Performance of no-till corn precision planter equipped with row cleaners

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Abstract: In the continuous annual wheat-corn cropping area of North China Plain, no-till planting that promotes soil conservation and crop yield while reducing operation cost has been gradually accepted by local farmers. However, previous wheat residue is the main limiting factor affecting the performance of existing planters in placing seeds at uniform spacing and optimum depth in residue covered fields. In order to solve this problem, a kind of ground-wheel-driven row cleaner was designed, developed and mounted on row units of a four-row pneumatic precision planter. The planter has two adjacent row units equipped with the newly designed row cleaners and the other two adjacent row units equipped with the commonly used inactive row cleaners. This was used for planting at three forward speeds (4 km/h, 6 km/h and 8 km/h) into half residue (HR) and whole residue (WR) plots. The amount of residue removal, seeding depth, emergence rate and indices of uniformity in seed spacing (missing-seeding index, quality of feeding index and precision index) were measured. The newly designed row cleaner performed better with regard to residue removal, with the average percentage of residue cleared as 63.0% compared to 40.3% for the inactive row cleaner. For the HR and WR plots, percentage of residue cleared of the newly designed row cleaner reached 57.1% and 68.9% respectively, suggesting that the newly designed row cleaner can work more effectively at high residue level. By contrast, with the percentage of residue cleared of the inactive row cleaner as 43.1% and 37.5% in HR and WR plots, suggesting that the inactive row cleaner just can work effectively under low residue condition. Values of missing-seeding index, QFI, precision index, coefficient of variation of depth and percent emergence for the newly designed row cleaner under whole residue level are comparable to those for the inactive row cleaner under half residue level. The result indicates that the effect of using the newly designed row cleaner is equal to that of reducing surface residue, and can help to maintain the uniformity of seed spacing and seeding depth. The newly designed row cleaner generally performed better at forward speed of 6 km/h, based on the distribution of seeds along rows and seeding depth uniformity.

Keywords: row cleaner, corn production, no-till planter, wheat residue management, annual double cropping system
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1 Introduction

No-till planting not only leads to further nitrogen accumulation in the soil but also improves soil aggregation and moisture holding capacity[1]. In addition, the no-till planting increases bacterial and fungal population[2] and crop yield in the long production period[1] while reducing fuel consumption and soil erosion[3]. Therefore, in recent years no-till planting has been gradually accepted in North China.

As the main agricultural production base, the North China Plain, which includes the provinces of Hebei, Henan, Shanxi, Shandong, Beijing, and Tianjin, has about 20 million hectares of farmland and represents 25% of total food production in China[4].

The main cropping system in that area is annual wheat-corn double cropping system[5]: winter wheat is seeded in early October and harvested in the following

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June, and corn is seeded immediately after the winter wheat is harvested.

Because fields were usually covered by heavy residue (more than 9.0 t/hm^2) after harvesting winter wheat and conventional corn planters were unable to plant corn seeds into soil under this condition, management of wheat residue has become a major problem for corn producers in those areas. To prevent corn planters being blocked, wheat residue was burned for a long time. However, with the increasing awareness of environmental protection, burning crop residue has been banned by Chinese government in recent years.

To solve the problems mentioned above, different kinds of row cleaners have been developed as valuable planter attachments to cut and remove residues in high residue conditions to guarantee the uniform seed spacing, desired seeding depth and good seed and soil contact. The row cleaners can be classified into two types, active and inactive, according to their structure and working principle.

The research of active row cleaners began from the last few years of the 20 century. Chen et al.[6] developed a kind of row cleaner, which consisted of a disc cutter and a straw press wheel, used for pressing wheat straw and cutting them at the same time. Test results indicated that the use of the row cleaner increased the emergence rate and yield of corn. Zhang et al.[7] designed a power driven disc for no-till planter to cut residue and determined the ideal rotation speed of the disc by theoretical analysis. Field test showed that the disc could cut through thick residue layer, but it was easy to be blocked by wheat straw. Zhang et al.[8] developed a strip chopping anti-blocking mechanism to cut residue on the strip where seeds should be dropped by a rotary blade. They found that no-till planter equipped with the row cleaners had excellent performance to avoid being blocked when residue was not more than 10 t/hm^2. Wu et al.[9] designed a saw-type row cleaner which cut residue by its saw bit cutter. Test results showed that more than 95% residue could be cut off successfully. Zhang et al.[10] designed a powered-chain anti-blocking mechanism which removed residue by chain fingers and cut residue by knife type openers. Field test showed that the mechanism could effectively reduce the trouble of planting units being blocked by residues. Zhu et al.[11] designed an anti-blocking device which broke and crushed crop stubble by rotary blades. Zhao et al.[12] developed a kind of row cleaner called supported roll-cutting anti-blocking mechanism. The cleaner consisted of an active and a passive horizontal rotating part, and the active one was used for cutting residue and the passive one was used for supporting residue to avoid them being thrown out by the cutting blade during cutting operation. All of these active row cleaners mentioned above were proved to be effective for preventing planters being blocked by residue and could guarantee the quality of planting operation, but they caused more power consumption and excessive soil disturbance because they were driven by PTO.

The research of inactive row cleaners aimed to overcome the disadvantages of the active row cleaner. Zhao et al.[13] designed a spring-tooth row cleaner used for pressing residue on ground by its spring tooth fingers to avoid seed openers being blocked. Field test showed that the row cleaner had good performance when residue was not more than 4.5 t/hm^2. Another kind of row cleaner was an inactive roller, which was mounted in front of furrow opener shank with a vertical shaft. The roller could not rotate by itself, however, when it was blocked by residue and lost its balance, it would rotate along its central shaft and throw residue away from the strip of seed bed. This row cleaner is simple in structure and can work stably when residue mass was less than 5.0 t/hm^2, so it is very popular and equipped on more than 90% no-till planters used at the North China Plain. However, all of these inactive row cleaners mentioned above could become ineffective when residue mass was more than 5.0 t/hm^2 [14].

Apart from the research in China, there are quite a few studies on row cleaners and their effects on seed placement, emergence rate and yield in other countries. Skeeles et al.[15] evaluated two types of row cleaners for their effects on stand establishment of corn in both corn and soybean stubbles. They concluded that when planting into corn stubble without tillage, the use of row cleaners increased the estimated number of plants per 50 m of row compared to rows where cleaners were not used. Raoufat et al.[16] evaluated the effects of planter coulter attachments, previous crop residue levels and tillage systems on plant establishment and uniformity of plants spacing. They concluded that chisel plowing followed by coulter-planting provided a suitable alternative to conventional systems, providing the advantages of conservation farming and improving plant establishment. Bahrani et al.[17] investigated the influence of various levels of wheat residue on irrigated corn yield in a modified tillage system. The tillage system consisted of chisel plowing followed by disking and planting with row cleaner planter. The highest grain yield (15.7 t/hm^2) was obtained when 25%-50% of wheat residues were soil incorporated. They recommend that complete residue removal or burning should be avoided. Raoufat et al.[18] designed a wheel-type free rotating row cleaner and evaluated the performance of a conventional corn planter equipped with that row cleaner. They concluded that the row cleaner significantly increased plant emergence rate and helped to maintain uniformity of planting depth and seed distribution. Fallahi et al. [19] compared the effects of three tillage systems and three types of planter attachment on the amount of surface and subsurface residue after planting, emergence rate, seed spacing and seeding depth of corn in a soil covered with previous wheat residue. They found that row cleaner retained less surface residue as compared to coulter attachment, and increased the quality of feeding index and decreased missing-seeding and precision indices.

The aim of this study was to develop a proper row cleaner for conventional precision planters used at North China Plain and evaluate the field performance of a planter equipped with the new row cleaners at various levels of previous wheat residue and working speed.

2 Materials and methods

2.1 Description of equipment

The newly designed row cleaner consisted of an active rotor and a residue separator (Figure 1). The active rotor was made up of a central shaft and several rods welded equidistantly around it. The rods were the main parts to contact and remove residue. According to the research results of Gu et al.[20], the shape of the rod was designed to be parabolic. The distance between the top of the parabola to the axis of the central shaft was set at 75 mm, which was also the biggest rotation radius of the rotor. The rod was 8 mm in diameter made from high-carbon steel. The number of the rods was set at 5 to ensure the rotor could remove residue without break while working. The height of the rotor was set at 320 mm based on the biggest thickness of residue measured from different locations at North China Plain to ensure that most residue could be removed by the rotor.

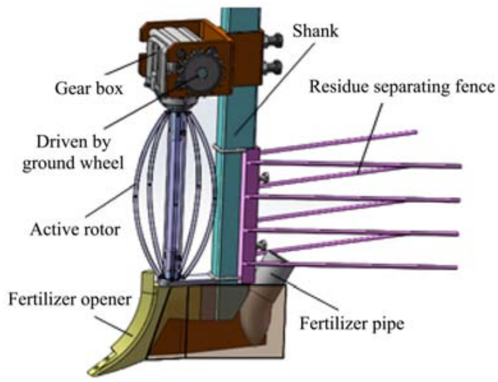

Figure 1 Row cleaner installed on planter furrow opener

The residue separator was designed to be a "V" shape, with its two walls placed at 30° angle to each other welded on a specially designed plate. Each wall consisted of 4 rods with diameter of 5 mm and length of 400 mm. The distance between adjacent rods was set at 100 mm based on the fact that the length of most wheat residue was between 200 mm to 300 mm.

The row cleaner was mounted on the shank of fertilizer furrow opener. The active rotor was installed in front of the shank and driven by ground wheel through chain and sprockets and a pair of bevel gear to change the horizontal rotation to vertical rotation (Figure 1). The residue separator was fixed on the furrow opener shank at the rear of the active rotor with its two walls arranged symmetrically relative to the furrow opener. The distance from the upper surface of the furrow opener to the first rod of the residue separator was set at 20 mm, so the height of the residue separator was 320 mm.

In this study, the row cleaner was mounted on a precision pneumatic planter. When the planter moved ahead, the active rotor rotated around its vertical axis along a certain direction and removed residue from the seed row and the two walls of the residue separator prevented residue to fall back again into the seed row, so the planter will not be blocked by residue and seed bed is clean enough for planting.

In order to remove residue in time, the rotational speed of the active rotor is very crucial. If the speed is not high enough, residue will be pushed forward by the active rotor and accumulate more and more in front of the active rotor, and as a result the planter will be blocked by residue. The rotational speed of the active rotor depends on the forward speed of planter, the transmission ratio from the ground wheel to the active rotor and the diameter of the ground wheel. In this study, the diameter of the ground wheel was set at 500 mm and the transmission ratio from the ground wheel to the active rotor was set at 1.36 based on calculation and simulation. So even when the forward speed of planter was maintained at high speed of 10 km/h, the rotational speed of the active rotor could reach to 130 r/min, which was efficient enough to remove residue in time.

A four-row pneumatic precision planter was modified to allow simultaneous mounting of two different row cleaners (the newly designed one and the inactive row cleaner commonly used at North China Plain), with two adjacent row units equipped with the newly designed row cleaners and the other two adjacent row units equipped with the inactive row cleaners (Figure 2). Because majority of existing planters on local farms use the inactive row cleaners, therefore that kind of row cleaner was used in this study to compare with the newly designed one. Each row unit was independently mounted on a four-bar parallel linkage equipped with joint springs to apply downward force on the row unit. The metering devices used on the planter were air-pressure type precision meters and each of them was adjusted for a nominal seed spacing of 200 mm in the row. The planter was calibrated in the laboratory before field operation.

a. The newly designed row cleaner

b. The inactive row cleaner

c. The four-row modified precision planter for no-till planting

Figure 2 Row cleaners and planter used in the experiments

2.2 Experimental methods

Field experiment was conducted in June 2014 on a research field at Gu'an County (39°19′N, 116°18′E), Hebei province, North China Plain, which is located in a typically semi-arid region and has a continental climate. Average annual temperature for this area is 11.5°C with 188 frost-free days. Annual total rainfall is 548 mm with 80% falling in corn growing season, from June to mid-September. The soil composed of 17.8% clay, 45.4% silt and 36.8% sand, was classified as light loam. In the top 10 cm layer before planting, soil bulk density was 1.56 g/cm^3 and soil moisture content was 16% dry basis.

Residue from the previous wheat crop was on the field. The wheat was harvested using a combine harvester leaving all the wheat straw and stubble on the field. The average length of wheat straw was 28.8 cm and the average height of stubble was 21.7 cm. The quantity of wheat residue was measured immediately after harvest by collecting and weighing all surface residues from three square areas (1 m×1 m) per plot. The average residue mass before planting was 10.8 t/hm^2 and the average moisture content of residue was 23%.

The study was arranged in a randomized complete block design as a 2×3×2 factorials with 12 treatments and three replications. The variables were two row cleaner types (the newly designed one and the inactive row cleaner), three planting speeds (4 km/h, 6 km/h and

8 km/h, respectively) and two levels of residue (half-residue, HR 50% initial weight and whole-residue, WR 100% initial weight, 10.8 t/hm^2). The half-residue and whole-residue levels mean fields with half of the previous wheat residue taken away and retained all residue in field, respectively. Sizes of experimental plots were 30 m in length and 3 m in width. Corn seed (Zhengdan 958) with 1000-kernel weight of 307 g was planted at 83 333 seeds per hectare in 600 mm rows with a theoretical seed spacing of 200 mm and a nominal depth of 50 mm.

After planting, the measurements taken in each plot were: weight of the residue on seed row zone, the distance between seedlings, depth of seed placement and number of seeds emerged per day.

Surface residue from three areas (length of 5 m and width of 0.15 m) randomly selected on each seed row zone were collected immediately after planting and washed and dried at 105°C to constant weight, and weighted to estimate surface residue after planting.

The distances between adjacent plants for about 100 plants in each row were measured in the field 30 days after planting. The uniformity of seed distribution along the length of the row was analyzed using the methods described in Kachman et al.[21] Missing-seeding index is the percentage of plant spacings that are greater than 1.5 times the nominal seed spacing and indicates the percentage of missed seed locations or skips. Quality of feeding index (QFI) is the percentage of plant spacings that are more than half but no more than 1.5 times the nominal spacing and indicates the percentages of single seed drops. Larger values of QFI indicate better performance than smaller values. Precision (PREC) is the coefficient of variation of the spacings (length) between the nearest plants in a row that are classified as singles after omitting the outliers consisting of misses and multiples.

The depths of the seeds beneath the soil surface were measured approximately six weeks after seed emergence. A mark was made on the plant at the ground level. The plant was then dug out and the entire stem length below the mark was taken as the effective planting depth. Ten seedlings selected randomly in each row were measured. Mean planting depth and coefficient of variation of depth were calculated from these measurements.

Seedling counts were made in 30 m of row per treatment every day during the emergence period. Emergence counts were discontinued when no further increase in emerged counts was observed. From these counts, mean emergence time (MET) and percent emergence (PE) were calculated as[22]:

$$\mathrm{MET} = \frac{N_1T_1 + N_2T_2 + \ldots + N_nT_n}{N_1 + N_2 + \ldots + N_n} \tag{1}$$

$$\mathrm{PE} = \frac{S_{te}}{n} \tag{2}$$

where, $N_{1,\ldots,n}$ is the number of seedlings emerging since the time of previous count; $T_{1,\ldots,n}$ is the number of days after sowing; S_{te} is the number of total emerged seedlings per meter; n is the number of seeds sown per meter; MET is the mean emergence time, in days and PE is the percent emergence.

Data were analyzed statistically using the SPSS analytical software package (2003) to test differences among treatments. Mean values and standard errors (SE) were calculated for each set of measurements, and ANOVA was used to assess treatment effects on the measured variables. Means were declared significantly different using a protected LSD (0.05) value.

3 Results and discussion

3.1 Performance of residue removal

Comparison of means of residue retained on seed row area showed that the newly designed row cleaner resulted in significantly more residue removal from the seed row area as compared to the treatment with inactive row cleaner (Table 1). The data showed that the newly designed row cleaner retained an overall average residue cover of 2.84 t/hm^2 on seed row area as compared to 4.91 t/hm^2 for rows planted with inactive row cleaner, which indicated a significant improvement with regard to soil-seed contact and uniformity of seeding depth.

For the half residue and whole residue plots, the residue retained on seed row areas with inactive row cleaner amounted to 3.07 t/hm^2 and 6.75 t/hm^2, respectively, equivalent to the percentage of residue cleared as 43.1% and 37.5% (Table 2). This indicates that the inactive row cleaner can work effectively under low residue conditions, but it is not fit for high residue conditions. However, when using the newly designed row cleaner, the residue retained on the half and whole residue plots were 2.32 t/hm^2 and 3.36 t/hm^2, respectively, equivalent to the percentage of residue cleared as 57.1% and 68.9%. This indicates that the newly designed row cleaner can work effectively under different residue levels, especially high residue conditions. The reason for this finding may be attributed to the different working principles of the two kinds of row cleaners. The newly designed cleaner can rotate and remove residue from seed rows continuously, and can prevent residue fall back again on seed row area. As a result, residue retained on seed row area will not be affected by previous residue conditions. However, the inactive cleaner cannot rotate continuously and has no function to prevent residue to fall back, so it cannot work effectively under high residue condition.

Table 1 Effects of row cleaners on residue removal, seed spacing, seeding depth and seed emergence

Types of row cleaners	Residue retained on row/t·hm^{-2}	Percentage of residue cleared/%	Missing-seeding index/%	QFI/%	Precision index /%	Mean depth /mm	Coefficient of variation of depth /%	MET/d	PE/%
Newly designed row cleaner	2.84 b *	63.0 a	4.6 b	91.8 a	12.9 b	47 a	11.3 b	9.0 a	82.6 a
Inactive row cleaner	4.91 a	40.3 b	10.9 a	83.4 b	19.7 a	44 b	16.0 a	8.5 b	76.8 b

Note: * Means followed by same letter within a column are not significantly different at $p < 0.05$.The same below.

Table 2 Effects of initial residue levels on residue removal, seed spacing, seeding depth and seed emergence

Types of row cleaners	Residue levels	Residue retained on row area/t·hm^{-2}	Percentage of residue cleared/%	Missing-seeding index /%	QFI/%	Precision index /%	Mean depth /mm	Coefficient of variation of depth /%	MET/d	PE/%
Newly designed row cleaner	Half residue	2.32 d *	57.1 b	3.1 c	93.1 a	10.8 d	49 a	8.6 c	9.2 a	85.7 a
	Whole residue	3.36 b	68.9 a	6.0 b	90.4 b	14.9 c	45 c	13.9 b	8.7 c	79.4 b
Inactive row cleaner	Half residue	3.07 c	43.1 c	5.8 b	90.3 b	15.7 b	47 b	13.5 b	9.0 b	80.2 b
	Whole residue	6.75 a	37.5 d	15.9 a	76.4 c	23.6 a	41 d	18.4 a	7.9 d	73.4 c

Comparison of residue cleared rate on seed row area showed that there is an increasing trend in residue removal with the increase of forward speed when using the newly designed row cleaner. However, when using the inactive row cleaner, the residue cleared rate decreased as the forward speed increasing (Figure 3). This indicates that the newly designed row cleaner has better performance of residue removal at higher forward speeds; nevertheless, the inactive row cleaner is just fit for lower forward speeds. The reason for this finding is that the newly designed row cleaner is driven by ground wheels and its rotation speed will increase with the increase of forward speed and hence its ability of residue removal at higher forward speeds can be ensured. But on the contrary, the inactive row cleaner has no power supply and its rotation speed cannot change, so when the forward speed increases, residue in front of it will increase, but it does not have enough ability to remove more residue from seed row, and as a result it performs worse at higher forward speeds.

After planting, field surfaces of the two kinds of row cleaners were shown in Figure 4. The seed row area of the newly designed row cleaner was very clean and residue was removed away from it. However, the seed row area of the inactive row cleaner was filled with residue.

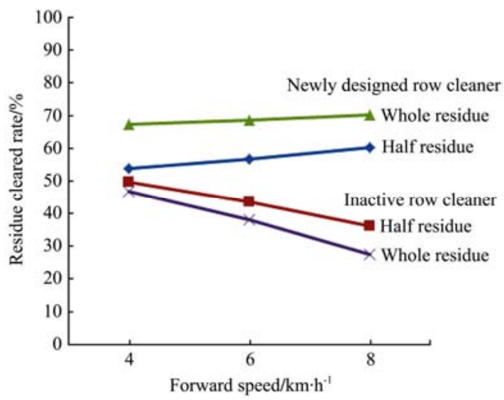

Figure 3 Residue cleared rate by the newly designed and inactive row cleaners at various forward speeds and residue levels

a. Field surface using the newly designed row cleaner

b. Field surface using the inactive row cleaner

Figure 4 Field surfaces after planting operation

3.2 Uniformity of seed spacing

Parameters taken into consideration in the evaluation of the effects of row cleaners, forward speeds and residue levels on the seed distribution performance are missing-seeding index (%), quality of feeding index (%) and precision index (%).

3.2.1 Evaluation of missing-seeding index

With the theoretical spacing of 20 cm in this study, the missing-seeding index is the percent of spacings which are greater than 30 cm. Smaller values of this index indicate better performance than larger ones.

Comparison of means of missing-seeding index showed that the data for the newly designed row cleaner were significantly smaller than that for the inactive row cleaner (Table 1). The results showed that the row units with the newly designed row cleaner had the overall average missing-seeding index of 4.6% as compared to 10.9% for the row units with the inactive row cleaner. The mean missing-seeding index of 4.6% indicates that the newly designed row cleaner is effective for reducing seed missing under different residue levels. The reason for this result is that the newly designed row cleaner can remove residue from seed row areas effectively and hence improve soil-seed contact, and as a result the planted seeds have more chance to emerge. However, the average missing-seeding index of the inactive row cleaner (10.9%) is bigger than the China national standard (8%) of precision planter. A close observation of the inactive row cleaner performance showed that quite a few seeds were dropped on residue which could not be removed from seed row area by the inactive row cleaner, especially in whole residue plots. Of course the seeds on residue were not easy to emerge, which caused the missing-seeding index to increase. The result indicates that, to obtain better planting performance and desirable distribution of seeds, proper row cleaner should be used for removing certain amount of previous residue from seed row areas.

For the half residue and whole residue plots, the best value of missing-seeding index (3.1%) was obtained when using the newly designed row cleaner under half residue level, and the worst value of missing-seeding index (15.9%) was obtained when using the inactive row cleaner under whole residue level (Table 2). Further comparison revealed that the missing-seeding index value on plots planted with the newly designed row cleaner under WR conditions (6.0%) is comparable to that of plots planted with the inactive row cleaner under HR conditions (5.8%). The results indicated that, with regard to the missing-seeding index, the effect of using the newly designed row cleaner is equal to that of reducing surface residue.

Figure 5 reveals that, for the row unit with the newly designed row cleaner, planting at a moderate speed of 6 km/h is helpful to reduce the missing-seeding index. However, for the row unit with the inactive row cleaner, the missing-seeding indices increase with increasing of the forward speed. When the forward speed reaches 8 km/h at half residue level, the missing-seeding index of the inactive row cleaner is 9.4%, moreover, the missing-seeding indices under whole residue condition are more than 11.5%, which indicates that the inactive row cleaner is just fit for low residue level and slow forward speed. By contrast, most values of missing-seeding index for the newly designed row cleaner are less than 8% except the treatment WR×V_3 (9.3%), which indicates that the newly designed row cleaner can guarantee planting quality under both half and whole residue conditions and different forward speed. However, in order to get better performance, it is recommended that the forward speed should not be more than 8 km/h when working at whole residue field.

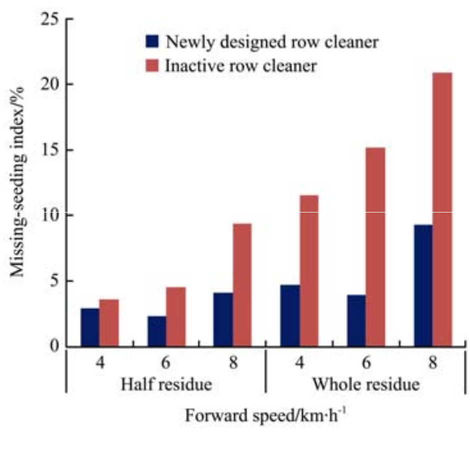

Figure 5 Comparison of means of missing-seeding index for various row cleaners, forward speeds and residue levels

3.2.2 Evaluation of quality of feeding index

The QFI (quality of feeding index) is the percentage of spacings which are longer than half but shorter than 1.5 times the theoretical spacing. This index indicates how often the spacings are close to the nominal spacing[21]. Larger values of QFI indicate better performance than smaller values.

Comparison of means of QFI showed that the overall average of QFI for the newly designed row cleaner is 91.8% as compared to 83.4% for the inactive row cleaner (Table 1). This 8.4% QFI improvement indicates that the newly designed row cleaner is effective for increasing the quality of planting operation. Other finding showed that the QFI value increases as the surface residue reduces from WR to HR level (Table 2). Further comparison revealed that the mean QFI value on plots planted with the newly designed row cleaner under WR conditions (90.4%) is comparable to that of plots planted with the inactive row cleaner under HR conditions (90.3%). The results also indicated that, with regard to the quality of feeding index, the effect of using the newly designed row cleaner is equal to that of reducing surface residue.

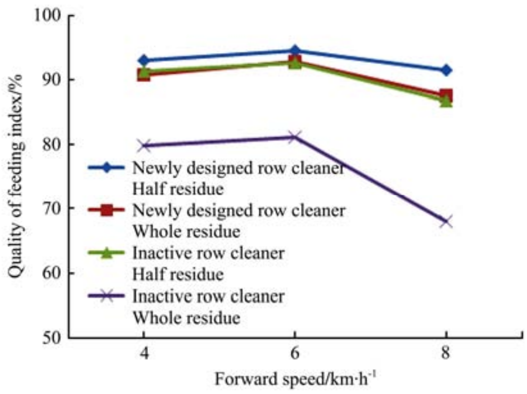

Figure 6 Comparison of means of quality of feeding index as affected by forward speeds

Comparison of the QFI values, as affected by forward speed, revealed that planting at forward speed of 6 km/h resulted in the highest value for this index (Figure 6). The same results were obtained for both the newly designed and inactive row cleaners. The highest (94.7%) and the lowest (87.7%) QFI values of the newly designed row cleaner were obtained for treatments HR×V_2 and WR×V_3, respectively. The latter is still better than the China National Standard of Precision Planter (≥85%). However, the QFI values of the inactive row cleaner at different forward speeds under whole residue level are all less than the National Standard, especially at the forward speed of 8 km/h, which indicate that the inactive row cleaner is not fit for heavy residue covered field.

3.2.3 Evaluation of precision index

Precision index is a measure of the variability in spacings between plants after accounting for variability due to both multiples and skips. A practical upper limit for precision index is 29%. Smaller values of precision index indicate better performance than larger values[21].

Comparison of data on overall average precision index as affected by row cleaners revealed that using the newly designed row cleaner resulted in lower values of the precision index (12.9%) than the inactive row cleaner (19.7%) (Table 1). This 6.8% improvement of the precision index indicates that the newly designed row cleaner is effective for increasing the uniformity of seed distribution. Table 2 shows that as the surface residue increases from HR to WR level, the precision index tends to increase. However, the mean precision value for the newly designed row cleaner under whole residue conditions (14.9%) is lower than that of the inactive row cleaner under half residue conditions (15.7%).

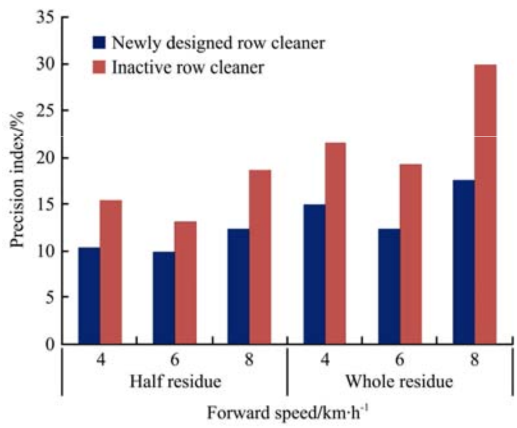

Figure 7 Comparison of means of precision index for various row cleaners, forward speeds and residue levels

Comparison of the precision values, as affected by forward speed, revealed that planting at forward speed of 6 km/h resulted in the lowest values of this index for both types of row cleaners (Figure 7). The lowest (9.8%) and the highest (29.9%) precision index values occurred for treatments HR×V_2 in the presence of the newly designed row cleaner and WR×V_3 in the presence of the inactive row cleaner. The range of precision index for the newly designed row cleaner working at forward speeds of

4 km/h, 6 km/h and 8 km/h and under both half and whole residue conditions was 9.8%-17.5% which is well below 29% and therefore is acceptable.

3.3 Uniformity of seeding depth

Comparison of data of the row cleaners showed that the mean seeding depth of the newly designed row cleaner (47 mm) is closer to the nominal seeding depth (50 mm) than that of the inactive row cleaner (44 mm) (Table 1). Further analysis revealed that the coefficient of variation of depth for the newly designed row cleaner (11.3%) is smaller than that for the inactive row cleaner (16.0%). The results indicate that the newly designed row cleaner is effective to maintain the uniformity of seeding depth.

Table 2 showed that increasing the residue level from HR to WR caused the mean seeding depth to decrease and the coefficient of variation of depth to increase, which indicates that residue level really interferes with target seed placement. Similar findings have been reported by Erbach et al.[23] who attributed the shallower planting depth and the greater variability in seed depth of no-till compared with moldboard plowing to the presence of more residues in no-till. They concluded that a larger amount of residue on the soil surface interferes with the planter depth gauging wheels and the planter furrow opener. As a result, the number of seeds planted shallower than the desired depth increase rapidly.

According to Figures 8 and 9, increasing the forward speed affected the performance of row cleaner and the depth of seed placement, and caused the mean seeding depth to decrease and the coefficient of variation of depth to increase. The actual mean seeding depths are nearly equal to nominal seeding depth at the forward speed of 4 km/h. The results support reports from Karayel[24] who found that the uniformity of sowing depth changed worse at faster forward speeds.

While the best uniform seeding depth occurred for the newly designed row cleaner at the forward speed of 4 km/h under the half residue condition (with the coefficient of variation of depth of 7.9%), the worst result occurred for the inactive row cleaner at the forward speed of 8 km/h under the whole residue condition (with the coefficient of variation of depth of 22.1%). Other data showed that when planting into WR plot with inactive row cleaner, the forward speed should not be more than 6 km/h, otherwise the depth of seed placement (35 mm) and its uniformity (22.1%) will not fit for the requirement of precision planting.

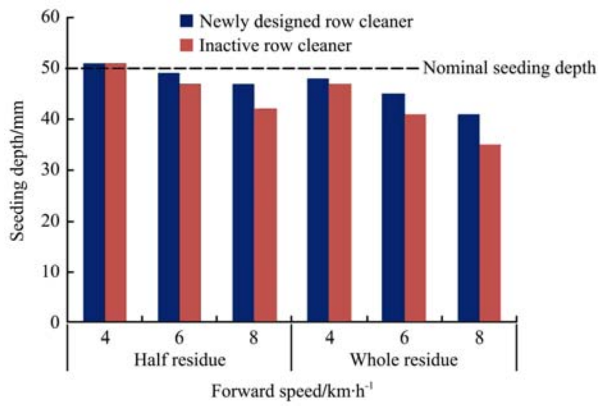

Figure 8 Comparison of means of seeding depth for various row cleaners, forward speeds and residue levels

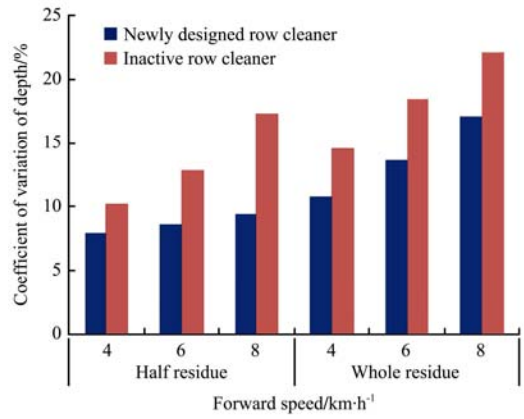

Figure 9 Comparison of means of coefficient of variation of depth for various row cleaners, forward speeds and residue levels

3.4 Evaluation of seed emergence

Comparison of means of MET as affected by row cleaners revealed that using the newly designed row cleaner resulted in longer mean emergence period (9 d) than the inactive row cleaner (8.5 d), and the reason might be deeper seeding depth when planting with the newly designed row cleaner. Furthermore, planting with the newly designed row cleaner resulted in higher percent emergence (82.6%) as compared to the inactive row cleaner (76.8%), and the reason might be more residue removal, better soil-seed contact and more uniform seeding depth using the newly designed row cleaner (Table 1). This is in agreement with findings of Raoufat et al.[18] who reported that planting with row cleaners can significantly increase plant emergence rate.

Other findings showed that as the surface residue increases from HR to WR level, the mean emergence time and percent emergence tend to decrease (Table 2). The decrease of mean emergence time might be shallower seeding depth under WR condition, and the decrease of percent emergence might be that high residue would provide poorer soil-seed contact condition and resulted in worse seed emergence. Further analysis showed that the percent emergence for the newly designed row cleaner under whole residue condition (79.4%) is comparable to that of the inactive row cleaner under half residue condition (80.2%). The results indicated that the newly designed row cleaner is effective for maintaining seed emergence rate.

The forward speed of 8 km/h resulted in the least mean emergence time, and the reason might be shallower seeding depth at this relatively high forward speed. Moreover, with the increase of the forward speed, the percent emergence tends to decrease (Figure 10). The reason might be that increasing the forward speed affected the performance of row cleaners and the placement of seeds, and caused the final percent emergence to decrease. The forward speed of 4 km/h had the greatest percent emergence, due to the most uniform seeding depth.

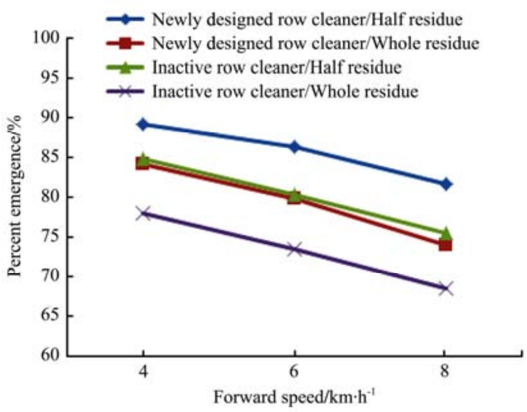

Figure 10 Comparison of means of percent emergence as affected by forward speeds

4 Conclusions

A practical solution to manage wheat residue for precision corn planters commonly used in annual wheat-corn double cropping system in North China Plain has been presented. The possible impact of this research is that local farmers can benefit from advantages of no-till planting by modifying their existing planters. On the basis of this research specific conclusions can be drawn as follows:

1) The newly designed row cleaner can remove more residues (with the average percentage of residue cleared as 63.0%) from seed row area than the conventional inactive row cleaner (with the average percentage of residue cleared as 40.3%), and as a result improve the condition of soil-seed contact and the uniformity of seed spacing and seeding depth.

2) The row cleaner exhibits its highest cleaning capacity at forward speed of 8 km/h, but indices of plant establishment and uniformity in seed spacing are best obtained at forward speed of 6 km/h.

3) Although seed spacing and seeding depth are hampered by residue level, the newly designed row cleaner can help to maintain the uniformity of seed spacing and seeding depth even under whole residue condition. The values of missing-seeding index, QFI, precision index and coefficient of variation of depth for the newly designed row cleaner at whole residue level are comparable to those for the inactive row cleaner at half residue level. The results indicated that the effect of using the newly designed row cleaner is equal to that of reducing surface residue.

4) Using the newly designed row cleaner resulted in longer emergence time (9 d) and higher percent emergence (82.6%) as compared to the inactive row cleaner (8.5 d and 76.8%, respectively).

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