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Effects of Single-Seed Precision Sowing at Different Densities on Nutrient Uptake and Distribution in Peanut Postprint

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Abstract

Under field conditions, using the large-seeded peanut variety 'Huayu 22' as experimental material, this study investigated the differences in cumulative absorption and distribution characteristics of nitrogen, phosphorus, and potassium as well as yield in peanuts among three densities of single-seed precision planting—high (S1: 270,000 holes $\cdot$ hm^{-2}), medium (S2: 225,000 holes $\cdot$ hm^{-2}), and low (S3: 180,000 holes $\cdot$ hm^{-2})—and traditional double-seed hole planting (CK: 135,000 holes $\cdot$ hm^{-2}), and explored the appropriate single-seed precision planting density and its nutrient physiological basis for high yield. The results showed that, compared with CK, S1 and S2 both increased the cumulative absorption of nitrogen, phosphorus, and potassium in individual plants and the population to varying degrees; however, the increase in individual plants was smaller for S1 than for S2, and the absorption capacity of individual plants declined rapidly during the full fruit stage, with no significant change in population nutrient cumulative absorption compared with CK. S2 maintained high cumulative nutrient absorption in both individual plants and the population throughout the entire growth period, with particularly significant effects during the late growth stage. Although S3 had relatively high cumulative absorption of nitrogen, phosphorus, and potassium in individual plants, population cumulative absorption was relatively low. From the perspective of nutrient distribution characteristics, the pod nitrogen, phosphorus, and potassium distribution coefficients of S2 and S3 were significantly higher than those of CK, with no significant difference between S1 and CK. In terms of pod yield, S2 achieved the highest yield, with an 8.1% increase, followed by S1 with a 2.5% increase, while S3 showed a slight yield reduction. Analysis of yield components revealed that the significant yield increase in S2 was due to improved peanut agronomic traits resulting from rational planting method and density, which enhanced individual plant productivity and economic coefficient. Due to the higher population density in S1, the increase in individual plant productivity was not significant and the economic coefficient was lower, resulting in no significant yield increase. Although S3 had relatively high individual plant productivity, insufficient population quantity failed to achieve yield-increasing effects. Under high-yield field conditions, a single-seed precision planting density of 225,000 holes $\cdot$ hm^{-2} is more suitable for large-seeded peanuts, which is conducive to coordinating the relationship between individual plants and the population, enhancing nutrient absorption in peanuts and the allocation and transfer of nutrients to pods, thereby increasing yield.

Full Text

Effects of Single-Seed Sowing at Different Densities on Nutrient Uptake and Distribution in Peanut

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Abstract

Peanut (*Arachis hypogaea* L.) is an important oil and economic crop in China, and its sustained yield increase is significant for ensuring national edible oil security. Adopting advanced cultivation techniques and management models is a crucial approach to improving peanut yield. Currently, traditional double-seed sowing remains the dominant cultivation pattern in peanut production. However, the narrow plant spacing within the same hole and high planting density in this mode intensify inter-plant competition, restrict individual plant development, deteriorate the population environment during mid-to-late growth stages, cause premature leaf senescence, and limit further yield improvement. Additionally, traditional double-seed sowing requires large seed quantities and is not conducive to mechanization, increasing production costs. Single-seed precision sowing is an effective cultivation technology that saves seeds while maintaining high yield and efficiency. By changing from traditional double-seed to single-seed sowing and increasing the number of holes while reducing seeds per hole, this technique not only saves seed quantity but also facilitates mechanization. Previous studies have demonstrated that under high-yield conditions, changing from double-seed to single-seed sowing can fully exploit individual plant productivity and is more conducive to population-level high yield. Field experiments and production demonstrations have shown that compared with tra-

ditional double-seed sowing, single-seed precision sowing can increase yield by approximately 10% while saving 20% of seeds, substantially reducing production costs. Research also indicates that single-seed precision sowing can effectively coordinate the root-shoot ratio, strengthen both individual plants and the population, fully exploit single-plant production potential, enhance post-flowering reactive oxygen metabolism, delay senescence, and increase pod dry matter accumulation.

Nitrogen, phosphorus, and potassium are essential macronutrients for peanut growth, and their accumulation and distribution in plants form the basis of yield formation. Rational planting patterns and appropriate density can promote nutrient absorption and allocation to reproductive organs. However, current research on peanut nutrient accumulation and distribution primarily focuses on basic pattern exploration, variety comparisons, and responses to fertilization, while studies on the effects of different density single-seed precision sowing on peanut nutrient uptake and distribution remain scarce. This experiment established high, medium, and low density treatments under single-seed precision sowing, using traditional double-seed sowing as a control, to compare differences in nutrient accumulation, distribution characteristics, and yield among treatments. The objective was to explore the nutrient physiological basis for high yield at appropriate single-seed sowing densities and provide theoretical support for promoting this technology.

1. Materials and Methods

1.1 Experimental Site The field experiment was conducted in 2013 and 2014 at the Yinmaquan Experimental Station of the Shandong Academy of Agricultural Sciences. The soil type was sandy loam with the following properties in the plow layer: organic matter 11.0 $g \cdot kg^{-1}$, alkaline hydrolysis nitrogen 82.7 $mg \cdot kg^{-1}$, available phosphorus 36.2 $mg \cdot kg^{-1}$, available potassium 94.5 $mg \cdot kg^{-1}$, and exchangeable calcium 14.9 $g \cdot kg^{-1}$. The previous crop was maize.

1.2 Experimental Design The large-seed peanut variety 'Huayu 22' with high individual plant productivity was selected for plastic film mulching cultivation in double-row ridges. Three single-seed precision sowing density treatments were established: high density (S1: 270,000 $holes \cdot hm^{-2}$), medium density (S2: 225,000 $holes \cdot hm^{-2}$), and low density (S3: 180,000 $holes \cdot hm^{-2}$), with hole spacing of 9.3 cm, 11.1 cm, and 13.9 cm, respectively, and one seed per hole. Traditional double-seed sowing (CK) served as the control at a density of 135,000 $holes \cdot hm^{-2}$ with 18.6 cm hole spacing and two seeds per hole. The experiment employed a randomized block design with three replications. Each plot contained eight ridges measuring 7.5 m in length with 80 cm ridge spacing and 30 cm row spacing on ridges. Before sowing, basal fertilizers were applied at the following rates: decomposed chicken manure 12 $t \cdot hm^{-2}$, nitrogen (N) 90 $kg \cdot hm^{-2}$, phosphorus (P_2O_5) 120 $kg \cdot hm^{-2}$, potassium (K_2O) 150 $kg \cdot hm^{-2}$, and slow-release nitrogen fertilizer 90 $kg \cdot hm^{-2}$. Sowing occurred on May 3, 2013 (harvested September 4) and May 1, 2014 (harvested September 2). Other cultivation management followed high-yield peanut cultivation requirements.

1.3 Sampling and Measurement Methods Samples were collected at 30 days after emergence (seedling stage), 50 days (flowering-pegging stage), 70 days (pod-setting stage), and 100 days (pod-filling stage). Six uniform plants were selected from each treatment, washed, and separated into roots, stems, leaves, and pods, then oven-dried at 105°C for 30 minutes and at 80°C to constant weight. Dried samples were ground and analyzed for total nitrogen by the Kjeldahl method, total phosphorus by vanadium molybdate yellow colorimetry, and total potassium by flame photometry. Single-plant NPK accumulation was calculated based on dry weight and nutrient content percentages; population accumulation was calculated from single-plant accumulation and plant density per unit area. Pod NPK distribution coefficient was calculated as the ratio of pod accumulation to total plant accumulation.

At maturity, six uniform plants per plot were selected to investigate main stem height, branch length, branch number, and pods per plant. Population pod yield and biomass were determined by harvesting two uniform ridges (2 m length) per plot, followed by pod removal, air-drying, and measurement of pod yield and total biomass. Economic coefficient was calculated as the ratio of pod yield to total biomass.

1.4 Data Processing and Analysis Data processing and graphing were performed using Microsoft Excel 2003. Statistical analysis and significance testing were conducted using SPSS 19.0 software.

2. Results

2.1 Effects of Single-Seed Sowing Density on Nitrogen Accumulation and Distribution

2.1.1 Nitrogen Accumulation As shown in [Figure 1: see original paper], both single-plant and population nitrogen accumulation increased gradually throughout the growing season, peaking at the pod-filling stage. Significant differences existed among treatments at each growth stage. For single-plant nitrogen accumulation, all single-seed treatments (S1, S2, S3) exceeded CK at the seedling and flowering-pegging stages. At the pod-setting and pod-filling stages, S2 and S3 were significantly higher than CK, with differences most pronounced at pod-filling (22.5% and 31.0% higher, respectively), while S1 showed no significant difference from CK. For population nitrogen accumulation, S1 and S2 were significantly higher than CK at the seedling stage, while S3 was not significantly different. At flowering-pegging, S1 and S2 were significantly higher than CK (by 12.8% and 14.0%, respectively), whereas S3 was significantly lower. At pod-setting, S1 and S2 remained significantly higher than CK, while S3 was significantly lower. At pod-filling, S2 was significantly higher than CK, S1 showed no significant difference, and S3 was significantly lower.

2.1.2 Nitrogen Distribution Characteristics As shown in , distinct differences existed among treatments in nitrogen accumulation and distribution across plant parts and pod distribution coefficients. During the seedling and flowering-pegging stages, nitrogen accumulated primarily in leaves and stems, with the highest content in leaves, followed by stems, and the lowest in roots. Treatment differences varied by stage: S1 and S2 showed significantly higher nitrogen accumulation in roots, stems, and leaves compared to CK, while S3 was similar to or lower than CK. At pod-setting, nitrogen accumulation shifted to pods, with decreasing accumulation in vegetative organs. S2 achieved the highest pod nitrogen accumulation, followed by S1 and CK, with S3 lowest. At pod-filling, most nitrogen had transferred to pods, with pod distribution coefficients reaching 0.73–0.76. Both S2 and S3 were significantly higher than S1 and CK, with S2 showing the highest pod nitrogen accumulation (10.0% higher than CK). S1 was slightly higher than CK, while S3 was lowest but not significantly different from CK. These results demonstrate that the medium-density single-seed treatment (S2) not only increased nitrogen accumulation in all plant parts but also enhanced nitrogen allocation to pods.

2.2 Effects of Single-Seed Sowing Density on Phosphorus Accumulation and Distribution

2.2.1 Phosphorus Accumulation As shown in [Figure 2: see original paper], phosphorus absorption dynamics were similar to nitrogen, with both single-plant and population phosphorus accumulation increasing gradually throughout the growing season. For single-plant accumulation, S2 and S3 maintained higher levels than CK throughout all growth stages, while S1 was significantly higher than CK before pod-filling but showed no significant difference thereafter, suggesting that high-density single-seed sowing advantages diminished in later growth stages, possibly due to premature senescence under high population density. For population accumulation, differences among treatments were small and non-significant at the seedling stage. At flowering-pegging, S1 was significantly higher than CK, S2 was not significantly different, and S3 was significantly lower. Similar patterns occurred at pod-setting. At pod-filling, neither S1 nor S2 differed significantly from CK, while S3 was significantly lower, indicating that medium-density single-seed sowing (S2) maintained population phosphorus absorption despite reduced density.

2.2.2 Phosphorus Distribution Characteristics As shown in , all treatments showed consistent phosphorus distribution patterns across growth stages, with vegetative organ allocation decreasing and reproductive organ allocation increasing progressively. At the seedling stage, most phosphorus was allocated to stems and leaves, with leaf distribution coefficients of 0.49–0.57. S2 and S3 leaf phosphorus distribution coefficients were 12.8% and 0.43 higher than CK, respectively. After flowering-pegging, leaf distribution coefficients decreased slightly (0.47–0.54) while stem coefficients increased (0.42–0.49), with S2 and S3 stem phosphorus distribution coefficients exceeding CK. At pod-setting, most phosphorus transferred to pods, with pod distribution coefficients of 0.46–0.52, where S2 and S3 were significantly higher than CK while S1 was not significantly different. At pod-filling, pod phosphorus distribution coefficients peaked, with S2 and S3 reaching 0.75 and 0.74, respectively, both significantly higher than CK. These results indicate that appropriate single-seed sowing densities can enhance phosphorus translocation to pods.

2.3 Effects of Single-Seed Sowing Density on Potassium Accumulation and Distribution

2.3.1 Potassium Accumulation As shown in [Figure 3: see original paper], both single-plant and population potassium accumulation increased initially then decreased, peaking at pod-setting and declining slightly at pod-filling. Treatment differences varied by stage and measurement scale. For single-plant accumulation, all single-seed treatments (S1, S2, S3) significantly improved potassium accumulation during early growth (seedling and flowering-pegging), with S2 and S3 showing more pronounced effects. After pod-setting, S1 showed no significant difference from CK, and was slightly lower at pod-filling, indicating that while all single-seed densities enhanced early-stage potassium uptake, high-density advantages disappeared in later stages. For population accumulation, S2 maintained significantly higher levels than CK throughout all growth stages. S1 exceeded CK before pod-filling but was slightly lower (non-significantly) afterward, while S3 was higher than CK only at seedling stage and lower at pod-setting and pod-filling stages. These results demonstrate that increasing population potassium accumulation requires both enhanced single-plant uptake and sufficient population density.

2.3.2 Potassium Distribution Characteristics As shown in , potassium distribution patterns were consistent across treatments but varied in magnitude. During vegetative growth, potassium accumulated primarily in leaves and stems. At seedling, leaf distribution coefficients were 0.55–0.61 and stem coefficients 0.35–0.40, with all single-seed treatments exceeding CK. After flowering-pegging, leaf coefficients decreased slightly (0.45–0.49) while stem coefficients increased (0.49–0.53). At pod-setting, coefficients in both leaves and stems decreased progressively, reaching minimum values at pod-filling (leaf coefficients 0.16–0.18; stem coefficients 0.31–0.32). The higher stem coefficients at maturity indicate lower potassium translocation from stems compared to leaves. At pod-filling, pod potassium distribution coefficients were 0.48, 0.50, and 0.51 for S1, S2, and S3, respectively, with S2 and S3 significantly higher than CK. These results suggest that appropriately reduced density under single-seed sowing enhances pod potassium distribution and utilization efficiency.

2.4 Effects on Yield, Yield Components, and Agronomic Traits As shown in , significant differences existed among treatments in pod yield, yield components, and agronomic traits. The medium-density single-seed treatment (S2) achieved the highest pod yield (8.1% increase over CK), followed by S1 (2.5% increase), while S3 showed a slight but non-significant yield decrease. Yield component analysis revealed that S2 improved branch number and pods per plant, enhanced agronomic traits, increased single-plant productivity, and raised the economic coefficient. The high-density treatment (S1) increased plant height but did not significantly improve branch number or pods per plant, showing no significant differences from CK in biomass or economic coefficient, resulting in non-significant yield increases. Although the low-density treatment (S3) exhibited high branch number and pods per plant, insufficient population density led to lower group biomass and slightly reduced pod yield compared to CK.

3. Discussion and Conclusion

High biological accumulation is the prerequisite for high-yield and high-quality crop production, which fundamentally depends on nutrient absorption. Nitrogen, phosphorus, and potassium are the three primary nutrient elements, and their absorption and accumulation in plants form the basis of crop yield formation. The same variety exhibits different nutrient absorption and distribution patterns under varying environmental conditions and cultivation modes. This study demonstrated that medium-density single-seed sowing (S2) significantly improved both single-plant and population NPK accumulation throughout the growing season. Low-density single-seed sowing (S3) enhanced single-plant NPK accumulation but reduced population nutrient absorption, likely due to insufficient population density. High-density single-seed sowing (S1) showed advantages in single-plant and population NPK accumulation during early growth stages, but these advantages diminished or disappeared in later stages, possibly due to intensified inter-plant competition, prominent individual-population conflicts, and premature senescence under excessive density, which affected late-stage nutrient absorption. Previous research by Feng et al. indicated that changing from traditional double-seed to single-seed sowing with appropriately reduced seeding rates could enhance antioxidant enzyme activity, delay senescence, and increase yield, consistent with our findings. Additionally, the improved nutrient absorption capacity under single-seed sowing may be closely related to root system development, as studies have shown that single-seed sowing promotes root growth and improves root morphology and distribution, providing the foundation for enhanced nutrient uptake.

The basis of high crop yield lies in increasing population photosynthetic biomass and transferring a larger proportion to economic organs. Research by Wan et al. indicated that high-yield peanut varieties primarily achieve yield increases through improved economic coefficients—that is, increased nutrient allocation to pods—while biomass enhancement also plays an important role. Therefore, improving the economic coefficient represents a crucial pathway for increasing peanut yield. Nutrient absorption and distribution characteristics depend not only on variety traits but also on cultivation techniques. Zhao et al. demonstrated that different planting patterns affect soybean dry matter accumulation and nutrient absorption and distribution. Damisch and Wiberg suggested that appropriate wheat planting density can maintain high leaf area, facilitate sugar conversion, and improve nitrogen utilization, thereby increasing grain yield. Our results showed that medium- and low-density single-seed treatments effectively improved pod NPK distribution coefficients and increased peanut economic coefficients, indicating that appropriately reduced seeding rates on the basis of changing from double-seed to single-seed sowing can enhance nutrient translocation to pods. Similar conclusions were drawn in studies on spring soybean by Zhai and on cotton in Xinjiang by Lou et al., which found that medium and low densities favored nutrient transfer to reproductive organs and improved individual plant yield, and that appropriate density could enhance nutrient allocation to reproductive organs and increase yield.

Sun et al. proposed that establishing an appropriately sized population structure with coordinated individual and population development to achieve more and fuller pods constitutes an important task for high-yield peanut cultivation. The medium-density single-seed treatment (225,000 holes $\cdot$ hm^{-2}) changed the traditional double-seed pattern while appropriately reducing density (16.7% seed reduction), improved peanut agronomic traits, increased pods per plant, and effectively enhanced single-plant productivity. Despite reduced planting density, this treatment maintained high population biomass and pod yield. Therefore, appropriate-density single-seed precision sowing technology not only saves seeds but also fully exploits variety potential and increases economic yield. Similar conclusions have been reached for rice and wheat precision sowing high-yield cultivation techniques: appropriately reducing seeding rates and basic seedling numbers promotes robust individuals, balances individual-population relationships, establishes rational population structures, improves canopy photosynthesis, enhances photosynthate synthesis and accumulation during mid-to-late growth stages, and ensures high and stable yields.

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