Effect of travel speed on seed spacing uniformity of corn seed meter

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Abstract: Both seeding performance of seed metering unit and travel speed of seed planter have significant effects on seeding quality, thereby affecting crop growth and yields. In order to determine the effects of different travel speeds on seed spacing uniformity, four different types of seed meters were evaluated at five different travel speeds on seed meter test bench and in field. The tested seed meters included a finger pickup seed meter, a scoop-wheel seed meter, an air-pressure type seed meter and an air-blowing type seed meter. The seeding performance of the horizontal distribution of seeds within a row was described by using the coefficient of variation, the quality of feed index, the multiple index and the miss-seeding index. Experiments were performed in laboratory and field, respectively. Results indicated that different travel speeds have statistically significant effects on seed spacing uniformity. The four types of seed meters performed better on the seed meter test bench than in the field. Coefficient of variation increases and quality of feed index decreases as the travel speed of seed planter increases. The best seed spacing uniformity was obtained with the air-pressure type seed meter, followed with the air-blowing type seed meter, the finger pickup seed meter and the scoop-wheel seed meter. There were considerable differences between the performances of the scoop-wheel seed meter in the bench test and field test; the seeding qualities were much better in the bench test than in the field test. The scoop-wheel seed meter is more sensitive to vibration than the other types of seed meters.
Keywords: corn seed meter, travel speed, seed spacing uniformity, precision corn planter, field test, test bench
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1 Introduction

Corn is the main food crop in China, with an estimated annual production of 22 million tons from 3.70 million hm^2 in 2014, which accounted for approximately 20% of the total world corn seed production. Corn precision seeding technology has been widely used in corn seeding operations for its seed-saving and labor-saving advantages. As the core component of a planter, a precision seed meter has the characteristics of good versatility and well-adapted, stable and reliable performance, and it can be divided into two types based on working principle: mechanical and pneumatic seed meters.

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Seed spacing uniformity is an important indicator in evaluating seed drill performance, because a uniform distribution of seeds can not only provide maximum space for each plant but also make for uniform root size, which can increase yields and reduce harvest loss[1]. Ensuring that the seeds be put at a desired depth and spacing within the row is the main objective of precision seeding. Uniform seed spacing and depth is propitious to higher emergence rate and increasing yield by decreasing competition between plants for available light, water and nutrients[2]. A wide variety of measures had been used to quantify seed drill performance with regard to seed spacing[3-9]. The distribution of spacing between plants in a soil bin or in the field had been used as a performance parameter[10-14]. Data collected to measure seeding accuracy of a planter compose of a series of distance of plants. The distance between plants within a row was influenced by some factors, such as failure of seed to be dropped, multiple seeds dropped at the same time, failure of seeds to emerge, and the position variability around the drop point[15]. The five parameters are the main index of seeding accuracy including the quality of feed index, the multiple index, the miss-seeding index, the mean spacing and the coefficient of variation (CV). Seed spacing uniformity was usually described using the mean spacing and the CV. The mean seed spacing was influenced by both the seed density and the intra-row distribution. For common grain drills, a CV of 20% is an acceptable seeding accuracy achieved by mechanical and pneumatic seeders when they are performing well[16]. The mean spacing and the coefficient of variation are the two characteristics of plant spacing distribution for single seed planters. Karayel et al.[2] stated that the optimal seeding quality were guaranteed when a precision planter was used after preparing the soil with tillage implement, including the most uniform depth of seeding, the best uniformity of seed spacing, and the maximum rate of emergence. The multiple index, the miss-seeding index, and the quality of feed index was not influenced by different tilling conditions.

Sugar beet planting performance was evaluated by Panning et al.[17] for a general-purpose seeder suitable for row crops, a precision seeder suitable for the shallow planting of small seeds, and a vacuum-metering general-purpose seeder suitable for row crops. In their field test, the most uniform seed spacing for each seeder configuration occurred at the lowest travel speed, which was 3.2 km/h. For all seeder configurations, the seed spacing uniformity decreased as the travel speed increased from 3.2 km/h to 8.0 km/h. The seed spacing uniformity determined in field tests was less than or equal to the seed spacing uniformity determined in laboratory experiments.

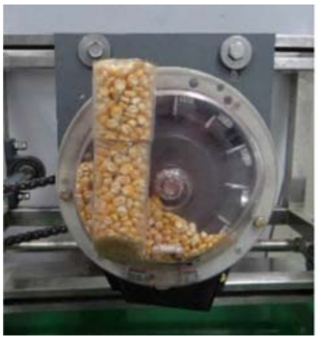
Row crop planter performance in a field test was evaluated and the vacuum-type planter was tested using cotton and corn seeds by Moody et al.[18] at travel speeds of 4.8 km/h, 7.2 km/h and 9.7 km/h. From the study, conclusion was drawn that the variability in seed spacing increased with the increase of seed meter speed.

Chhinnan et al.[19] evaluated an inclined plate seeder for seeding peanut seeds at planting speeds of 1.6 km/h, 3.2 km/h and 4.8 km/h. Conclusion was drawn from the study that as the seeder speed increased, the average seed spacing and the coefficient of variation both increased, meaning the uniformity of seed spacing decreased.

The objectives of this study were to obtain seed spacing data of different seed meters at different travel speeds under both laboratory and field conditions, and compare the effects of different travel speeds on seed spacing uniformity. The significance levels of the effect were also investigated.

2 Materials and methods

Experiments were performed in the laboratory and in the field, respectively. Experiment in the laboratory was conducted firstly. Four types of seed meters were selected to test, including a finger pickup seed meter (Figure 1a), a scoop-wheel seed meter (Figure 1b), an air-pressure type seed meter (Figure 1c) and an air-blowing type seed meter (Figure 1d). The first two seed meters are mechanical seed meters, and the other two are pneumatic seed meters, which are all typical precision seed meters.



a. Finger pickup seed meter

b. Scoop-wheel seed meter

c. Air-pressure type seed meter

d. Air-blowing type seed meter

Figure 1 Four types of seed meters used on the seed meter test bench experiment and in field test

The finger pickup seed meter is driven by the PTO of the tractor when working, finger pickup pressure plate and finger pickup plate rotate synchronously. Twelve spring-loaded fingers are mounted on a vertical disk which rotates in a seed hopper. As they travel on their circular path, the fingers ride on a stationary disk which is concentric with the rotating disk. Fingers opened and closed in regular time with the action of the cam and a fine spring. When each finger passes through the bottom of the hopper, it opened and picked up one or more seeds. The finger passes over an indentation in the stationary disk, causing it to grip one seed while any others fall back into the seed hopper. With further movement, the finger passes across an opening in the stationary disk and the seed is ejected into the seed placement belt for transport to the seed tube[20].

The working principle of the scoop-wheel seed meter works like this: eighteen scoops are installed on a vertical disk which rotates in a seed hopper. When each scoop passes through the bottom of the hopper, the scoop grips one or more seeds while any others fall back into the seed hopper. With further movement, the finger passes across an opening in the stationary disk and the seed is ejected into the seed-guiding chamber for transport to the seed tube.

The working principle of the air-pressure type seed meter is like this: twenty five seed holes on a vertical seed plate. When each seed hole passes through the bottom of the hopper, differential pressure holds one or more seeds in the cell. With continued movement, superfluous seeds fall back into the seed hopper with the action of seed-cleaning device. As each cell nears the seed tube, a rear shell cuts off the air supply to the cell and the seed falls into the seed tube by gravity[21].

The air-blowing type seed meter work like this: twenty four tapered holes evenly distributed on the outside circumference surface. When the tapered hole passes through seed hopper, one or more seeds entered the tapered hole by gravity and friction between the seed and the seed plate. Superfluous seeds are cleaned with the airflow from the nozzle above the seed plate. Only one seed is left at the bottom of the tapered hole. With continued movement, the tapered hole passes across the seed outlet and the seed in it falls into the seed tube[22].

The laboratory experiment was performed using a type JPS-12 computer vision performance seed meter test bench (Figure 2). The seed meter test bench was used to test precision seeding, bunch planting and drilling, and real-time detection of seeding performance was performed based on computer vision technology. The index of seeding performance of the precision seed meter can be determined, including the mean spacing, the variation coefficient of seed spacing, the quality of feed index, the multiple index and the miss-seeding index. The bench can also output experimental data and charts that meet the requirements of government standards. Parameters can be regulated during the laboratory experiment, including the rotation of the seed disc, the positive pressure and the travel speed of conveyor belt.

Figure 2 Type JPS-12 computer vision performance seed meter test bench

The finger pickup seed meter was first fixed into the mounting rack of the seed meter test bench, and the location of the video camera and the outlet of the oil pipe were rearranged to ensure that images of the seeds be captured by the video camera easily. Sufficient oil was required on the top surface of the belt to capture seeds onto the belt surface with minimum rolling or bouncing. The scoop-wheel seed meter was the second one to be examined, and the air-blowing type seed meter was the third one. The pressure value was set at 3.5 kPa for the two types of pneumatic-type seed meter. The seeding performance indexes of the three types of seed meters were tested on the seed meter test bench, including the finger pickup seed meter, the scoop-wheel seed meter and the air-blowing type seed meter. The seeding performance indexes of the air-pressure seed meter were obtained by a method of high-speed photography, not by the video camera of the seed meter test bench. The main reason for this was that the high positive pressure in the outlet of the seed meter would blow away the oil on the delivery belt, causing that seeds dropped from the seed meter could not be attached to the oil strip. The laboratory experiment was performed at five different travel speeds of seed belt (7.0, 8.7, 9.7, 11.0 and 12.2 km/h) with three replications.

The vibration of the seed meter in the test bench was less than that occurring in the field due to the moving parts of the seeder, and the oil strip in the test bench could keep the seeds more firmly from the seed meter than the soil in the field, so the seeding performance of the seed meter in the field might be different from that obtained in the test bench. Therefore, it was necessary to do the field test to learn about the seeding performance comprehensively, and obtain the data of seed spacing uniformity.

A field test was established in a field located in Gu’an city, Hebei Province, China, in September 2015. The area belongs to the warm temperate zone, continental semi-arid and semi-humid climatic zone, with four seasons, adequate light, and a large difference in temperature. The annual total rainfall is 548.6 mm, and the mean temperature is 11.5°C. The experimental field is flat, and the soil type is clay loam. The soil bulk density measurement was performed for a depth of 0-10 cm, using soil sampler with an inside diameter and height of 50 mm. A soil compaction meter (Field Scout SC 900, Spectrum Technologies, Inc. of Plainfield, Illinois, USA), was used to measure the penetration resistance of the soil in the experimental field, and the moisture content was measured using the oven drying method.

As shown in Figure 3, the four types of seed meters were fixed in four row units of the 2BYJMFQC-4 air-blowing-type corn no-till precision seeder, respectively, which was developed by the Agricultural Machinery and Equipment Laboratory for Corn Production at the College of Engineering, China Agricultural University. Key components of the row unit included a double disk furrow opener, coping wheel, seed meter and drive wheel. The four types of seed meters were installed on four row units, respectively. The installed order was shown in Figure 3. The seed metering system on the corn seeder was adjusted for the target seed spacing of 0.22 m, which is the common seed spacing for planting corn. The transmission system of the corn seeder was composed of three triple chain-and-sprocket drives, the transmission ratios of each row unit were determined based on the number of holes. The transmission ratios were changed by replacing the previous sprockets with the appropriate sprockets. A fan provided positive pressure for the two pneumatic seed meters through a circular tube. Two pressure limiting valves were installed in two outlets of the circular tube and outlet pressure was limited to 3.3-3.7 kPa, respectively. The seed depth was set at 50 mm for corn seeder by adjusting the position of the coping wheel.

Figure 3 Rear view of corn seeder with four types of seed meters

The experimental field with an area of 50 m × 2.4 m was prepared under cultivation by rotary tiller. The plots and the blocks were separated by buffer strips of 15 m in length and 0.5 m in width. Five travel speeds were considered the treatments, and three replications were used. The four seed meters were the finger pickup seed meter, the scoop-wheel seed meter, the air-pressure type seed meter and the air-blowing type seed meter. The travel speeds of the corn seeder were set at 7.0 km/h, 8.7 km/h, 9.7 km/h, 11.0 km/h and 12.2 km/h, which were at the same travel speeds as in test bench experiment.

Spacing measurements were performed in each plot after 20 d. As shown in Figure 4, line 1 to line 4 were the distribution of corn seedlings from the seeds sown by the finger pickup seed meter, the scoop-wheel seed meter, the air-pressure type seed meter and the air-blowing type seed meter at the travel speed of 9.7 km/h, respectively. The seed spacing was measured with a measuring tape.

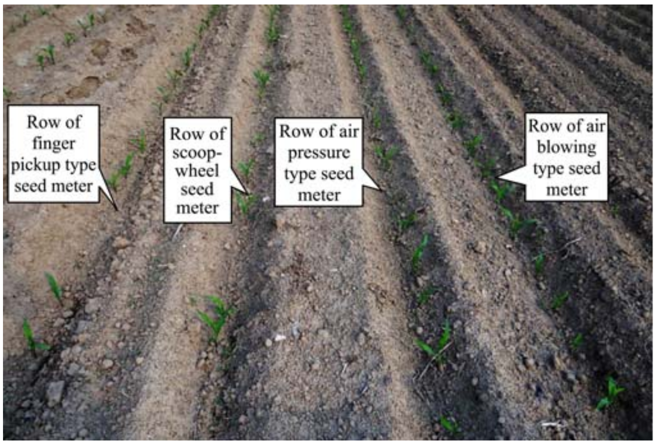


Figure 4 Distribution of corn seedlings in four rows

Seed spacing uniformity is evaluated by four indexes including the variation coefficient of seed spacing, the quality of feed index, the multiple index and the miss-seeding index. The variation coefficient of seed spacing is used to quantify the distribution of seed spacing. The quality of feed index (QTFI) is the percentage of occasions that the seed spacing is more than half but no more than 1.5 times of the theoretical spacing and is a measure of the percentage of single seed drops. The multiple index (MULI) is the percentage of occasions that the seed spacing is less than or equal to half of the theoretical spacing. The miss-seeding index (MISI) is the percentage of occasions that the seed spacing is greater than 1.5 times of the theoretical spacing. The data were analyzed using the IBM SPSS statistics software package. The 'univariate' command included in 'general linear model' was used to perform the analysis of variance, which was appropriate for a randomized complete block design. The means were compared using Duncan's multiple range tests included in 'post hoc multiple comparisons'. Statistical significance was evaluated at the level of $p<0.05$.

3 Results and discussion

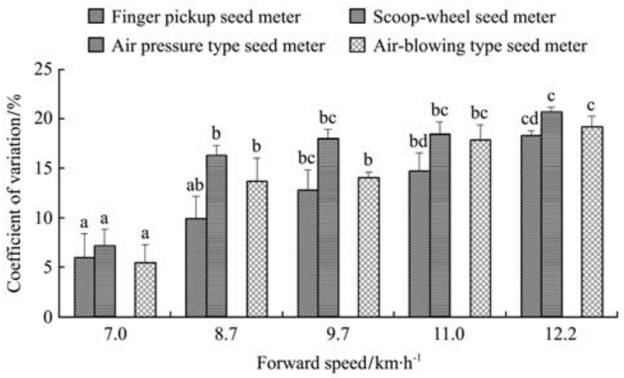
Parameters are taken into consideration in the assessment of the effect of travel speed on seed spacing uniformity both on the seed meter test bench and in the field test, which include the coefficient of variation of seed spacing, the quality of feed index, the multiple index and the miss-seeding index.

Table 1 and Figure 5 illustrate analysis of variance (p values) and the mean comparisons of the seed spacing values at five different travel speeds in the laboratory experiment, respectively. The CV of the air-pressure seed meter was not shown in Table 1, because the laboratory experiment was conducted by the high-speed video equipment, the CV of the air-pressure seed meter could not be obtained, so was the significance level of the travel speed's effect on the CV. The significance levels indicated that the effects of the travel speed on the CV and QTFI of each seed meter are statistically significant, except the QTFI of the finger pickup seed meter. The CV of all seed meters except the air-pressure type seed meter increase with the increase of the travel speed. The minimum value is 5.49% when the air-blowing type seed meter operated at the speed of 7.0 km/h, and the maximum value is 20.66% when the scoop-wheel seed meter operated at the speed of 12.2 km/h. The QTFI of the four types of seed meters decline with the increase of travel speed, it indicates that travel speed has a statistically significant effect on the QTFI of all the seed meters except the finger pickup seed meter. The largest drop in the QTFI of the scoop-wheel seed meter (from 96.51% to 84.15%) occurs as the travel speed increases from 7.0 km/h to 12.2 km/h, and the smallest drop occurs in the QTFI of the finger pickup seed meter (from 92.61% to 87.87%). The air pressure type seed meter has the highest QTFI among all the seed meters at five different travel speeds. The variations in the MULI and the MISS of all the seed meters are not significant with the increase of the travel speed.

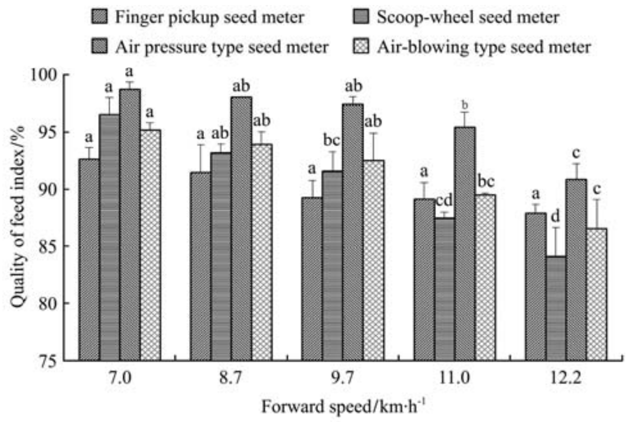
Table 1 Analysis of variance (*p* values) of travel speed's effect on seed spacing uniformity in laboratory experiment

Source	CV[a]	QTFI	MULI	MISI
Finger pickup seed meter	0.010[b]	0.249ns	0.170ns	0.971ns
Scoop-wheel seed meter	0.000[b]	0.002[b]	0.232ns	0.011[b]
Air-pressure type seed meter	—	0.001[b]	—	0.001[b]
Air-blowing type seed meter	0.001[b]	0.029[b]	0.224ns	0.094ns

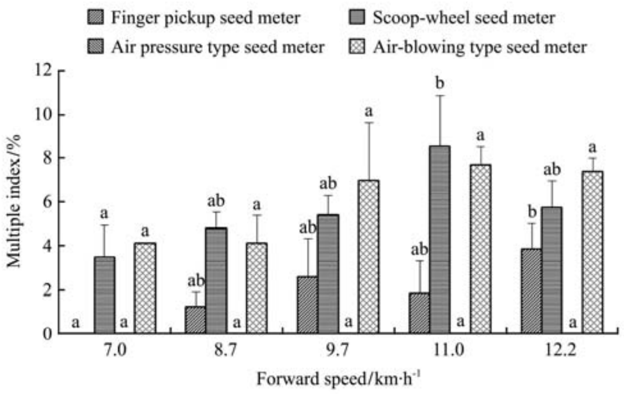
Note: [a]: CV is the variation coefficient of seed spacing; QTFI is the quality of feed index; MULI is the multiple index; MISI is the miss-seeding index; [b]: Significance level <0.05; ns: Non-significant.



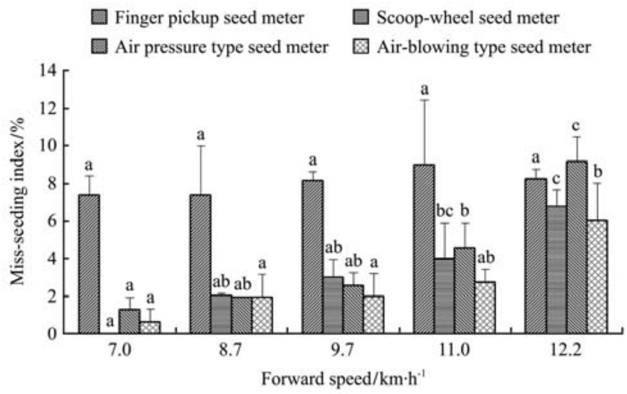
a. Coefficient of variation of seed spacing of four types of seed meters in laboratory experiment



b. Quality of feed index of four types of seed meters in laboratory experiment



c. Multiple index of four types of seed meters in laboratory experiment



d. Miss-seeding index of four types of seed meters in laboratory experiment

Note: The lowercase and uppercase letters between every two seed spacing values at different speeds indicate significance differences for finger pickup seed meter and scoop-wheel seed meter respectively. The italic lowercase and uppercase letters between every two seed spacing values at different speeds indicate significance differences for air pressure type seed meter and air-blowing type seed meter respectively. The same below.

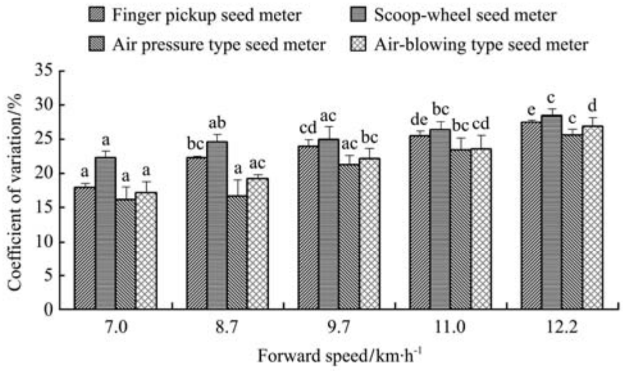
Figure 5 Mean comparisons of the effects of different travel speeds on seed spacing uniformity for four seed meters in laboratory experiment

Analysis of variance (*p* values) and the mean comparisons of the seed spacing values at five different travel speeds in field test are shown in Table 2 and Figure 6. From an overall perspective, the CV and the MISI of the four seed meters increase with the increase of travel speed, the QTFI of four seed meters decrease with the increase of travel speed. The variation law for MULI is not obvious with the increase of travel speed. It can be concluded that travel speed has a significant effect on the CV and the QTFI of four seed meters except the QTFI of the air-pressure type seed meter.

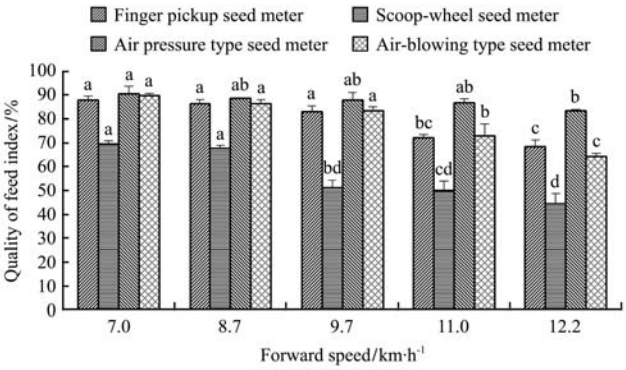
Table 2 Analysis of variance (*p* values) of travel speed's effect on seed spacing uniformity in field test

Source	CV[a]	QTFI	MULI	MISI
Finger pickup seed meter	0.000[b]	0.000[b]	0.222 ns	0.000[b]
Scoop-wheel seed meter	0.043[b]	0.000[b]	0.355 ns	0.000[b]
Air pressure type seed meter	0.009[b]	0.233 ns	0.615 ns	0.063 ns
Air-blowing type seed meter	0.007[b]	0.000[b]	0.022[b]	0.000[b]

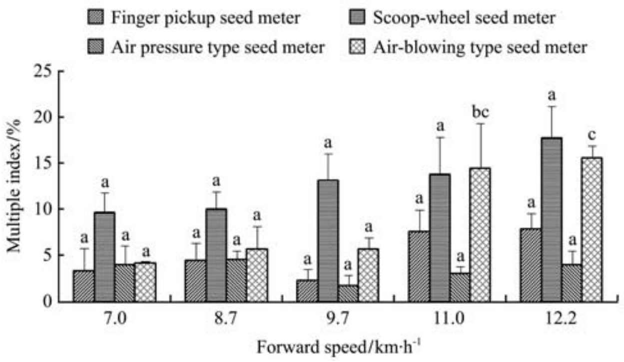
Note: [a]: CV is the coefficient of variation of seed spacing; QTFI is the quality of feed index; MULI is the multiple index; MISI is the miss-seeding index; [b]: Significance level <0.05; ns: Non-significant



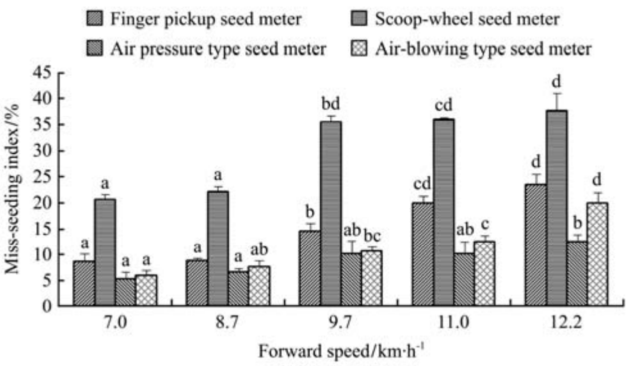
a. Coefficient of variation of seed spacing of four types of seed meters in field test



b. Quality of feed index of four types of seed meters in field test



c. Multiple index of four types of seed meters in field test



d. Miss-seeding index of four types of seed meters in field test

Figure 6 Mean comparisons of the effects of various travel speeds on seed spacing uniformity for four seed meters in field test

As for the air-pressure type seed meter, travel speed has no significant effect on the four seeding performance indicators except the CV, which indicates that the pressure-type seed meter performances best at five different travel speeds compared with other three seed meters. An increase in travel speed led to a significant increase in the CV, which increased from 16.24% at the travel speed of 7.0 km/h to 25.55% at the travel speed of 12.2 km/h, the major reason may be that collision and bounce caused by mechanical vibration was aggravated in the seed from the inner wall of the seed tube, resulting in the seed experiencing difficulties in obtaining accurate delivery into the seed bed with the high planting speed. Based on the CV, QTFI and MISI, the air-pressure type seed meter produces the best seed spacing uniformity, followed by air-blowing type seed meter, the finger pickup seed meter, and the scoop-wheel seed meter. That is, the two pneumatic-type seed meters produce more uniform seed spacing compared with the two mechanical-type seed meters, especially at high travel speeds.

There is a characteristic that the CV and MISI of each seed meter in the field test are greater than in the laboratory experiment, and the QTFI of each seed meter in the field test is less than in the laboratory experiment at the same travel speed. The results indicate that vibration from the components of the corn seeder had a significant effect on the seed spacing uniformity of four kinds of seed meters. The maximum value of QTFI of the scoop-wheel seed meter was 69.62% when the corn seeder operated at the travel speed of 7.0 km/h, which was much less than the maximum (96.51%) in the laboratory experiment; and the same is true when the travel speed was 8.7 km/h, 9.7 km/h, 11.0 km/h and 12.2 km/h. It can be concluded that the scoop-wheel seed meter is more sensitive to vibration than the other three kinds of seed meters. The reason may be that the effective contact area and force were smaller between seed and scoop in the scoop-wheel seed meter than in the other three kinds of seed meters. Under the action of vibration, seeds are easy to drop into the seed-filling area from the scoop when scoops are moving from the seed hopper to the seed-eliminating area.

For the air-blowing type of seed meter, the QTFI is less than 80% when the travel speed was equal to or greater than 11.0 km/h, which was lower than the index in laboratory experiment. The main reason may be that the discharge capacities between the air-pressure type seed meter and the air-blowing type seed meter are different in the high-pressure condition. The MISI of the finger pickup seed meter is 20.01% in the field test, which is much more than 9.00% in the laboratory experiment at the travel speed of 11.0 km/h, and the difference increased at the travel speed of 12.2 km/h between the field test and the laboratory experiment, the possible reason is that the vibration intensity in the field test is much more than that in the laboratory experiment. Seeds located in the seed-filling area in the field test can not be picked up so easily by the finger of the finger pickup seed meter as in the laboratory experiment, and seeds fall into the seed-filling area under the action of vibration when they are moving with fingers.

It can be concluded that the effects of travel speeds on the CV and QTFI of four kinds of seed meters are statistically significant (p<0.05), and the seed spacing uniformities become worse with the increase of travel speed both in the laboratory experiment and in the field test.

4 Conclusions

The coefficient of variation of seed spacing increased with the increase of travel speed, and travel speed had a significant effect on the coefficient of variation of seed spacing both in the laboratory experiment and in the field test. The variation coefficients of seed spacing in the field test were greater than in the laboratory experiment at the same travel speed. The quality of feed index decreased with the increase of travel speed both in the laboratory experiment and in the field test. The scoop-wheel seed meter performed much better in the laboratory experiment than that in the field test, and it is most sensitive to vibration among the four types of seed meters. Four kinds of seed meters performed better in the laboratory experiment than those in the field test at the same travel speed. The best seed spacing uniformity results were obtained with the air-pressure type seed meter, followed by air-blowing type seed meter, the finger pickup seed meter, and the scoop-wheel seed meter.

Acknowledgements

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