·农业装备工程与机械化·

Design and experiment of blades-combined no and minimum-till wheat planter under controlled traffic farming system

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Abstract: During the operation of agricultural machinery, farmland soil compaction caused by the combination weight of tractor and implements resulted in reduction of soil porosity and increase of soil bulk density, which have a negative effect on soil tilth. The controlled traffic conservation tillage is the combination of controlled traffic tillage and conservation tillage, a tillage system takes measures as follows: straw mulching, seeding in no-till or minimum-till field, and separating the crop growth zone from the tractor track. To reduce soil compaction, improve the environmental conditions for plant growth and strengthen the technology convergence of agricultural machinery and agronomy, a no and minimum-till wheat planter for controlled traffic tillage was developed based on the requirements of mechanized conservation tillage technology. This individual profiling planter consists of a frame, straw chopping devices for anti-blocking, wedge-shaped openers for fertilization, double-disk openers for seeding, and seed & fertilizer boxes. The anti-blocking straw chopping devices was combined by a wedge shaped opener with Y and L type blades. The opener's blade front edge embedded into Y type blades' front fork (overlap depth is about 10 mm). But the two edges are non-interference. Y type blades crushed straw while kicking out the straw and stubble from opener shanks. L type blades are equipped on both sides of the opener's front edge, the included angle α of Y-type blade was set to 120° and L-type blade Φ was designed to 120°. Each opener has three sets of blades (three Y type blades and six L type blades). While the planter is working, the tractor would pull the planter with a forward speed of 3-5 km/h. The tractor tires and land wheels of planter would roll on the tractor track. Power from the tractor PTO shaft is transmitted to the driver cutter shaft trough the gearbox and power transmission system. The rotating cutter shaft would lead to the high-speed rotation of flails which chop the straws to help the wedge-shaped openers with furrowing and fertilizing. Subsequently, a double-disk opener would do the second-furrowing to accomplish seeding，pressing and soil-covering. A field experiment was conducted on June, 2011 in the conservation tillage experimental field located in Zhuozhou city, Hebei province. During the experiment, the planter showed stable working performance and good passing ability. The results also indicated that this planter could plant effectively under no and minimum-till, and all the indicators met the design requirements for no-till planter. According to the comparison experiments on two treatments, the controlled traffic tillage and uncontrolled traffic tillage, it was concluded that all the performance indicators under the controlled traffic tillage system were slightly superior to the ones under uncontrolled traffic tillage system, although the no and minimum till planter designed for controlled traffic tillage could also meet the seeding requirements under uncontrolled traffic tillage system. For controlled traffic tillage system, the average seeding depth was 3.6 cm with a qualified rate of 87.9%, and the average fertilizer application depth was 8.2 cm with a qualified rate of 84.8%, which met the design requirements.The two-year experiment results indicated that, compared with the uncontrolled traffic tillage, the controlled traffic tillage could save fuel consumption by 22.49% because of better tire adhesion. It might proved that the controlled traffic conservation tillage technology could improve the soil structure and reduce the costs significantly. Controlled traffic no and minimum-till seeding technique is a technology which not only improve the seeding quality, but also save the fuel, and finally realize the energy conservation and emission reduction. With the promotion of land circulation policy, this research result could be of value for the scale cultivation and efficient management of land.
Keywords: agriculture machinery; design; crops; controlled traffic; conservation tillage; seeder; fuel consumption
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0 Introduction

Soil compaction, a phenomenon caused by machinery tires during the process of agricultural machinery in the field work, lead soil inner pore lost, porosity decreased and the soil density increased, and then to influence the tilth and fertility of soil[1]. A large number of studies[2-4] have shown that soil compaction could reduce the storage and supply of the soil's moisture and nutrients, enlarge the extra fertilizer demand and the cost of agricultural products. At the same time, less fresh organic can be poured into the soil, accordingly, soil compaction can reduce nutrient cycle, decrease the soil microbial activity, and hinder the growth of crop roots.

Controlled traffic conservation tillage technology, a farming technology combined controlled traffic operations

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and conservation tillage, its features are as follows: mulching with straw, no-till/minimum-till seeding and the farm machine tracks separated from crop growing area[5]. A research[6] showed that controlled traffic conservation tillage technology could reduce the fuel consumption by about 23.7%, and exhaust smoke by about 20%. Li et al.[7] suggested that controlled traffic could improve soil structure, increase soil water storage capacity and reduce surface runoff. Studies[8] showed that controlled traffic conservation tillage technology has an obvious advantage of improving soil, reducing investment, and decreasing production cost.

With the promoting of Chinese land circulation policy, and the continually appearing of Agricultural Cooperation, the Agricultural Machinery Cooperation, Large-scale Agricultural Machinery Farmers and large-scale grain-production household, the scaled land management consistently enlarged[9-10] controlled traffic no-tillage seeding technology improved the level of farmland efficient management, reduced the operating cost, improved the soil structure and promoted the agriculture sustainable development[11-12]. At present, some researchers have started to study on controlled traffic conservation tillage technology, however which mainly focused on the effects of controlled traffic conservation tillage while less were researched on no-till implements. Therefore, the researches of no-tillage wheat seeder for controlled traffic with conservation tillage technology have certain guiding significance to scaled land management in China.

1 Design implement

1.1 Design idea

In annual double cropping areas in northern China, no-till seeding wheat in maize straw mulching field faces the condition of large quantity of maize straw and insufficient time for seeding. The machines are easy to block. Therefore, it is important to study the anti-blocking unit while designing controlled traffic wheat no-till seeder[13]. In addition, for the controlled traffic tillage, the track of the tire requires to be separated from the seeding zone, so the tire of the tractor and the driving wheel of the seeder are required to run in the certain zone to mitigate the degree of the soil compaction (Fig.1).

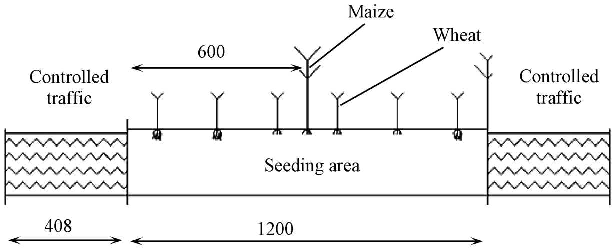
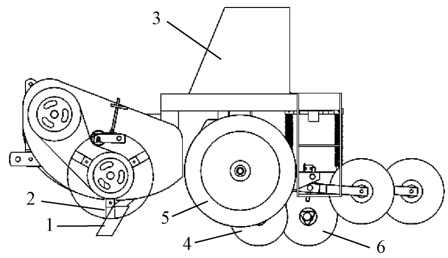


Fig.1　Arrangement of controlled traffic tillage

The working width of controlled traffic no-till seeder mainly depends on the size of the tractor's tire and the tractor's tread (John·Deere/JD5-754). For the controlled traffic conservation tillage, the track's center distance is 1608 mm, the width of the track zone is 408 mm, the width of seeding zone is 1200 mm. According to the size of the controlled traffic tillage, 3 rows of maize and 6 rows of wheat are in the seeding zone.

1.2 Overall structure and working principle

As shown in Fig.2, the controlled traffic wheat no-till seeder is mainly consisted of a framework, a straw chopping anti-blocking device, a wedge shaped fertilizing opener, a double-disk seeding opener and fertilizer and seeding box. The seeding system adopts a monosomic hinged profiling mechanism. During the operation, the tractor pulls the seeder at the speed of 3-5 km/h. The tractor's tire and the seeder's driving wheel go through the traffic zone. Tractor PTO shaft transfers power to the active tool axis through gearbox and power transmission system, drives the tool axis rotating in a high speed. The wedge shaped fertilizing opener[14] opens a furrow, fertilizes and avoids blocking with the tool axis. Then the double-disk seeding opener opens the furrow at a second time to seed, press, and cover the seed.



1.Wedge-shaped opener　2.Y and L type blade　3.Fertilizer and seeding box　4.Double disk opener　5.Driving wheel　6.Compaction wheel

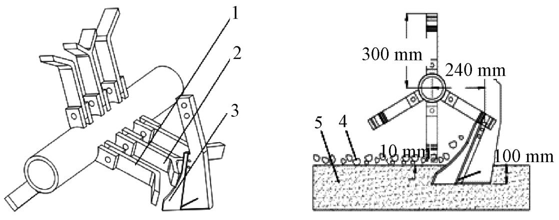
Fig.2　No-tillage wheat seeder for controlled traffic

1.3 Design of key components

1.3.1 Anti-blocking opener

In annual double cropping areas in northern China, the straw coverage is about 3.0 kg/m² when seeding wheat on corn stubble field. The quantity of maize straw is large, and their size is different. Disk opener is good at anti-blocking, but it's hard to dig into the soil. Wedge shaped opener is good at digging into the soil, but it's easy to be blocked. In this paper, we designed an anti-blocking trenching equipment. As shown in Fig.3, it is combined by a wedge shaped opener with Y and L type blades. The opener's blade front edge embedded into Y type blades' front fork (overlap depth is about 10 mm). But the two edges are non-interference. Y type blades crushed straw while kicking out the straw and stubble from opener shanks. L type blades are equipped on both sides of the opener's front edge. Each opener has three sets of blades (three Y type blades and six L type blades). Space between adjacent blades is 5 mm. Blade doesn't dig into the soil when it's working. And it is above ground at about 10 mm. The tool axis and the opener's horizontal space is 240 mm.

Otherwise, to avoid blades damaging when rolling fast and bumping against the hard obstruction (such as stones), blades are hinged connected on the tool axis. When blades bump against the hard obstruction, the blades rotate as the center of rotation. So it can avoid damages. The opener digs into the soil by 100 mm.



a. Axis view b. Front view

1.L-type blade 2.Y-type blade 3.Wedge-shaped opener 4.Residue 5.Soil

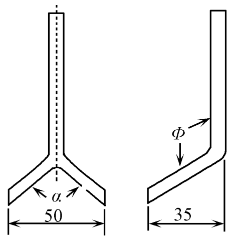
Fig.3 Sketch of strip chopping anti blocking and opening mechanism

1) Y-type blade

The main effect of Y-type blade is smashing the straw and stubble right in front of furrow opener,cleaning up the straw and stubble hitched on the fertilizer placer's shovel shaft.

As shown in Fig.4, the angle α of Y-type blade is the angle between the two front blades, if the angle is too large, the bending point of the blade will come into contact with straws first, increasing the cutting resistance. If the angle is too small, the point of the blade will first come into contact with the straws and stubbles, blades will interfere with the fertilizer shovel shaft of opener. According to structure design and operation requirements, the included angle α of Y-type blade was set to 120°.

The outermost span of Y-type blade is d, the blade cannot beat the straw hitched on the fertilizer shovel shaft of opener efficiently if d is too big. But blade will tend to interfere with the fertilizer placer's shovel shaft if d is too small. In comprehensive consideration of the basis of the parameters, such as the cooperation with the fertilizer shovel shaft of opener and machine structure, the span d was set to 50 mm.



a. Front view b. Side view

Note: α is angle between two front blades, Φ is angle between tangent plane and side of plane of L-type blade.

Fig.4 Sketch of hammering blade of Y-type and L-type

2) L-type blade

The main effect of L-type blade is smashing the straw and stubble right in front of furrow opener further, throwing the part of stubble aside, and reducing the straw cover of the seed tapes. Cutting tool adopts single blade structure.

The angle Φ is the angle between tangent plane and side of plane of L-type blade. The point of blade will come into contract with stubble first if it is too big, which leads to the decline of tool life. The bending point will comes into contract with stubble first if it is too small, which leads to the increase of cutting resistance. Thus, L-type blade Φ was designed to 120°.

Ditching parameter, machine structure, material strength, and power consumption were taken into consideration in the design of Cutting width L. The main effect of L-type blade is smashing the stubble right in front of furrow opener further insuring both the fertilizer placer and seed placer have good performance of ditching. The width of L-type blade is designed to 35 mm.

1.3.2 The determination of the knife shaft speed

Indoor straw cutting test-bed is concluded by laboratory test. The cutting speed of the blade is 25-50 m/s when rotating without support. Select the blade speed as 45 m/s by considering both the straw crushing rate and power consumption problem, and referring to domestic and foreign research data and results[15-16]. It can meet the needs of cutting off corn straw in theory.

The crushing blade shaft speed:

$$n = \frac{60v}{2\pi \cdot \gamma}. \qquad (1)$$

Where n is for the crushing blade shaft speed, r/min；v is the linear velocity on the blade knife, m/s; γ is the turning radius of the blade knife, mm. It is known that the shaft tube radius is 80 mm, the distance between blade holder and shaft tube is 60 mm, the distance between blade knife and blade holder is 110 mm, that is γ =250 mm.

Bring the linear velocity on the blade knife v =45 m/s, turning radius of the blade knife γ=250 mm in the formula（1）and calculate: crushing blade shaft speed n=1 720 r/min.

The power take-off shaft speed of tractor is 720 r/min, using the transmission(transmission ratio 1:2.43) for speed change. Using the flat belt (transmission ratio 1:1) for transmit. The result of crushing blade shaft speed in theory by calculation is 1750 r/min, then calculate the corresponding linear velocity on the blade knife is 45.8 m/s which is greater than 45 m/s, satisfies the demand of cutting off corn straw.

2 Field trial and result analysis

2.1 Experimental conditions

A field experiment was conducted in Zhuozhou city, Hebei province. The plot was established in June, 2011. It covers an area of about 0.97 hm^2 with 210 m in length and 46 m in width. A wheat-maize annual double cropping system is adopted. The soil is sandy loam. The experiment was conducted in October, 2013 (Fig5), the wheat species is Beinong 9549, seeding rate is 375 kg/hm^2, the average mass water content of the soil in 0-10 cm depth is 14.7% during the seeding period, the soil is irrigated before getting frozen by mobile flexible hose. Straw coverage of maize is 2.78 kg/m^2. Control field which conducted no-tillage farming was established in the same area in June, 2011. The tractor used for experiment was John Deere 754. Soil disturbance quantity, straw coverage, drying rate of seed etc were determined after seeding.

2.2 Methodology

2.2.1 Anti-blocking

The eligibility criteria of anti-blocking performance of no-till planter is, under the condition of 2.0-4.0 kg/m^2 coverage as well as a field length longer than 60 m, if the machine could complete a round trip without blocking or with only one slight blocking, it is believed that the planter could meet the requirements.

Fig.5 Seeding in field

2.2.2 Soil disturbance

It is an important indicator to test no-till planter performance of soil disturbance, which could reflect the disturbance index of soil by agricultural machinery, according to formula (2), the data were collected after seeding in randomized profile in the shape of “Z” on the field with six replications, and the average was calculated[17].

$$\eta = \frac{D}{S}. \qquad (2)$$

Where η is soil disturbance; D is furrow width, mm; S is seeding line width, mm.

2.2.3 Straw coverage

It was marked in a 20-m-long nylon rope at every 10 cm. Before and after seeding, the rope was straightened in the testing field and put on the ground softly, the number of marks under which has straw was counted and divide by the total marks and get the straw coverage. Get the mean value with five tests in each area[18].

2.2.4 Drying rate of seed

After seeding, chose 12 points randomly in the shape of “Z” in the seeding zone, and 5 m in the front and back of the point as observing area. Firstly, observed the seeds number leaked on the ground with naked eyes, then pushed soil aside to count the seeds placed on straws, calculate the average value and the number of drying seeds[19].

2.2.5 Fuel consumption

The fuel consumption monitor in this experiment is CTM-2003B Agricultural machinery comprehensive tester, which could track operation speed, time, distance and instantaneous fuel consumption[20]in each treatment is conducted in 6 replications.

2.2.6 Emergence rate

Observe the emergence status after the seeding of 18 days, take 5 sections in the seeding zone，record the number of the sprouts in 1 m of each section and get the average value.

2.3 Results and analysis

2.3.1 Anti-blocking performance, soil disturbance and change of straw coverage

According to the experimental method of no-till planter performance, the anti-blocking performance, soil disturbance and straw coverage were tested during the seeding period,. Results of stubble mulching ratio were shown in table 1.

Table 1 Stubble mulching ratio

Measurement Area	Straw coverage/%	
Between rows	Before sowing	100
	After sowing	100
Seeding zone	Before sowing	100
	After sowing	37.9

1) The designed “L” and“Y” flail knife with Wedge knife opener has a good performance of anti-blocking, the planter completed a continuous 210 m round operation without blocking or with a slight block.

2) The straw coverage decreased from 100% before seeding to 37.9% after seeding, indicated that throw effect of “L” flail knife could throw the straw aside, reduce straw coverage, which is effective to reduce drying of seed, and the drying rate of seed is only 2.7%.

3) In the controlled traffic tillage pattern, soil disturbance is 29%, it is low that could reduce operation consumption.

2.3.2 Comparison of seeding quality under the controlled traffic tillage and the non-controlled traffic tillage

The results in Table 2 showed that the seeding quality which satisfied the seeding requirements was slightly different under the two models. After two years continuous test in controlled traffic regions, machines had good working stability on machine working trails whose compaction had been increased. Seed and fertilizer depth in controlled traffic regions was shallower than in general regions, while the distance between seed and fertilizer was bigger in controlled traffic regions (46 mm). In addition, controlled traffic wheat no-till seeder had good performance of furrowing in controlled traffic regions and general regions (uncontrolled traffic) with trenching width of 58 mm and 62 mm, respectively. The smaller trenching width under controlled traffic produced less soil disturbance (29%), which reduced the consumption of fuel.

Table 2 Seeding quality comparison experiment

Items	Treatments	Average/mm	Qualification rate/%	Variable coefficient/%
Seeding depth	Controlled traffic tillage	36	87.9	7.2
	Non-controlled traffic tillage	45	83.1	10.2
Fertilizing depth	Controlled traffic tillage	82	84.8	10.1
	Non-controlled traffic tillage	86	81.7	11.7
Seed-fertilizer distance	Controlled traffic tillage	46	85.2	9.7
	Non-controlled traffic tillage	41	81.9	10.6
Furrow width	Controlled traffic tillage	58	/	3.9
	Non-controlled traffic tillage	62	/	4.1

2.3.3 Fuel consumption contrast test

Two years of test was conducted in controlled traffic regions and general regions to compare fuel consumption of controlled traffic wheat no-till seeder. Test parameters (seed and fertilizer depth, straw mulching quantity, etc) were basically the same. The seeder was powered by John Deer 754 with speed of 4.2 km/h and rotary speed of 1 750 r/min.

Fuel test results showed that diesel consumption was decrease by 8.35 L/hm^2 under controlled traffic (28.77 L/hm^2). The reason could be concluded that two years of the controlled traffic operation increased soil compaction, reduced tire deformation and sinkage and increased driving power of tractor wheels. Moreover, wedge type opener has a relatively smaller soil disturbance, which reduced useless power consumption, thus decreasing per unit area fuel consumption.

2.3.4 Emergence of wheat

Wheat had emergence with mean emergence of 636×10^4 hills/hm^2, germination rate of 87.2%, emergence rate of 83.7%, which satisfied the planting requirements.

3 Discussions

1) Controlled traffic minimum tillage technology that combines controlled traffic technology and conservation no/min-till technology, increased soil compaction in the working belt, reduced tire deformation and sinkage and soil disturbance[21] with the disturbance of 29%, increased driving power of tractor wheels and reduced the input through reducing power consumption[22].

2) Controlled traffic minimum tillage technology which separates the crop belt and machine working belt improves soil structure, increases soil fertility, provides better environment[23-24] for crop growth. A small scale controlled traffic no/min-till wheat seeder was developed in test stage. Although land use efficiency was low, the large scale planting will be increasingly common following the premonition of land circulation policy. With the adoption of large width no/min-till wheat seeders, land use efficiency will be significantly improved by applying multiple year controlled traffic no/min-till seeding. Moreover, soil density in controlled traffic belt increased, which had a significantly influence on increasing driving power of tractor wheels and reducing machine operation difficulty.

4 Conclusions

1) The embedded construction of “L” and “Y”flail knife with wedge knife opener could chop the straw effectively for anti-blocking.

2) The technique of controlled traffic no/min-tillage provide two zones respectively for machine and crop trails, in which the adhesive force of tractor tire is increased while fuel consumption is decreased.

3) The designed minimal and no-tillage wheat seeder for controlled traffic could separate the zone of machinery and crops effectively, satisfy the requirements of wheat seeder for depth and percent of pass of seed and fertilizer, offer a technical support to popularize the seeding technique of controlled traffic for minimal and no-tillage farming system.

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组合刀式固定道小麦免少耕播种机设计与试验

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摘　要：为了减少农机作业对农田土壤的压实，改善作物生长环境，加强农机与农艺融合，该文结合固定道和保护性耕作技术要求，开发了固定道小麦免少耕播种机，设计了一种楔刀型开沟器与“Y”型、“L”型刀具相结合的防堵开沟装置，并确定了“Y”型、“L”型刀具等关键部件的参数，田间对比试验表明，所设计的固定道小麦免少耕播种机通过性能良好，各项指标满足免耕播种机设计要求。固定道模式下机具各项性能指标均略优于非固定道，种、肥深度合格率均达到 84%以上，且一致性好，种肥间距加大 5 mm，合格率达到 85.2%，有效减少了烧种现象。固定道免少耕作业实施 2 年后，与非固定道作业模式相比，作业油耗降低 22.01%，节油效果显著。因此，固定道免少耕播种技术能够提高播种质量，降低作业功耗。另外，随着中国土地流转政策地推进，研究成果将对土地规模化种植、高效化管理具有一定指导意义。
关键词：农业机械；设计；作物；固定道；保护性耕作；播种机；油耗