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Research Article

Study on Negative-pressure Precision Millet Seed-metering Device

Huali Yu, Xiaoshun Zhao, Zhanliang Liu, Xiong Du and Cong Tian
College of Mechanical and Electrical Engineering, Agriculture University of Hebei,
Baoding 071000, P.R. China

Abstract: Traditional millet drilling method has a problem of labor-intensive artificial thinning-out, so a negative-pressure precision millet seed-metering device was designed to realize millet precision dibble seeding. Single factor experiment researches effect of rotational speed and air-chamber vacuum of seed-metering device on its seed-metering passing rate, repeat-sowing rate and leak-sowing rate. By means of orthogonal experiment method, optimal parameters of seed-metering device were defined, which was 20 r/min rotational speed, 4 mm bore diameter, 1.5 KPa air-chamber vacuum and 55 mm air cut valve arc length. The field test result shows that the seed-metering device meets completely standards of “Single-seed (Precise) Seeder Technological Requirements” and agronomic requirements.

Keywords: Millet, negative-pressure, orthogonal experiment, precision, seed-metering device

INTRODUCTION

As the head of grains, millet is nutritious and rich in protein, fat, carbohydrates, crude fiber and trace elements, containing 11.42% average gross protein value. The planting areas for millet in north China occupies 10-15% of the grain-sown area, ranking the third following those for wheat and corn. To ensure the seedling emergence, full stand and healthy seedling, it still adopts the traditional vast seeding drill method due to special agricultural requirements of millet growth, which wastes seeds. Moreover, it has great worker's labor intensity for manual thinning out and high labor cost during the millet seeding stage (Yang and Zhao, 2007; Guo *et al*., 2012; Bian *et al*., 2007). Therefore millet precise seeding is the crucial process of production. During the popularization of fine seeds, it has urgent need for the research of relevant key technology and equipments of precise seeding for seeding promotion, to save seeds and to lowering labor intensity for manual thinning out. Seed-metering device is the decisive part of the seeding precise of the seeder (Liao *et al*., 2012; Liu *et al*., 2008; Zhao *et al*., 2011). At present generally used seed-metering devices include mechanical ones and pneumatic ones. Pneumatic seed-metering devices include pneumatic, barometric and air-swept ones. The commonly applied pneumatic seed-metering device in China is mainly used in corn seeding. Seed-metering devices for millet seeding are mostly roller types or indented ones, which are uneasy to control seeding amount and easy to clog, also having high seed losses, because of extremely tinny millet seed, light thousand grain weight and low seeding amount (Zhang, 2005). It is hard to ensure fine and precise seeding of millet due to the adverse effects to seeding uniformity and stability (Yang *et al*., 2011; Liu *et al*., 2009). Tests have proved that seed metering performance of pneumatic seed-metering device is far superior to that of mechanical seed-metering device, which saves seeds, injuring no seed. It is universal to seeds of different dimensions, having high seeding uniformity and being easy to achieve precise seeding (Zhao *et al*., 2013).

Considering millet has small seed diameter, light weight and irregular shape, to research a kind of pneumatic millet precise seeder is effective for seed suction shaped orifice stoppage and seed destroy and for millet precise seeding.

SEED-METERING DEVICE STRUCTURE AND OPERATING PRINCIPLES

As shown in Fig. 1, negative-pressure precise seed-metering device is composed by seed-metering device shell, hollow mandrel, air-cutting valve, air-cutting valve support, adjusting spring and sealing cover.

Seed-metering device shell and sealing are fixed by securing bolt and sealant, operating by land wheel driving chains. When it works, seeds flow to the seed chamber from the grand seed box by soft catheter, fixing the hollow mandrel as the airway, connecting with the fan inlet scoop through the inlet pipe. The seed metering shell operates with the land wheel, installing air-cutting valve in the seed metering shell suction

Corresponding Author: Xiaoshun Zhao, College of Mechanical and Electrical Engineering, Agriculture University of Hebei, Baoding 071000, P.R. China, Tel.: 13630851145

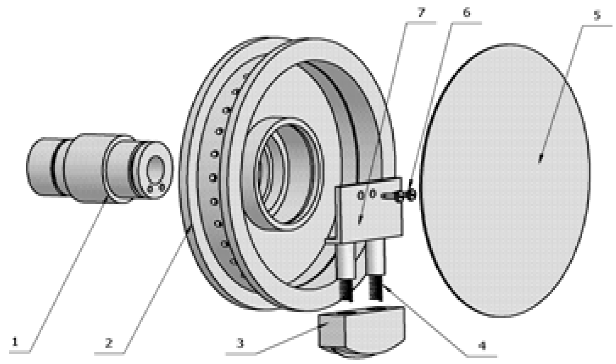

Fig. 1: Structure diagram of the seed-metering device; 1: Hollow mandrel; 2: Seed-metering device shell; 3: Air cut valve; 4: Adjusting spring; 5: Sealing cover; 6: screw; 7: Air cut valve support

chamber, fixing it onto the hollow mandrel by adjusting spring and air-cutting valve support to act as air cut. The air-cutting valve projection may squeeze seeds out which cannot be fallen by dead weight so that they are fallen into seed suction shaped orifice. When the fan works, the vacuum space (air space) which has negative pressure produces the pressure difference in both sides of the seed suction shell, under the action of the negative pressure, seeds in the seed chamber are sucked onto the shaped orifice and rotate with the seed-metering device. When the seeds rotate to the pressure relief area where there is no negative pressure, under the action of dead weight, the seeds fall into the trenches through the trumpet seed pipe. As the seed metering wheel continuously rotating, shaped orifice entered into the vacuum space a second time, under the action of the pressure difference (negative pressure), sucks seeds again, continuously to realize the seed metering.

SEED-METERING DEVICE SINGLE-FACTOR AND ORTHOGONAL EXPERIMENTS

Experiments on the influence of rotating speed to seed metering performance: It performs experiments under the conditions that the airspace vacuum degree is 1.0 kPa, seed-metering device rotating speed is 15, 20, 25, 30, 35 r/min, respectively, making conclusions about the influence of seed-metering device rotating speed to seed metering uniformity and making curved lines as shown in Fig. 2.

Figure 2 shows that when the rotating speed is 20 r/min, it has the best the seed metering qualification index and leakage sowing index. Considering population effect of millet seedling emergence and agronomic requirement, minimizing leakage sowing, combining re-seeding index curve diagram (Fig. 2c), it confirms that when the rotating speed is 20 r/min, the seed-metering device has stable seed metering performance and better seed metering uniformity.

Experiments on the influence of airspace vacuum degree to seed metering performance the influence: Firstly, according to the formula in bibliography (Hu *et al*., 1981) it calculates the lowest critical value Hcmin of airspace vacuum degree. For seed suction to the shaped orifice, when the seed-metering device works, vacuum degree in the airspace must be greater

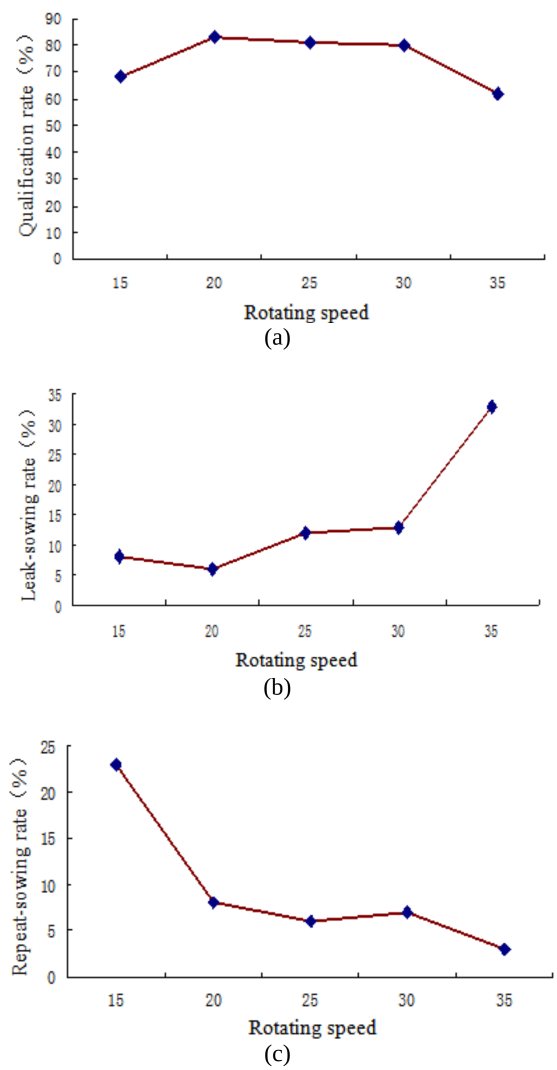

Fig. 2: Effect of rotational speed on seed uniformity

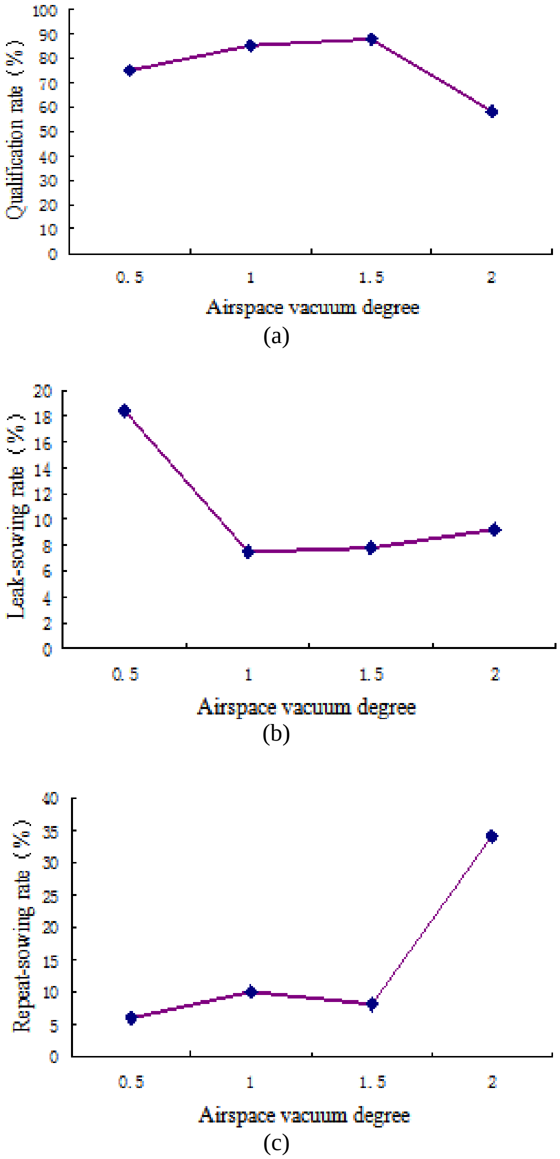

Fig. 3: Effect of air-chamber vacuum on seed uniformity

than critical value Hcmin. Therefore it needs proper high vacuum degree in seed filling area and seed carrying area to ensure seed suction. Generally considered, it sketched that the seed metering chamber vacuum degree is 1.0~2.5 kpa. Under the condition that seed-metering device rotating speed is 20 r/min, it performs experiments selecting airspace vacuum degree 0.5, 1.0, 1.5, 2.0 kpa, respectively to get the influence of airspace vacuum degree to seed metering uniformity and make curve diagrams as shown in Fig. 3.

Figure 3 shows that when airspace vacuum degree decreases (pressure increases), seed metering qualification index increases and then decreases, leakage sowing index generally decreases and re-seeding index is in rising trend. When airspace vacuum degree is between 1.0~1.5 kPa, it has stable seed metering performance and the best seed metering uniformity.

Table 1: Orthogonal experiment factors and levels

Level	X1/mm	X2/KPa	X3/mm
1	3	1.5	40
2	4	2.0	50
3	5	2.5	55

X1 means diameter of suction hole; X2 means air-chamber vacuum; X3 means air cut valve arc length

Orthogonal experiment: Single-factor experiments to seed-metering device show that it has the best seed metering performance when the rotating speed is 20 r/min. Moreover, arc length dimension structure of the air-cutting valve in the seed-metering device is another important parameter effective to seed metering. Too short air-cutting valve arc length makes bad effect of air cut and intermittent seed fall. Too long arc length makes simultaneous air cut of two shaped orifices and the increase of re-seeding rate. Therefore it performs orthogonal experiments to seed suction shaped orifice diameter, airspace vacuum degree and air-cutting valve arc length dimension under the condition of seed-metering device rotating speed 20 r/min. It respectively takes three levels of three factors. Due to equal factor level, it takes L9(3^4) equal orthogonal array (Table 1), repeating each test three times and taking the average value.

Tests proves that, according to the range (R), the descending order of three factors influence to qualification rate is X_2, X1, X3; the descending order of the influence to re-seeding rate is X1, X2, X3; the descending order of the influence to leakage sowing rate is X2, X3, X1. According to the influence of each factor level to seed metering performance, it confirms that the optimal combination scheme of qualification rate is A2B1C3; the optimal combination scheme of re-seeding rate is A3B3C2; the optimal combination scheme of leakage sowing rate is A2B3C1. Arc length dimension X3 of the air-cutting valve has the minimum influence to seed metering performance and the designed 40~55 mm are all available. According to the agronomic requirements it makes predominant consideration of the qualification rate, it takes 55 mm as the optimized selection. While airspace vacuum degree X2 has the maximum influence to the seed metering qualification rate and leakage sowing rate, under the condition that seed suction shaped orifice aperture is 4 mm, it respectively reached 92 and 88%. Considering the abovementioned single-factor experiments, it confirms that the airspace vacuum degree X2 1.5 KPa is the best. Seed suction shaped orifice aperture has a proper great influence to the seed metering qualification rate and the maximum influence to re-seeding rate and it takes the proper numerical value 4mm. According to test results, the optimal combination of the three factors is that the seed suction shaped orifice diameter is 4 mm, the airspace vacuum degree is 1.5 KPa and the air-

Table 2: Orthogonal test results

Test number		X1	X2	X3	Qualification rate (A%)	Repeat-sowing rate (D%)	Leak-sowing rate (M%)
1		1	1	1	76	16	8
2		1	2	2	72	18	10
3		1	3	3	52	42	6
4		2	1	2	92	8	0
5		2	2	3	88	6	6
6		2	3	1	42	32	26
7		3	1	3	66	32	2
8		3	2	1	70	24	6
9		3	3	2	36	56	8
Qualification rate	K1	200	234	188			
	K2	222	230	200			
	K3	172	130	206			
	k1	66.7	78.0	62.7			
	k2	74.0	76.7	66.7			
	k3	57.3	43.3	68.7			
	R	16.7	34.7	6.0			
Repeat-sowing rate	K1	76	56	72			
	K2	46	48	82			
	K3	112	80	80			
	k1	25.3	18.7	24.0			
	k2	15.3	16.0	27.3			
	k3	37.3	26.7	26.7			
	R	22.0	10.7	3.3			
Leak-sowing rate	K1	24	10	40			
	K2	32	22	18			
	K3	16	40	14			
	k1	8.0	3.3	13.3			
	k2	10.7	7.3	6.0			
	k3	5.3	13.3	4.7			
	R	5.3	10.0	8.7			

Table 3: Field experiment data and results

Average seed number per hole	Average hill spacing (cm)	Repeat-sowing rate (%)	Leak-sowing rate (%)	Total numbers per meter
3.11	8.94	2.13	36.17	17.72
2.75	9.11	4.54	21.31	19.71
3.24	9.00	4.17	47.08	17.14
3.23	9.68	0	29.03	17.14
3.15	9.21	3.22	47.05	17.43
2.84	8.76	10.21	17.16	23.14
4.21	9.34	5.55	15.78	5.71
3.92	9.75	3.44	34.21	11.14
3.30	10.36	3.13	39.39	13.44

cutting valve arc length dimension is 55 mm. The seed metering qualification rate reached 92%, the re-seeding rate 8% and the leakage sowing rate zero.

Tests analyzes seed-metering device qualification index, leakage sowing index and re-seeding index and the results after calculation and extreme difference processing are shown in Table 2.

FIELD EXPERIMENTS

On June 26, 2013, the seeding tests of the millet seeder were conducted in Baoding City Hebei Province, which seeding area is around 20 hm^2.

After the field seeding experiments, it needs to investigate and survey millet seedling emergence to improve the millet seeder. The author took samples and records of millet seedlings emergence on July 15, 2013. Because it is impossible to investigate all seeding development in a short period due to large seeding area, it investigates and records the seeding by Mechanical sampling method with the following requirements and principles:

- Taking 3.5 m as the statistical distance, it makes parallel statistics of seeding in six lines, including total holes, hill spacing, seed number per hole, total numbers in each line per 3.5 m, of which 3.5 m >(8 cm~10 cm) * 32.
- It makes statistics according to requirements of Item (1) at the spacing of 10 m or 15 m.
- It repeats Item (2) twice and makes statistics strictly according to the spacing distance instead of selective statistics.
- It investigates three sections, 3.5 m per section, six groups of data per section, totally 18 groups of data.
- It calculates average seed number per hole, average hill spacing, leakage sowing rate, re-seeding rate, total numbers/meter. It keeps original statistic data for other research and analysis.

- If hill formation is not obvious, it shall measure specific distance from one seedling to another.

It respectively takes samples of millet emergence of seedlings from three plots to summary data as shown in Table 3. It is obvious that the millet seeder fundamentally satisfies technology parameters and performance requirements of millet negative-pressure seeding.

CONCLUSION

- A kind of millet negative-pressure seed-metering device was designed, the sigle factor experiment shows that it has stable seed metering performance and the best seed metering uniformity under 20 r/min rotating speed and 1.0~1.5 kPa airspace vacuum degree.
- Airspace vacuum degree has obvious influence to seed metering qualification rate and the leakage sowing rate and the designed ideal value is 1.5 KPa. The seed suction shaped orifice diameter has obvious influence to re-seeding rate and the designed ideal value is 4 mm.
- Under the combination of seed-metering device seed suction shaped orifice diameter 4 mm, air-cutting valve arc length dimension 55 mm, suction chamber vacuum degree 1.5 Kpa, rotating speed 20 r/min, it has the best seed metering performance, completely meeting standards of Single-seed (Precise) Seeder Technological Requirements (JB/T10293-2001).

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