diameter ratios ([FIGURE:3B,C]).

2.2 Effects of Planting Density and Sowing Method on Photosynthetic Product Accumulation and Distribution

2.2.1 Effects on Photosynthetic Product Accumulation As shown in , dry matter accumulation in peanut leaves and stems+petioles under different planting densities was well-fitted by logistic curves, with correlation coefficients (R^2) reaching significant or highly significant levels, indicating that logistic growth curves effectively described vegetative growth and photosynthetic product accumulation in saline soils. The R^2 for leaf fitting was highest under M5 density at 0.9944 (highly significant).

Under single-seed precision sowing, maximum growth rate (Vm) of leaves and stems+petioles in saline soils showed parabolic responses to planting density, with M4 producing the highest Vm values of 0.4925 $g \cdot plant^{-1}$ for leaves and 0.8783 $g \cdot plant^{-1}$ for stems+petioles, while M1 produced the lowest. Under double-seed sowing, Vm responses differed: for leaves, $M8 > M6 > M7$; for stems+petioles, $M7 > M8 > M6$. At equivalent plant populations, Vm values were higher for M5 than M7 and for M4 than M6. Across all methods and densities, leaf Vm was approximately half that of stems+petioles.

The timing of maximum growth rate (Tm) was significantly affected by planting density. Under single-seed sowing, Tm occurred earliest for M4 regardless of organ, at 42.7 days after emergence for leaves and 38.1 days for stems+petioles, with leaf rapid growth occurring approximately 5 days earlier than stems+petioles. Under double-seed sowing, Tm was earliest for M7 and latest for M8. At equivalent plant populations, Tm under double-seed sowing lagged significantly behind single-seed sowing: leaf Tm for M7 lagged M5 by 3.5 days, M6 lagged M4 by 6.5 days; stem+petiole Tm for M6 lagged M4 by 10.6 days. The rapid accumulation period for photosynthetic products in leaves and stems+petioles occurred primarily during the flowering-pegging and pod-swelling stages.

2.2.2 Effects on Photosynthetic Product Distribution As shown in , planting density and sowing method significantly affected photosynthetic product accumulation in various organs at different growth stages but had minimal impact on distribution ratios. During the seedling stage, distribution ratios to stems+petioles showed no significant differences among treatments. During flowering-pegging and podding stages, distribution ratios to stems+petioles and leaves also showed no significant differences. At pod-filling stage, distribution ratios to roots, leaves, and pods showed no significant differences among treatments.

The pattern of photosynthetic product allocation was consistent across densities: at flowering-pegging stage, leaf > stem+petiole > root; at podding stage, stem+petiole > leaf > root > pod; at pod-filling stage, pod > leaf > stem > root. This indicates rapid growth of photosynthetic organs (leaves and stems) in early stages, establishing a foundation for later development; in mid-stage, higher allocation to stems+petioles facilitated product transport; in late stage, allocation to vegetative organs decreased while pod allocation increased to maximum values. At pod-filling stage, pod distribution ratios under single-seed sowing ranked M5 > M4 > M3 > M2 > M1, with M5 reaching 38.10% and M1 35.63%. Under double-seed sowing, the ranking was M6 > M7 > M8. At equivalent densities, pod distribution ratios were higher for M5 than M7 and for M4 than M6, indicating that single-seed sowing was superior to double-seed sowing. The M4 and M5 densities facilitated photosynthetic product transport to pods, while higher densities reduced pod allocation.

2.3 Effects of Planting Density and Sowing Method on Leaf Area Index (LAI) Dynamics

As shown in [Figure 4: see original paper], planting density and sowing method did not affect LAI at 19 and 56 days after emergence, with no significant differences among treatments. Under single-seed precision sowing, LAI for M2 was higher than M1 throughout the growing season, with significant differences only at 106 days after emergence. Under M3, M4, and M5, LAI decreased with increasing density, with M5 being significantly lower than M3 and M4 at 32 and 85 days after emergence, but no significant differences at other stages. Under double-seed sowing, LAI during early growth (emergence to 76 days) decreased with increasing density, but increased significantly with density from 85 days (pod-filling) to maturity.

Under single-seed sowing, M2 showed the greatest increase (23.48%), while under double-seed sowing, M6 showed the greatest decrease (51.67%). At peak LAI, the maximum value under single-seed sowing was 6.59 for M2, while the minimum was 5.13 for M5. Under double-seed sowing, LAI values ranked M7 (5.64) > M6 > M8 (4.64). At equivalent plant populations, LAI was lower for M5 than M7 and higher for M4 than M6, with significant differences only at 85 and 76 days after emergence, indicating slight superiority of single-seed sowing at appropriate densities.

Throughout the growing season, LAI remained above 3.0 for over 50 days in M4, M3, M2, M1, and M7, and above 4.0 for over 29 days, demonstrating that M2, M3, and M4 densities facilitated efficient light utilization.

2.4 Effects of Planting Density and Sowing Method on Peanut Yield and Yield Components

As shown in , pod yield under both sowing methods increased initially then decreased with increasing planting density. Under single-seed precision sowing, significant differences existed among treatments, with yield ranking M4 > M3

> M5 > M2 > M1, and M4 achieving the highest yield of 5,403.26 kg $\cdot$ hm^{-2}. Under double-seed sowing, significant differences existed between M7 and M8, with yield ranking M7 > M6 > M8. Single-seed sowing produced higher yields than double-seed sowing.

The trends for 100-pod weight, 100-kernel weight, and kernel rate were similar to yield, increasing initially then decreasing with density, with M4 producing the highest values. Fruit number per kg showed the opposite trend, decreasing initially then increasing. Under single-seed sowing, M1 had significantly higher fruit number (778.19 fruits $\cdot$ kg^{-1}) than other densities, while no significant differences existed among M5, M4, M3, and M2 for 100-pod weight and fruit number. Kernel rates for M5, M4, and M3 were significantly higher than for M2 and M1, with M4 reaching 73.09% and M1 65.68%. Under double-seed sowing, 100-pod weight, 100-kernel weight, and kernel rate were significantly higher for M6 and M7 than M8, with M7 producing the maximum values of 147.43 g, 71.43 g, and 67.76%, respectively. M8 had significantly higher fruit number (884.50 fruits $\cdot$ kg^{-1}) than M6 and M7. These results demonstrate that yield increases under appropriate planting density and sowing method resulted from increased 100-pod weight, 100-kernel weight, and kernel rate, along with reduced fruit number per kg.

2.5 Effects of Planting Density and Sowing Method on Main Quality Traits of Peanut in Saline Soils

As shown in , no significant differences existed among treatments for kernel soluble sugar, protein, fat content, or oleic/linoleic acid (O/L) ratio under different planting densities and sowing methods, indicating that planting density had minimal impact on kernel quality.

3.1 Changes in Agronomic Traits of Peanut in Saline Soils

For both semi-spreading and erect peanut varieties, optimal main stem height is generally 40–50 cm; heights exceeding this indicate excessive vegetative growth, while heights below 30 cm indicate poor vegetative growth requiring promotion-oriented cultivation measures. Under our experimental conditions in moderately saline soils, main stem height and branch length ranged 19.3–25.6 cm and 24.5–26.8 cm, respectively, substantially lower than in non-saline conditions, confirming that soil salinity stress inhibited vegetative growth and reduced redundant growth. Developing appropriate cultivation measures to promote coordinated vegetative and reproductive growth and maintain high stable yields in saline soils requires further investigation.

Previous studies on planting density effects have reported inconsistent results: some found no significant changes in main stem height and branch length with increasing density, while others reported increases. Under single-seed precision sowing, main stem height and branch length increased with density in low-density ranges (135,000–195,000 plants $\cdot$ hm^{-2}), while branch numbers, effective branch numbers, pods per plant, double-kernel fruit rate, and filled pod rate decreased with increasing density. In contrast, our study found that in saline soils, main stem height, branch length, primary and secondary branch numbers, and Vm of stem+leaf dry matter accumulation decreased with increasing density in the 180,000-235,000 plants · hm^{-2} range. Basal stem elongation rate exceeded cross-sectional area increase rate, with both parameters stabilizing in later growth stages. Leaf Vm was approximately half of stem+petiole Vm, with leaf rapid growth occurring about 5 days earlier.

The rapid accumulation period for photosynthetic products in leaves and stems+petioles occurred mainly during flowering-pegging and pod-swelling stages. Across all densities and methods, LAI, pod distribution ratio, 100-pod weight, 100-kernel weight, kernel rate, and yield increased with density in the 180,000-235,000 plants · hm^{-2} range, while fruit number per kg decreased. Planting density had minimal impact on kernel soluble sugar, protein, fat, and O/L ratio, consistent with findings in other crops. For single-seed precision sowing in moderately saline soils, the optimal planting density was 190,000-235,000 plants · hm^{-2}.

Recent improvements in crop source-sink characteristics and cultivation levels have made source-sink imbalance a major constraint on high stable yields. As a dicotyledonous crop with underground product organs, peanut readily exhibits excessive aboveground vegetative growth, slow pod swelling, reduced photosynthetic product allocation to pods, and increased empty/immature pods (source-sink imbalance). Research has focused on stem vascular bundles and basal stem dimensions. Stem diameter correlates significantly with per-plant yield and serves as an important selection index for high-yield breeding. Our results showed that planting density did not affect the decreasing trend of basal stem length with development; under single-seed sowing, basal stem length decreased with increasing density within a certain range. Basal stem length decreased rapidly before flowering, stabilizing at 0.65-1.22 cm from podding to maturity. Basal stem diameter increased most rapidly from initial flowering to podding, tending to be greater under single-seed than double-seed sowing. The relationship between basal stem characteristics and stem flow rate and source-sink coordination requires further investigation.

3.2 Optimal Planting Density for Peanut in Moderately Saline Soils

Peanut exhibits indeterminate growth with strong self-regulation capacity. Research and application of high-yield cultivation techniques for non-saline soils in arid and semi-arid regions are well-established. Conventional peanut cultivation typically uses ridge planting with plastic film mulching and double-seed hole sowing, with optimal densities established for different soil fertility levels, yield targets, sowing dates, and varieties. For yields above 3,500 kg · hm^{-2}, optimal density is 146,600-207,200 holes · hm^{-2}; for large-seed varieties yielding above 5,000 kg · hm^{-2}, optimal density is 175,000-257,000 plants · hm^{-2}; for the small-seed variety 'Luhua 12' yielding above 4,000 kg · hm^{-2}, optimal density is 185,000–258,000 plants · hm^{-2}. In Henan Province, optimal spring-sowing density ranges 180,500–210,000 holes · hm^{-2}; in central-southern Hebei, optimal density for 'Jihua 4' in spring and wheat-intercropped systems is 150,000–210,000 holes · hm^{-2}; for 'Shangyan 9658' at optimal sowing dates, density is only 135,000–165,000 holes · hm^{-2}; for 'Qianhuasheng 4' yielding 2,847 kg · hm^{-2} in Tongren City, optimal density is 150,000–187,500 holes · hm^{-2}.

Single-seed precision sowing has demonstrated strong advantages in cost, individual and population performance, and yield. Studies in non-saline soils have shown that small-seed varieties have higher optimal densities than large-seed varieties (225,000 vs. 210,000 holes · hm^{-2}). In Yunnan, high-yielding populations (2,500–3,083 kg · hm^{-2}) required densities around 270,000 plants · hm^{-2}. Under single-seed precision sowing, optimal density is 200,000 seeds (holes) · hm^{-2}, with yields exceeding those of double-seed sowing at appropriate densities. Under our experimental conditions in moderately saline soils, optimal density for spring-sown single-seed precision peanuts yielding 4,000–5,400 kg · hm^{-2} with good quality was 190,000–235,000 plants · hm^{-2}, slightly higher than for non-saline soils at comparable yield levels.

Developing peanut production in saline-alkali land to expand cultivation area and increase edible oil supply is important for adjusting agricultural planting structures in saline regions, increasing farmer income, and ensuring oil security. Research and practice on high-yield and efficient cultivation theories and techniques for saline soils are just beginning, and further investigation is needed on appropriate cultivation measures for maintaining high stable yields in these environments.

References

[1] Zhang J F, Zhang X D, Zhou J X, et al. World resources of saline soil and main amelioration measures[J]. Research of Soil and Water Conservation, 2005, 12(6): 28–30

[2] Guan Y X, Liu G H, Wang J F. Regionalization of salt-affected land for amelioration in the Yellow River delta based on GIS[J]. Acta Geographica Sinica, 2001, 56(2): 198–205

[3] Abrol I P, Yadav J S P, Massoud F I. Salt-affected Soils and Their Management[R]. Rome: Food and Agriculture Organization of the United Nations, 1988

[4] Wan S B. The Cultivation Theory and Technology of High Quality, Safety and Efficiency of Peanut[M]. Beijing: China Agricultural Science and Technology Press, 2009

[5] Li M, Li W X. Regulation of fertilizer and density on sink and source traits and yield of maize[J]. Scientia Agricultura Sinica, 2004, 37(8): 1130–1137

[6] Chen G P, Wang R H, Zhao J R. Analysis on yield structural model and key

factors of maize high-yield plots[J]. Journal of Maize Sciences, 2009, 17(4): 89-93

[7] Yang G H, Li X, Wang C L, et al. Study on effects of plant densities on the yield and the related characters of maize hybrids[J]. Acta Agriculturae Boreali-occidentalis Sinica, 2006, 15(5): 57-60

[8] Wan S B, Zheng Y P, Liu D Z, et al. Optimization of peanut-wheat intercropping system on date, fertilizer and plant density[J]. Chinese Journal of Oil Crop Sciences, 2006, 28(3): 319-323

[9] Sun Y H, Tao S X, Chen D X. Effect of fertilizer application with higher level to preceding crops on summer peanut[J]. Peanut Science and Technology, 2000(1): 15-18

[10] Wang C B, Cheng B, Sun X S, et al. Effect of distribution modes of nitrogenous fertilizer on wheat and peanut yields and the nitrogenous fertilizer utilization ratio under the wheat-peanut cropping system[J]. Acta Agriculturae Nucleatae Sinica, 2002, 16(2): 98-102

[11] Wan S B, Wang C B, Zhao P J, et al. Optimized disposition of intercropping date and planting density for wheat-peanut cropping system[J]. Chinese Journal of Oil Crop Sciences, 2004, 26(4): 55-58

[12] Zheng Y P, Wang C B, Cheng B, et al. Yield effect and optimized-measure combination of N fertilizer and plant density for different peanut variety types under single-seed planting[J]. Agricultural Research in the Arid Areas, 2007, 25(1): 201-205

[13] Zhang Z M, Ci D W, Ding H, et al. Indices selection and comprehensive evaluation of salinity tolerance for peanut varieties[J]. Chinese Journal of Applied Ecology, 2013, 24(12): 3487-3494

[14] Wu J H, Zhang J M, Xiao Z J, et al. Effect of different planting period and density rate on Main agronomy characters and yields of Spanish peanut variety Yuanza 9307[J]. Chinese Agricultural Science Bulletin, 2005, 21(9): 151-153

[15] Gao F, Zhai Z X, Wang M L. Effects of plant density on photosynthetic characteristics and yield in summer-planting peanut[J]. Chinese Agricultural Science Bulletin, 2011, 27(9): 320-323

[16] Yi Y, Wen S W, He L Z, et al. Influence of different density on the yield and economic traits of Qianhuasheng No.4[J]. Hubei Agricultural Sciences, 2012, 51(6): 1098-1099

[17] Cheng Z S, Xu G Z, Wang Y B, et al. Effect of sowing time and planting density on yield and quality in peanut[J]. Chinese Agricultural Science Bulletin, 2006, 22(7): 190-193

[18] Hou Z F, Yang T H, Tian W D, et al. Effect of planting density on yield and main character in peanut[J]. Tillage and Cultivation, 2012(2): 15-16

[19] Zheng Y P, Xu T T, Zheng Y M, et al. Study on single-seed sowing density of peanut under different planting patterns[J]. Subtropical Agriculture Research, 2012, 8(2): 82-84

[20] Zhao C X, Shao C L, Wang Y F, et al. Effects of different planting densities on population ecological characteristics and yield of peanut under the mode of single-seed precision sowing[J]. Journal of Agriculture, 2013, 3(2): 1-5

[21] Hofmann W C, Kittock D L, Alemayehu M. Planting density in relation to cotton emergence and yield[J]. Agronomy Journal, 1988, 80(5): 834-836

[22] Cui H Y, Jin L B, Li B, et al. Effects of shading on stalks morphology, structure and lodging of summer maize in field[J]. Scientia Agricultura Sinica, 2012, 45(17): 3497-3505

[23] Liu H J, Shi C Y, Chai S S. Difference and related reason for assimilate distribution of sweet potato varieties with different root tuber yields[J]. Acta Agronomica Sinica, 2015, 41(3): 440-447

[24] Zhou Q L. Research of dry matter accumulating characters on autumn sweet potato varieties of different types[D]. Chongqing: Southwest University, 2007: 41-42

[25] Wang S S, Meng P T, Gao C C, et al. Experimental research on the fertility index and yield of wheat and maize under different irrigation[J]. China Rural Water and Hydropower, 2015(6): 86-90

[26] Li X B, Li Y X, Wang C W, et al. Effect of different nitrogen application on stalk characteristics of summer maize[J]. Journal of Henan Institute of Science and Technology, 2015, 43(2): 7-10

[27] Wu J H, Li K, Su R F. Study on dry matter accumulation and physiological characteristics of a new high oleic acid peanut variety Shangyan 9658[J]. Journal of Peanut Science, 2010, 39(4): 27-30

[28] Ge Z W, Yang L Y. Influence of different planting density on growth, development and yield in peanut[J]. Journal of Peanut Science, 2002, 31(3): 33-35

[29] Guo F, Wan S B, Wang C B, et al. Comparative study on peanut plant growth and development, photosynthesis for different peanut variety types under single-seed planting[J]. Journal of Peanut Science, 2008, 37(4): 18-21

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

Source: ChinaXiv —Machine translation. Verify with original.