Experimental study on seed-filling performance of maize bowl-tray precision seeder

Mao Xin, Yi Shujuan*, Tao Guixiang, Yang Li, Liu Haiyan, Ma Yongcai

(*Engineering College, Heilongjiang Bayi Agricultural University, Daqing 163319, China*)

Abstract: According to the requirement of assorted maize transplanting machine, a maize bud-seed precise sowing device was presented for use in cold areas. Experiments were performed to optimise the parameters of a maize bowl-tray precise seeder to improve the seed-filling performance. When the diameter of brush seed wheel was 78 mm, the clearance of brushing seed was 3 mm, with the maize varieties Demeiya 1, the moisture content about 40%, the depth of shaped hole 6 mm, the two major factors, the diameter of shaped hole and the velocity of seed box, were tested at five levels for each factor using the orthogonal rotational regression experiment. The effects on the single-seed rate, multi-seed rate, empty-seed rate, broken-bud rate and damage rate were investigated. The test results indicated that the factors affecting the single-seed rate and the multi-seed rate were the diameters of shaped hole and the velocity of seeds box, and the factor affecting the empty-seed rate was primarily the diameter of shaped hole. This study determined the optimal parameters, and verified the results, which provide the basis for the design and performance improvement of the maize bud-seed bowl-tray precision seeder.

Keywords: bowl-tray precision seeder, maize bud-seeds, seed-filling performance, orthogonal rotary regression experiment

DOI: 10.3965/j.ijabe.20150802.1809

Citation: Mao Xin, Yi Shujuan, Tao Guixiang, Yang Li, Liu Haiyan, Ma Yongcai. Experimental study on seed-filling performance of maize bowl-tray precision seeder. Int J Agric & Biol Eng, 2015; 8(2): 31－38.

1 Introduction

Maize is a primary crop (second only to wheat) in China, a large agricultural country. Be considered as "the king of feed" for the first variety of its production area and yield , maize also serves as an important industrial raw material[1]. Because of the short frost-free period in Heilongjiang with big changes of temperature annually, the direct seeding method during spring sowing will easily cause cold damage to the emergence and seedlings, and in the late stage of corn growth, it is often compromised by early frost, which is extremely unfavourable to corn production[2]. Dryland cultivation of major crop is the primary method of sowing, but the required area of seedling planting is quite large[3].

Maize seedling transplanting technology, which extends the growth period by more than one month, can fully solve the drought problem of seedlings emergence and guarantee their quality. The transplantation of maize seedlings has become one of the best planting techniques in recent years. In the mid-1970s, the first mechanical approach for maize planting was developed in China[4]; Subsequently, continued research and development gradually led to the introduction of a variety forms of vegetables, tobacco, sugar beet and other crops that were suitable for use with planting machinery. However, such planting machinery was not used widely

Received date: 2014-12-15 **Revised date:** 2015-03-23

Biography: **Mao Xin**, PhD candidate, Majoring in maize sowing device, Email: mx1631@163.com; **Tao Guixiang**, PhD, Majoring in rice sowing device, Email: tgx1996@163.com; **Yang Li**, Master, Majoring in rice harvest, Email: yl636188@tom.com; **Liu Haiyan**, Master candidate, Majoring in grain physical properties, Email: sdlhy618@qq.com; **Ma Yongcai**, PhD candidate, Majoring in maize bowl-tray, Email: myc1631@163.com.

***Corresponding author: Yi Shujuan**, PhD, Majoring in rice sowing device, Heilongjiang Bayi Agricultural University No.2, Xinyang Road, Longfeng district, Daqing 163319, China. Tel: 0459-6819310. Email: yishujuan_2005@126.com.

due to the backward nursery technology, poor matching performance and low overall efficiency. No tillage planter as a new technology of conservation agriculture is gradually started and the benefits have been widely recognized[5]. Precision seeding technology is a new seeding technology promotion based on no tillage seeding, which is seeding a single grain seed in the soil with a suitable distance[6]. Much research has been performed on the development of precision planter and recent achievement[7-9].

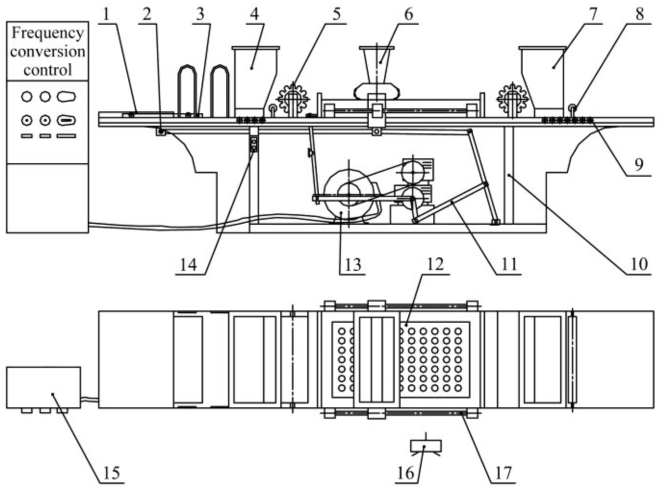
Seeding technology of air suction is developing very fast in Europe, America and Japan, etc.[10], various of monitoring devices are generally installed in the seeding planter and some operating controls are electronic[11]. Yu et al.[12] investigated the relationship between the positive pressures and the negative ones of nozzles on pneumatic precision metering device for rapeseed through developing fluid models of chamber and conducting the k-ε turbulence model. Great Plains of Manufacturing company developed single seed metering device which can change the seeding wheel to meet various crops. The uniformity is suitable for circular corn seed, but not proper for flat corn seed[13]. Li et al.[14,15] studied on tilt disc spoon type precision seed-metering device angle and rotating speed on the performance of maize seed species. Liao et al.[16-18] did a lot of research on the horizontal plate precision meter for corn seed, putting forward the corresponding measures and methods on reducing the broken seed rate. Yu et al.[9,19,20] studied on the corn precision metering device with concave metering inner-cell, with single seed rate of about 90% and empty seed rate less than 3.5%. Seed size was required strict of these mechanical seed meter, and seed-filling was not high enough. Xia et al.[7] studied on precision seed-metering device for pelleted corn seeds, the single seed rate could earn up 98%. However, these researches were focus on dry-seed which is not suitable for transplanting, and germinal precision seeding meter is rare. Wu et al. [21] presented an automatic precision seeding system which has high automatic level, and the experiment result showed that the miss index and multiple index for corn seeds were 3.70% and 4.62% respectively.

The main objective of this study was to investigate the seed-filling performance of a maize bowl-tray precision seeder while performing basic single maize sowing with the target of reducing the damage and determining the optimum parameters. Single-grain maize bud-seed sowing techniques are important for reducing waste, ensuring the germination rate and improving maize production, which is conducive to the promotion of rational use of resources and improved varieties to achieve large-scale, intensive and commercial production.

2 Materials and method

2.1 Test device and operating principle

A maize bowl-tray precision seeder is shown in Figure 1, which is mainly composed by subsoil box, compaction wheel, seed box, brushing seeds wheel, shaped hole plate, plate-turnover, seed raising trays, push rod of seeds box, surface soil box, frame, motor, transmission chain, speed reducer and connecting rod frame body.



1. Table-board 2. Adjusting control of pushing 3. Installation of pushing bow-tray 4. Subsoil box 5. Compaction wheel 6. Seed box 7. Surface soil box 8. Scraper 9. Roller 10. Frame work 11. Assembly of link mechanism 12. Plate of shaped hole 13. Motor 14. Switch control 15. Control cabinet of frequency conversion 16. High-speed camera 17. Reaction member

Figure 1 Schematic diagram of experiment platform of the maize bowl-tray precision seeder

The operating principle: The plate pusher and sowing body will execute longitudinal parallel movements based on the drive of motor via the chain transmission, the speed reducer and the crank-link mechanism. The crank fixed on both ends of the output shaft of the speed reducer. When the crank makes a round, the crank-link mechanism will drive the plate pusher and sowing device to move a distance of one group of seed raising trays, which arrives below the subsoil box after finishing the compaction of soil. Then, the compacted seed raising trays reaches below the seeding apparatus. The shaped-hole plates are used to fill the seed trays twice. In the seed-filling process, the crank drives connecting rod of plate pusher to perform the reciprocating linear motion of the seed box through push rod of seed box.

The seed box, which equipped with a baffle inside, can control the falling of maize seeds. The two sides of seed box were equipped with brush wheels, each of which had a diameter of 78 mm, to follow its movement, and the clearance of brush wheel was 3 mm. In seed-filling process of the sowing device, the baffle was opened; maize seeds fell to the surface of shaped-hole plate by gravity. Under the drive of the brush wheel, seeds were filled through shaped hole, and the spare seeds were brushed out to guarantee that approximately one seed was placed in shaped hole, and the shape of which is cylindrical, with a diameter of 12-16 mm and depth of 6 mm. Which one group of trays is filled, the seed box could finish one reciprocating motion to enable the completion of the second seed-filling processes. After filling, with the cooperation between flap assembly installed at the bottom of shaped-hole plate and plate-turnover, the shutter was opened through the drive of instruments at both ends of the output shaft of speed reducer. Under the action of their own gravity and inertial force, the maize seed in shaped hole fell into the seed raising tray. In this manner, the sowing process was completed. The seed-filling link was the highest priority in seeding process, so this study only considered the seed-filling process.

2.2 Test materials and methods

The combination factors affecting the performance of seed-filling apparatus were further studied based on the preliminary tests and single factor tests[22]. The seeds used in this test were maize named Demeiya 1 in Heilongjiang province, for which one-thousand kernel weight (TKW) is approximately 246 g. The germinal length is approximately 1 mm, moisture content is about 40%, and depth of the shaped hole is 6 mm. This study considered the diameter of shaped hole (x_1) and the velocity of seed box (x_2) as the test factors. The single-seed rate, multi-seed rate, empty-seed rate, broken-bud rate and damage rate were taken as indices using the quadratic orthogonal rotary regression experiment design. The coding of factor levels is presented in Table 1. Computer simulation and optimisation were used to determine the optimal combination of two factors and changing trend.

Table 1 Code and level of factors

Code value	Diameter of the shaped hole x_1/mm	Velocity of the seed box x_2/mm·s^{-1}
asterisk on the arm (+y)	16	135
upper level (1)	15.41≈15	129.14 ≈129
zero level (0)	14	115
lower level (−1)	12.59 ≈13	100.86 ≈101
asterisk under the arm (−y)	12	95
Δ_j (j=1, 2)	1	6

Before the test began, a certain amount of maize was filled into seed box, and the switch of box was closed. When the frequency converter was changed to specified frequency and motor speed was stable, the switch of seed box was turned on. Seeds filled shaped holes due to the action of gravity, the brushing seed wheel and the scraping seed plate. When the box finished reciprocating seed-filling, the trial operation was finished, and the test was completed before the flap was opened.

3 Results and discussion

3.1 The test results

According to the initial experimental design, results of quadratic orthogonal rotary regression experiment are presented in Table 2. The reported value is the average from three observations.

3.2 Regression equation and secondary order of experimental factors

The test data were analysed using DPS (Data Processing System[23]). The regression equations were determined between each experimental factor and performance index, as shown below:

$$\begin{aligned} y_1 = {} & 92.05375 - 16.37931x_1 + 8.78422x_2 - \\ & 13.21750x_1^2 - 21.65250x_2^2 + 5.89250x_1x_2 \end{aligned} \tag{1}$$

$$y_2 = 2.52500 - 5.80922x_1 - 0.15320x_2 + 3.21250x_1^2 - 0.08250x_2^2 + 2.18500x_1x_2 \quad (2)$$

$$y_3 = 5.42125 + 22.18853x_1 - 8.63103x_2 + 10.00500x_1^2 + 21.73500x_2^2 - 8.07750x_1x_2 \quad (3)$$

where, y_1 is single-seed rate, %; y_2 is empty-seed rate, %; y_3 is multi-seed rate, %; x_1 is diameter of shaped hole, mm; and x_2 is t velocity of seeds box, mm/s.

Table 2 Experimental results

Serial number	Diameter of the shaped hole x_1/mm	Velocity of the seed box x_2/mm/s	Single-seed rate/%	Empty-seed rate/%	Multi-seed rate/%	Broken-bud rate/%	Damage rate/%
1	15	129	56.19	0.95	42.86	0	0
2	15	101	26.67	0	73.33	0	0
3	13	129	82.14	7.69	10.17	0.60	0.60
4	13	101	76.19	15.48	8.33	0	0
5	12	115	82.15	17.15	0.70	0.50	0.80
6	16	115	42.86	0	57.14	0	0
7	14	95	33.33	0	66.67	0	0
8	14	135	57.94	3.97	38.09	0	0
9	14	115	88.57	3.11	8.32	0	0
10	14	115	97.14	0.97	1.89	0	0
11	14	115	94.26	4.03	1.71	0	0
12	14	115	91.42	2.51	6.07	0	0.20
13	14	115	95.57	0.49	3.94	0	0
14	14	115	87.43	3.50	9.07	0.15	0
15	14	115	92.43	5.56	1.91	0	0
16	14	115	89.54	0.13	10.33	0	0

The results indicated that no significant relationship existed between performance index broken-bud rate and damage rate for experimental factors, and the values were very small. Thus, the time relationship between factors and two performance indexes (broken-bud rate and damage rate) were ignored.

In order to verify the significance of regression equation, the F test was used for Equations (1), (2) and (3). According to the lack-of-fit test, F_{11}=3.56, F_{12}=1.95 and F_{13}=4.13 were all less than $F_{0.05}(3,7)$=4.35, the lack of fit was significant at the level of α=0.05 because F_{21}=76.46, F_{22}=16.12 and F_{23}=77.44 are all higher than $F_{0.05}(5,10)$=5.46; the regression equation is significant at the level of α=0.01; and the equation fits well with the experimental data according to the T test of the regression coefficients, reaching a significance level of 0.05. Eliminating the insignificant factors, the models between experiment factors and performance index are as follows:

$$y_1 = 92.05375 - 16.37931x_1 + 8.78422x_2 - 13.21750x_1^2 - 21.65250x_2^2 \quad (4)$$

$$y_2 = 2.52500 - 5.80922x_1 + 3.21250x_1^2 \quad (5)$$

$$y_3 = 5.42125 + 22.18853x_1 - 8.63103x_2 + 10.00500x_1^2 + 21.73500x_2^2 - 8.07750x_1x_2 \quad (6)$$

The test of the regression coefficients of Equations (4)-(6) indicated that the primary and secondary order of the factors affecting the single-seed rate and multi-seed rate was the diameter of shaped hole and the velocity of seed box; the factor affecting empty-seed rate was the diameter of shaped hole.

3.3 Discussion of the effect of the two factors

The quadratic regression equation between diameter of shaped hole, velocity of seed box and single-seed rate, multi-seed rate and empty-seed rate was obtained. According to the equation, the relationships among single-seed rate, multi-seed rate, empty-seed rate and various factors are shown in Figures 2-4.

3.3.1 Effect of experimental factors on single-seed rate

Figure 2 exhibits the interaction of shaped hole diameter and velocity diameter of the seed box on single-seed rate. As shown in Figure 2, a higher region of single-seed rate appears when diameter of shaped hole and velocity of seed box are all approximately at the zero level. When velocity of the seed box is fixed, the single-seed rate initially increases with decrease of shaped hole diameter and then decreases slowly; when the diameter of shaped hole is fixed, single-seed rate increases with the increase of shaped hole diameter initially and then decreases. The highest point (96.94%) appears when velocity of seed box is at the zero level. When velocity of the seed box is below zero, the single-seed rate increases with the increase of velocity of seed box; when the velocity of seed box is above zero, the single-seed rate decreases with increase of velocity of seed box. In the course of interaction of the diameter of shaped hole and the velocity of seed box, the diameter of the shaped hole is the main factor influencing the seeding rate.

3.3.2 Effect of experiment factors on empty-seed rate

Figure 3 shows the interaction of the diameter of shaped hole and the velocity of seed box on empty-seed rate. As shown in Figure 3, the lower region of empty-seed rate appears when the diameter of shaped hole is approximately one level. When the diameter of shaped hole is fixed, the change of empty-seed rate with vertical displacement of the maize seeds is almost negligible; when the velocity of seed box is fixed, empty-seed rate initially decreases slightly with decrease of the diameter of shaped hole and then increases rapidly. When the diameter of shaped hole is at approximately one level, the empty-seed rate is effectively at minimum (0%). When the diameter of shaped hole is below the first level, the empty-seed rate decreases with the diameter of shaped hole increasing; when the diameter of shaped hole is above the 1 level, the empty-seed rate increases with diameter of shaped hole increasing. During the interaction course of the diameter of shaped hole and the velocity of seed box, the diameter of shaped hole is the main factor influencing seeding rate.

3.3.3 Effect of experiment factors on multi-seed rate

Figure 4 shows the interaction of the diameter of shaped hole and the velocity of seed box on multi-seed rate. As shown in Figure 4, the effective lower region of multi-seed rate appears when the diameter of shaped hole is approximately at the -0.5 level and the velocity of the seed box 0.5 level.

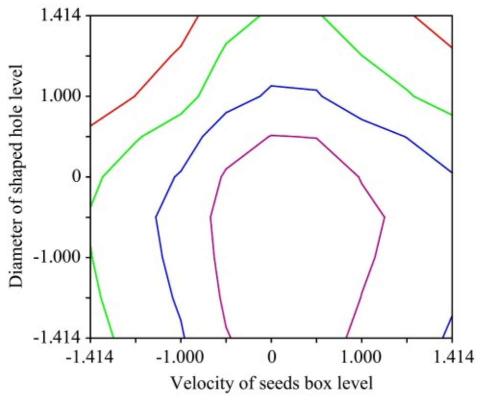


Figure 2a Contour of the interaction of shaped hole diameter and the velocity of seed box

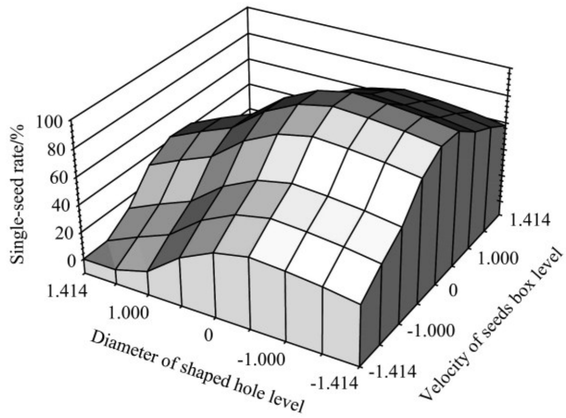


Figure 2b Surface of the interaction of shaped hole diameter and velocity of the seed box

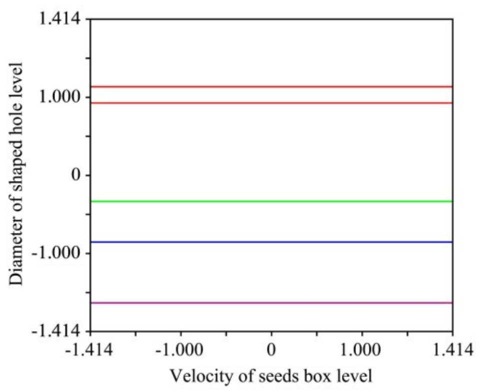


Figure 3a Contour of the interaction of shaped hole diameter and velocity of seed box

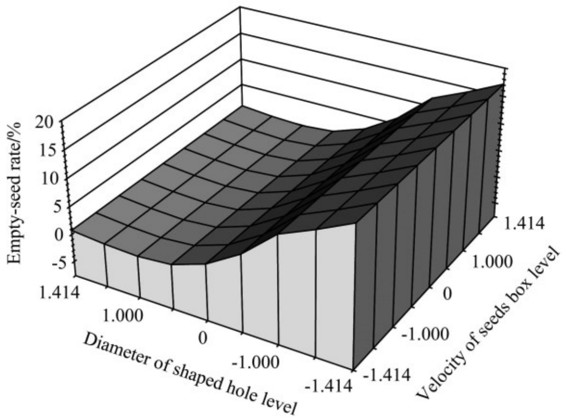


Figure 3b Surface of the interaction of shaped hole diameter and velocity of seed box

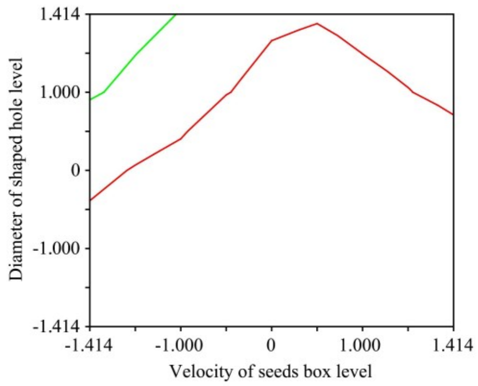


Figure 4a Contour of the interaction of shaped hole diameter and velocity of seed box

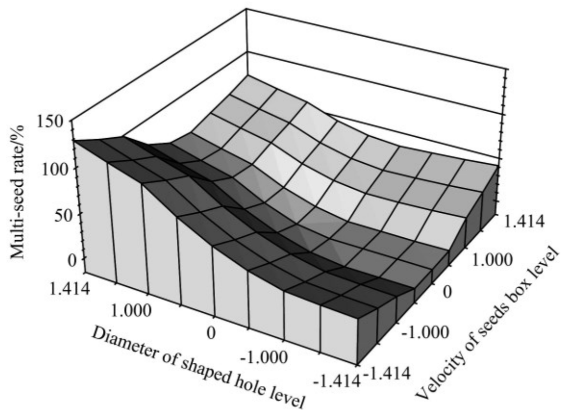


Figure 4b Surface of the interaction of shaped hole diameter and velocity of seed box

When the velocity of seed box is fixed, the multi-seed rate increases with the diameter of shaped hole increasing; when diameter of shaped hole is fixed, the multi-seed rate decreases with the velocity of seed box increase initially, and then increases.

The effective lowest point (0%) appears when the velocity of seed box is approximately at the 0.5 level. When the velocity of seed box is below the 0.5 level, the multi-seed rate decreases with velocity of seed box increasing; when the velocity of seed box is above zero, the single-seed rate increases with velocity of seed box increasing.

During the interaction course of the diameter of shaped hole and the velocity of seed box, the diameter of shaped hole is the main factor influencing the seeding rate.

4 Optimisation of the performance index

According to seed-filling performance requirement of maize bowl-tray precision seeder, three regression equations of the performance index of single-seed rate, multi-seed rate and empty-seed rate are taken as the index. The main objective function method[24] was used with MATLAB to optimise the solution, achieving the improved parameter combination scheme under different objective functions.

The optimization model can be obtained when the single-seed rate is as the objective functions:

$$\text{Max}\ \ 92.05375-16.37931x_1+8.78422x_2-13.21750x_1^2-21.65250x_2^2$$

$$\text{s.t.}\ \ 0\le 2.52500-5.80922x_1+3.21250x_1^2\le 10$$

$$0\le 5.42125+22.18853x_1-8.63103x_2+10.00500x_1^2+21.73500x_2^2-8.07750x_1x_2\le 15$$

$$-1.414\le x_1\le 1.414,\ \ -1.414\le x_2\le 1.414$$

The optimization model was obtained when choosing empty-seed rate as the objective functions:

$$\text{Min}\ \ 2.52500-5.80922x_1+3.21250x_1^2$$

$$\text{s.t.}\ \ 80\le 92.05375-16.37931x_1+8.78422x_2-13.21750x_1^2-21.65250x_2^2\le 100$$

$$0\le 5.42125+22.18853x_1-8.63103x_2+10.00500x_1^2+21.73500x_2^2-8.07750x_1x_2\le 15$$

$$-1.414\le x_1\le 1.414,\ \ -1.414\le x_2\le 1.414$$

Choosing multi-seed rate as objective functions:

$$\min\ \ 5.42125+22.18853x_1-8.63103x_2+10.00500x_1^2+21.73500x_2^2-8.07750x_1x_2$$

$$\text{s.t.}\ \ 80\le 92.05375-16.37931x_1+8.78422x_2-13.21750x_1^2-21.65250x_2^2\le 100$$

$$0\le 2.52500-5.80922x_1+3.21250x_1^2\le 10$$

$$-1.414\le x_1\le 1.414,\ \ -1.414\le x_2\le 1.414$$

The optimum parameter combinations are presented in table 3.

Table 3 Optimum combinations of parameters of different objective functions

Objective function	Diameter of shaped hole x_1/mm	Velocity of seed box x_2/mm·s^{-1}
Single-seed rate	13.72	119.20
Empty-seed rate	14.43	118.92
Multi-seed rate	13.13	110.10

Considering the first two indices of single-seed rate and empty-seed rate are relatively importance, the value of optimum parameters are: the diameter of shaped hole is 14 mm and the velocity of seed box is 119 mm/s.

5 Experimental verification

According to above research, the performance indices are a single-seed rate of 94.29%, an empty-seed rate of 2.84%, a multi-seed rate of 2.86%, a broken-bud rate of 0.0%, and a damage rate of 0.71% under the condition of a rectangular seed box with a baffle; a seed-brush wheel diameter of 78 mm; a clearance of the brush wheel of 3 mm; and a cylindrically shaped hole with a diameter of 14 mm and depth is 6 mm. The velocity of seed box is 119 mm/s, and the maize seeds of Demeiya 1 have a germinal length of approximately 1 mm. The test was repeated five times and took the average. The performance index can meet technical requirements[20]. The results of experiment are more preferable than analogous maize seeding device[15,21].

6 Conclusions

1) Through a quadratic orthogonal rotary regression analysis, a nonlinear regression model was established. This model illustrates the relationship among the diameter of shaped hole, the velocity of seed box and single-seed rate, empty-seed rate, and multi-seed rate, which lays a theoretical foundation for parameters improvement of the maize bowl-tray precision seeder.

2) The factors affecting single-seed rate and multi-seed rate were in the order of the diameter of shaped hole and the velocity of seeds box. The factor affecting empty-seed rate was almost the diameter of shaped hole.

3) The optimal parameters of maize bowl-tray precision seeder determined in this study are the diameter of 14 mm for shaped hole and a velocity of 119 mm/s for seed box.

4) The performance indexes verified through experiment are the single-seed rate of 94.29%, empty-seed rate 2.84%, multi-seed rate 2.86%, broken-bud rate 0%, and damage rate 0.71%. The resulting performance indexes met the technical requirements.

Single-grain maize bud-seed sowing techniques are important for reducing waste, ensuring germination rate, and improving maize production, which is conducive to the promotion of rational use of resources and improved varieties to achieve large-scale, intensive and commercial production.

Acknowledgements

We acknowledge that the research was funded by the Science and Technology Research Project of Education Department of Heilongjiang Province (12531458), Specialized Research Fund for the Doctoral Program of Higher Education jointly funded subject (20132305110003), Natural Science Foundation of Heilongjiang Province (E201331).

[References]

[1] Du Y C, Zhao W, Chen G. The development trend of single seed precision planting of China's corn. Seed World, 2010; 1: 1–5. (in Chinese with English abstract)

[2] Feng J, Gu S K, Zeng A J, Song W T, Liu Y J, Hu H L. Study on transplanter with chute and seedling aid springs (Part 1): Present situation and prospects of the mechanization of maize seedling transplantation in China. Transactions of the CSAE, 1998;14(1): 103–107.

[3] Fang X F. Present situation and development of mechanical transplanting technology on dry land in our country. Farm Machinery, 2010; 1: 35–36. (in Chinese with English abstract)

[4] Beijing Agricultural Machinery Research Institute. Hanging maize transplanting machine of 4 rows. Agricultural Machinery Intelligence Data, 1974; 1: 1–5. (in Chinese with English abstract)

[5] He J, Zhang Z Q, Li H W, Wang Q J. Development of small/medium size no-till and minimum-till seeders in Asia: A review. Int J Agric & Biol Eng, 2014; 7(4): 1–12. doi:10.3965/j.ijabe.20140704.001

[6] Singh R C, Singh G, Saraswat D C. Optimisation of design and operational parameters of a pneumatic seed metering device for planting cottonseeds. Biosystem Engineering, 2005; 92(4): 429–438.

[7] Xia L M, Wang X Y, Geng D Y. Precision seed-metering device for pelleted corn seeds. Transactions of the CSAM, 2011; 42(6): 53–57. (in Chinese with English abstract)

[8] Fu W, Li S F, Sun J Y, Yang H Y, Kan Z. Design of compulsory clamp-type precision seed-metering device for corn. Transactions of the CSAE, 2011; 27(12): 38–42. (in Chinese with English abstract)

[9] Yu J Q, Ma C L, Zuo C C. Analysis of the clearing process

of seeds in corn precision metering device with concave metering inner-cell. Transactions of the CSAM, 2000; 31(5): 35–47. (in Chinese with English abstract)

[10] Kachman S D, Smith J A. Alternative measures of accuracy in plant spacing for planters using single seed metering. Transaction of the ASAE, 1995; 38(2): 379–87.

[11] Karayel D. Performance of a modified precision vacuum seeder for no-till sowing of maize and soybean. Soil and Tillage Research, 2009; 104(1): 121–125.

[12] Yu J J, Liao Y T, Cong J L, Yang S, Liao Q X. Simulation analysis and match experiment on negative and positive pressures of pneumatic precision metering device for rapeseed. Int J Agric & Biol Eng, 2014; 7(3): 1–12. doi: 10.3965/j.ijabe.20140703.001

[13] Li Ch H, Ma C L, Yu H Y. Experimental study on tilt disc spoon type precision seed-metering device for corn seed. Transactions of the CSAM, 1999; 30(2): 38–42. (in Chinese with English abstract)

[14] Li C H, Xia J M, He B. Analysis of seed throwing procedure by declined scope metering device. Transactions of CSAM, 2005; 36(3): 48–50. (in Chinese with English abstract)

[15] Liao Q X, Gao H W. Experimental study on performance of horizontal disc precision meter for corn seed. Transactions of the CSAE, 2003; 19(1): 99–103. (in Chinese with English abstract)

[16] Liao Q X, Gao H W, Zang Y. Experimental study on the cell of the horizontal plate precision meter for corn seed. Transactions of the CSAE, 2003; 19(2): 109–113. (in Chinese with English abstract)

[17] Liao Q X, Gao H W. Experimental study on corn seed damaging in a horizontal plate precision metering. Transactions of the CSAM, 2003; 34(4): 57–59. (in Chinese with English abstract)

[18] Yu J Q, Ma C L, Yang H K, Ma X. Study on cell of combination inner-cell corn precision seed-metering device. Natural Science Journal of Jilin University of Technology, 2000; 30(1): 16–20. (in Chinese with English abstract)

[19] Yu J Q, Ma C L, Zuo C C, Wang W L. Experiment study on precision maize seed metering device of step type inner cell. Transactions of the CSAE, 1997; 13(4): 94–97. (in Chinese with English abstract)

[20] GB/T 6973-2005 Testing methods of single seed drills (precision drills). State Standard of the People's Republic of China, 2005-10-24 (in Chinese)

[21] Wu W F, Zuo C C, Yan H Y, Liu Y. Development of Automatic Precision Seeding System. Transactions of the CSAE, 2001; 17(6): 69–72. (in Chinese with English abstract)

[22] Tang Q Y, Zhang C X. Data processing system (DPS) software with experimental design, statistical analysis and data mining developed for use in entomological research. Insect Science, 2012, 20: 254–260.

[23] Yi S J, Liu Y F, Wang C, Tao G X, Liu H Y, Wang R H. Experimental study on the performance of rice bowl-dish precision seeder. Int J Agric & Biol Eng, 2014; 7(1): 17–25. doi:10.3965/j.ijabe.20140701.002.

[24] Tao G X, Yi Sh J, Wang Ch, Mao X, Wang R H. Performance experiments of bowl dish precision seeder for rice in filling processing. Transactions of the CSAE, 2013; 29(8): 44–50. (in Chinese with English abstract) doi:10.3969/j.issn.1002-6819.2013.08.005.

[25] Yazgi A, Degirmencioglu A. Optimisation of the seed spacing uniformity performance of a vacuum-type precision seeder using response surface methodology. Biosystems Engineering, 2007; 97(3): 347–356.

[26] Gaikwad B B, Sirohi N P S. Design of a low-cost pneumatic seeder for nursery plug trays. Biosystems Engineering, 2008; 99(3): 322–329.

[27] SUZUTEC セルトレイ播種機. 播種機総合カタログ, 2009 年版, p2–5.

[28] 三谷誠次郎.中山間地における水田作の機械化技術. 農業機械学会誌, 2009; 7(2): 4–7 ISSN : 0285-2543.

[29] Zhao Z H. Determination of seed cell plate aperture of nursery tray precision seeding with brush type repeller wheel. Transactions of the Chinese Society for Agricultural Machinery, 2005; 36(3): 44–47. (in Chinese with English abstract)

[30] Wang C, Guo Z B, Liu T X. Rice Precision Seeder of Bowl Rotary-Plate. China Patent: 200810137167.7, 2009-02-10. (in Chinese)

[31] Wang Y C, Qiu L C, Zhang W J, Li Q C. Design and experiment of friction vertical plate precision seed-metering device. Transactions of the CSAE, 2011; 28(1): 22–26. (in Chinese with English abstract)

[32] Liu S G, Shang S Q, Yang R B. Test and optimization of parameters for the storing device of plot seeder. Transactions of the CSAE, 2010; 29(9): 101–108. (in Chinese with English abstract)

[33] Tao G X, Yi S J, Wang C, Mao X. Observation and analysis on rice bowl dish precision sowing device in dropping processing by high-speed photograph. Transactions of the CSAE, 2012; 28(S2): 197–201. doi:10.3969/j.issn.1002-6819.2012.z2.034