Design of depth-control planting unit with single-side gauge wheel for no-till maize precision planter

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Abstract: No-till planters are very popular for maize seeding in fields covered with residue in annual wheat-maize double cropping system in North China Plain. However, there is no suitable depth control mechanism for existing no-till maize planters, and as a result, it is hard to obtain consistent planting depth, uniform emergence, and good passing ability at the same time. For the above reasons, a proper planting unit with a new type of depth-control mechanism was developed in this study. The mechanism consists of a single-side gauge wheel, a parallel four-bar linkage, a pair of double-disc opener, a V-shape press wheel and a depth regulator, which can adjust the planting depth from 30 mm to 90 mm to satisfy the agronomic requirement under different field conditions. Based on analysis and calculation, the width of gauge wheel was set to 50 mm while the length of parallel four-bar linkage was set to 350 mm. Field experiment was conducted and the results indicated that the newly designed planting unit with single-side gauge wheel performed well with regard to planting depth uniformity and anti-blocking ability. The planting depth uniformity and seed spacing quality were 95.45% and 91.90%, respectively, when the average height of stubble was 22.5 cm and residue amount was 0.64 kg/m^2 in the field. It can satisfy the requirement of no-till maize planting on the cropland with residue and stubble in North China Plain.

Keywords: no-till planter, maize precision planter, planting unit, depth control, single-side gauge wheel, residue, stubble

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1 Introduction

No-till planters were usually used for maize seeding in the field covered with stubble in wheat-maize double cropping system in North China Plain. Practices have proven that no-till planting has the vital significance with the benefits of conserving water and soil, reducing costs and simplifying operating procedure[1,2].

In China, maize has become the most predominant crop with its increasing total output and planting area. Precision planting, including precision seed spacing, row spacing and planting depth, is the trend of maize production[3,4]. Vertical distribution of seeds in soil reflects the planting depth and its uniformity, and then affects crop emergence and yield[5,6].

The uniformity of planting depth depends on seed

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furrow which is created by seed opener. In order to keep the furrow depth accurate, a depth-control mechanism is necessary[7]. Planting depth control can be realized with an overall depth-control mechanism or each row depth-control mechanism. The former is applied on small size planters, which can only adjust the planting depth of all rows together. The latter with a parallel four-bar linkage and a pair of gauge wheels, can adjust the planting depth of each row individually according to variable field surface to keep the planting depth uniform. There are three kinds of gauge wheels, i.e., front gauge wheel, side gauge wheel and rear gauge wheel, according to its position relative to seed opener[8,9].

By experiment and simulation analysis, the depth-control mechanism with side gauge wheel performed better than the other two depth-control mechanisms in terms of the uniformity of planting depth at high speed[10-13]. Recently, although methods of hydraulic depth control, photoelectric depth control and electro-hydraulic depth control have been researched and applied, mechanical depth control is still widely used with its outstanding stability and simplicity[14-16].

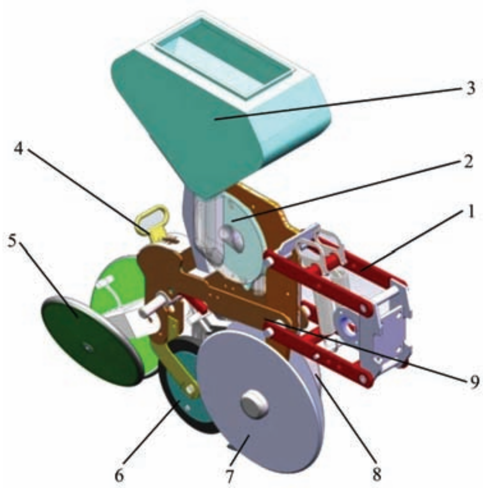
In field covered with residue, the working part of planter, such as opener, is easy to be tangled by stubble and residue, resulting in bad passing ability and planting performance. Meanwhile, the no-till cropland surface is less flat than traditional one, which restricts the uniformity of planting depth[17-20]. The traditional depth-control mechanism with side gauge wheel is not suitable for this field because the planting units could be lifted by residue or stubble due to their large lateral dimension. The existing two/three-row small planters have to use tractor hydraulic suspension system to control planting depth roughly because they are not equipped with depth control mechanism. Some no-till planters adopted rear gauge wheel to control planting depth, although it has good passing ability, the performance of depth control is not satisfactory. Therefore, the above two methods could not achieve uniform planting depth[19].

To solve the problems mentioned above, a new type of no-till maize planting unit with depth-control mechanism, which consisted of a single-side gauge wheel, a parallel four-bar linkage, a pair of double-disc opener and a depth regulator, was designed, and its field performance was evaluated.

2 Main structure and working principle

2.1 Main structure of the depth-control planting unit

The depth-control planting unit consisting of a parallel four-bar linkage, a seed-metering device, a seed hopper, a depth regulator, a pair of press wheel, a seed firmer, a pair of double-disc opener, a single-side gauge wheel and a crossbeam is shown in Figure 1. The single-side gauge wheel was mounted on one side of the double-disc opener which was installed just under the seed dropping point of seed-metering device, i.e., the seed-metering device and the gauge wheel were arranged on one vertical line.



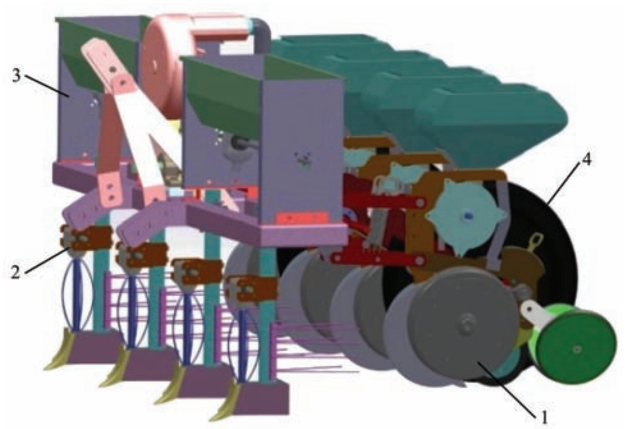
Note: 1. Parallel four-bar linkage 2. Seed-metering device 3. Seed hopper 4. Depth regulator 5. Press wheel 6. Seed firmer 7. Double-disc opener 8. Single-side gauge wheel 9. Crossbeam

Figure 1 Main structure of the planting unit with a single-side gauge wheel

The planting unit was fixed on planter frame via a parallel four-bar linkage, together with a ground wheel system, an air supply system, an anti-blocking mechanism and a fertilizer mechanism to assemble the 2BYJMFQY-4 pneumatic no-till maize precision planter, as shown in Figure 2. The seed and fertilizer planting depths can be adjusted within the range of 30-90 mm and 60-130 mm, respectively.

2.2 Working principle

During working, planter was mounted on the suspension system of a tractor. The anti-blocking mechanism mounted in front of the planter removed residues from row area to create desired planting condition;



1. Depth-control planting unit 2. Anti-blocking mechanism 3. Fertilizer mechanism 4. Ground wheel system

Figure 2 Main structure of no-till maize precision planter

meanwhile, it opened a fertilizer furrow with its acute angle opener whose depth could be adjusted by ground wheels. The single-side gauge wheel on the side of the double-disc opener walked on the flat fertilizer furrow, so the planting unit would not be lifted irregularly by residue and stubble, and as a result, the uniformity of planting depth could be ensured. Planting depth is determined by the vertical distance between gauge wheel and double-disc opener. The position of gauge wheel can be adjusted by depth regulator on the rear of planting unit. A position stopper at the end of depth adjustment mechanism was used to keep the upper limit position of gauge wheel arm as well as the gauge wheel. There are several levels set on depth adjustment mechanism to adapt to different planting depth requirements.

The tension springs on parallel four-bar linkage provided enough down force to make the depth-control mechanism touch ground closely all the time. Seeds dropped to the seed furrow were fixed immediately by seed firmer which makes seeds fully contact with soil. V-shape press wheels compact the soil over seeds to create an appropriate environment for seed germination, seedling emergence and later growth.

3 Design of key parts and parameters

3.1 Position of single-side gauge wheel

As the single-side gauge wheel works on the fertilizer furrow, the sectional view of the fertilizer furrow was measured and analyzed. The shape parameters includes ridge height (h_1), furrow depth (h_2), furrow width (l), groundbreaking area (s_2) and loosing area (s_1)[20]. The sectional view is shown in Figure 3.

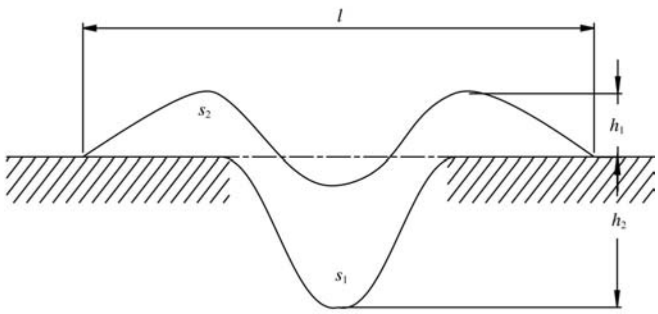


Figure 3 Sectional view of fertilizer furrow

The parameters of furrow shape measured are listed in Table 1.

Table 1 Parameters of fertilizer furrow cross section

h_1/cm	h_2/cm	l/cm	s_1/cm^2	s_2/cm^2
4.65	10.21	28.24	68.45	110.14

Gauge wheels used on planters in developed countries have a large transverse width of 110-130 mm, which are not suitable for residue covered field. In this design, narrow gauge wheel with the width of 50 mm was selected, so that it could improve passing ability on field with residue and stubble.

Three types of positional relationship between gauge wheel and double-disc opener are shown in Figure 4. In POSITION I, fertilizer opener and seed opener were designed on a straight line, and seeds were above the fertilizer vertically. In this condition, two gauge wheels walked on residue covered field surface, and their movement would be affected easily by rough surface condition. In POSITION II, the transverse distance between fertilizer opener and seed opener was set as 50 mm, and one gauge wheel walked on fertilizer furrow and the other walked on residue covered field surface. Since there is a height difference between fertilizer furrow and field surface, the stability of planting unit would be reduced and the uniformity of planting depth could not be maintained. In POSITION III, the transverse distance between fertilizer opener and seed opener was still set as 50 mm, but the planting unit just has one gauge wheel which walked on fertilizer furrow. Because the soil surface of fertilizer furrow is flat, so the uniformity of planting depth could be ensured.

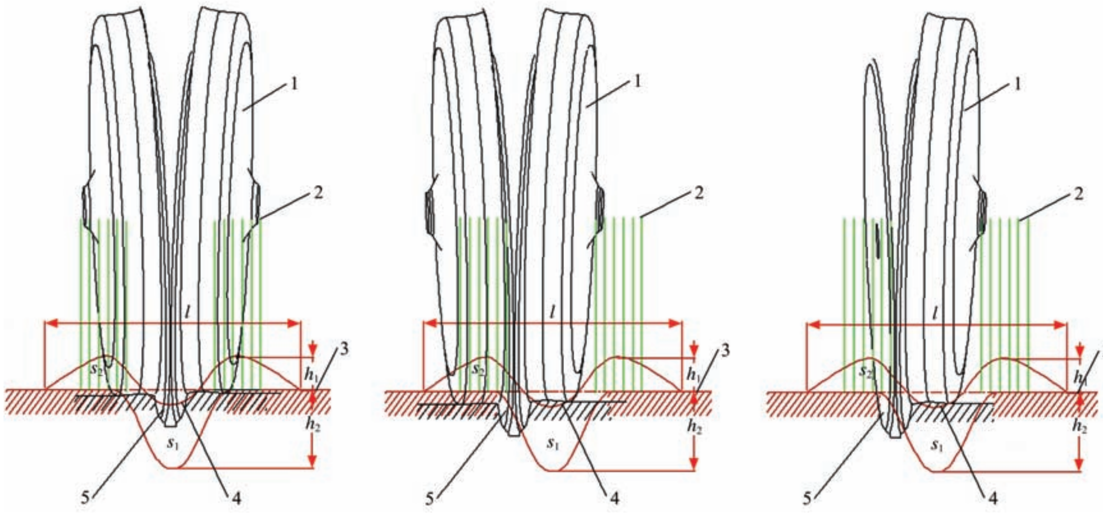


Figure 4 Positional relationship between gauge wheel and double-disc opener

Analysis and comparison results show that the single-side gauge wheel could fit for the fertilizer furrow when its width was 50 mm. The actual ground situation after planting is illustrated in Figure 5.

Figure 5 Field surface after planting with single-side gauge wheel

3.2 Positional relationship between gauge wheel and double-disc opener

When planting on residue covered field, the single-side gauge wheel should cling to the double-disc opener closely to avoid clods and residues entering into gauge wheel. When the adjustment range of planting depth was determined, the optimal parameters could be obtained by analysis.

Position of gauge wheel and double-disc opener is shown in Figure 6: O is the center of double-disc opener; O_1 and O_2 are centers of gauge wheel at lower and upper limit positions; O_3 is the rotation center of gauge wheel arm; β is the angle between horizontal line and line OO_3 which defines the position of double-disc opener; γ is the swing angle of gauge wheel arm, and l is the length of gauge wheel arm.

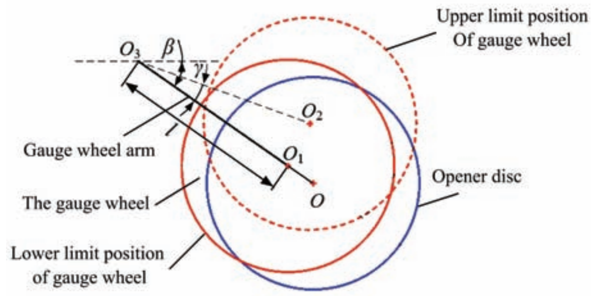


Figure 6 Structure diagram of gauge wheel and double-disc opener

In practice, planting unit worked better when gauge wheel arm was shorter and its swing angle was smaller. In this research, l was selected as 300 mm. The position of double-disc opener was fixed firstly with β=35°.

To obtain desired planting depth, there were two kinds of schemes to arrange the positions between the gauge wheel and the double-disc opener. (1) The swing angle γ changed from 0° to 15°, and then the planting depth was adjusted from 29 mm to 93 mm. When γ = 0°, the gauge wheel center O_1, opener disc center O and gauge wheel arm were at one straight line. Under this condition, the distance between the gauge wheel and the opener disc was zero, which was the optimal working situation. When γ = 15°, the distance between the gauge wheel and the opener disc was 5.44 mm, which was wide enough for the entry of clods and residues. (2) The swing angle γ changed from −7.5° to 7.5°, and then the planting depth was adjusted from 27 mm to 91 mm.

When γ=−7.5° or γ=7.5°, the distance between the gauge wheel and the opener disc was 1.36 mm, which was small enough that could be ignored. Therefore, based on the comparison of planting depth adjustment and working performance, the second scheme with the swing angle γ changed from −7.5° to 7.5° was adopted.

3.3 Planting depth adjustment mechanism

Planting depth adjustment mechanism is a key component to adjust planting depth. It consists of depth regulator, double-disc opener, limiting stopper, gauge wheel and gauge wheel arm (Figure 7).

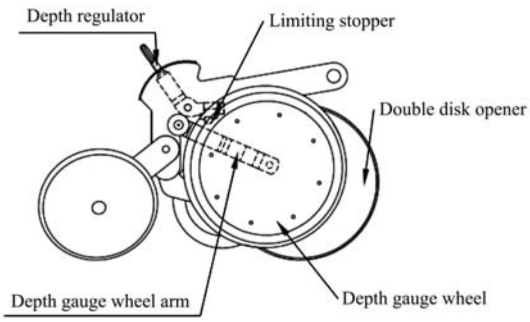


Figure 7 Component of depth adjustment mechanism

Depth regulator has several levels to change the position of limiting stopper to limit upper position of gauge wheel arm. When the position of depth regulator is changed, the vertical position of gauge wheel thus is changed, and then the planting depth is changed as well.

Depth regulator consists of depth adjustment plate (Figure 8), depth shifts on the plate and adjustment handle. Adjustment handle changes its coordinate in depth shifts hole on the depth adjustment plate, and thus the planting depth is changed. There are six shifts holes in total to fit the requirement of different planting depth in different planting condition.

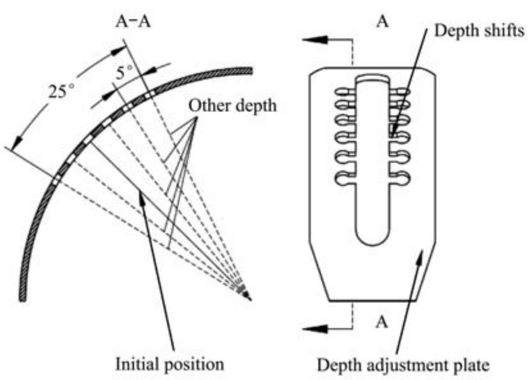


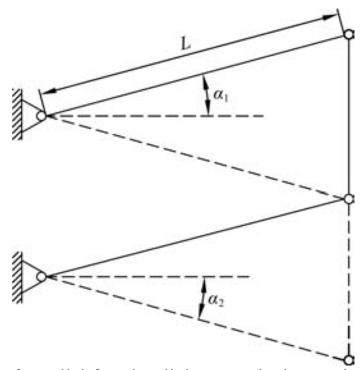
Figure 8 Depth adjustment plate

The angle between adjacent holes was designed to be 5°. Then planting depths of 10 mm, 30 mm, 50 mm, 70 mm, 90 mm and 110 mm could be obtained to meet the range of planting requirement of 30-90 mm.

3.4 Parameters of parallel four-bar linkage

The parallel four-bar linkage, combined with gauge wheel, was used for keeping planting unit oscillating up and down to maintain required planting depth. The dimension of parallel four-bar linkage was determined according to the required range of planting depth[21].

The maximum upward swing angle and downward swing angle and the length of parallel four-bar linkage were set as α_1, α_2 and L, respectively (Figure 9).



Note: L is length of parallel four-bar linkage; α_1 is the maximum upward swing angle, and α_2 is the maximum downward swing angle.

Figure 9 Swing position of parallel four-bar linkage

The maximum upward swing distance and downward swing distance were set as h_1 and h_2.

$$\begin{cases} h_1 = L\sin\alpha_1 \\ h_2 = L\sin\alpha_2 \end{cases} \tag{1}$$

To obtain favorable effects, h_1 or h_2 is usually within the range of 80-120 mm. Moreover, to ensure the working stability of planting unit, α_1 and α_2 should be as small as possible; meanwhile, L should be as long as possible. However, the length of parallel four-bar linkage was impossible to be long enough because of the unit dimension. Therefore in this research, L was designed as 350 mm. As the maximum swing angle was 10°-20° generally[22], so α_1 and α_2 were designed as 15°. Then the maximum upward and downward distance are both 90 mm.

4 Materials and methods

4.1 Experiment and materials

The experiment was conducted in June 2015 on the field covered with wheat residue at Gu'an county (39°19'N, 116°18'E), Hebei province of China. The amount of residue was 0.64 kg/m^2 and the mean height of stubble was 22.5 cm. Row spacing of traditional wheat is 16 cm while the no-till planter with newly designed depth-control planting unit was 0.6 m and the total width of the four-row planter was 2.4 m. The planter was driven by Dongfanghong-454 tractor whose matching power was 33.1 kW. Maize seeds (Zhengdan 958) with 1000-kerenl weight of 330 g were planted with a rate of 75 700 seeds per hectare, and theoretical seed spacing of 220 mm, normal depth of 50 mm, and planting speed of 4.8 km/h.

4.2 Experimental method

The situation of field experiment is shown in Figure 10.

Figure 10 Field surface and experiment

4.2.1 Passing ability of the planter

The qualified standard of passing ability was defined as operating performance with no stoppage or just short stoppage in a round trip within the distance of 60 m when planter worked in the field with stubble and residue.

4.2.2 Seed and fertilizer depth

Five plots with the length of successive 21 seeds spacing were chosen. The actual seeding depth was the distance from seed to field surface. Seed exposed rate is the number of seeds outside soil in 10 m distance. The quality index of planting depth is the percentage of seeds whose depth is within the range of ±10 mm to the target depth, and the measurement of fertilizer depth is as same as planting depth. Ten groups of seed and corresponding fertilizer were dug out, and the qualified distance from seed to fertilizer was 3-6 cm[23].

4.2.3 Uniformity of seed spacing

The planting uniformity in the row was analyzed using the methods described by Kachman and Smith[24]. The multiple index (MULI) is the percentage of plant spacing that is less than or equal to half of the nominal spacing and indicates the percentage of multiple seed drops. The miss seeding index (MISI) is the percentage of plant spacing greater than 1.5 times of the nominal seed spacing and indicates the percentage of missed seed locations or skips. The quality of feed index (QFI) is the percentage of plant spacing that is more than half but no more than 1.5 times the nominal spacing. Precision (PREC) is the coefficient of variation of the spacing (length) between the nearest plants in a row that are classified as singles after omitting misses and multiples.

4.2.4 Consistency of seed emergence

Mean emergence time (MET) was determined using the following equation[25]. The quality index of emergence time (QIET) is the percentage of qualified seeds whose emergence time is within the range of one day in advance or delay of MET in the whole seeds.

$$MET = \frac{N_1T_1 + N_2T_2 + ... + N_nT_n}{N_1 + N_2 + ... + N_n} \tag{2}$$

where, $N_{1...n}$ is number of seedlings emerging since the time of previous count; $T_{1...n}$ is the number of days after planting.

5 Results and discussion

5.1 Residue clearance and passing ability

The residue amount on planting row was 0.25 kg/m^2 after planting, reducing by 60.9% compared with the initial amount of 0.64 kg/m^2. At the same time, there was no blockage happened during three round-trip operations.

5.2 Seed and fertilizer depth uniformity

Data were measured after planting operation. The mean test value, qualified index and coefficient of variation for actual seed depth (ASD), actual fertilizer depth (AFD) and actual distance between seed and fertilizer (ADSF) are shown in Table 2.

Table 2 Planting depth performance

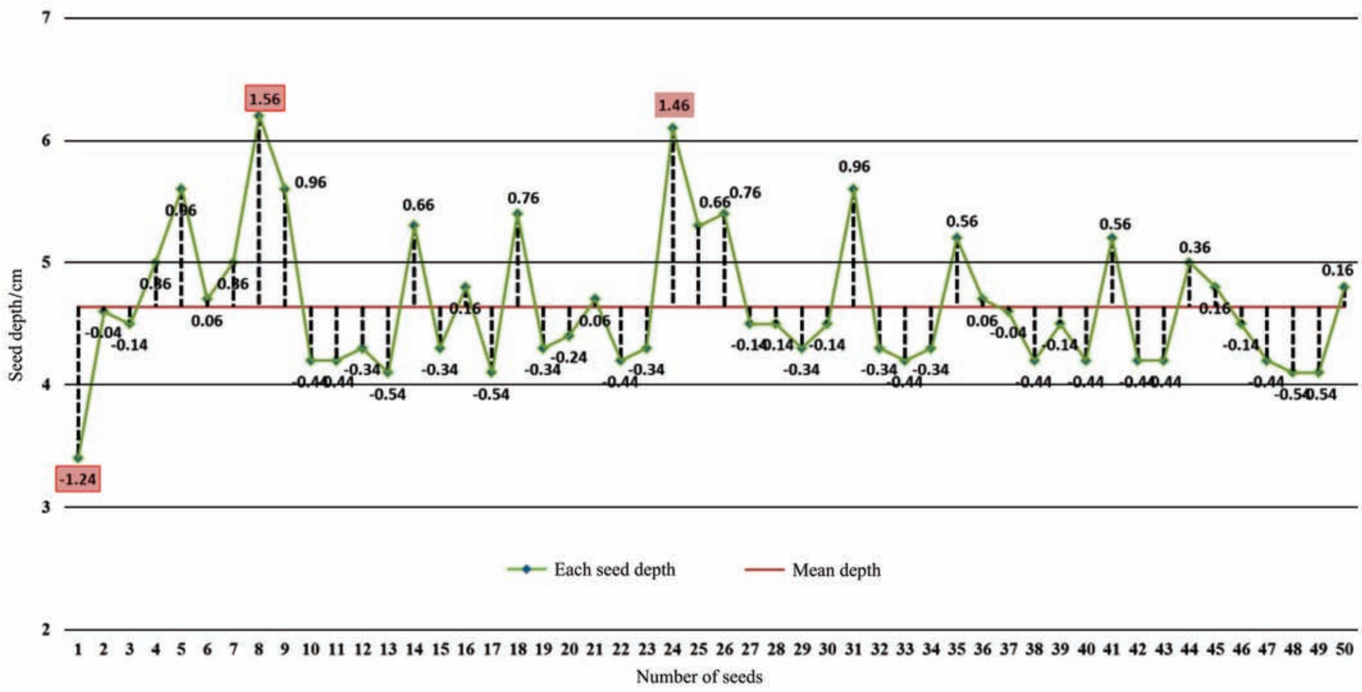
Index	Mean values/cm	Qualified index/%	Coefficient of variation/%
ASD	4.6	95.45	13.91
AFD	9.1	94.00	13.09
ADSF	4.5	96.00	12.78

Note: ASD is actual seed depth, AFD is actual fertilizer depth, and ASFD is actual distance between seed and fertilizer.

Both qualified indices of ASD and ADSF are more than 95%, and their coefficients of variation are less than 15%, which indicates that the newly designed planting unit can maintain the uniformity of seed depth effectively.

The vertical differences of each seed and mean planting depth are shown in Figure 11.

Meanwhile, a traditional no-till planter without depth control mechanism was used to compare with the designed planting unit. The vertical differences of each seed and mean planting depth are shown in Figure 12. The qualified index of planting depth was 76.46% and the coefficient of variation was 20.89%. The results indicated that the newly designed planting unit with single-side gauge wheel had better performance on planting depth uniformity than traditional one.



Note: The red data were unqualified planting depth; The target depth was 5 cm. The same below.

Figure 11 Differences of each seed depth and the mean depth of the planter with the newly designed planting unit

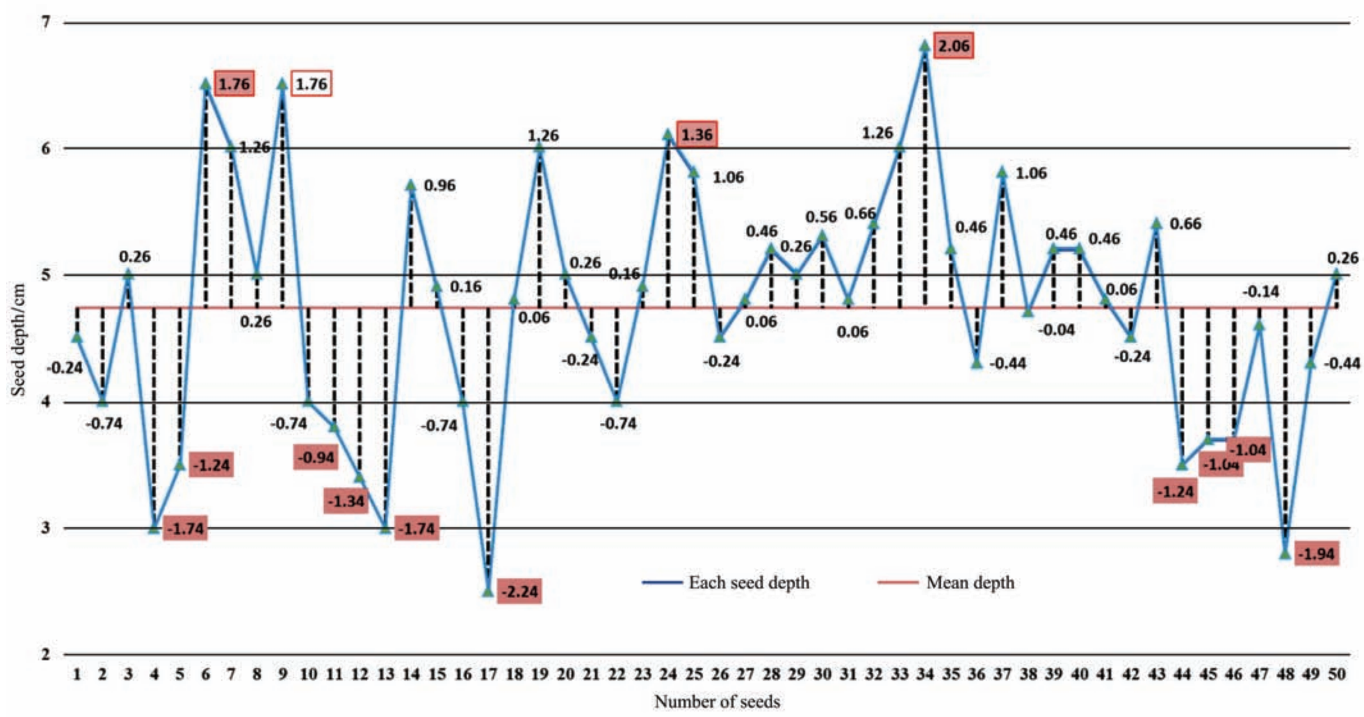


Figure 12 Differences of each seed depth and the mean depth of a conventional planter

5.3 Seed spacing uniformity

The results of seed spacing uniformity are shown in Figure 13, along with the corresponding data of seed-metering device on test bench and the traditional no-till maize planter used as comparison.

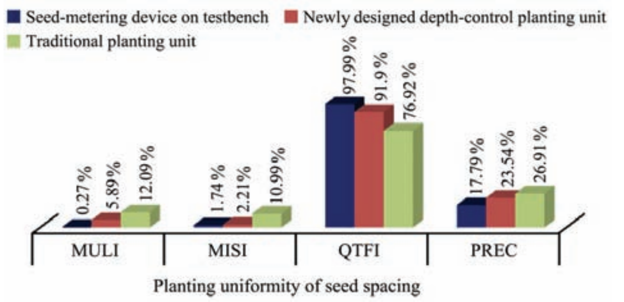


Figure 13 Comparison of the planting uniformity of seed spacing

The MULI, MISI, QFI and PREC of the newly designed planting unit were 5.89%, 2.21%, 91.90% and 23.54%, respectively. These indices were slightly poorer than those of seed-metering device on test bench, which were 0.27%, 1.74%, 97.99%, and 17.79%, respectively. The reason for this result might attribute to unstable air force to seed-metering device in field and imperfect germination rate of seeds. However, the MISI and QFI of the newly designed planting unit were good enough to fit for the need of precision planting. Meanwhile, the indices of traditional planting unit were 12.09%, 10.99%, 76.92% and 26.91%, respectively, which were much worse than those of the newly designed planting unit. Results showed that the depth-control planting unit with single-side gauge wheel can satisfy precision planting on residue covered field successfully.

5.4 Seed emergence consistency

According to the measurement data after field experiment (Figure 14), the mean emergence time (MET) was 6.43 d. There are 22.2% seedlings emerged on the 6th day and 65.7% seedlings emerged on the 7th day, which means that 87.9% seedlings emerged on these two days.

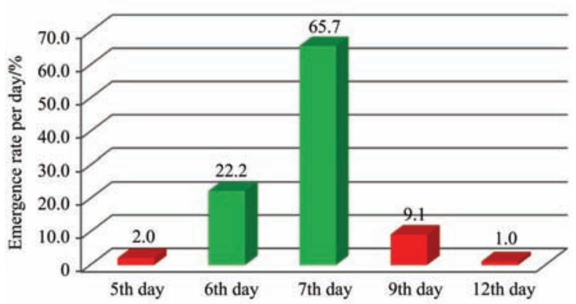


Figure 14 Emergence rate per day

The results indicated that the newly designed planting unit is helpful for maintaining the uniformity of planting depth, and as a result, the emergence time was concentrated and the emergence quality was improved.

6 Conclusions

A practical solution to improve the performance of no-till precision maize planter on residue covered field was outlined. On the basis of this research, specific conclusions can be drawn as follows:

1) The newly designed depth-control planting unit, consisted of single-side gauge wheel, double-disc opener and parallel four-bar linkage, could maintain the uniformity of planting depth effectively with the single-side gauge wheel walking on flat fertilizer furrow stably, and as a result, could help to concentrate emergence time and improve emergence quality.

2) Structure parameters and relative position of each key parts of the planting unit were determined based on the consideration of planting depth range of 30-90 mm and the single-side gauge wheel working on the furrow created by fertilizer opener to prevent being lifted by residue and stubble.

3) Field experiment results showed that the planting depth uniformity, seed spacing uniformity and seedling emergence consistency of the newly designed planting unit were much better than the indices of conventional no-till maize planter used currently. The newly designed depth-control planting unit can satisfy the requirement of no-till maize planting on the cropland with residue and stubble in North China Plain.

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