Planting uniformity performance of motor-driven maize precision seeding systems

Shuo Yang[1,2,3], Changyuan Zhai[1,2,3], Yuanyuan Gao[4], Hanjie Dou[2,3], Xueguan Zhao[2,3], Yakai He[2], Xiu Wang[1,2,3*]

(1. *Research Center of Information Technology, Beijing Academy of Agriculture and Forestry Sciences, Beijing 100097, China*;
2. *Intelligent Equipment Research Center, Beijing Academy of Agriculture and Forestry Sciences, Beijing 100097, China*;
3. *National Engineering Research Center for Information Technology in Agriculture, Beijing 100097, China*;
4. *School of Agricultural Equipment Engineering, Jiangsu University, Zhenjiang 212013, Jiangsu, China*)

Abstract: Low accuracy planting uniformity affects yield. Seed meter type and forward speed typically interfere with the planting uniformity accuracy of motor-driven seeding systems. Two types of maize precision planters equipped with motor-driven planting systems are investigated in this study to ascertain the rule of planting uniformity in both simulated and field speeds. The simulated speed increases from 5 to 12 km/h at a 1 km/h interval in a laboratory environment. The test results show that the quality of feed index (QTFI) of the two planters decreased by 16.79% and 9.88%. This is primarily attributed to the increase in the miss index (MISS) by 11.62% and 9.70%, respectively. The field speed was set to four levels from 5 to 12 km/h in a field environment. The plant spacing scatter distribution results were analyzed, and the results of the two planters indicated that the average positive difference of the two planters linearly increased with the forward speed, and the negative difference of the two planters did not exhibit a linear correlation. The number of positive moving average points was 2.49 times greater than that of the negative moving average points of the finger pick-up maize precision planter, and 4.49 times in the air-suction maize precision planter. The results indicated that the increase of the positive difference of plant spacing is the major effect factor in the field planting uniformity of the two motor-driven maize precision planters. In addition, the plant spacing corresponded to the distribution frequency of the two planters in field was close to the target seed spacing of 25 cm with a max coefficient of variation (CV) of 21.55% and 20.66%, respectively, and those plant spacing values corresponded to max distribution frequency of the two planters at the four level field speeds were (24.69±0.63) cm and (25.63±0.32) cm, respectively. However, the multiples index (MUL) changed randomly affected by the increasing speed. The research results provide a direction for the optimization design of motor-driven maize precision planters.

Keywords: electric drive metering, planting uniformity, maize precision planting, quality evaluation
DOI: 10.25165/j.ijabe.20221505.5911

Citation: Yang S, Zhai C Y, Gao Y Y, Dou H J, Zhao X G, He Y K, et al. Planting uniformity performance of motor-driven maize precision seeding systems. Int J Agric & Biol Eng, 2022; 15(5): 101–108.

1 Introduction

With the improvement of the seed quality and the non-destructive detection of seed viability[1], Seedling emergence is significantly increased. The aim of maize precision planting is to equidistantly sow a single maize seed in a row. With the advantage of the low seed quantity required to produce a high yield, precision planting has become the primary method of seed maize[2]. Planting uniformity is a standard to evaluate sowing amount distribution[3-5]. A better planting uniformity indicates the higher precision of the seeding rate, which affords a high yield[6,7]. When a maize planter is sowing in the field, the rotate speed of the seed plate changes accordingly with the forward speed of the planter. However, owing to the unstable seeding performances of seeders in different forward speeds or other aspects, problems such as miss-seeding, reseeding, and non-uniform seeding typically occur. Miss-seeding can cause reduced production, whereas reseeding causes not only seed wastage, but also increased labor costs for thinning out seedlings. Meanwhile, non-uniform seeding can reduce the control precision of the demonstrative quantity of seeds. To realize better planting uniformity, the effect of forward speed must be considered in the parameter optimization of maize planters. Those parameters include the planting unit of the maize planter[8,9], seed meter structure[10-12], and driving method of seeding[13-15].

Seed meter type and forward speed significantly affect precision planting uniformity[16]. The working forward speed is directly correlated with the precision planting uniformity. Studies have shown that maize-soybean interplanting seeders possess the maximum quality index, lowest miss index, and lowest multiple index at the speed of 4-5 km/h[17]. By pursuing good planting quality while increasing planting efficiency, a farmer benefits from reduced labor costs and increased food production. Hence, planting uniformity according to the forward speed is an important

Received date: 2021-05-22 **Accepted date:** 2022-08-31
Biographies: Shuo Yang, PhD, research interest: intelligent equipment for agriculture, Email: yangshuo@nercita.org.cn; **Changyuan Zhai**, Professor, research interest: precision agriculture, Email: zhaicy@nercita.org.cn; **Yuanyuan Gao**, PhD, research interest: intelligent equipment for agriculture, Email: gaoyy0910@ujs.edu.cn; **Hanjie Dou**, PhD, research interest: intelligent equipment for agriculture, Email: douhj@nercita.org.cn; **Xueguan Zhao**, PhD, research interest: precision agriculture, Email: zhaoxg@nercita.org.cn; **Yakai He**, PhD, research interest: machinery equipment for agriculture, Email: hlyakai@163.com.
***Corresponding author: Xiu Wang**, Professor, research interest: intelligent equipment for agriculture. No. 11, Shuguang Huayuan Middle Road, Haidian District, Beijing 100097, China. Tel: +86-10-51503686, Email: wangx@nercita.org.cn.

standard to evaluate the performance of a precision planter. Miller et al.[18] investigated the planting uniformity of three types of maize vacuum seed meters based on four forward speeds; the results showed that the seed plate type imposed no effect on the planting uniformity when the forward speed was less than 8 km/h but affected the planting uniformity significantly when the forward speed exceeded 11.3 km/h. Liu et al.[19] investigated the effects of different types of maize precision drills on planting uniformity, where ground-wheel-driven sowing was performed at the speed of 7-12 km/h; the results showed that the planting performance of a pneumatic seed meter was better than that of a mechanical seed meter, and that the forward speed significantly affected the coefficient of variation (CV) and the quality of feed index (QTFI). Li et al.[20] designed a planting uniformity experiment to compare ground-wheel-driven seeding and motor-driven seeding performed at a speed of 9-12 km/h using a pneumatic maize precision seed meter; the results showed that the motor-driven seeding was more suitable for high-speed sowing. Many researchers have proven that motor-driven maize precision planting yields better sowing uniformity than ground-wheel-driven maize planting for the same forward speed[15,21,22]. Furthermore, it has been proven that motor-driven maize precision seeding yields better uniformity than ground-wheel-driven maize precision seeding at a speed of 6 km/h and a plant spacing of 24 cm, and that the motor-driven planting method affords fuel conservation[23]. Few studies have focused on the changing trend in planting uniformity of motor-driven metering systems at increasing forward speeds for different types of maize precision planters. However, this trend is crucial for optimizing motor-driven planting systems.

The abovementioned studies have primarily focused on obtaining the seed meter type that yields the best performance in a small range of forward speed and lacked the investigation of trends pertaining to key evaluation parameters of planting uniformity when using motor-driven precision planting. To investigate the planting uniformity of a motor-driven precision maize sowing system based on the forward speed, mechanical and air-suction maize precision drills with a motor-driven seeding control system were used in this study.

2 Materials and methods

Mechanical precision metering by a 2BJY-4 finger pick-up planter (Figure 1a). and pneumatic precision metering by a 2BFQ-6 air-suction planter (Figure 1b) were used as the experimental objects. Seeding was performed by the two planters through a motor-driven maize planting system. The system of the planter 2BJY-4 used ground wheels to measure the forward speed. An arrow shovel furrowing opener was used for ditching, and the distance from the seed exit to the seed bed was 130 mm.

The system of the planter 2BFQ-6 measures the forward speed similarly to the finger-pick-up maize precision planter. The planter was installed on a double-disc ditch, and the distance from the seed exit to the seed bed was 50 mm. The air suction fan received power from the power take-off with an output rotate speed of 540 r/min. The working gas pressure range of the air-suction seed meter was from −6.22 to −6.76 kPa.

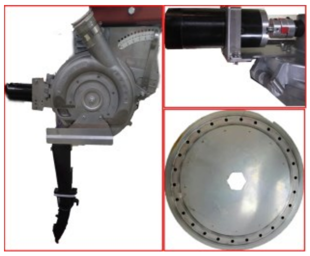
As shown in Figure 2, the two planters were driven by an electric metering system. The finger pick-up seed meter comprised a seed plate containing 18 fingers and was driven by a motor (JCF76R-60R, Beihe, Baoding, Hebei, China) equipped with an encoder (K380600P/R, GTEACH, Jinan, Shandong, China). For the air-suction seed meter, the seed plate contained 26 holes, the diameter of the hole was 4.5 mm, the seed meter was driven by a customized motor (AQMD3608BLS, Aisikong, Chengdu, Sichuan, China), and a gas pressure sensor (CYYZ31, Xingyi, Beijing, China) was used to monitor its working pressure. The electric-driven metering system (Figure 3) used in the simulated speed experiment was the same as that of the field experiment. The metering system comprised a human machine interface (HMI), a metering control electronic control unit (ECU), and a metering monitor ECU. The system was powered by a DC 12 V vehicle-mounted battery and communicated using a CAN-Bus.

a. Finger pick-up motor-driven maize precision planter

b. Air-suction motor-driven maize precision planter

Figure 1 Two types of motor-driven maize precision planters

a. Finger pick-up seed meter



b. Air-suction seed meter

Figure 2 Two types of motor-driven precision maize seed meter

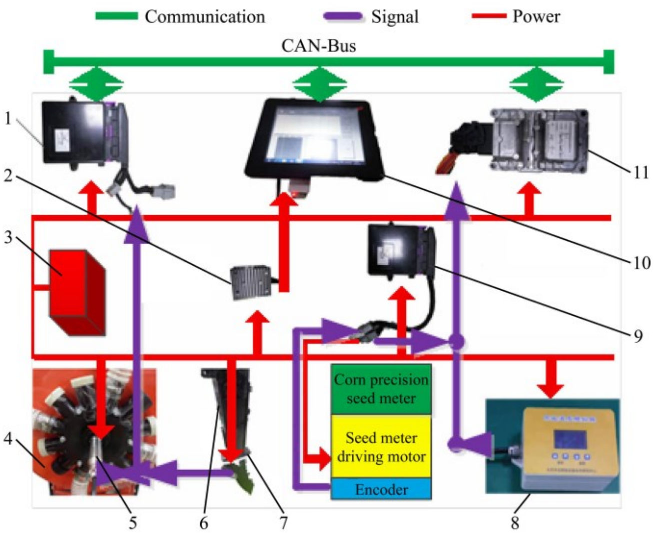
The electric drive metering system can actively control the seeding rate. The target rotate speed of the seed plate can be calculated as follows:

$$n = \frac{50v}{3kp} \tag{1}$$

where, n is the target rotation speed of the seed plate, r/min; v is the forward speed, km/h; k is the number of sowing seeds in each rotation; p is the plant spacing, m.

The metering control ECU controlled the rotate speed of the seed plate ordered by the CAN-Bus message. The metering control ECU monitored the feedback value of the rotate speed through an encoder and controlled the speed of the motor-driven seed meter by outputting the analog signal to the motor driver [24]. The metering monitor ECU detected the seeding signal through the seeding monitor sensor. Subsequently, the planting uniformity was evaluated based on those seeding signals according to ISO

7256-1 (ISO, 1984), and the planter gas pressure and rotate speed of the driving motor were measured.



1. Metering monitor ECU 2. Stabilized voltage module 3. Battery 4. Air suction fan 5. Gas pressure sensor 6. Seed tube 7. Seeding monitor sensor 8. Forward-speed-simulated unit 9. Motor driver 10. HMI 11. Metering control ECU

Figure 3 Electric-driven metering system

The HMI was used for setting the control parameters, monitoring the work state of the electric drive metering system, and displaying the working performance (Figure 4). The uniformity performances of the two planters were investigated using the electric-driven metering system based on the simulated and field speeds. In the simulated speed experiment, the system obtained the speed from the forward-speed-simulated unit and was functioning statically. The QTFI, the multiples index (MUL), and the miss indexes (MISS) of the two planters were evaluated by a self-designed software of the HMI. The experimental seed was Zhendan 958, and the thousand-seed weight was 307 g. The plant spacing and the row spacing were set to 25 cm and 60 cm, respectively. The simulated forward speed increased from 5 to 12 km/h at an interval of 1 km/h. For each speed pass, the system collected 100 seeds to evaluate the QTFI, the MUL, and the MISS. The process was repeated thrice in each speed pass, and the average was obtained for the same speed.

In the field experiment, the seed spacing and the row spacing were also set to 25 cm and 60 cm, respectively. The experimental seed of the field test was the same as the simulated speed test. The two planters were working on the condition of ditching without covering soil after rotary tillage. Four levels of experimental forward speeds were selected for the two planters, i.e., from 5 to 12 km/h with an equal interval according to the actual planter speed. The update time cycle for the system to read the forward speed was 1 s.

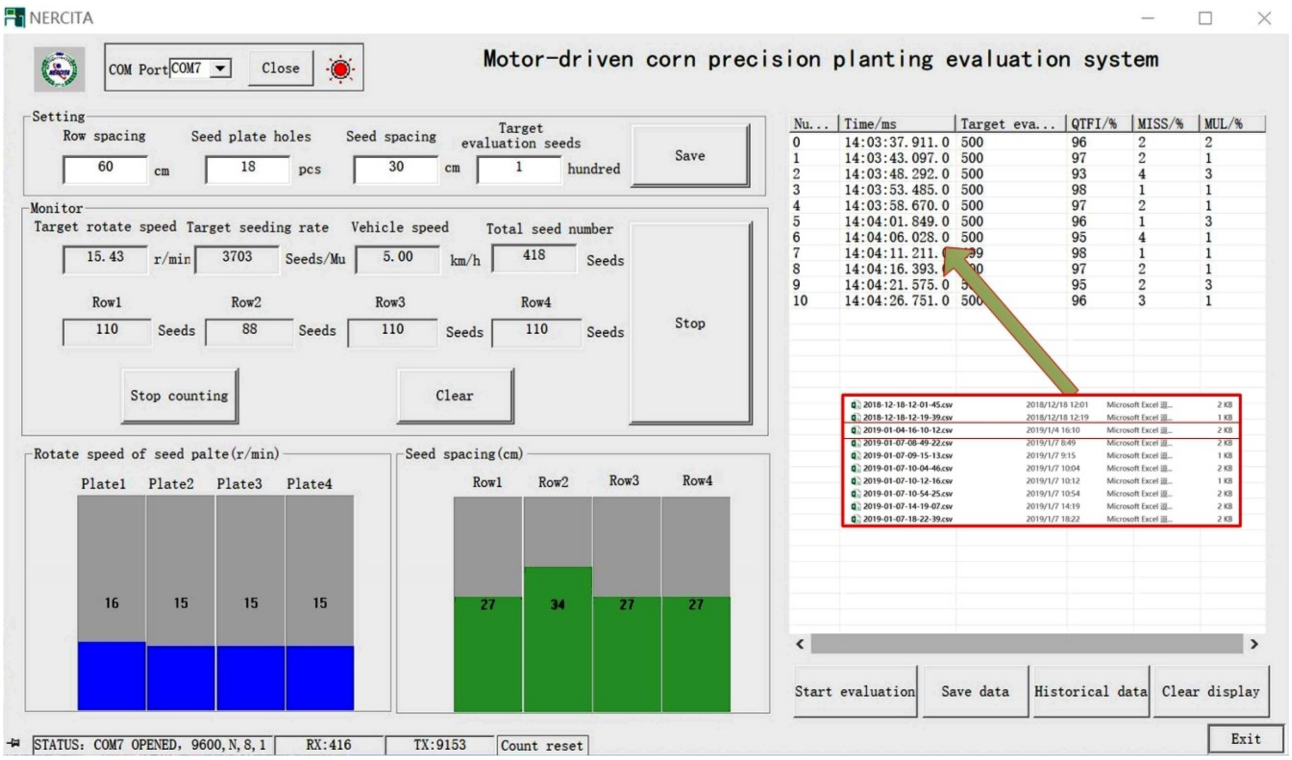


Figure 4 Interface of the HMI software

The vehicle speeds of the finger pick-up motor-driven seeding maize precision planter were divided into four levels, which were 5.70 km/h (Level 1), 6.38 km/h (Level 2), 8.48 km/h (Level 3), and 11.50 km/h (Level 4), and those of the air-suction motor-driven seeding maize precision planter were 5.48 km/h (Level 1), 6.89 km/h (Level 2), 8.63 km/h (Level 3), and 12.67 km/h (Level 4). More than 250 plant spacings were measured in 2-3 rows at each forward speed on the same day (Figure 5). The 250 plant spacings of the two planters were analyzed in each speed pass. First, the plant spacing scatter distributions of the two planters were constructed using MATLAB. A moving average curve of 10 plant spacings was used to analyze the change in plant spacing when the plant spacing was changed continuously at the four speeds. The difference between the actual and target plant spacing at each speed pass may indicate the error direction of the planting uniformity. The difference between the actual and target plant spacing was positive when the actual plant spacing was greater than the target value, and vice versa. Furthermore, the frequency distribution of plant spacing of each planter at the four forward speeds was analyzed, and a third-order B spline method was used to analyze the consecutive frequency trend of the plant spacing. Finally, the QTFI, MISS, MUL, and CV were calculated according to the ISO 7256/1(1984) to evaluate the performance of the motor-driven precision maize sowing planter.

Figure 5 Measurement of plant spacing in field

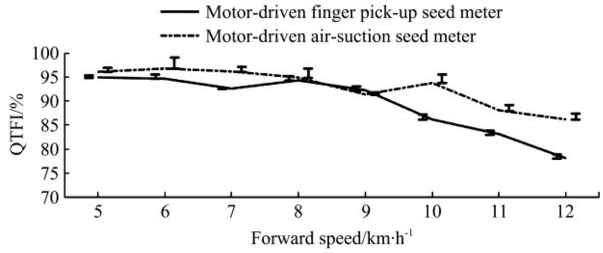
3 Results and discussion

3.1 Uniformity performance in the simulated forward speed experiment

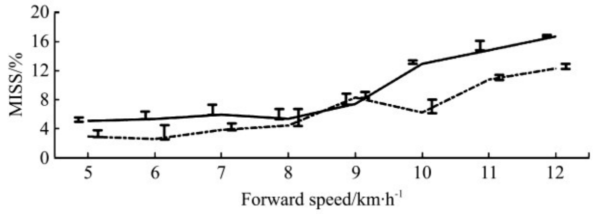
When the forward speed increased from 5 to 12 km/h at an interval of 1 km/h, the QTFI of the finger pick-up and air-suction motor-driven seed meters declined from 94.91% to 78.12% and from 96.06% to 86.18%, respectively (Figure 6). The QTFI of the two seed meters exhibited a cross point when the forward speed was from 8 to 9 km/h. The slope is an indication of the effect of speed on the evaluated indexes. The maximum slope of the QTFI of the finger pick-up seed meter was reduced by 6.08 percentage points when the speed increased from 9 to 10 km/h. The maximum slope of the QTFI of the air-suction seed meter was reduced by 5.68 percentage points when the speed increased from 10 to 11 km/h. The QTFI coefficient variation of the two seed meters was 7.03% and 4.28% when the forward speed increased from 5 to 12 km/h at an interval of 1 km/h.

When the speed increased from 5 to 12 km/h at an interval of 1 km/h, the MISS of the two seed meters increased from 5.08% to 16.70% and from 2.60% to 12.30%. The two MISS curves showed a cross point when the forward speed increased from 8 to 9 km/h. The maximum slopes of the MISS of the two seed meters increased by 5.51% and 4.53% when the speed increased from 9 to 10 km/h, and from 10 to 11 km/h, respectively. The MISS coefficient variation of the two seed meters was 52.24% and 57.07%. The MUL of the two seed meters was affected by the increased speed. When the forward speed increased from 5 to 8 km/h, the seeding uniformity changed relatively smoothly, and the lowest QTFI, the maximum MISS, and the maximum MUL of the two motor-driven seed meters were 94.29% and 94.88%; 5.38%, and 4.46%; and 1.46% and 0.65%. However, when the forward speed increased from 8 to 12 km/h, the seeding uniformity decrease significantly; the lowest QTFI, maximum MISS, and maximum MUL of the two seed meters were 78.12% and 86.18%; 16.70% and 12.30%; and 5.17% and 1.51%. When the seeding rate was greater than the inherent seeding performance of the two seed meters, the seeding uniformity demonstrated a greater decrease. The results implied that the greater decrease in the QTFI with increased speeds was primarily caused by the greater increase in the miss-seeding.

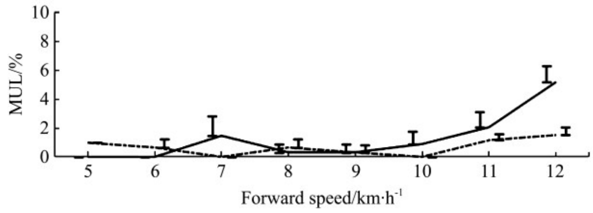
The QTFI and the MISS of the two seed meters decreased and increased linearly, respectively. However, the MUL of the two seed meters exhibited a random trend. With the increase in the forward speed, the descending order of the CV of those indexes was QTFI, MISS, and MUL, and the descending order of the absolute value of those indexes was QTFI, MISS, and MUL.



a. The results of QTFI



b. The results of MISS



c. The results of MUL

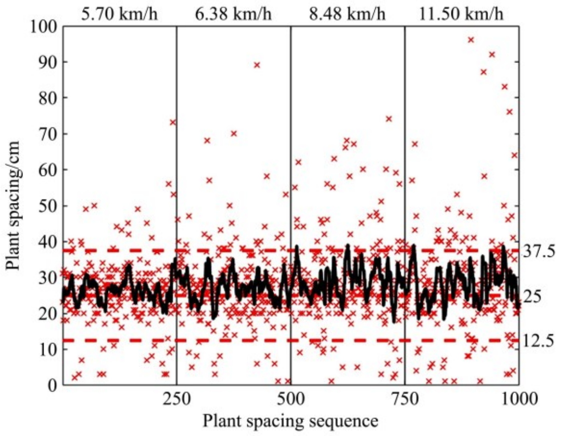
Note: QTFI: Quality of feed index; MISS: Miss indexes; MUL: Multiples index.

Figure 6 Planting uniformity performance effect by the simulated forward speed

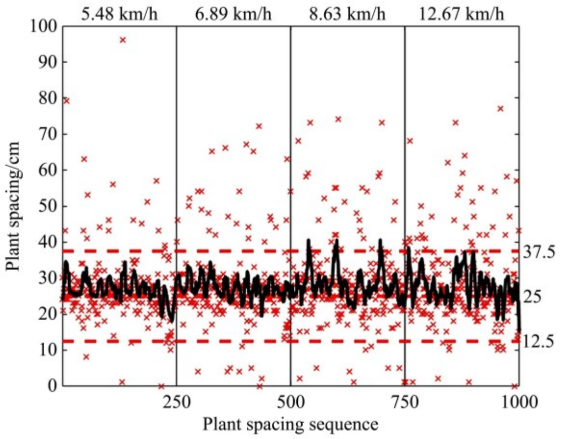
3.2 Plant spacing distribution results of the field experiment

The plant spacing scatter distribution results of the finger pick-up maize precision planter are shown in Figure 7a. According to the results, the fluctuation ranges of the plant spacing at a constant forward speed were the same. Alternating changes of increasing and decreasing trends were observed in the moving average curve. Furthermore, the difference between the plant spacing value of the moving average and the setting value of the plant spacing indicated the precision of the plant spacing control. At the four forward speeds of 5.70 km/h, 6.38 km/h, 8.48 km/h, and 11.50 km/h, the average positive differences were 2.90 cm, 3.87 cm, 5.06 cm, and 5.50 cm, respectively; the standard deviations were 2.21, 2.41, 3.24, and 3.35, respectively; and the numbers of the positive differences were 175, 179, 212, and 180, respectively. The averages of the negative difference at the four forward speeds were −2.03 cm, −2.23 cm, −2.12 cm, and −2.39 cm; the standard deviations were 1.22 cm, 1.59 cm, 1.59 cm, and 1.64 cm; and the numbers of the negative differences were 75, 71, 83, and 70, respectively. The results show that number of positive difference points was greater than that of the negative difference points. Under the four levels of vehicle speeds, the number of positive moving average points was 2.49 times that of negative moving average points. The effect of the forward speed on the motor-driven maize precision planting system was manifested in the greater plant spacing control. The average positive difference linearly increased with the forward speed, but the negative difference was not affected significantly.

The plant spacing scatter distribution of the air-suction maize precision planter is shown in Figure 7b. The actual plant spacing exhibited a narrow fluctuation range, which was in the typical plant spacing range (the distance was greater than 12.5 cm but less than 37.5 cm) at the forward speeds of 5.48 km/h and the 6.89 km/h. Except for three peaks, the curve of the experimental plant spacing at the forward speed of 8.63 km/h exhibited a fluctuation range similar to those of the two forward speeds above. The curve at the forward speed of 12.67 km/h exhibited a greater fluctuation range than the three forward speeds above.



a. Distribution of plant spacing of finger pick-up maize precision planter



b. Distribution of plant spacing of air-suction maize precision planter

Figure 7 Distribution diagram of plant spacing of the two planters under different forward speeds

At the forward speeds of 5.48 km/h, 6.89 km/h, 8.63 km/h, and 12.67 km/h, the average positive difference was 2.78, 3.12, 4.23, and 4.25 cm, respectively, with the standard deviation of 2.35 cm, 2.20 cm, 3.56 cm, and 3.28 cm, respectively; meanwhile, the average negative difference was −2.60 cm, −1.42 cm, −1.57 cm, and −2.05 cm, respectively, with the standard deviation of 2.23 cm, 1.30 cm, 1.01 cm, and 1.95 cm, respectively. The numbers of positive moving average points at the four forward speeds were 209, 215, 204, and 190, respectively, and the numbers of negative moving average points were 41, 35, 46, and 60, respectively. Under the four levels of vehicle speeds, the number of positive moving average points was 4.49 times that of negative moving average points. Same with the finger pick-up maize precision planter, the number of positive moving average points was significantly greater than that of the negative moving average points, and the average positive difference linearly increased with the forward speed.

The results of the two planters indicated that the average positive difference of the two planters linearly increased with the forward speed, the number of positive moving average points was significantly greater than that of the negative moving average points, and the negative difference of the two planters did not exhibit a linear correlation. The positive difference of the air-suction maize precision planter was smaller than that of the finger pick-up planter at the four level forward speeds. The above results indicate that the increase in the positive difference of plant spacing is the major effect factor in the planting uniformity of the two motor-driven maize precision planters.

3.3 Frequency distribution of plant spacing in the field experiment

The results of the finger pick-up planter are shown in Figure 8.

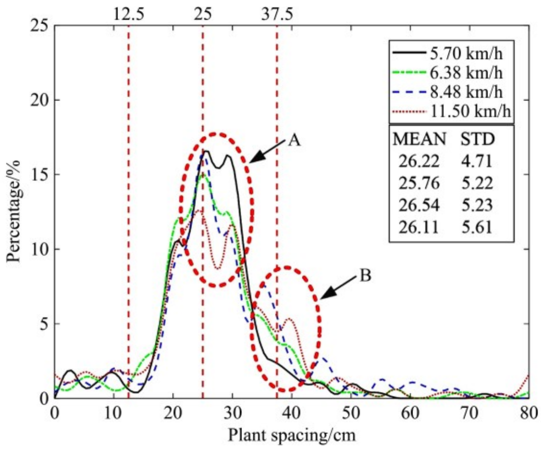


Figure 8 Frequency histogram of finger pick-up planter affected by forward speed

Those plant spacing values corresponded to max distribution frequency varied in the range of (24.69±0.63) cm at the four speeds. The frequencies of normal seeds at the four forward speeds were 87.20%, 83.60%, 77.20%, and 76.00%; the frequencies of misses were 6.80%, 11.60%, 16.40%, 16.00%; and the frequencies of multiple seeds were 6.00%, 4.80%, 6.40%, and 8.00%, correspondingly.

The peak value of the frequency curve in region A decreased with the forward speed, whereas that in region B (the plant spacing was greater than 35.00 cm but smaller than 43.75 cm), which was approximately the maximum value of the typical plant spacing, was greater compared with the value near the minimum value of the typical plant spacing. Furthermore, it increased with the forward speed at 8.48 km/h and 11.50 km/h. The frequency of the plant spacing that was less than 12.50 cm or more than 43.75 cm was relatively smaller than those of other cases, and it changed randomly with the increase of the forward speed.

The frequency distribution of plant spacing of the air-suction motor-driven maize precision planter in the field was shown in Figure 9. At the four forward speeds, those plant spacing values corresponded to the max distribution frequency and had a minor range of (25.63±0.32) cm. The frequencies of the normal seeds were 90.0%, 86.0%, 84.8%, and 80.4%; the frequencies of misses were 7.2%, 10.8%, 11.6%, and 14.4%; and the frequencies of the multiple seeds were 2.8%, 3.2%, 3.6%, and 5.2%, correspondingly.

Some of the trends shown in Figure 7 were similar to those in Figure 8. The peak value of the frequency curve in region A also decreased when the forward speed increased, whereas that in region B (the plant spacing was greater than 35.00 cm but smaller than 43.75 cm) was also bigger compared with the value near the minimum typical plant spacing. Furthermore, it increased with the forward speed at 8.63 and 12.67 km/h. The frequency of the plant spacing that was less than 12.50 cm but more than 43.75 cm was relatively smaller compared with those of other cases, and it changed randomly with the increase in the forward speed.

At the same forward speed level, the plant spacing that corresponded to the peak values in Figures 8 and 9 was a coincidence. Furtherly, the frequency distribution shown in Figure 9 was more concentrated, and the peak value of the plant spacing frequency was greater. The frequency range of plant spacing in region B was approximate when the maize seed was sown normally; it was primarily affected by the control error between the actual and theoretical planting rates. The control error can be improved by improving the system control performance, such as by improving the detection precision of the forward speed[24].

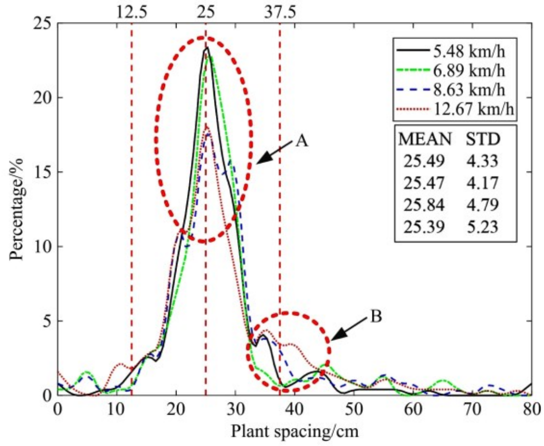
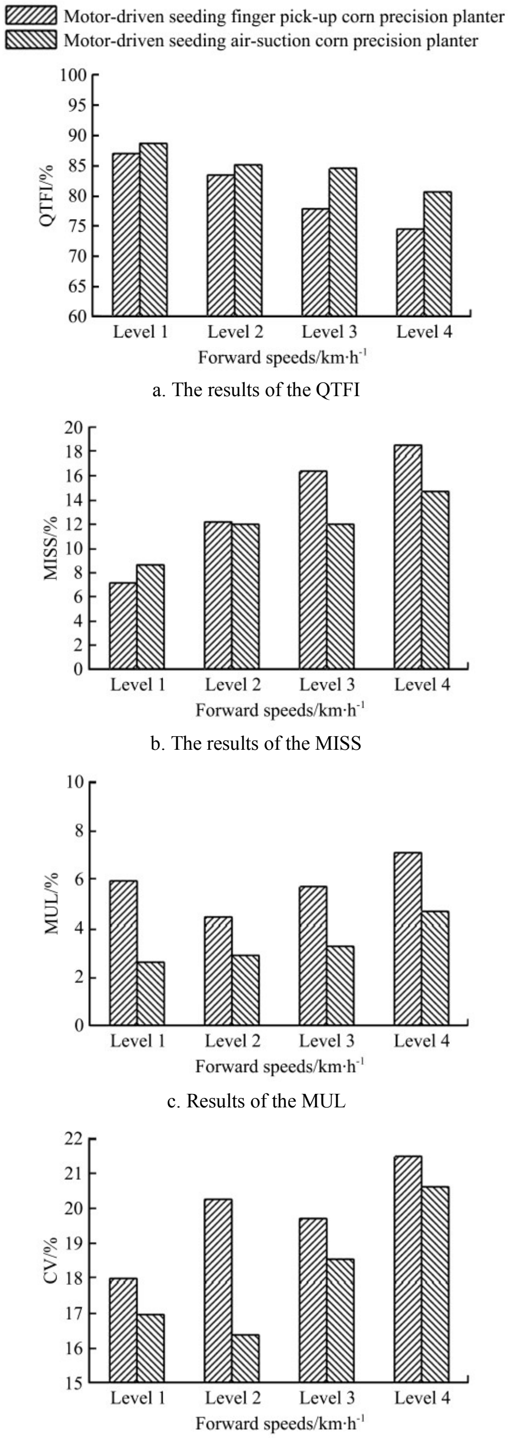


Figure 9 Frequency histogram of air-suction seed meter affected by forward speed

3.4 Evaluation of planting uniformity in the field

The maize precision planting uniformity was evaluated based on the QTFI, MUL, MISS, and CV (Figure 10). The QTFI and MISS of the two planters decreased and increased with the forward speed, respectively. The maximum QTFI of the finger pick-up planter was 86.96% with a maximum decrease of 12.49%, the maximum QTFI of the air-suction planter was 88.72% with a maximum decrease of 8.14%, and the air-suction planter with motor-driven seeding had a less significant effect on the planting uniformity with increasing forward speed. The two planters using motor-driven planting showed a small difference in the QTFI at medium and lower forward speeds. The MUL of the air-suction planter increased with the forward speed, but the MUL of the finger pick-up planter did not always show a positive correlation with the forward speed. The minimum value of the MUL of the finger pick-up planter was 16% at 6.38 km/h. The motor-driven planting control method (Equation (1)) could not solve the problem associated with the greater value of the MUL. The new maize precision planting control method for compensating the seeding spacing difference to further improve maize precision planting uniformity must be further investigated. The CV of the finger pick-up planter at 8.48 km/h was less than that at 6.38 km/h. The maximum CV at the four forward speeds was 21.55% with a change extent of 5.35%, whereas that of the air-suction planter at 6.38 km/h was less than that at 5.37 km/h. The maximum CV at the four forward speeds was 20.66% with a change extent of 2.69%. The CV of the two planters showed a small shift owing to those forward speeds. Unlike the forward speed that imposed a significant effect on the CV and QTFI of the ground-wheel-driven seeding maize precision planter[19], this study showed that the forward speed imposed only a slight effect on the CV when the maize precision planter with a motor-driven seeding system was used. Furthermore, Zhai et al.[26] also proved that, for the John Deere ExactEmerge™ with an electric-driven metering system, the plant spacing has a small CV with a maximum of 14.3% even when the forward speed increased.



a. The results of the QTFI

b. The results of the MISS

c. Results of the MUL

d. Results of the CV

Note: CV: Coefficient of variation.

Figure 10 Uniformity evaluation of the two planters sowing in the field

The average MISS and MUL of the motor-driven seeding finger pick-up maize precision planter were 9.65% and 5.18% at the two lower forward speed levels, respectively; and 17.43% and 6.40% at the two higher forward speed levels, respectively. The average MISS and the average MUL of the motor-driven seeding air-suction maize precision planter were 10.32% and 2.77% at the two lower forward speed levels, respectively; and 13.40% and 3.98% at the two higher forward speed levels, respectively. The results showed that the MISS had a greater absolute value and change more significantly when the forward speed increased.

In the simulation experiment, the simulated speed is accurate and controllable, and the planting uniformity evaluation results preliminarily verify the response performance of the motor-driven seed metering system to the two types of seed metering devices. In the field speed experiment, the vehicle speed fluctuates caused of the driving stability of the tractor, wheel skip, and rough ground.

The average reduction of the QTFI of the two planters in the simulation experiment and in the field experiment was relatively close, which was 13.34% and 10.32%, respectively. However, under the same speed level, the QTFI of the two types of planters in the field experiment is lower than that in the simulation speed experiment, which shows that the motor-driven seed metering control performance of the system facing the fluctuating speed in the field needs to be optimized.

Comparing the simulation experiment, the MISS of the two planters in field experiment was greater at the same level of forward speed, and the MUL of both tests showed random characteristics. The greater MISS caused the planting uniformity of the two planters to deteriorate when the forward speed increased. The current solution is to change the ground wheel driving mechanism to the motor-driven mechanism. However, the seeding rate control method still relates to Equation (1). This method would result in a seeding amount error that cannot be eliminated when the forward speed increases, and the sowing amount error is always negative. Therefore, further studies on new motor-driven maize precision seeding methods are necessary to solve the above-mentioned problem.

4 Conclusions

1) The planting uniformity became worse with the increased speed both in the laboratory and the field, although the two planters were equipped with a motor-driven seed metering system. The MISS gradually increased with the speed of the two types of planters, while the MUL showed randomness. Thus, the optimization of motor-driven seed metering system is expected to improve the problem that the increasing speed affects the planting uniformity by reducing the MISS.

2) The plant spacing scatter distribution of the two planters in the field experiment was analyzed. The results indicated that the average positive difference of the two planters linearly increased with the forward speed, the number of positive moving average points was significantly greater than that of the negative moving average points, which was 2.49 times and 4.49 times, respectively. The above results indicate that the increase in the positive difference of plant spacing is the major effect factor in the planting uniformity of the two motor-driven maize precision planters.

3) A third-order B spline method was used to analyze the consecutive frequency trend of the seed plant spacing at the four level field speeds. The plant spacing corresponded to distribution frequency of the two planters in field was close to the target seed spacing of 25 cm with those plant spacing values corresponding to max distribution frequency of the two planters at the four level field speeds were (24.69±0.63) cm and (25.63±0.32) cm, respectively.

4) The QTFI of the two planters in simulated speeds and field speeds was analyzed. The results showed that the average reduction of the QTFI of the two planters in the simulation experiment and in the field experiment was relatively close, which was 13.34% and 10.32%, respectively. However, under the same speed level, the QTFI of the two types of planters in the field experiment is lower than that in the simulation speed experiment, which indicated that the motor-driven seed metering control performance of the system facing the fluctuating speed in the field needs to be optimized.

Acknowledgements

This work was financially supported by the Beijing Rural Revitalization Science and Technology Project (20220614-02), National Key Research and Development Plan Project (2019YFE0125200), Hebei Province key research and development program (21327205D). Thanks to the researchers of the Precision Spraying Department of the National Engineering Research Center for Information Technology in Agriculture for their efforts in this research.

[References]

[1] Xia Y, Xu Y F, Li J B, Zhang C, Fan S X. Recent advances in emerging techniques for non-destructive detection of seed viability: A review. Artificial Intelligence in Agriculture, 2019; 1: 35–47.

[2] Yang L, Yan B X, Zhang D X, Zhang T L, Wang Y X, Cui T. Research progress on precision planting technology of maize. Transactions of the CSAE, 2016; 47(11): 38–48. (in Chinese)

[3] Hao Y, Cui T, Bora G, Zhang D, Wei J, He X, et al. Development of an instrument to measure planter seed meter performance. Applied Engineering in Agriculture, 2017; 33(1): 31–40.

[4] Yin X, Noguchi N, Yang T X, Jin C Q. Development and evaluation of a low-cost precision seeding control system for a corn drill. Int J Agric & Biol Eng, 2018; 11(5): 95–99.

[5] Yin Y X, Chen L P, Meng Z J, Li B, Luo C H, Fu W Q, et al. Design and evaluation of a maize monitoring system for precision planting. Int J Agric & Biol Eng, 2018; 11(4): 166–170.

[6] Yang L, Zhang X Y, Chen S Y, Shao L W, Sun H Y, Niu J F. Increasing the planting uniformity improves the yield of summer maize. Agron J, 2017; 109(47): 1463–1475.

[7] Gesch R W, Kim K I, Forcella F. Influence of seeding rate and row spacing on cuphea seed yield in the Northern Corn Belt. Ind. Crops Prod, 2010; 32: 692–695.

[8] Yang L, Zhang R, Gao N N, Cui T, Liu Q W, Zhang D X. Performance of no-till corn precision planter equipped with row cleaners. Int J Agric & Biol Eng, 2015; 8(5): 15–25.

[9] Değirmencioğlu A, Cakmak B, Yazgi A. Prototype twin vacuum disk metering unit for improved plant spacing uniformity performance at high forward speeds. Turk J Agric For, 2018; 42: 195–206.

[10] Jia H L, Chen Y L, Zhao J L, Guo M Z, Huang D Y, Zhuang J. Design and key parameter optimization of an agitated soybean seed metering device with horizontal seed filling. Int J Agric & Biol Eng, 2018; 11(2): 76–87.

[11] Lyu J Q, Yang Y, Li Z H, Shang Q Q, Li J C, Liu Z Y. Design and experiment of an air-suction potato seed metering device. Int J Agric & Biol Eng, 2016; 9(5): 33–42.

[12] Wang J W, Tang H, Wang J F, Li X, Huang H N. Optimization design and experiment on ripple surface type pickup finger of precision maize seed metering device. Int J Agric & Biol Eng, 2017; 10(1): 61–71.

[13] He X T, Ding Y Q, Zhang D X, Yang L, Cui T, Wei J T, et al. Design and evaluation of PID electronic control system for seed meters for maize precision planting. Transactions of the CSAE, 2017; 33(17): 28–33.

[14] Cay A, Kocabiyik H, May S. Development of an electro-mechanic control system for seed-metering unit of single seed corn planters Part I: Design and laboratory simulation. Comput Electron Agric, 2018; 144: 71–79.

[15] Yin X, Noguchi N, Yang T, Jin C. Development and evaluation of a low-cost precision seeding control system for a corn drill. Int J Agric & Biol Eng, 2018; 11(5): 95–99.

[16] Siemens M C, Gayler R R. Improving seed spacing uniformity of precision vegetable planters. Appl Eng Agric, 2016; 32(5): 579–587.

[17] An X, Wang S, Duan H, Yang C, Yu Y. Test on effect of the operating speed of maize-soybean interplanting seeders on performance of seeder-metering devices. Procedia Eng, 2017; 174: 353–359.

[18] Miller A E, Rascon J, Koller A, Porter M W, Taylor K R, Raun R W, et al. Evaluation of corn seed vacuum metering systems. Dallas, Texas, July 29 - August 1, 2012, ASABE Paper No. 121337167.
[19] Liu Q W, He X T, Yang L, Zhang D X, Cui T, Qu Z, et al. Effect of travel speed on seed spacing uniformity of corn seed meter. Int J Agric & Biol Eng, 2017; 10(4): 98–106.
[20] Yang L, He X T, Cui T, Zhang D X, Shi S, Zhang R, et al. Development of mechatronic driving system for seed meters equipped on conventional precision corn planter. Int J Agric & Biol Eng, 2015; 8(4): 1–9.
[21] Cay A, Kocabiyik H, May S. Development of an electro-mechanic control system for seed-metering unit of single seed corn planters Part II: Field performance. Computers and Electronics in Agriculture, 2018; 145, 11–17.
[22] Chen L Q, Xie B B, Li Z D, Yang L, Chen Y X. Design of control system of maize precision seeding based on double closed loop PID fuzzy algorithm. Transactions of the CSAE, 2018; 34(9): 33–41. (in Chinese)
[23] Zhai J B, Xia J F, Zhou Y, Zhang S. Design and experimental study of the control system for precision seed-metering device. Int J Agric & Biol Eng, 2014; 7(3): 13–18.
[24] Yang S, Wang X, Gao Y Y, Zhao X G, Dou H J, Zhao C J. Design and experiment of motor-driving bus control system for corn vacuum seed meter. Transactions of the CSAM, 2019; 50(2): 57–67. (in Chinese)
[25] Ding Y Q, Yang L, Zhang D X, Cui T, He X T, Zhong X J. Control system of motor driving maize precision planter based on GPS speed measurement. Transactions of the CSAM, 2018; 49(8): 42–49.
[26] Zhai C Y, Long J, Taylor R, Weckler P, Wang N. Field scale row unit vibration affecting planting quality. Precision Agriculture, 2020; 21(3): 589–602.