COMPARATIVE EXPERIMENTAL STUDY ON OPERATION PERFORMANCE AND YIELD OF MAIZE SEEDERS OF DIFFERENT TYPES IN WHEAT STUBBLE FIELD
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麦茬地不同型式玉米播种机作业性能及产量对比试验研究

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DOI: https://doi.org/10.35633/inmateh-74-37

***Keywords:** mechanical seeding quality; plant spacing qualified rate; plants height consistency; yield of maize; seeder type; operation efficiency*

ABSTRACT
Mechanical seeding quality is a key factor affecting the yield of maize in stubble fields. To choose for high-performance seeders and determine the appropriate operating speed, comparative sowing tests were conducted using spoon-wheel seeders, lightweight and heavyweight finger-clip seeders, and air-suction seeders in six districts of Shandong Province. Three working speeds, low speed, medium speed and high speed, were set up to determine the qualified rate of plant spacing, the consistency of plants height and the yields under different working speeds. The results showed that the qualified plant spacing rate, plants height consistency, and yield of the spoon-wheel and lightweight finger-clip seeders were significantly affected by the operating speed, decreasing as the speed increased. At high speeds, the qualified plant spacing rates were less than 80%, and plants height consistency were less than 85%. Heavyweight finger-clip and air-suction seeders' qualified plant spacing rates, plants height consistency, and yields were not significantly affected by the operating speed, remaining stable across different speeds and significantly higher than those of the spoon-wheel and lightweight finger-clip seeders. The differences in qualified plant spacing rates and plants height consistency were more significant at higher speeds, along with obvious yields increase advantage. The yields increase ranged from 3.50% to 7.84% at low speeds, 4.32% to 9.31% at medium speeds, and 7.64% to 11.65% at high speeds. This study provides a reference for the selection of high-performance seeders for maize in stubble fields and the determination of suitable operating speeds.

摘要
机械播种质量是影响麦茬地玉米产量的关键因素，为筛选高性能播种机，并确定适宜的作业速度，使用勺轮式、指夹式（轻型、重型）和气吸式播种机在山东省 6 个区县进行播种对比试验，试验设置低速、中速和高速 3 种作业速度，测定不同作业速度下的株距合格率、苗高一致性和产量，结果表明：勺轮式和轻型指夹式播种机的株距合格率、苗高一致性以及产量均受作业速度影响显著，随作业速度增大而降低，高速作业时株距合格率小于 80%，苗高一致性小于 85%；重型指夹式和气吸式播种机株距合格率、苗高一致性以及产量受作业速度的影响不显著，各速度下株距合格率、苗高一致性以及产量均较稳定，显著高于勺轮式和轻型指夹式播种机，并且作业速度越高，株距合格率和苗高一致性差异越显著，增产优势也越明显，低速增产幅度为 3.50%～7.84%，中速增产幅度为 4.32%～9.31%，高速增产幅度为 7.64%～11.65%。本研究为麦茬地玉米高性能播种机的筛选和适宜作业速度的确定提供参考。

INTRODUCTION
Maize is an important grain crop, high-quality feed, and industrial raw material. China imports an average of 20 million tons of maize annually (*Zhong et al., 2024*). With limited arable land resources, it is important to increase maize production to get rid of the dependence on imports (*Bao et al., 2023; Wang et al., 2023*).

The quality of mechanized sowing significantly impacts maize yield, and uniform seed spacing and consistent planting depth are the main embodiment of good sowing quality (*Du et al., 2023; Yang et al., 2016; Suan et al., 2021; Sanavi et al., 2006; Badua et al., 2021*). *Gan et al, (1995),* found that the depth of sowing directly affects the seedling emergence rate of seeds, which results in a reduction of yield due to the increase of sterile plants. *Griepentrog et al., (1998),* pointed out that the spacing of sowing affects the crop's use of light, water and soil nutrients, which influences the level of yield. Li Yueming found that different seed viability at different sowing depths and various seed traits had different effects on yield (*Li et al., 2019*). Fu Weiqiang found that the inconsistency of seeding depth seriously affected the uniformity of seedling stage and the yield in later stage (*Fu et al., 2019*). Han Dandan and Zhang Shaohua pointed out that poor plant spacing uniformity fails to meet agronomic requirements and would cause a lot of waste of seeds (*Han et al., 2023; Zhang et al., 1981*). Under the same conditions of the previous crop's surface, the performance of the seeder is the main factor affecting the quality of sowing. Currently, there are various types of maize seeders on the market, with differing performances and varying sowing quality (*Cheng et al., 2023*). The seed metering device and furrow opener are the key components that significantly influence the quality of sowing (*Gao et al., 2021; K. et al., 2022*). Seed metering devices mainly include spoon wheel type, the finger-clip type and the gas suction type, and the openers mainly include the hoe shovel type, the double disc type and the hoe shovel double disc combined type (*Zhao et al., 2022; Singh et al., 2005; Yazgi et al., 2007; Vamerali et al., 2006; Aliakbar et al., 2013*). In order to choose high performance seeder and improve the quality of maize seeding, comparative tests of maize seeding were carried out in different districts of Shandong Province.

MATERIALS AND METHODS

Test locations and materials

The locations of the tests were relatively concentrated plots in six areas, Wenshang County, Hanting District, Huantai County, Shanghe County, Qihe County, and Zoucheng City, of Shandong Province. Based on local climatic conditions and production practices, commonly used spoon-wheel type, finger-clip type and air-suction type maize seeders from the market were selected. The row spacing, plant spacing, theoretical sowing amount, and other parameters were determined, as shown in Table 1. The test plots had relatively consistent conditions in terms of light, moisture, and soil nutrients, with flat terrain and no slopes. The length of the plot was no less than 70 meters, and the wheat straw from the previous crop was returned to the field in full cover, without ploughing or straw treatment in any way.

Table 1

The basic situation of sowing in each experimental site

Test site	Maize variety	Seeder type	Trencher type	Seeder weight (kg)	Theoretical spacing (cm)	Theoretical seeding amount (grain/hm^2)
Wenshang county	**Huamei No.1**	Spoon-wheel type	Hoe shovel	685	17	98 040
		Heavyweight finger-clip type	Double-disc	1 260	17	98 040
		Air-suction type	Double-disc	1 600	17	98 040
Hanting district	**Denghai 605**	Spoon-wheel type	Hoe shovel	1 000	23	72 465
		Lightweight finger-clip type	Hoe shovel	890	23.5	70 920
		Air-suction type	Double-disc	1 970	22.3	74 745
Huantai county	**Denghai 1966**	Spoon-wheel type	Hoe shovel	310	25	66 660
		Lightweight finger-clip type	Hoe shovel	295	25	66 660
		Air-suction type	Double-disc	2 300	25	66 660
Shanghe county	**Denghai 605**	Spoon-wheel type	Hoe shovel	300	24	69 450
		Lightweight finger-clip type	Hoe shovel	360	24	69 450
		Air-suction type	Double-disc	1 520	24	69 450
Qihe county	**Denghai 605**	Spoon-wheel type	Hoe shovel	350	20	83 340
		Heavyweight finger-clip type	Hoe shovel + Double-disc	1 280	20	83 340
		Air-suction type	Hoe shovel + Double-disc	1 500	20	83 340
Zoucheng city	**Denghai 1717**	Spoon-wheel type	Hoe shovel	690	23	72 465
		Lightweight finger-clip type	Hoe shovel	570	23	72 465
		Air-suction type	Double-disc	1 410	23	72 465

Test methods

The test was set up with three working speeds: low speed (5±1 km/h), medium speed (7±1 km/h), and high speed (9±1 km/h), across nine test plots. Unify seed bed conditions, operator, seeding time and field management after sowing. After 10 days of emergence, the plant spacing and plant height were measured, then the plant spacing qualified rate and plant height consistency were calculated. The theoretical yield of maize was measured before harvest.

Test metrics

(1) Plant spacing qualified rate

Two seeding rows were randomly selected on the round trip of the seeding plot (a total of four rows). In the stable seeding area, the plant spacing of 20 plants was measured consecutively in each row. The plant spacing qualified rate Z was calculated according to equation (1). Take an average of four lines of measurement results.

$$Z = \frac{Z_H}{20} \times 100\% \tag{1}$$

where: Z_H is the numbers of qualified plant spacing, which was greater than 0.5 times the theoretical plant spacing and less than or equal to 1.5 times the theoretical plant spacing, pcs.

(2) Plant height consistency

Two seeding rows on the round trip of the seeding plot (a total of four rows) were randomly select. In the stable seeding area, the height of 20 plants was measured consecutively. The plant height consistency H was calculated according to equation (2) - (5). Take an average of four lines of measurement results.

$$h = \frac{\sum_{i=1}^{20} h_i}{20} \tag{2}$$

$$H_0 = \sqrt{\frac{\sum_{i=1}^{20}(h_i - h)}{20-1}} \tag{3}$$

$$p = \frac{H_0}{h} \times 100\% \tag{4}$$

$$H = 1 - p \tag{5}$$

where: h is the average plant height, cm; h_i is the height of plants, cm; H_0 is the standard deviation of plants height, cm; p is the coefficient of variation of plants height; H is the coefficient of plant height consistency.

(3) Yield of maize

During the harvest period, the method of artificial actual production measurement was adopted. For each experimental treatment, three measurement points were selected using the diagonal sampling method, and 2 rows of maize, 10 meters long, were selected from each point. The actual area S of the harvesting sample point was calculated according to equation (6).

$$S = 10 \times 2 \times b \tag{6}$$

where: S the actual sampling area, m^2; b is the maize planting row spacing, m.

The cobs in the sample points were harvested and weighed manually, and 20 cobs selected randomly were threshed and weighed manually. The seed rate α was calculated according to equation (7).

$$\alpha = \frac{g}{G} \times 100\% \tag{7}$$

where: α is the value of seed yield rate of the sampled cobs, %; g is the value of grain weight of 20 cobs, kg; G is the value of total weight of 20 cobs, kg.

Maize moisture content was measured with a moisture tester, and the average value β was measured at three measuring points. The yield Q per hectare of each test point was calculated according to equation (8), and the average of three measurements was taken.

$$Q = \frac{W \times \alpha \times (1-\beta) \times 10000}{S \times (1 - 14\%)} \tag{8}$$

where: Q is the value of yield per hectare, kg/hectare; W is the total weight of harvested cobs, kg.

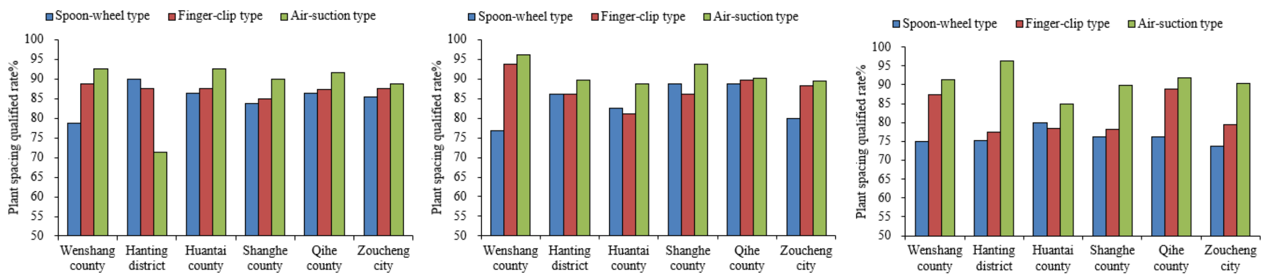
Data Processing

Microsoft Excel 2016 was used for data analysis and processing.

RESULTS AND ANALYSIS

(1) Plant spacing qualified rate analysis

The uniformity of plant spacing affects the effective use of light, water and soil nutrients, and the uniformity of plant spacing is conducive to the high yield of crops. Figure 1 shows the qualified rates of plant spacing for different types of seeders at low, medium, and high operating speeds. As can be seen from the figure, at the same speed, except for low-speed treatment in Hanting District, the qualified rate of plant spacing of air-suction seeder is significantly higher than that of spoon-wheel and lightweight finger-clip seeder, being around 90%, with the highest reaching 96.25%. This indicates that the air-suction seeder has better seeding performance, especially in medium-high speed operation, where the plant spacing is more stable. The analysis shows that the reason for the lower qualified rate of plant spacing for the air-suction seeder in the low-speed treatment in Hanting District is that, under low-speed operation, the tractor's power take-off shaft speed is low, resulting in insufficient fan wind pressure. This leads to missed seeding occurrences, which causes the qualified rate of plant spacing to be lower. In Wenshang County and Qihe County, the qualified rates of plant spacing for the heavyweight finger-clip seeders are not significantly different from those of the air-suction seeder, and both are higher than those of the spoon wheel seeders. In other areas, the qualified rates of plant spacing for the lightweight finger-clip seeders are not significantly different from those of the spoon wheel seeders, and both are significantly lower than those of the air-suction seeder.



(a) low speed (b) medium speed (c) high speed

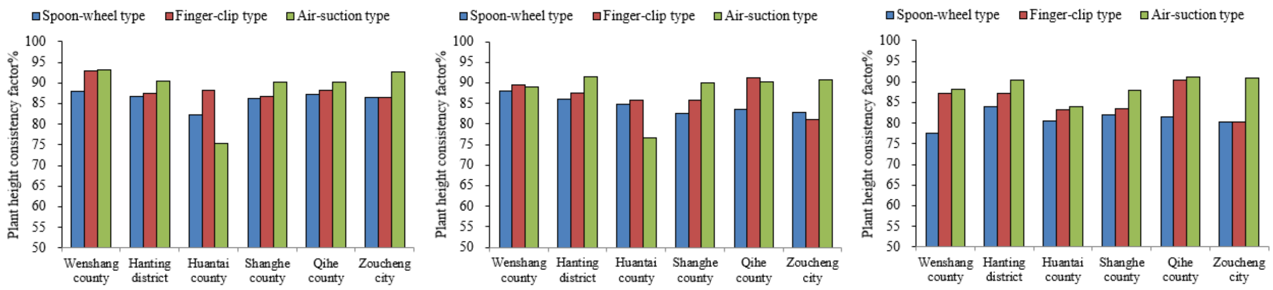
Fig. 1 - Plant spacing qualified rate at different working speeds

Through the analysis of plant spacing qualified rate, it can be seen that under the same operation speed, the seeding uniformity of air-suction seeder and heavyweight finger-clip seeder is higher than that of spoon wheel and lightweight finger-clip seeder. This difference is particularly significant at high operating speeds. Comparing the qualified rates of plant spacing for the same seeder at different operating speeds reveals that the spoon wheel and lightweight finger-clip seeders are significantly affected by speed. The qualified rate of plant spacing decreases as the speed increases, dropping below 80% at high speeds. In contrast, the heavyweight finger-clip and air-suction seeders are not significantly affected by speed, with their qualified rates of plant spacing generally remaining above 90% even at high speeds.

(2) Plant height consistency analysis

Overall, the plant height consistency of the spoon wheel and lightweight finger-clip seeders is significantly affected by operating speed. As the operating speed increases, plant height consistency decreases, dropping below 85% at high speeds. In contrast, the plant height consistency of the air-suction and heavyweight finger-clip seeders is not significantly affected by speed, maintaining a uniformity of around 90% ± 2% across different speeds. Comparing the plant height consistency at the same speed, the air- suction type and heavyweight finger-clip seeders have higher uniformity than the spoon wheel and lightweight finger-clip seeders. This difference is especially significant at medium and high speeds. The reason is that the air-suction type and heavyweight finger-clip seeders have a heavier overall weight (greater than 1200 kg), providing sufficient individual downforce. Additionally, the four-bar linkage contour-following mechanism performs well in contouring, and the use of double-disc openers with depth limiters ensures stable furrow depth. However, due to the light weight of the whole machine (less than 1000 kg), the opener of the spoon-wheel and lightweight finger-clip seeder have serious bumps during high-speed operation in the stubble field. Although there is a four-link imitation, the pressure of the single unit is limited, especially in the case of stubble, large soil and large amount of straw, maize seeding monomer jumps significantly and the depth of the furrow is unstable.

At the same time, hoe-shovel openers have poor soil backfill performance at high-speed operation, resulting in uneven soil thickness covering the seeds and poor plant height consistency. Nevertheless, in Figure 2, the consistency of plant height of the air-suction seeder in Huantai County is lower than that of the spoon wheel type and the traditional finger-clip type at the same speed. The investigation revealed that the stubble height of Huantai test site was greater than 25 cm and the straw cutting length was greater than 20 cm due to the rush to harvest wheat before rain. Moreover, on the test day, the air humidity was high, which increased the toughness of the straw, making it difficult to cut off. During the seeder's operation, slight clogging occurred, with root stubble being dragged by the straw clearing discs and accumulating on the seedbed (as shown in Figure 3). This accumulation affected soil coverage and led to inconsistent sowing depth. Furthermore, the uncut long straw was pressed into the seed furrow by the double discs, so that the seeds could not be in close contact with the soil. This affected the emergence time and resulted in poor consistency of plant height, as shown in Figure 4.



(a) low speed (b) medium speed (c) high speed

Fig. 2 – Plants height consistency at different operating speeds

Fig. 3 – Passive clearing of seed bed unevenness due to straw tray congestion

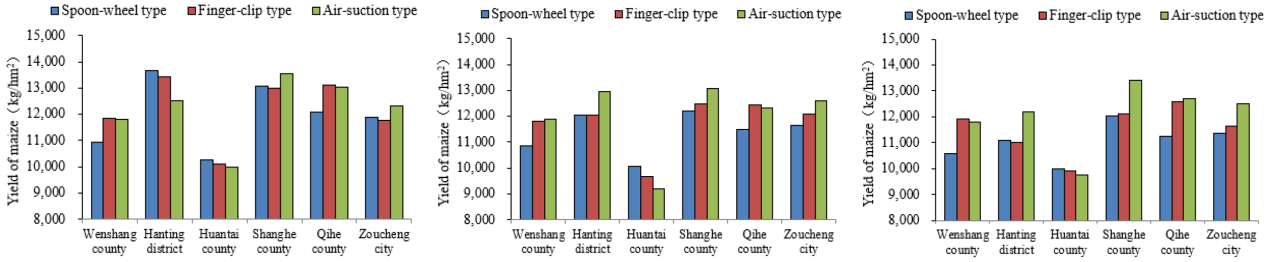
Fig. 4 – Seedling emergence of maize sown on straw and not sown on straw

Through the analysis of plant height consistency, it is evident that compared to hoe-shovel openers, double-disc openers are better at ensuring consistent seeding depth. However, the crop residue and root stubble from the previous crop must meet operational requirements for this advantage to be realized. Finger-clip and air-suction seeder used in Qihe County installed hoe-shovel opener in front of the double-disc opener, broke the stubble first and then used the double-disc opener. The consistency of plant height was more than 90%, indicating that hoe-shovel and double-disc opener were more suitable for maize seeding in the stubble field.

(3) Maize yield analysis

Figure 5 shows maize yields at different operating speeds. Comparing the yields of the same seeder at different operating speeds reveals that, overall, the yields of spoon wheel and lightweight finger-clip seeders decrease as the operating speed increases. In contrast, the yields of heavyweight finger-clip and air-suction seeders are less affected by speed, with no significant differences in yield across different speeds. Comparing the output of different types of seeders at the same speed, it can be seen that there is little difference in the output of spoon wheel type and lightweight finger-clip type on the whole. Except for the air-suction seeder in Hanting District, which experienced missed seeding at low speeds, and the lower yield of the air-suction seeder in Huantai County due to previous crop stubble, the yields of the spoon wheel and lightweight finger clip seeders in other areas were significantly lower than those of the heavyweight finger-clip and air-suction seeders.

This indicates that heavyweight finger-clip and air-suction seeders are conducive to achieving higher maize yields. At low speeds, the yield increase ranges from 3.50% to 7.84%; at medium speeds, the yield increase ranges from 4.32% to 9.31%; at high speeds, the yield increase ranges from 7.64% to 11.65%. This demonstrates that the yield advantage of heavyweight finger-clip and air-suction seeders becomes more significant under higher operating speeds.



(a) low speed (b) medium speed (c) high speed

Fig. 5 – Maize yield at different operating speeds

CONCLUSIONS

This study conducted sowing comparison tests in six counties in Shandong Province to analyse the plant spacing, plant height consistency, and yields of four types of seeders—spoon wheel, lightweight finger-clip, heavyweight finger-clip, and air-suction—at different operating speeds. The following conclusions are drawn:

(1) The plant spacing, plant height consistency and yield of spoon-wheel and lightweight finger-clip seeder were significantly affected by speed, and decreased with the increase of speed, so these seeders are not suitable for high-speed operations. The plant spacing, plant height consistency, and yield of heavyweight finger-clip and air-suction seeders are not significantly affected by operating speed. These metrics remain stable across different speeds and are significantly higher than those of spoon wheel and lightweight finger-clip seeders. Moreover, the higher the operating speed, the more pronounced the differences become.

(2) Spoon-wheel and lightweight finger-clip seeders are suitable for medium and low speed operations, and the operating speed is generally not more than (7±1) km/h. The air-suction and heavyweight finger-clip seeders are suitable for high, medium, and low-speed operations. However, when operating at low speeds with air-suction seeders, it is important to increase the fan speed to prevent missed seeding.

(3) Compared with the hoe-shovel opener, the double-disc opener can better ensure the consistency of sowing depth. However, the stubble and root residue from the previous crop must meet operational requirements. To ensure consistent seeding depth, a hoe-shovel opener can be installed in front of the double-disc opener to first clear the stubble, followed by the use of the double-disc opener for furrowing. For plots with more straw, it is also possible to install an active stubble-breaking and straw-clearing device in front of the double disc opener to prevent seeder clogging.

ACKNOWLEDGEMENTS

This work was supported by the Shandong Province Science and Technology Smets Innovation Ability Improvement Project（NO.2023TSGC0339 and 2024TSGC0271）and Shandong Province Major Agricultural Technology Collaborative Extension Project (No. SDNYXTTG-2024-03 and SDNYXTTG2023-01).

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