Stalk cutting mechanism of no-tillage planter for wide/narrow row farming mode

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Abstract: A no-tillage planter of narrow row spacing was designed according to the agronomic requirements of wide/narrow row farming mode in the black soil region of Northeast China. Due to the narrow spacing of the seeder unit, a gear-tooth stalk cutting mechanism was designed in order to prevent residues from blocking the planter. The basic parameters, number and edge curve of the stalk cutting blade were designed and optimized. Three-factor and three-level combined orthogonal experiments were conducted using the factors of working speed (1.12 m/s, 1.57 m/s and 2.02 m/s), tillage depth (75 mm, 90 mm and 105 mm) and cutter spacing (15 mm, 30 mm and 45 mm), which significantly affected stalk cutting rate and soil disturbance rate. The optimal combination is the working speed of 1.62 m/s, tillage depth of 92 mm and cutter spacing of 35 mm. Under this condition, the stalk cutting rate is more than 90% and soil disturbance rate is 7.5%-12.0%. The performance of the new no-tillage planter was tested by using the above parameters. The results showed that the no-tillage planter of narrow row spacing came up to the relevant national standards in China.

Keywords: conservation tillage, no-tillage planter, wide/narrow row farming, stalk cutting mechanism, soil disturbance rate, direct sowing, corn, Northeast China
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1 Introduction

The black soil region in Northeast China, together with the Ukraine plain and American Mississippi River basin are the three major black soil regions in the world. The Northeast China black soil region mainly covers Heilongjiang, Jilin, Liaoning and Inner Mongolia, including Songnen Plain, Liaohe Plain and Sanjiang Plain[1]. Black soil, also called Mollisols in America[2], is highly fertile and suitable for crop planting, so the Northeast China black soil region is a major commodity grain base in China. Large-scale agricultural reclamation only conducted hundred years, but excessive scale and intensity led to soil degradation seriously[3]. Traditional intensive cultivation has some disadvantages that are the main causes for land degradation, such as frequent plowing, severe soil disturbance and uncovered soil between autumn harvest of first year and spring sowing of next year. According to practical research in China and other countries, cultivated land and ecological environment can be effectively protected by conservation tillage (CT)[4-8].

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Gebhardt's research showed that conservation production systems combine tillage and planting practices to reduce soil erosion and water loss from farmland[9]. Hill[10] analyzed the impacts of traditional tillage and CT on soil physical properties. Holland[11] researched European CT, which is mainly used to reduce the production cost and also can prevent soil erosion and hold soil moisture. Madarász et al.[12] suggested tillage type was a more important factor in the question of yields by studying CT in Central Europe (Hungary), but the technological change would lead to the initial reduction of crops.

Mechanized CT experiments were conducted by China Agricultural University, Chinese Academy of Agricultural Sciences and Agricultural Machinery Bureau of Shanxi Province in Shanxi and Hebei Province since 1991. The results showed that CT is applicable and feasible in north China[13]. Now the conservation agriculture practised area is more than 8 Mhm^2 in China and is offering promising prospects of both enhanced yields and environmental services[14]. According to experience of conservation tillage in the US, Jia et al.[15] put forward the proposal on development mode of CT for black soil region of northeast China. Liu's research showed that maize wide/narrow planting pattern can improve soil fertility and maize yield[16].

There are three modes of maize CT in the Northeast China black soil region, especially Jilin Province: (1) three-year rotational farming mode for the Northeast China ridged cultivation region, (2) stubble mulching and row (ridge) and inter-row (furrow) alternate farming mode, and (3) wide/narrow row alternate fallow farming mode. The third mode changed uniform ridge (65 cm) farming to wide-row (90 cm) and narrow-row (40 cm) farming (Figure 1). Deep scarification was conducted in the wide row. High-stubble was retained in the narrow row in autumn harvest and can be returned to field naturally. The next spring seeding in the wide row of last year forms a new narrow-row seeding strip. Deep scarification was conducted in the new wide row. This forms the wide/narrow row farming mode of seeding strip rotation and alternate planting.

A no-tillage planter of uniform row spacing cannot meet the agronomic requirements of the wide/narrow row farming mode, which needs narrower spacing of seeder unit, so a new no-tillage planter of narrow row spacing is needed. When the row spacing is reduced from 65 cm to 40 cm, surface residues more easily block the planter. Therefore, a gear-tooth stalk cutting mechanism was designed, which can cut stalk and stubble, loosen soil and provide a favorable working environment for the new planter.

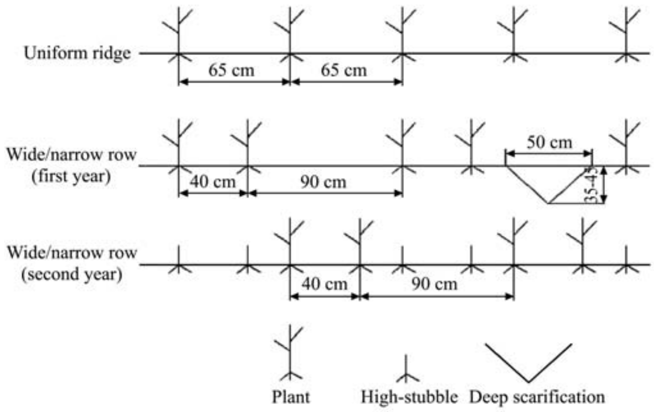
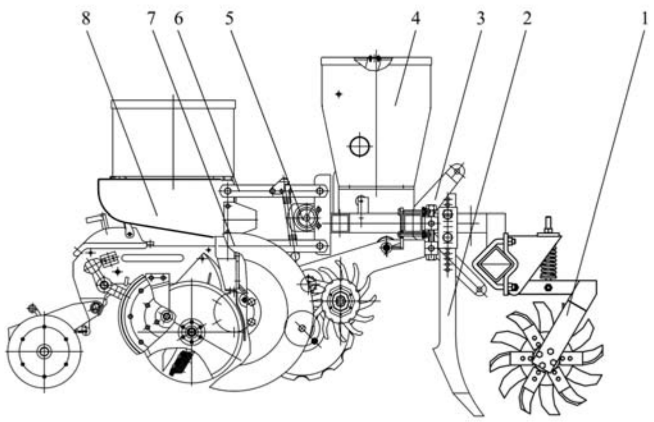


Figure 1 Sketch map of the uniform ridge and wide/narrow row farming mode

2 Overall structure and technical parameters

According to the agronomic requirements of the wide/narrow row farming mode in the Northeast China black soil region, we designed the new no-tillage planter, which is capable of cutting crop residues, fertilizing, seeding, covering and rolling at a time (Figure 2).



1. Stalk cutting mechanism 2. Fertilizer opener 3. Rack 4. Fertilizer box 5. Transmission mechanism 6. Parallel link mechanism 7. Land wheel 8. Seeder unit

Figure 2 Structure diagram of the no-tillage planter of narrow row spacing

The seeder unit mainly consists of picker finger precision seed metering unit, finger-type anti-blocking residue-cleaner, double-disc seeding opener, covering wheel, and rolling wheel. The main technical parameters of the new no-tillage planter are listed in Table 1.

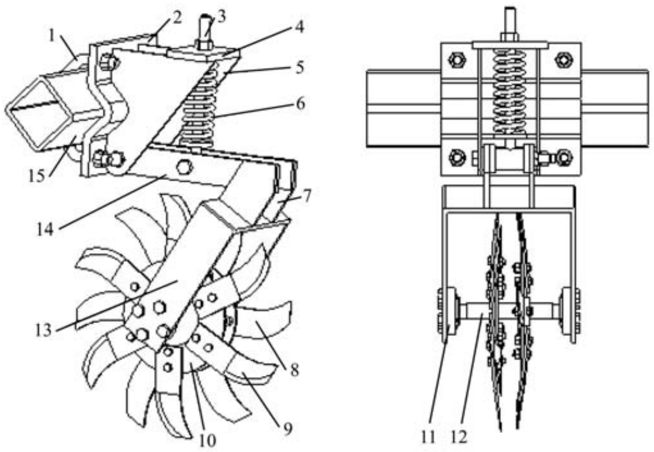
Table 1 Main technical parameters

Items	Parameters
Boundary dimension (L×W×H) /mm	2850×2210×1340
Mass /kg	980
Mating power /kW	55.1 (75 Hp)
Working speed /km·h^{-1}	4-7
Working lines	4
Working width /mm	2600-3000
Seeding depth /mm	30-60
Fertilizer sowing depth /mm	60-100
Fertilizer sowing amount /kg·hm^{-2}	400-1000

3 Gear-tooth stalk cutting mechanism

3.1 Structural features and working principle

The structure of the gear-tooth stalk cutting mechanism is shown in Figure 3[17].



1. U-type clip 2. Junction plate 3. Fixed axle 4. Fixed plate 5. Holder upper plate 6. Spring 7. Holder under plate 8. Left stalk cutting blade 9. Right stalk cutting blade 10. Cutter 11. Bearing block 12. Cutter shaft 13. Holder 14. Holder middle plate 15. Beam

Figure 3 Schematic diagram of the gear-tooth stalk cutting mechanism

The stalk cutting blade of the stalk cutting mechanism unitized traditional stalk cutting blade, which uses a combined blade structure to reduce the vertical pressure. Each cutter has 6 sets of mounting holes and fixed 6 blades. Two cutters are welded by 30° and modestly distant on the cutter shaft. The left and right blades are staggered on the cutter. When the cutter works, the blades rotate under a couple of holder thrust and soil counter-force, so the left and right blades cut straw and loosen the soil in turn. The blade cuts straw by pressing the straw above ground, at meanwhile it can lever and lift the soil. When the blades come out of the soil, the lifting soil is released. It can enhance both performances of straw cutting and soil loosening, and maintainability by changing blades.

3.2 Design of basic parameters of stalk cutting blade

The stalk cutting blade is the core part of the stalk cutting mechanism, as its working parameters could influence the stalk cutting effect. The average value of maize secondary root is 70-80 mm[18], so the tillage depth that insures the stalk cutting blade completely cuts off the underground stubble is 90 mm. To ensure the strength and stability, we design the blade length is 160 mm, and the length of fixed end to be 50 mm. The blade is fixed by two mounting holes on a disc structure (Figure 4). To meet the structure of the no-tillage planter, we design the working radius to be 210 mm.

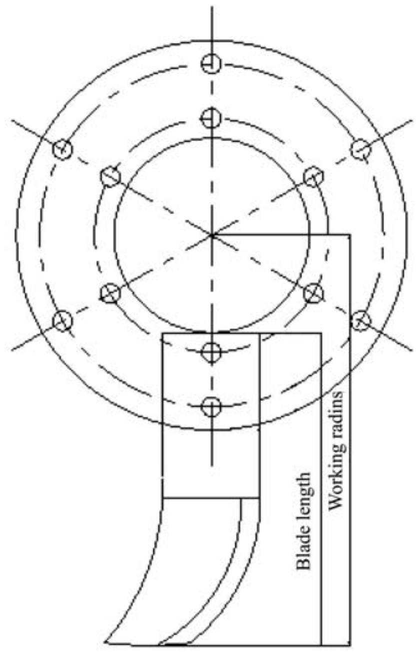


Figure 4 Schematic diagram of the blade

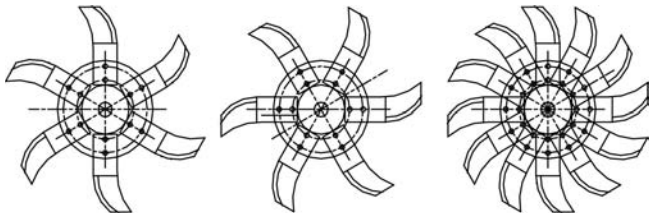
The blade thickness was design to be 3.5 mm. The blade thickness δ (mm), referred to as empirical formula of disc harrow, is computed as follows:

$$\delta=0.008D \tag{1}$$

where, D is mean working diameter of the blade, mm.

3.3 Design of blades number

The working radius and length of the stalk cutting blade were 210 mm and 160 mm, so the inner radius was 50 mm. The core concept of this design was to unitize a traditional stalk cutting blade to reduce the vertical pressure and maintain easily. Because of the bad field environment, stalk would block the blade if the blade gap is too small, but the blade would miss the stalk if it is too big. Thus, double cutters were designed. Two sets of blades were staggered along the axial direction. It can solve the problem of stalk blocking and ensure the cutting effect. Figure 5 shows the schematic diagram of left and right cutters.



a. Left cutter b. Right cutter c. Side projection

Figure 5 Schematic diagram of left and right cutters

Figure 6 shows two adjacent blades are cutting stalk. In this figure, *OA* and *OB* respectively are the polar radius of the preceding blade and succeeding blade. ∠*AOB* is the included angle of two adjacent blades. *OB* is 210 mm, *OC* is 190 mm, ∠*AOB*=25.2°, and the number of stalk cutting blades is 14 (360º/25.2º≈14). Each cutter was designed to be an even number when the number of stalk cutting blades was 6. By this time, ∠*AOB*=30°, which meets the design requirements.

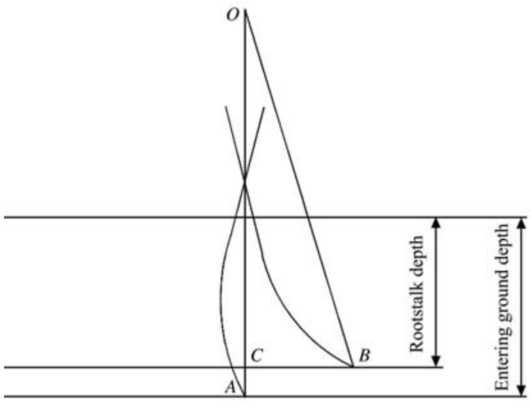


Figure 6 Schematic diagram of two adjacent blades

3.4 Design of the outside edge curve of blade

During the process of stalk cutting, the blades moving along the tractor direction would squeeze out soil and cut stalk. If the blade gets into soil from the end of the blade that is far from the rotation center, this can cause the tractor vibration and complicate the stalk cutting. If the blade gets into soil from the outside edge that is near the rotation center, or namely slide cutting into soil, this can reduce the vibration and improve the quality of cutting stalk. As shown in Figure 7, the *x*-axis is the orientation of the tractor, and the *y*-axis is the orientation from the gyration centre to the ground, so the outside edge curve (ρ) was design as the spiral of Archimedes.

$$\rho=\rho_0+K\theta \tag{2}$$

where, ρ_0 is the polar radius of the beginning of the spiral, mm; K is the increment of polar radius per radian, mm; θ is the polar angle of any on spiral, rad.

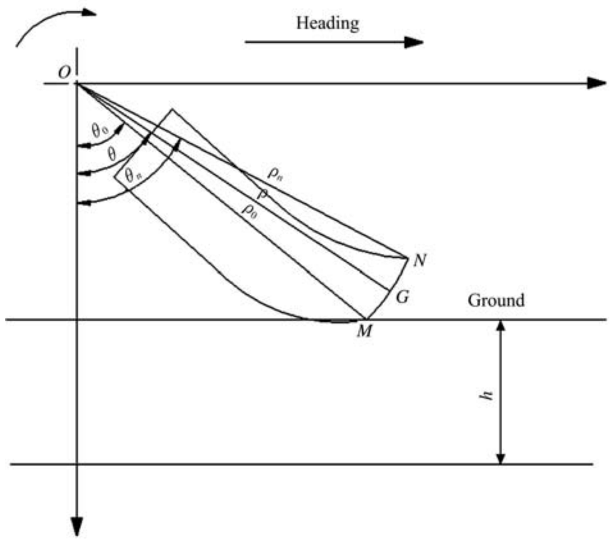


Figure 7 Schematic diagram of the outside edge curve count

M is the pointcut, θ_0 is the initial cut angle, ρ_0 and ρ_n respectively are the initial and final cut polar radius, and G is the arbitrary point of the cutting edge. The condition that the pointcut is not an endpoint of the stalk cutting blade is:

When $\theta>\theta_0$, $\rho\cos\theta<\rho_0\cos\theta_0$, substitute Equation (2) into it:

$$\rho_0(\cos\theta-\cos\theta_0)<K(\theta_0\cos\theta_0-\theta\cos\theta) \tag{3}$$

A cosine function is a decreasing function, so $\cos\theta-\cos\theta_0<0$, and we analyze the increase-decrease characteristics of $\theta\cos\theta$.

$f(\theta)=\theta\cos\theta$, $\theta\in(0,0.5\pi)$, $f'(\theta)=\cos\theta-\theta\sin\theta$, $\theta\in(0,0.5\pi)$. When $f'(\theta)=0$, $\theta=0.274\pi$.

When $\theta\in(0,0.274\pi)$, $f'(\theta)>0$, so $f(\theta)$ is an increasing function.

$$K<\frac{\rho_0(\cos\theta_0-\cos\theta)}{\theta\cos\theta-\theta_0\cos\theta_0} \tag{4}$$

When $\theta\in(0.274\pi,0.5\pi)$, $f'(\theta)<0$, so $f(\theta)$ is a decreasing function.

$$K>\frac{\rho_0(\cos\theta-\cos\theta_0)}{\theta_0\cos\theta_0-\theta\cos\theta} \tag{5}$$

The working radius of the stalk cutting blade is 210 mm, the tillage depth is 90 mm, $\theta_0 = 0.28\pi$, ρ_0 =205 mm, ρ_n=210 mm, and $\theta_n = 0.35\pi$. Since $\theta_n = \frac{\rho_n - \rho_0}{\rho_n} \tan\tau_n$, then $\tau_n = 0.344\pi$. We obtain K= 4.55 mm, which meets Equation (5). The edge curve of the blade can slide-cut from the endpoint, which is near the gyration center.

3.5 Design of the inside edge curve of blade

The inside edge curve will squeeze out soil and cut off the stalk, so it should be capable of sliding cutting. A good cut slip effect can be achieved when corn stalk and stalk slide along the inside edge curve. Currently, there are several mainly cutting edge curves: Eccentric arc, Sine exponential curve, and Archimedes spiral.

We refer to the star harrow design choice as an eccentric circular curve of the broken knife blade curve stalk. The notching slip between the velocity vectors can be defined as a point on the blade edge with the point of the angle between the normal. Cutaway slip determines the size of the soil and crop stalk on the broken edges are cut to produce slip. When a broken stalk knife works, a larger friction angle between chamfered edge slippery metal and corn stalk should be ensured. When the notching slip is larger, the cutting resistance is smaller and slide-cut performance is better, but the grass is not easily wrapped around.

In Figure 8, the edge curve is a circular arc *JK* of an eccentric circle, and its parametric equations are:

$$c^2 - 2b\cos\beta = l^2 - b^2 \quad (6)$$

$$c = b\cos\beta + l\sin\tau \quad (7)$$

$$\tau = \arccos(\frac{b\sin\beta}{l}) \quad (8)$$

where, b is the eccentric distance; c is the distance between the arbitrary point of the edge curve and the gyration center; l is the radius of the eccentric circle; β is the included angle between the arbitrary point of the edge curve connected to the gyration center and that arbitrary point connected the center of the eccentric circle; τ is the slide-cutting angle of the edge curve at a point.

The average height of stalk above ground is 120 mm, so the inside edge curve of the blade and the radius of eccentric circle respectively were designed to be 152 mm and 95 mm. Substituting them into Equation (8), we get τ=23°. It is the minimum friction angle between metal and maize straw.

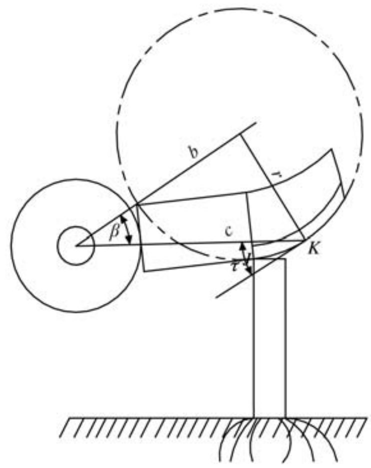


Figure 8 Schematic diagram of the blade cutting the top of stalk

4 Experimental conditions and methods

The performance tests of the new no-tillage planter were tested according to Chinese national standards GB/T 5262-2008 (Measuring Methods for Agricultural Machinery Testing Conditions-General Rules)[19] and GB/T 20865-2007 (No-Tillage Fertile-Seeding Drill)[20]. All of the experiments were conducted on May 2013 at the Agricultural Testing Farm (44°15′N; 125°18′E; elevation 239 m) of Jilin University in Changchun, China. The experimental field is 50 m long and 15 m wide. The soil type is chernozem. The soil volumetric moisture content was 10.7% at 5 cm depth and 13.9% at 15 cm depth measured with a FieldScout TDR 300 soil moisture meter (Spectrum Technologies Inc.). The soil penetration resistance was 2.05 MPa at 5 cm depth and 2.68 MPa at 15 cm depth detected with a FieldScout SC 900 soil compaction meter (Spectrum Technologies Inc.). The moisture content of the stalk was 17.79%. The coverage rate and average mass of the stalk/stubble respectively were 42% and 0.64 kg/m^2.

The experiments considered 3 factors that could affect the stalk cutting rate (y_1) and soil disturbance rate (y_2) of the stalk cutting mechanism: the working speed V, tillage depth h and cutter spacing D.

$$y_1 = \frac{m}{n} \times 100\% \quad (9)$$

$$y_2 = \frac{M}{N} \times 100\% \tag{10}$$

where, m is the number of cut stalk; n is the total number of stalk in experimental field; M is the width of soil disturbance; N is the row spacing[21,22].

The combined orthogonal experiments of three factors and three levels were conducted by using the Design-Expert software according to Box-Behnken combination principle, and using stalk cutting rate and soil disturbance rate as the indices. Experimental factors and level codes are showed in Table 2.

Table 2 Experimental factors and levels codes

Levels	Factors		
	x_1 /m·s^{-1}	x_2 /mm	x_3 /mm
−1	1.12	75	15
0	1.57	90	30
1	2.02	105	45

Note: x_1 is working speed; x_2 is tillage depth; x_3 is cutter spacing.

5 Results and discussion

5.1 Results of stalk cutting mechanism

When test working performance of the stalk cutting mechanism, we did not add seed and fertilizer to the planter. The stalk cutting rate and soil disturbance rate are showed in Table 3, based on different levels of factors.

Table 3 Test scheme and results

Text number	x_1	x_2	x_3	y_1 /%	y_2 /%
1	1	1	0	92.94	11.55
2	1	0	1	92.07	9.3
3	1	0	−1	89.59	7.98
4	1	−1	0	88.15	8.08
5	0	1	1	93.16	11.66
6	0	1	−1	90.55	10.2
7	0	−1	1	88.99	7.62
8	0	−1	−1	86.27	7.4
9	−1	1	0	89.70	10.28
10	−1	0	1	89.51	9.28
11	−1	0	−1	87.05	7.94
12	−1	−1	0	86.07	7.48
13	0	0	0	90.55	8.54
14	0	0	0	90.53	8.56
15	0	0	0	90.51	8.52
16	0	0	0	80.49	8.5
17	0	0	0	90.47	8.52

Based on the data in Table 3, two secondary multiple regression equations for stalk cutting rate (y_1) and soil disturbance rate (y_2) respectively were fitted as follows:

$$y_1 = 90.51 + 1.3x_1 + 2.11x_2 + 1.28x_3 + 0.29x_1x_2 - 0.74x_1^2 - 0.55x_2^2 - 0.21x_3^2 \tag{11}$$

$$y_2 = 8.53 + 0.24x_1 + 1.64x_2 + 0.54x_3 + 0.17x_1x_2 + 0.71x_2^2 \tag{12}$$

Analysis of variance shows that x_1, x_2, x_3, x_1x_2, x_1^2, x_2^2 and x_3^2 all have a significant effect on the stalk cutting rate (Table 4). Analysis of variance shows that the soil disturbance rate significantly affected by x_1, x_2, x_3, x_1x_2 and x_2^2, but not by x_1x_3, x_2x_3, x_1^2 or x_3^2 at p=0.05 (Table 5).

Table 4 Analysis of variance of stalk cutting rate

Source of variation	Quadratic sum	Degree of freedom	Mean sum of square	F	p
Model	66.81	9	7.42	1781.17	0.0001
x_1	13.57	1	13.57	3256.36	0.0001
x_2	35.57	1	35.57	8535.47	0.0001
x_3	13.18	1	13.18	3163.28	0.0001
x_1x_2	0.34	1	0.34	80.71	0.0001
x_1x_3	0.00001	1	0.0001	0.024	0.8813
x_2x_3	0.0003025	1	0.003025	0.73	0.4224
x_1^2	2.31	1	2.31	555.08	0.0001
x_2^2	1.29	1	1.29	309.78	0.0001
x_3^2	0.19	1	0.19	46.16	0.0003
Lack of fit	0.025	3	0.0008	8.39	0.0336
Pure error	0.0004	4	0.0001		
Total	66.84	16			

Table 5 Analysis of variance of soil disturbance rate

Source of variation	Quadratic sum	Degree of freedom	Mean sum of square	F	p
Model	27.01	9	3	36.7	0.0001
x_1	0.47	1	0.47	5.7	0.0484
x_2	21.48	1	21.48	262.8	0.0001
x_3	2.35	1	2.35	28.8	0.0010
x_1x_2	0.11	1	0.11	1.37	0.02797
x_1x_3	0.0001	1	0.0001	0.001223	0.9731
x_2x_3	0.38	1	0.38	4.7	0.0668
x_1^2	0.053	1	0.053	0.65	0.4470
x_2^2	2.11	1	2.11	25.76	0.0014
x_3^2	0.00094	1	0.00094	0.012	0.9159
Lack of fit	0.57	3	0.19	365.5	0.0001
Pure error	0.00208	4	0.0005		
Total	27.58	16			

Response surface method (RSM) was used to analyze the effects of the three factors on stalk cutting rate and soil disturbance rate by fixing one factor at zero level.

1) The effects of working speed (x_1) and tillage depth (x_2) on stalk cutting rate (y_1) were tested when the cutter spacing was fixed at 30 mm. The relation of y_1 with x_1

and x_2 is expressed as follows:

$$y_1 = 90.51 + 1.3x_1 + 2.11x_2 + 0.29x_1x_2 - 0.75x_1^2 - 0.57x_2^2 \tag{13}$$

Figure 9 shows that tillage depth has more significant effect on stalk cutting rate than working speed under the test levels.

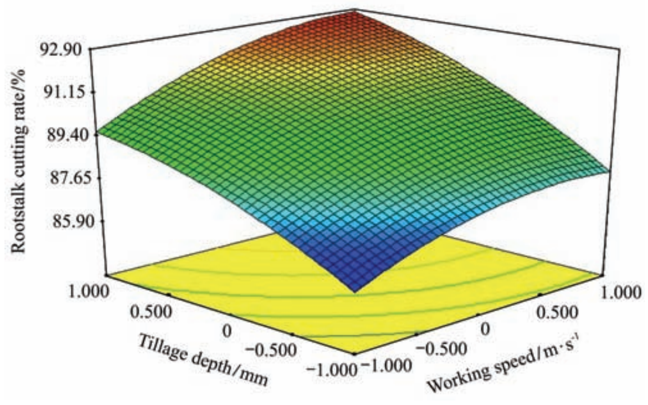


Figure 9 Response surface showing effects of working speed and tillage depth on stalk cutting rate

2) The effects of working speed (x_1) and tillage depth (x_2) on soil disturbance rate (y_2) were tested when the cutter spacing was fixed at 30 mm. The relation of y_2 with x_1 and x_2 is expressed as follows:

$$y_2 = 8.53 + 0.24x_1 + 1.64x_2 + 0.17x_1x_2 + 0.11x_1^2 + 0.71x_2^2 \tag{14}$$

Figure 10 shows that tillage depth has more significant effect on soil disturbance rate than working speed under the test levels.

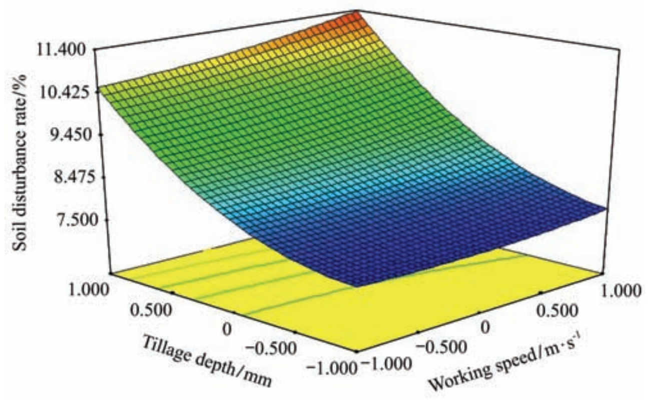


Figure 10 Response surface showing effects of working speed and tillage depth on soil disturbance rate

3) The effects of working speed (x_1) and cutter spacing (x_3) on stalk cutting rate (y_1) were tested when the tillage depth was fixed at 90 mm. The relation of y_1 with x_1 and x_3 is expressed as follows:

$$y_1 = 90.51 + 1.3x_1 + 1.28x_3 - 0.77x_1^2 - 0.24x_3^2 \tag{15}$$

Figure 11 shows that cutter spacing has more significant effect on stalk cutting rate than working speed under the test levels.

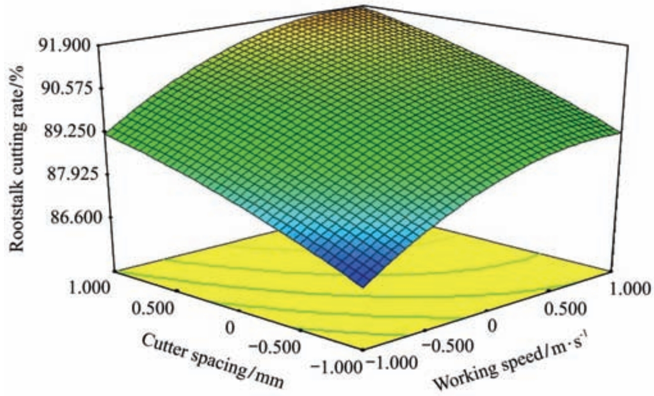


Figure 11 Response surface showing effects of working speed and cutter spacing on stalk cutting rate

4) The effects of working speed (x_1) and cutter spacing (x_3) on soil disturbance rate (y_2) were tested when the tillage depth was fixed at 90 mm. The relation of y_2 with x_1 and x_3 is expressed as follows:

$$y_2 = 8.53 + 0.24x_1 + 0.54x_3 + 0.15x_1^2 + 0.022x_3^2 \tag{16}$$

Figure 12 shows that cutter spacing has more significant effect on soil disturbance than working speed under the test levels.

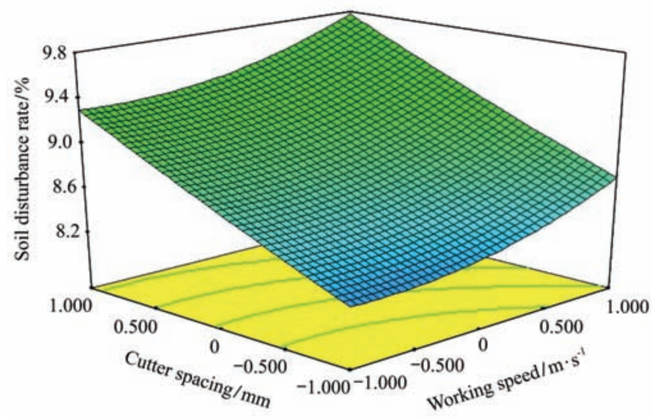


Figure 12 Response surface showing effects of working speed and cutter spacing on soil disturbance rate

5) The effects of tillage depth (x_2) and cutter spacing (x_3) on stalk cutting rate (x_3) were tested when the working speed was fixed at 1.57 m/s. The relation of y_1 with x_2 and x_3 is expressed as follows:

$$y_1 = 90.51 + 2.11x_2 + 1.28x_3 - 0.59x_2^2 - 0.25x_3^2 \tag{17}$$

Figure 13 shows that tillage depth has more significant effect on stalk cutting rate than cutter spacing under the test levels.

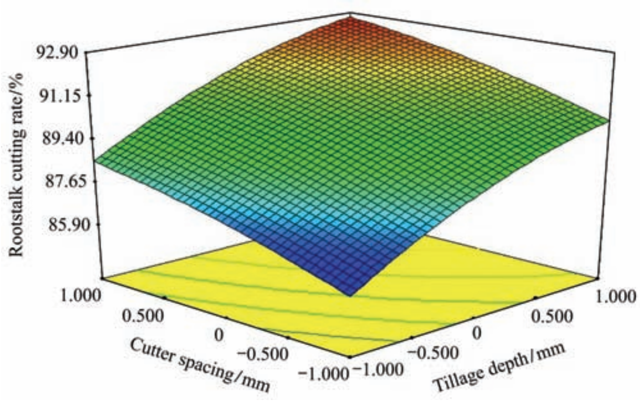


Figure 13 Response surface showing effects of tillage depth and cutter spacing on stalk cutting rate

6) The effects of tillage depth (x_2) and cutter spacing (x_3) on soil disturbance rate (y_2) were tested when the working speed was fixed at 1.57 m/s. The relation of y_2 with x_2 and x_3 is expressed as follows:

$$y_2 = 8.53 + 1.64x_2 + 0.54x_3 + 0.31x_2x_3 + 0.71x_2^2 \quad (18)$$

Figure 14 shows that tillage depth has more significant effect on soil disturbance rate than cutter spacing under the test levels.

Based on the test results analysis and model fitting, we further optimized the experimental parameters on Design-Expert to guarantee that the stalk cutting rate is more than 90% and soil disturbance rate is within 7.5%-12%. The best combination of stalk cutting rate and soil disturbance is the working speed of 1.62 m/s, the tillage depth of 92 mm, and the cutter spacing of 35 mm.

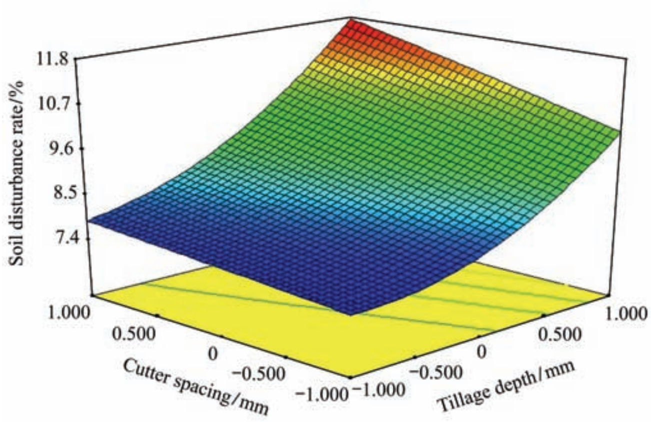


Figure 14 Response surface showing effects of tillage depth and cutter spacing on soil disturbance rate

5.2 Results of seeding and fertilization performance

During the tests of seeding and fertilization performances, the cutter spacing was 35 mm, the tillage depth was 90 mm, and the working speed was 1.62 m/s in order to achieve the best effect. The planter was adjusted to normal operation condition, the sowing depth was 5 cm, the fertilize depth was 8 cm, the seed spacing was 20 cm. The tractor forward speed was 1.62 m/s, and by this time, the slide of the ground wheel was 8.7%. Test results are shown in Tables 6 and 7. The emergence rate was determined to be 96% after seeding. The results showed that the new no-tillage planter comes up to the relevant national standards in China. Figure 15 shows the stalk breaking effect and emergence situation.

Table 6 Results of seeding performance

	Seed spacing						Sowing depth		
	Seed spacing /cm	Standard deviation /cm	Variable coefficient/%	leakage sowing rate /%	Replay rate /%	Qualified rate /%	Sowing depth /cm	Standard deviation/cm	Variable Coefficient/%
1	22.7	2.23	13.6	1.57	10.7	89.7	5.32	0.25	4.7
2	20.8	1.97	14.7	2.0	9.3	92.0	5.41	0.26	4.8
3	21.6	2.14	14.2	1.6	10.4	91.5	5.34	0.36	6.7
4	22.3	2.51	13.5	2.0	11.6	90.8	5.49	0.27	4.9
Mean	21.85	2.21	14.0	1.79	10.5	91	5.39	0.29	5.4

Table 7 Results of fertilization performance

	Fertilize depth			Fertilizing amount		
	Depth/cm	Standard deviation/cm	Variable coefficient/%	Fertilizing amount /kg	Instability/%	Inconsistency/%
1	3.18	0.33	10.4	684	1.78	0.8
2	3.20	0.47	14.3	670	2.56	
3	3.42	0.40	11.7	680	1.54	
4	3.29	0.35	10.6	678	1.67	
Mean	3.27	0.39	11.9	680	1.89	/

a. Stalk breaking effect

b. Emergence situation

Figure 15 Field experiment

6 Conclusions

According to the agronomic requirements of wide/narrow row alternative fallow farming mode in the black soil region of Northeast China, a new no-tillage planter of narrow row spacing was designed, which is capable of cutting crop residues, fertilizing, seeding, covering and rolling at a time. A gear-tooth stalk cutting mechanism was designed, which can cut stalk and stubble, loosen soil and provide a favorable working environment for the new no-tillage planter.

Three-factor and three-level combined orthogonal experiments were conducted using the factors of working speed (1.12 m/s, 1.57 m/s and 2.02 m/s), tillage depth (75 mm, 90 mm and 105 mm) and cutter spacing (15 mm, 30 mm and 45 mm), which significantly affect stalk cutting rate and soil disturbance rate. The optimal combination was the working speed of 1.62 m/s, the tillage depth of 92 mm and the cutter spacing of 35 mm. The performances of the new no-tillage planter were tested by using above parameters, and the results showed that it comes up to the relevant national standards in China.

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