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Research Article

Design and Experiment of Swallow line Wheat Precision Seed-metering Device

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Abstract: In order to improve wheat seeding uniformity, a 7.5 cm rows-spacing seed-filling groove style precision seed-metering device is designed to replace traditional external groove-wheel seed-metering device. Size and number of seed groove, upper curve of curb plate to transfer seed, upper curve of blocking plate to clear seed and the diameter and width of seed metering wheel parameters are analyzed and computed. Field experiment of the seeder indicates that 7.5 cm row-space seeder seeds more uniformitier compared with the 15 cm row-space seeder in the same seeding amount. Primary and secondary roots number of seedlings of 7.5 cm row-space is relatively large. It had stocky stem and high tillering ability. By estimation yield, the yield of 7.5 cm rows-spacing increases 8.9% more than 15 cm rows-spacing.

Keywords: 7.5 cm row spacing, precision, seed-filling groove style, seed-metering device, wheat

INTRODUCTION

As wheat seeder performance and quality have direct influence to wheat cost and output, it is badly in need of the development of high quality wheat seeder in modern agriculture (Guo, 2007; Shao *et al*., 2006). Wheat precision drilling requires precise dropping distance, row distance and proper planting depth, reasonable arrangement, less seeds, taking full advantage of soil, sunshine and wind, in order to obtain good growth environment, to coordinate individual and whole relations for high yield (Ma, 2010, 2008; Sun *et al*., 2002; Zhang, 2006; Zhao, 2004). Wheat precision drilling saves large amount of high quality seeds and reduces the workload of seeds storage, cleaning and conveyance. Uniformly distributed seedling provides good ventilation and penetrating light, soil moisture and nutrients in order to flourish wheat seedling and promote output (Zhang, 2011).

Primary structure to impact seeder sowing precision is the seed-metering device (Liao *et al*., 2012; Liu and Zhao, 2008; Zhao *et al*., 2011). Present wheat seeder is generally 15 cm row distance, applying external Geneva wheel seeding machine. Uneven seeding of wheat seeder caused by its pulsatility leads to serious seedling missing, seedlingless ridge and wheat seedling crowding growth (Li and Li, 2004; Yang *et al*., 2009, 2011). Therefore present wheat seeder quality cannot meet requirements of high yield.

In order to meet agronomic requirements to improve wheat seeding uniformity and solve the problem that traditional external groove-wheel seed-metering device has seeding pulse, bad uniformity and high injuring seed rate, a 7.5 cm rows-spacing seed-filling groove style precision seed-metering device is designed. Wheat seeding row distance reduces to 7.5 cm, but seeding quantity is equal to that of 15 cm row distance, namely row distance reduces half and seeding quantity per row reduces half but total seeding quantity remains. The seeding method provides more evenly wheat distribution and uniform seeding depth for the purpose of high yield. Moreover, evenly distributed wheat provides water conservation (Chi and Zuo, 2003; Shao *et al*., 2006).

METHODOLOGY

Structure and operation principle seed-metering device:

Seed-metering device structure: Seeding machine is a kind of seed-filling groove style precision seeding machine between external groove-wheel drilling seeding machine and spot seeding machine, which is composed of seeding box, seed-filling wheel, side seed plate, brush, seed clearing plate, seed-filling slot, seed metering shutter, seed delivery groove, as illustrated in Fig. 1. Seed-filling cell is designed according to wheat dimension, having narrow distance between two seed cells. Beside the cell there is a seed groove to promote seed filling. It cancels seeds protecting to avoid that seeds are broken by seed protection board due to high rotating speed and quick seed-filling speed to obtain seeding effect between spot seeding and drilling.

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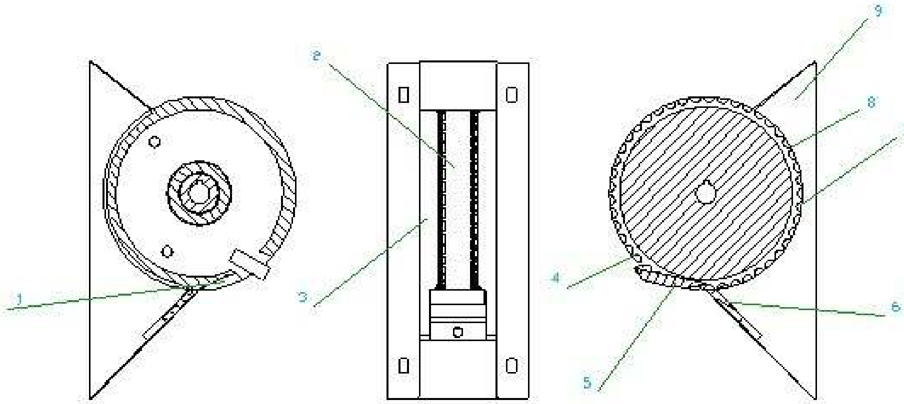

Fig. 1: Structure figure of the seed-metering device
1: Seed delivery groove; 2: Seed-filling wheel; 3: Side seed plate; 4: Seed-clearing slit; 5: Seed clearing plate; 6: Brush; 7: Seed-filling slot; 8: Seed metering shutter; 9: Seeding box

Seeding machine may sow two rows of seeds at one time. It has two side seed plates, which are fixed to both sides of the seeding box. Between them there are seed-filling wheels, on both sides of which there are seed-filling slots of staggered arrangement. Between two adjacent seed-filling slots in one side of the seed-filling wheel is seed metering shutter. In two sides of seed-filling wheel there are circular seed clearing slits penetrating seed metering shutter and seed-filling slots. Inside seed clearing slit there are seed clearing plates at the lower part of the brush, which is fixed on the seeding box with seed clearing plate.

Seed-metering device operation principle: Seed metering process of seed-filling groove style precise seeding machine includes seed filling, seed clearing and seed metering. As it operates, seed-filling box, seed clearing plate and side seed plate are static relative to the framework and seed-filling wheel are rotating relative to the framework.

There are arc transitions not only in two sides of the seed-filling wheel, but also nearby the seed-filling wheel in the side seed plate. Therefore seed-filling wheel and side seed plate compose a groove in seeding box, being available for a row of seeds. It fills seeds both in the upper part and side of the seed-filling slot. As the side seed plate works, seeds in the groove composed by seed-filling wheel and side seed plate fall into the seed-filling slot alongside the arc transition of the side seed plate. Seeds in the upper part of the seed-filling slot directly fall into the seed-filling slot. When the seeding machine works, the side seed plate and seed-filling wheel is relatively moved, mixing seeds around the seed-filling slot to be advantageous to seed filling.

In the seeding box, arc transitions of side seed plate nearby the brush become smaller and smaller, being disappeared till the brush, so that the groove composed by the seed-filling wheel and side seed plate cannot hold one seed. It is a seed-clearing area that the side seed plate clears seeds beside the seed-filling slot and the brush clears seeds on the seed-filling slot.

Considering larger wheat seeding quantity, faster rotating speed of seed metering wheel for individual seeding, narrower space of two adjacent seed-filling slots, to reduce damage rate, it cancels seeds protection process. To ensure seeds discharging in turn, after seed clearing, the seed clearing plate in the seed clearing slit compulsorily discharges seeds in the seed-filling slot. The designed seed clearing slit is at the inside nearby the seed-filling slot in the middle to avoid seeds are blocked between the internal wall of the seed-filling slot and the seed clearing plate. It designs a seed delivery groove at the side seed plate beside the seed clearing plate. As metering, seeds in the seed-filling slot are pushed out of the seed-filling slot by the flank of the seed clearing plate and discharged alongside the seed delivery groove, or directly guided out of the seed-filling slot by the seed clearing plate.

Design and calculation of seed-filling slot, arc transition on the side seed plate and arc transition on the seed metering shutter: It sets space rectangular coordinate system x-y-z. Seed-filling wheel axis is y-axis and x-z plane refers to the connecting part of seed-filling wheel flank and side seed plate. Side seed plate is in positive y-axis and seed-filling wheel is in negative y-axis. It sets cylindrical coordinate θ-y-ρ and two coordinates are illustrated as in Fig. 2.
The relation between two coordinates is:

$$x = \rho\cos\theta$$

$$y = y$$

$$z = \rho\sin\theta$$

For convenient calculation, it simplifies arcs on the seed metering and that on the side seed plate in y-ρ plane to straight lines.

Wheat length, width, thickness average value is, respectively l, b, a, maximum value, respectively l_{max},

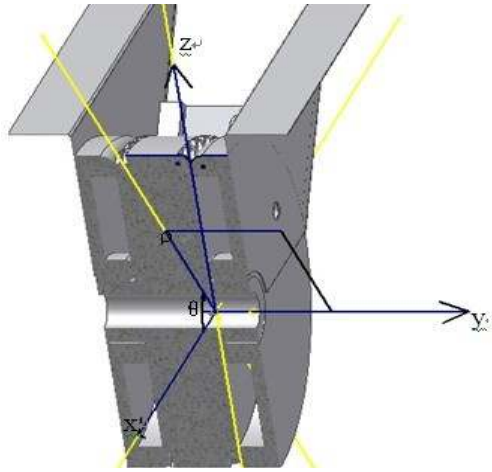

Fig. 2: Building of space coordinate system

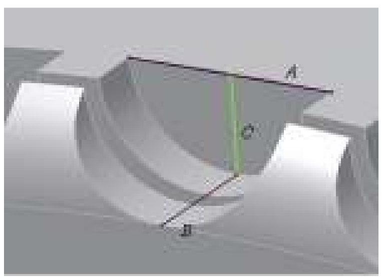

Fig. 3: The size of filling slot

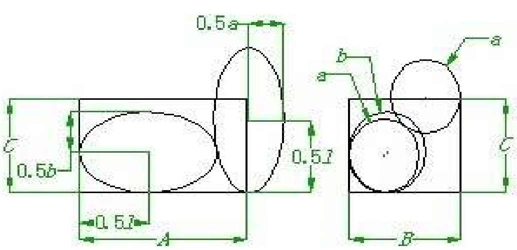

Fig. 4: Design calculation of filling slot's size

b_{max}, $a_{\max}$, seed-filling slot length A, width B, height C, as illustrated in Fig. 3, seed-filling wheel diameter d, there are several seed-filling slots in one side of the seed-filling wheel.

The linear equation of transition on the side seed plate is:

$$\rho = \mathrm{k}_1 \mathrm{y} + \mathrm{b}_1$$

The linear equation of transition on the seed metering shutter is:

$$\rho = \mathrm{k}_2 \mathrm{y} + \mathrm{b}_2$$

Generally seeds lie low, lie on side or stand in the seed-filling slot and mostly they lie low. Larger quantity of wheat seeding and faster rotating speed require more margins of seed-filling slot to avoid leakage sowing, so that it ensures seeds are easier to be filled into seed-filling slot. What's more, it makes seed-filling slot be available to contain only one seed instead of two, as shown in Fig. 4. Then:

$$l_{\max} < A < l + \frac{1}{2}a \quad (1)$$

$$b_{\max} < B < 2a \quad (2)$$

$$B < l \quad (3)$$

$$b_{\max} < C < \frac{1}{2}a + \sqrt{a^2 - (B-a)^2} \quad (4)$$

of which,

l_{max} = Wheat length maximum value
A = Seed-filling slot length
l = Wheat length average value
a = Wheat thickness average value
b_{max} = Wheat width maximum value
B = Seed-filling slot width
C = Seed-filling slot height

To avoid seeds stand in seed-filling slot, it requires lower seed-filling slot height and narrower seed-filling slot width. It sets seed-filling slot:

$$B > C \quad (5)$$

Two right-angle sides on the bottom of the seed-filling slot do not touch seeds when they lie low on the seed-filling slot. So it designs two right-angle sides on the bottom to be arc transition, as illustrated in Fig. 3.

The lower the lowest point of two arc transitions, the easier seed filling, but if the lowest point is lower than the seed-filling slot, it is not proper to guide seeds into the seed-filling slot because of the possibility to damage seeds. Therefore it designs that the lowest point of two arc transitions is at the bottom of the seed-filling slot, which shall ensure that when seeds are in the seed-filling slot, the gravity center is in the seed metering shutter, so that the seed metering shutter has sufficient power to push seeds in the seed-filling slot. Figure 5 illustrates that:

$$\mathrm{k}_2 \times (-B + \frac{1}{2}b) - (\frac{d}{2} - C + \frac{b}{2}) + \frac{d}{2} - \mathrm{C} > 0$$

$$\frac{\mathrm{k}_2 \times (-B + \frac{1}{2}b) - (\frac{d}{2} - C + \frac{b}{2}) + \frac{d}{2} - \mathrm{C}}{\sqrt{\mathrm{k}_2{}^2 + (-1)^2}} = \frac{b}{2}$$

$$\mathrm{k}_2 \times (-\frac{a}{2}) - (\frac{d}{2} - C + \frac{a}{2}) + \frac{d}{2} - \mathrm{C} > 0$$

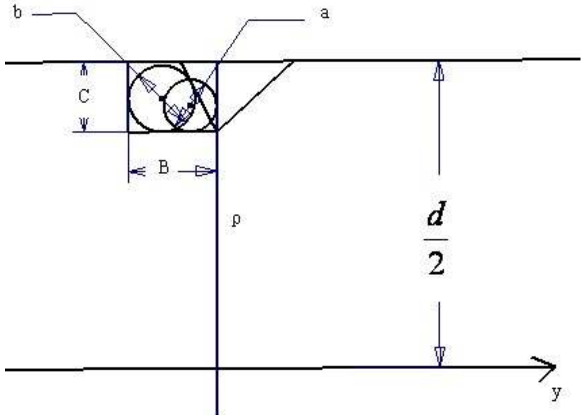

Fig. 5: Design calculation of k_2

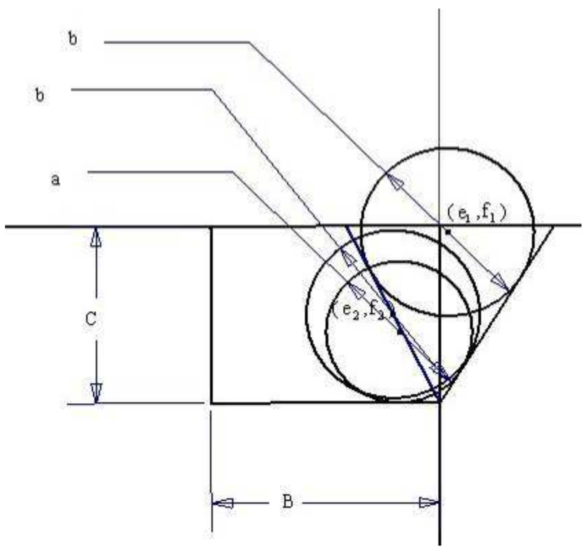

Fig. 6: Design calculation of k_1

Then,

$$k_2 = \frac{M^2 - 2M}{2 - 2M} \tag{6}$$

$$2 - \sqrt{2} < M < 1 \tag{7}$$

$$k_2 < -1 \tag{8}$$

of which,

$$M = \frac{b}{B} \tag{9}$$

In the seed-filling area, when the arc transition on the side seed plate does not become smaller and smaller, the groove formed by two arc transitions shall ensure that seeds "lie low" on the groove, namely, the gravity center of seeds shall be in the groove. When seeds are tangent with seed metering shutter and straight line on the side seed plate, respectively the gravity center shall be in the groove composed by two straight lines. When seeds are tangent with straight line on the side seed plate and seed-filling slot bottom, the gravity center shall be beneath the seed metering shutter straight line to ensure the seed metering shutter has sufficient power to push seeds in the seed-filling slot, as shown in Fig. 6. It calculates and the results are:

$$\frac{2k_2}{1-k_2^2} < k_1 < \frac{k_2(1-N^2)}{(1+N^2) - 2N\sqrt{k_2^2+1}} \tag{10}$$

of which,

$$N = \frac{b}{2C} \tag{11}$$

It substitutes Baomai-3, Shimai-18 dimension data (Table 1) into the equation mentioned above.

According to Eq. (1), $7.28<A\leq 7.73$, it selects A = 7.5 mm; according to Eq. (2), (3), (7) and (9), $408<B<5.86$, it selects B = 4.9 mm; according to Eq. (4) and (5), $4.08<C<4.15$, it selects C = 4.1 mm; then M = 0.70, N = 0.42, according to Eq. (6), k_2 = -1.52, according to Eq. (10), $2.32<k_1<3.56$, it selects k_1 = 2.94.

Design of seed metering wheel diameter, width and seed-filling slot numbers: Seeding machine width is related to thickness of seed metering wheel, side seed plate and seeding box. Whereas the seeding machine is connected with seed box by bolts and screw nuts, in the upper part of the seed metering box it needs to design a boss protruding to both sides, making holes on it to connect seed box. Considering that the seeding machine and seed box are connected by bolts and screw nuts, it shall remain sufficient installation space between two adjacent seeding machines for hands or tools to install the seeding machine. Because it needs sufficient installation space, if the seeding machine is too wide to be arranged in one row, it needs to design two driving shafts to arrange seeding machine in two lines which

Table 1: 3D measurement of wheat seeds (mm)

	Baomai-3			Shimai-18			Whole		
Parameters	Length	Width	Thickness	Length	Width	Thickness	Length	Width	Thickness
Average value	6.48	3.43	3.18	5.84	3.44	3.08	6.16	3.43	3.13
Maximum value	7.28	4.08	3.68	6.68	4.00	3.74	7.28	4.08	3.74

Table 2: Qualified index of seed-metering device

Parameters (mm)	Repeat sowing rate/%	Leakage sowing rate/%	Single seed rate/%
6.5	3	13.3	83.7
7.5	14	6.8	79.2
8.5	80	0	20

will not only increase the seed box width, but also will complicate the rotating design due to adding one driving shaft. As wheat seeder requires 7.5 cm row distance, to avoid that it cannot arrange all seeding machines in one row, it designs a seeding machine that may seed two rows of seeds. In both sides of the seed metering wheel there are seed-filling slots and in both sides there are side seed plates.

When it sets seed-filling slots in both sides of the seed metering wheel, if the distance between both sides is too near, it will influence seed-filling performance because seeds in the upper part of the seed-filling slot are too few to fall into the seed-filling slot on time. So it designs that in both sides of the seed-filling wheel there are seed-filling slots. The seed-filling wheel width is 30 mm, the distance between the two sides of the seed-filling slot 20 mm and side seed plate width 20 mm. Seed-filling wheel and side seed plate are made from nylon stick.

Seed-metering device test: It designs the confirmatory test to prove whether designed and calculated seed-filling slot dimension is proper. It makes the contrast test by selecting seed-filling slot width 5 mm, height 4 mm, seed-filling slot length 6.5, 7.5 and 8.5 mm, respectively, selecting Shixin-828 with agricultural chemicals and selecting 1 r/sec as the rotating speed. The test result is shown in Table 2.

The test shows that, when the seed-filling slot length is 6.5 mm, it has higher rate of voiding. When the seed-filling slot length is 8.5 mm, it has higher reseeding rate. So it selects seed-filling slot length 7.5 mm. It designs the seed-filling slot dimension length 7.5 mm, width 5 mm, height 4 mm, which are in coincidence with the calculation results.

SEEDER FIELD TEST AND ANALYSIS

Field test design: On Oct. 11, 2013, in the experimental base of science and technology project for food production of Hebei Agricultural University in Mazhuang Village Xinji City Hebei Province, in adjacent two test fields, it respectively selected the wheat seeder of 7.5 cm row distance and that of 15 cm row distance, selecting the same wheat seed, the same seeding quantity, treated by the same water and fertilizer in the lands of equal conditions. It ensures that all conditions are the same except for the row distance. It investigates the influence of two types of seeders to wheat planting under the abovementioned conditions:

- **Seed:** Jimai-585
- **Land preparation:**
    - Organic fertilizer, 1500 kg/ha
    - Compound fertilizer N-P_2O_5-K_2O, of which N, P, K proportion is 15-20-8, 900 kg/ha
    - Zinc sulfate, 22.5 kg/ha
    - Combined ploughing and rotating land preparation machine operation twice and leveling one time
- **Seeding quantity:** 206.3 kg/ha, 39 seeds/m at 7.5 cm row distance and 77 seeds/m at 15 cm row distance

Field test and analysis: It checked seedlings on Oct. 25, 2013. There are 76 seedlings in two rows per meter of 7.5 cm row distance, 5.07 million actual basic seedlings in 1 ha, 147 seedlings in two rows per meter of 15 cm row distance, 4.905 million actual basic seedlings in 1 ha.

Taking 10 cm as one section, it checks the seedling emergence of each section and calculates average seed numbers, standard deviation and variation coefficient of 7.5 cm row distance seeder and that of 15 cm row distance are, respectively 4.075, 1.058, 25.96 and 8.00, 3.59, 44.90. It shows that compared with 15 cm row distance seeder, 7.5 cm row distance seeder has equal seeding quantity, but has more uniform seeding.

On Nov. 29, 2013, it investigated the growing situation before winter of wheat by different treatments. Each treatment it selects 10 plants for each treatment. It shows that compared with that of 15 cm row distance treatment, the wheat seedling of 7.5 cm row distance treatment has more primary roots and secondary roots, shorter plant height and top expanded leaf length, more individual tillers, thicker stem and heavier air dry weight of the seedling.

Wheat yield estimation: On May 19, 2014 it estimated the yield of two treated wheat field. For each treatment it selects five spots, respectively measuring spike numbers of each treatment (5 spots) in 0.25 m^2, reckoning that there are 9.3 million spikes in 1 ha by 7.5 cm row and 7.98 million spikes in 1 ha by 15 cm row distance 1 ha. For each treatment (3 spots) it selects three spots to investigate the grain number per spike (taking the average) of 20 spikes. The result is that by 7.5 cm row distance it averagely has 25.5 seeds/spike and by 15 cm row distance averagely 27.3 seeds/spike. Generally Jimai-585 applied in this test has 1000-grain weight of 40~42 g (taking 1000-grain weight as 40 g). It reckons that 7.5 cm row distance output is 9,486 kg/ha and 15 cm output is 8,714 kg/ha. It shows that the yield of 7.5 cm row distance increased 8.9% than that of 15 cm row distance.

CONCLUSION

A 7.5 cm rows-spacing seed-filling groove style precision seed-metering device is designed. Its seeding performance is better than that of traditional external groove-wheel seed-metering device. It has more uniform seeding to satisfy technological requirements of wheat precision seeding. The yield of 7.5 cm row distance increased 8.9% than that of 15 cm row distance.

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