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Experiment and analysis of residue flow/blockage characteristics for no/minimum till seeding

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ABSTRACT. *In order to resolve the problem of residue-blockage in no/minimum till wheat seeding in maize-straw covered field in double cropping area of North China-Plain, a field experiment was conducted to study the residue flow characteristics with the widely used strip rotary seeder and a controlled seeder. High speed video analysis showed that during no-minimum till seeding process, residue had two major motion forms: translation and rotation, and two blocking forms: twining on one opener or blocked between openers. The strip-tillage seeder could throw the residue up and bury them with soil to reduce residue accumulation thus avoid blockage. Dual factors test of straw length and straw coverage showed that straw length and straw coverage significantly influenced anti-blockage performance, the longer the straw was,*

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the heavier the straw coverage was, the higher the blockage grade was. In order to archive a satisfied anti-blockage performance that do not impact no-till seeding, the maize straw length of straw should not be longer than 9.1cm. Working parameter test of the strip tillage seeder showed that travel speed and rotate speed significantly influenced blockage index and torque, while the travel speed become faster, the blockage index turned higher, and the torque turned up at fist then turned down at 4km/h, the higher the rotate speed was, the lower the blockage index was and the bigger the torque was, optimal working parameter was choose at 320r/min of rotate speed and 4km/h of travel speed.

Keywords. No/minimum till seeding; strip tillage seeder; residue blockage; high-speed camera.

1 Introduction

The conservation agriculture (CA) includes no/minimum tillage, residue coverage and crop rotation (Gao et al., 2004; FAO., 2010; Matin et al., 2015), could improve soil structure, retain soil and water, increase organic matter, reduce the release of greeenhouse gases, and increase crop production especially in arid lands (He et al., 2014; Gao et al., 2003, 2008). It is an advanced technology and good for sustainability of agriculture. No/minimum till seeding was one of the most important steps for CA, and in double cropping area of North-China Plain, due to the extremely high maize straw coverage, the seeder often get blocked by the residue, which lead to low stability of seeding depth, high working resistance and undesirable seeding quality (Bo, 2010). Thus, the anti-blocking performance, has been increasingly important for no/minimum till seeding.

In order to solve the above problem, a set of techniques and implements have been developed. Based on the method of straw handling, they could be categoried into three groups: increasing the space of seeder to accelerate straw flow in the seeder, such as increase row space by adopting muti-bridge rack or increase the height of seeder rack (Li et al., 2006); cutting off the residues by discs or motivated openers then let the opener go through the cutted residues (Baker et al., 2006); set the residue aside or throwing the residue away to the backward of the openers by picking-up, pushing and throwing, etc (Wang et al., 2013; Chen et al., 2016). The strip tillage seeder, which has a good anti-blocking performance and high seeding quality, was popular in the double cropping area of North-China Plain (Gao et al., 2008).

However, these researches mostly focused on the design and applying of the implement, and are limited to specific implements or devices, few researches have been conducted to study the characteristic of the straw flow and blockage during the seeding process. Zhao et al. (2004, 2009, 2011) found in an experiment that the straw status (straw length and stubble retaining) and straw coverage and their interaction has significant effect on the anti-blocking performance of the no/minimum till seeder, the anti-blocking performance tend to be poorer when the straw coverage increase and the straw stubble become higher. Liao et al. (2005) made analysis on the movement characteristic of straw under with high-speed camera, found that straw has a path of horizontal projectile, oblique projectile and rectilinear motion.

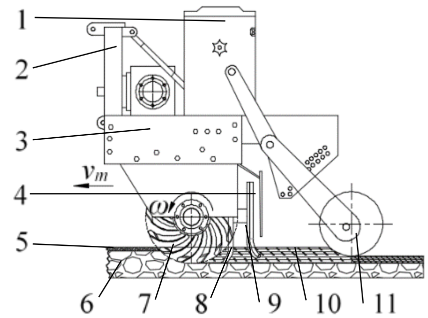
According to the problem of residue blockage in no/minimum seeding, this paper intended to conducted a field experiment on the strip tillage seeder and a non-anti-blocking seeder via high-speed camera, which would study the effect of working parameters and straw parameters on the straw flowing and blocking, and offer reference to improve the anti-blocking performace and develope better seeding implements.

2 Experimental procedure

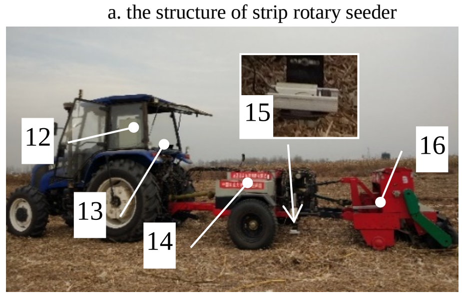
2.1 Field condition and equipment

The experiment was conducted in November, 2016 at an experiment station of China Agricultural University, located at Zhuozhou city, Hebei province (115º56’E, 39º28’N). The moisture content of straw was 17%; soil texture was sandy loam, and moisture content was 11.6%, 12.2% and 9.8% at depth of 0～10cm, 10～20cm and 20～30cm, respectively.

The test equipment (fig.1) involved a Lovol M904 tractor, a field testing vehicle, a strip tillage seeder, a non-anti-blocking-device seeder and a SVSI high-speed camera, etc. The field testing vehicle (Qiao et al., 2013) was developed by China Agricultural University, it could monitor torque, rotary speed and other data during no-till seeding, adjust rotary speed in 16 gears; the strip tillage seeder has a row space of 380mm and three sets of rotary blades were held in front of each opener, and each set has two blades; the non-anti-blocking device seeder was used as the controlled seeder, which has no anti-blocking device in front of the opener, and its row space was adjusted to 380mm to make comparision with the strip tillage seeder. The high-speed camera was implemented on the back of the testing vhicle and could advance with it, its position was adjusted beforehand so that it could capture two adjacent openers at the same time, so as to record the residue flow, the fps of the camera was set up at 36 fps/second with a resolution ratio of 640×480.



a. the structure of strip rotary seeder



b. the experiment equipment

Fig.1 Field experimental

1.seeder box 2.suspension system 3.rack 4.clod fender 5.straw in the surface 6.untilled field 7.anti-blocking implement 8.opener 9.tube of seeds and fertilizer 10. tilled field 11.compress roller 12. tractor 13.computer 14. field testing vehicle 15.high-speed camera 16. strip tillage seeder

2.2 Residue blockage evaluation

The GB/T 20865—2007 standard has grouped the residue blockage in to three categories, which made certain guidelines but could not judge the blockage degree quantificationally. Based on the field conditions, referenced to the work by Zhao et al. (2004, 2009, 2011) and Mead et al. (2003), we grouped the blockage in to 6 situations, corresponding blockage grades was made through observation of residue blockage and classification of the blockage situation. The Blockage performance grade index was shown in table1.

Tab.1 Blockage performance grade index

Classifications	Describe of the blockage	Blockage grades
Excellent	no obvoius entangling and blocking	0
very well	slitly entagling and the residue could flow easily	1
normal	much entangling but could flow away	2
not good	heavy blockage in 60m	3
bad	heavy blockage in 30m traveling	4
very bad	heavy blockage in 15m traveling	5

2.3 Experiment procedure

According to the GB/T 20865—2007 standard, the field was grouped into plots for experiment, each plot was 60m long and 2.4m wide. The experiment plots was completely at rondom and each test was conducted in three replications to obtain average value. Design-Expert 8.05 and SPSS 20.0 software was used for data processing and variance analysis. The experimental factors were shown as follows:

(1)Travel speed

The usual travel speed of wheat seeders was 4~9km/h, but for no/minimum till seeders, the residue flow would increases in the seeder with the increase of travel speed, and could trigger blockage more easily, thus the travel speed was choosed as 2, 4 and 6 km/h. And it was controlled by the gear and accelerator of the tracor.

(2)Rotary speed

The rotary speed of the roller has a influence on the initial throwing velocity of the residue, with the increase in rotary speed, the straw was more easily thrown up for anti-blocking, but the energy consumption wulld increase as well (Chen, 1985). Considering that normal rotary speed of the strip tillage seeder was at about 300r/min, we choose a testing range of

220~420r/min. The testing vehicle could adjust the speed in 16 gears from 0~1000r/min, and the final rotary speeds were 227, 320, 411r/min based on the adjustment.

(3)Straw length

The straw length was arranged by change the working time of the straw crushing and returning machine at 1, 2 and 3 times, then the straw length was detemined as 5.3cm, 9.1cm and 13.9cm, respectively.

(4)Straw coverage

The straw coverage was arranged by cutting away the straw in the field before straw crushing, 6, 4, and 2 rows of straw were remained un-cutted in the 2.4m wide pilot. After straw crushing and returning, the straw coverage was detemined as 0.8kg/m^2, 1.4kg/m^2 and 2.5kg/m^2 respectively.

3 Residue flow analyze with high-speed shooting

In order to study the residue flow and blockage characteristics during no-till seeding, high-speed camera was used to observe and analyze the seeding process of the strip tillage seeder and controlled seeder. Straw length was 9.1cm, straw coverage was 2.5kg/m2. Travel speed was 4km/h and tillage depth was 80mm for both seeders and rotary speed of the strip tillage seeder was 320r/min.

3.1 Residue flow of the controlled seeder

3.1.1 Residue movement analyze

When the controlled seeder started to work, the openers advanced with the seeder, then relative motion occurred between the opener and residue in the soil surface, as shown in fig.2. Assuming the opener as motionless, the movement of residue could be classified into two catagories: one was translation, when the opener came into soil, the surface soil was stirred up, and with the supporting of surface soil, the residue moved to inclined top, with the advance of the opener, the straw moved along to the zenith, then fell down to the backward of the opener, the opener gone through the residue without blocking, and the residue finally dislocated between the seeding rows; Second was rotation, since straw coverage was considerably high, the residues entangled with each other frequently and forming into clumps, with the advance of the opener, the clump was picked up and under the force of opener friction, ground friction and friction between straws, the clump rotated around the opener from the frond to the back, thus the opener passed by without blockage.

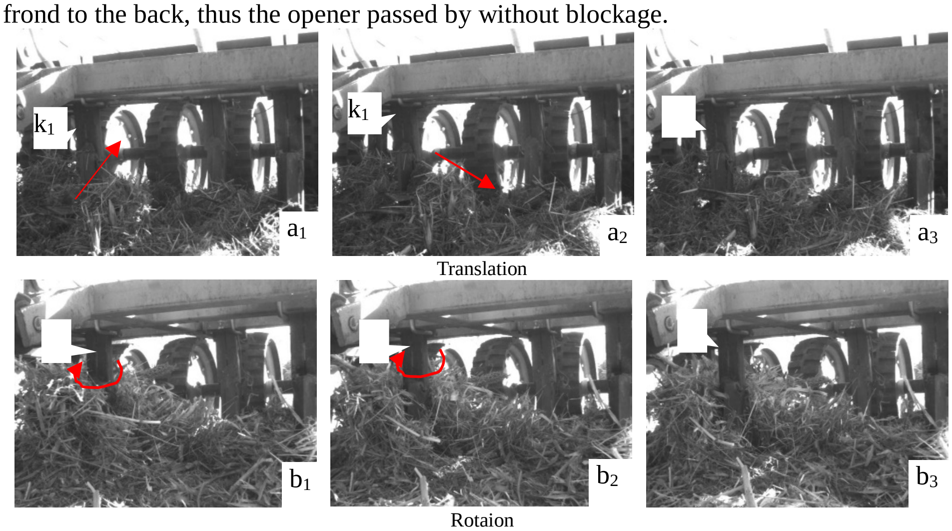


Fig.2 Residue move process of double rank no-till seeder

3.1.2 Residue blockage analyze

However, residue blocking did happens under some circumstances, based on the position where it occurred, two category can be classified: the first occurred between two adjacent openers. Since the straw were not always smashed evenly, some of the straw were not completely smashed and were quite long, if these long straw lied verticlly with the travelling direction of the seeder, they would be pushed forward by the opener and stayed there, consequently, the following up residues would be blocked by this long straw and can not flow through, with the advancing of the opener, more and more residue would be blocked and advance together untill completely blockage; The second case occurred in one opener first, as shown in fig.1.b, straw clump can be seen in front of each opener, since the straw clumps were heavy and friction force within the clump was high, they could not flow away timely. With the advance of the opener, more and more straw were accumulated there untill they come into reaction with the clump of the adjacent opener, severe blocking took place then. This was similar with the found of Zhang et al., (2000).

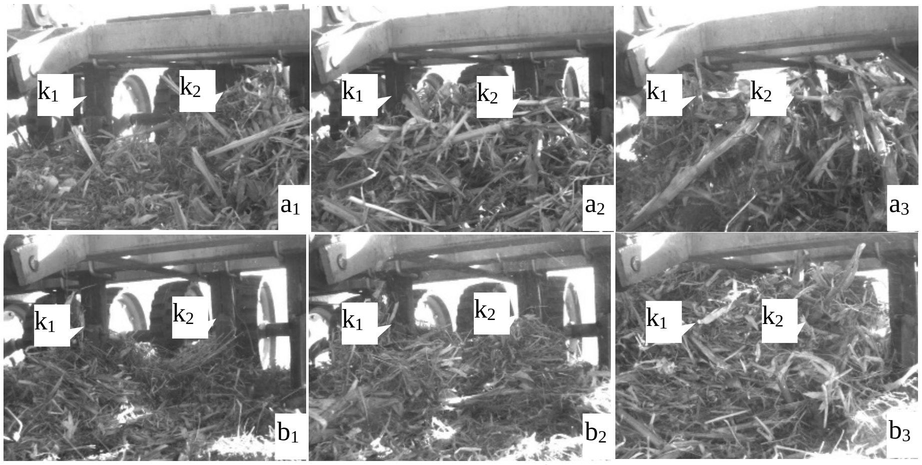
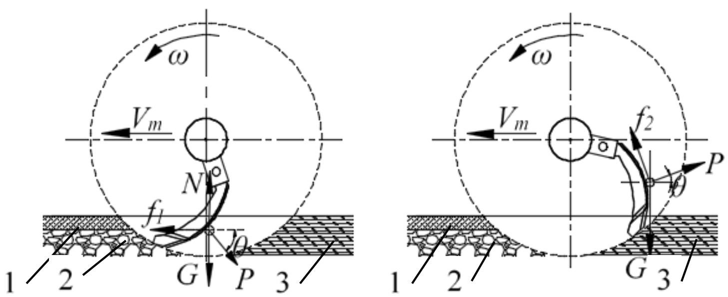


Fig.3 Residue accumulation process of double rank seeder

3.2 Residue flow of the strip tillage seeder

3.2.1Residue movement analyze

In the seeding process of strip tillage seeder, the blades rotated by the driven of the tractor and interacted with the residue all the time. Based on the straw motion state during seeding process, the residue movement could be grouped into two periods, downward movement period and throwing period.



a.Downward movement period b.Throwing period

1.surface residue 2.untilled field 3.tilled field

Fig.4 Force analysis and movement process of straw

(1) Downward movement period

When the seeder begun to operation, with the rotation of the roller, the blades rotated anticlockwise. Once the blade came into interaction with soil surface, it gave a inclined downward force P (fig.4) to the surface straw, since the rotary speed was lower than the required cutting speed (Zheng et al., 2016), a small proportion of the straw could be cutted off and most was bent due to the supporting force of soil. As shown in fig.4.a, the straw was bearing press force of the rotary blade, supporting and frictional force of the soil surface and the gravity:

$$\begin{cases} F_x = P\cos\theta - f_1 \\ F_y = P\sin\theta + G - N \\ f_1 = \mu \cdot N \\ G = mg \\ N = P\sin\theta + mg \end{cases} \qquad (2)$$

where F_x—resultant force in horizontal direction, N

F_y—resultant force in vertical direction, N

P—press force of the blade, N

N—supporting force of soil surface, N

f_1—frictional force of soil surface, N

m—straw weight, g

μ—frictional coefficient of soil and straw

θ—slide cutting angle of the blade, (°)

When the resultant force in horizontal direction $F_x > 0$, the straw moved backwards and being pressed into soil, when $F_x < 0$, the straw moved forwards, sliped away from the blade and stayed at the soil surface. This period was corresponded with fig5.a-c of the high-speed pictures, the blade k4 in the right of the opener k1 (3cm away) first encountered with soil surface and pressed the straw into soil. With the rotation of the blade, residue in the sides of opener were pressed into soil in succession, thus they can not accumulate around the opener and the blockage was handicaped.

(2) Throwing period

With the rotation of rotary blades, some of the straw gradually came out of soil under force P of the blade, some of the straw were in the soil surface above the blade, they came into the throwing period as shown in fig.4.b. At this moment the straw beared gravity G, pushing force of the blade P and frictional force f_2 :

$$\begin{cases} F_x = P\cos\theta - f_2\sin\theta \\ F_y = P\sin\theta + f_2\cos\theta - G \\ F_R = \sqrt{F_x^2 + F_y^2} \\ F_n = mr\omega^2 \\ f_2 = \mu' P \end{cases} \qquad (3)$$

Where f_2—frictional force of the blade, N

μ'—frictional coefficient between balde and straw

F_R—Resultant force of the straw, N

F_n—centrifugal force, N

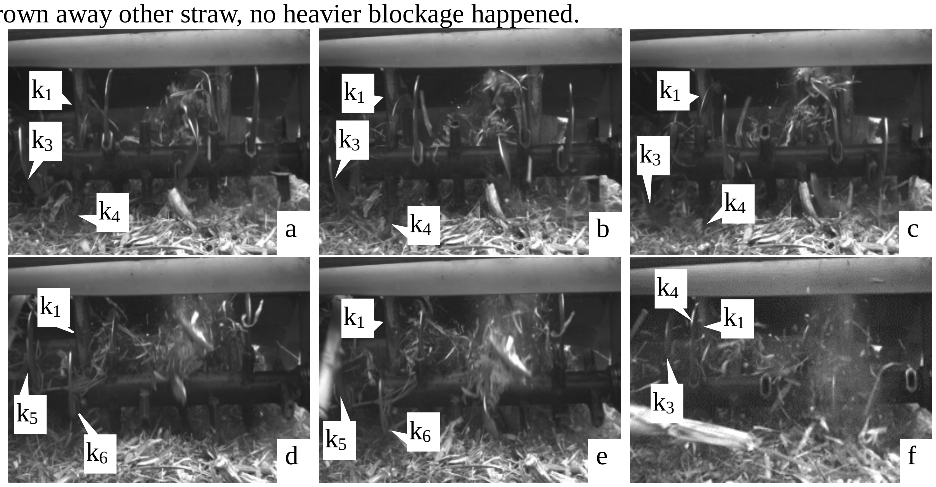
ω—angular velocity, rad/s

r—rotation radius, mm

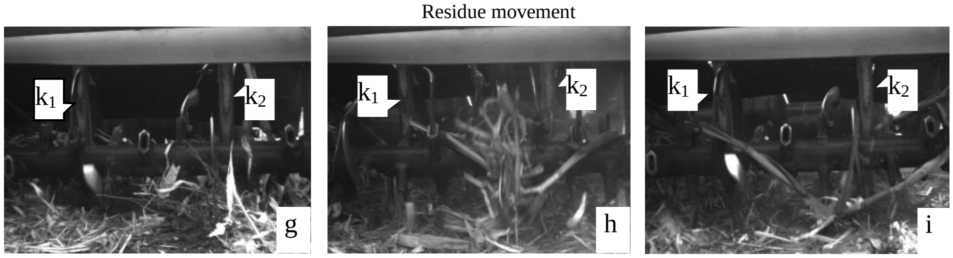
When $F_n > F_R$, namely centrifugal force bigger than resultant force of the straw, it would be thrown backwards. With the initial velocity from the blade, the straw could pass through the openers and fell down under air fricion of being stopped by the breast board, besides, soil particles were also observed being thrown up and falling down, thus some of the straws were finally mixed with soil. When $F_n < F_R$, namely centrifugal force smaller than resultant force, the straw would rotate together with the blade and being thrown to the forward of the seeder. Besides, Eq (3) indicated that rotate radius effect centrifugal force, the smaller the r was, the closer the straw was with rotation center, and the smaller the centrifugal force was, thus it would be more difficlut to be thrown away. As shown in fig.5 d-f, the blade k4 thrown up the straw after it came out of soil surface, and straw was seen throwing away both in forward and backward directions. Because that interacting point was not always in the centroid of the straw, oblique projectile motion and rotaion was also observed of the straw.

3.2.2 Residue blockage analyze

Residue blockage of the strip tillage seeder was as shown in fig.5 g-i, during the seeding process, unsmashed long straw entangled in the roller of the seeder (between opener $k_1$and k_2). Because the straw stayed at the tool apron of the roller, it was difficult to be thrown out or cutting off, thus resulted in slight blockage. However, the blade in front of the opener could still rotate and thrown away other straw, no heavier blockage happened.



Residue movement



Residue blockage

Fig.5 Residue flow process of strip rotary wheat seeder

4 Results and discussion

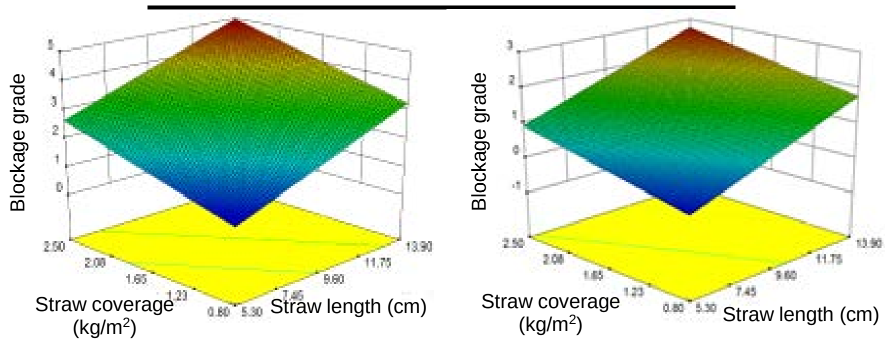
4.1 Anti-blocking performance under different straw conditions of the two seeders

According to the analysis of high-speed shooting pictures, the straw length and coverage may have a great influence on anti-blocking performance on no-till seeders. Thus, we conducted an experiment under different straw coverage and length for the two seeders. Travel speed was 4km/h and tillage depth was 80mm for both seeders and rotary speed of the strip tillage seeder was 320r/min.

According to the results shown in table2, the anti-blocking performance of strip tillage seeder was significantly better than the controlled seeder in all cases with lower blockage grades between 0.4-2.1. Straw coverage and straw length have both highly significant influence on blockage grades of strip tillage seeder while straw length has highly significant influence on blockage grades of controlled seeder and straw coverage has significant influence. Accroding to the response surface analysis of straw parameters in fig.7, straw length and coverage has a similar influnce trend on both seeders: with the increase in straw length and straw coverage, the blockage grades increased and the anti-blocking performance became poor. At a certain straw coverage, the anti-blocking performance became poor because the space between openers was fixed, long straw was more difficult to flow through, and more easily entangled in the opener or roller, then with its friction, the following residue coming in was more easily to accumulate and cause blockage. Zhao et al., (2011) found that straw coverage may impact straw throwing performance and less residue can be thrown out thus trigger heavier blockage.For strip tillage seeder, no heavy blockage was observed (blockage grade < 3), when straw length was shorter than 5.3cm, no matter how much straw coverage was, the blockage grade was always under 1 points, which means only slight blockage occurred, and when the straw coverage was 0.8 kg/m^2, no blockage happened; when straw length was equal to or shorter than 9.1cm, only slight blockage occurred (blockage grade < 2 points); when the straw length was at 13.9cm, heavy blockage happened at both 1.6 and 2.5 kg/m^2 straw coverage (2pints < blockage grade < 3 points). For controlled seeder, when straw length was at 5.1cm, no matter how much straw coverage was, only slight blockage happened; at 9.1cm, complete blockage happens at 2.5 kg/m^2 straw coverage; at 13.9cm, blockage was observed at all straw coverage. It can be concluded that reduce straw length and decrease straw coverage would be efficient way to reduce residue blockage, and in order to avoild complete straw blockage that heavily impact seeding quality, straw lengh should better controlled shorter than 9.1cm.

Tab.2 Tests scheme and results of straw parameters

Testing Plots	Straw coverage (kg/m^2)	Straw length (cm)	Blocking grades	
			Controlled seeder	Strip tillage seeder
1	0.8	5.3	1.1	0
2	0.8	9.1	2.1	0.8
3	0.8	13.9	3.4	1.7
4	1.6	5.3	1.4	0.5
5	1.6	9.1	2.9	1.3
6	1.6	13.9	4.2	2.4
7	2.5	5.3	1.5	1.1
8	2.5	9.1	3.6	1.6
9	2.5	13.9	4.9	2.8



a.Controlled seeder b. Strip tillage seeder

Fig.6 Respond surface of staw parameters to blockage index

4.2 Working parameters optimization of the strip tillage seeder

In order to analyze the anti-blocking performance of strip tillage seeder further, the effect of working parameters was examined in a field experiment. Straw manage was based on the most popular way in double cropping area in the North-China Plain with straw coverage of 2.5 kg/m2 and straw length of 9.1cm. The experiment scheme and results were shown in table 3.

Tab.3 Tests scheme and results of working parameters

Testing plot	A travel speed(km/h)	B Rotary speed (r/min)	Blockage grades	Torque (N·m)
1	4	227	1.4	140
2	4	320	1.0	167
3	4	411	0.5	202
4	6	227	1.7	216
5	6	320	1.3	280
6	6	411	1.2	311
7	8	227	2.7	149
8	8	320	2.3	157
9	8	411	1.5	234

Tab.4 Analysis of variance

Variance		Quadratic sum	Freedom	*F*	Significance
Blockage grades	A	4.348	2	326.083	**
	B	2.168	2	162.583	**
	error	0.06	27		
Torque	A	41314.311	2	18.703	**
	B	8397.378	2	3.082	*
	error	39761.2	27		

Note: *significant(P<0.05), **highly significant (P<0.01)

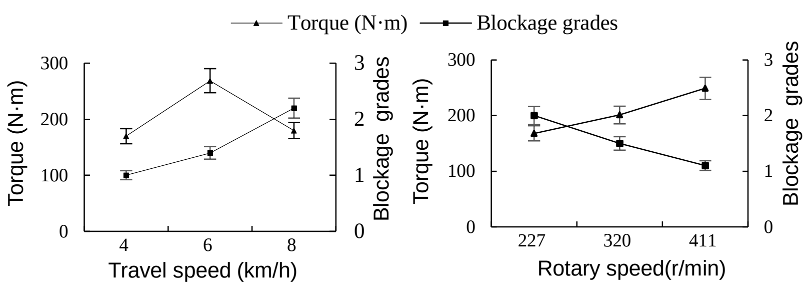


Fig.7 Influncing trend of factors on evaluation index

From the variance analysis in table3, travel speed and rotary speed highly significantly effect on blockage grades. As shown in fig.7, the blockage grades increased with the increase of travel speed, when travel speed was at 8km/h, heavy blockage occurred at both 227 r/min and 320 r/min of rotary speed. This trend was similar with the observation of Chen et al. (2016), because with the increase of travel speed, the straw flowed more into the seeder at given time, was harder pass through thus blockage grades was higher. The blockage grades decreased with the increase of rotary speed, the reason may be: (1) straw throwing at a given time increased thus more residue could be thrown out of the seeder (2) straw was more easily cutting off (3) the initial velocity of the thrown straw was higher thus it could travel further and pass by the opener (Li et al., 2004). Besides, no complete blockage was observed at all experiment, indicate that strip tillage seeder has a good anti-blocking performance at 9.1cm straw length, however, all experiment grades was higher than zero because of the high straw coverage of 2.5 kg/m2.

As shown in fig.7 the torque increased with the increase of rotary speed, this may because that pitch distance decreased and lead to: (1) more soil cutting, (2) more soil and straw throwing (Matin et al., 2015). The torque increased from 4 to 6 km/h, however decreased from 6 to 8 km/h of travel speed, because that the rotary tillage speed ratio λ decreased and lead to increase in pitch distance, thus soil cutting was reduced. Based on the results of blockage grades and torque, the optimal working parameter was choose at 320r/min of rotary speed and 4km/h of travel speed when no medium blockage was happened with a relative low energy consumption.

5 Conclusion

(1) During the no/minimum till seeding process, the movement of straw between openers were mainly translate and rotate, the the main blockage form was entangled at the opener or blocked between adjacent openers, and accumulate with the advance of seeder untill comlpete blockage occurred. The blade of the strip tillage seeder could hit and throw away the residue surrounds the opener and mix it with soil, thus reduce blockage.

(2) The anti-blocking performance of strip tillage seeder was better than controlled seeder at all straw conditions. With the increase of straw length and straw coverage, the blockage grades increased and in order to aovid complete blockage, straw lengh should be controlled shorter than 9.1cm.

(3) Travel speed and rotary speed have significant influence on anti-blocking performance and torque, with the increase in travel speed, the blockage grades increased; with the increase in rotary speed, the torque increased while the blockage grades decreased. Optimal working parameter was choose at 320r/min of rotary speed and 4km/h of travel speed.

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