

Optimized design and performance evaluation of an electric cup-chain potato metering device

Niu Kang^{1,2}, Fang Xianfa^{1,2}, Liu Yangchun², Lü Chengxu², Yuan Yanwei^{2*}

(1. College of Engineering, China Agricultural University, Beijing 100083, China; 2. State Key Laboratory of Soil-Plant-Machine System Technology, Chinese Academy of Agricultural Mechanization Sciences, Beijing 100083, China)

Abstract: The cup-chain metering device is commonly used in potato planters despite its problems of missing-seeding, double-seeding and ground wheel sliding. A mechanical-electrical design was developed for planters to resolve these problems. A regression experiment was conducted with three factors (chain speed, chain tightening distance and cup tilting) and two indicators (missing-seeding rate and double-seeding rate). Based on the results of regression experiment, a numerical regression model was built and a multi-objective optimization method was used to get an optimal solution. Subsequently, the optimized device was tested in the field. The device design presents a tilting seed cup with a guard plate and an electric control system. The laboratory test showed that the missing-seeding rate increased with the chain speed. It initially decreases and then increases with the chain tightening distance and cup tilting angle. The double-seeding rate declines with chain speed. It increases initially and declines afterward with the chain tightening distance. The optimization resulted in a missing-seeding rate of 4.39% and a double-seeding rate of 8.78% under the parameters of 0.32 m/s seeding speed, 0.94×10^{-3} m tightening distance, and 12.5° cup tilting angle. The field test demonstrated that electric control instead of ground wheel-driven chain enables fast seeding and precise intra-row seeding distance.

Keywords: potato planter, cup-chain metering device, multi-objective optimization, regression method

DOI: 10.3965/j.ijabe.20171002.2547

Citation: Niu K, Fang X F, Liu Y C, Lü C X, Yuan Y W. Optimized design and performance evaluation of an electric cup-chain potato metering device. *Int J Agric & Biol Eng*, 2017; 10(2): 36–43.

1 Introduction

Potato is the fourth largest staple crop in China. The potato planting area and production of China have ranked first in the world in recent years^[1]. In 2013, the planting area in China was 6.7 million hectares. The mechanical sowing rate was 23%^[2]. Currently, the common metering devices used in potato planters include

cup-chain, air suction and belt conveyor^[3-6]. Air suction metering devices work with high negative pressure and are only applicable for large power tractors. Belt conveyors have already been applied because of their high efficiency and less missing-seeding (a seed cup failed filled seed) and double-seeding (a seed cup filled with two seeds). However, the low metering spacing precision of belt conveyors as influenced by seed size needs to be improved^[7,8]. Cup metering is the most widely used metering device because of its high reliability, low cost and adjustable plant spacing. It can be utilized in intra-row and line spacing. However, cup metering still has the problem of missing-seeding (MS), double-seeding (DS), and ground wheel sliding^[9,10].

Capacity and accuracy of plant spacing are the main indicators of machine performance. High accuracy of plant spacing results in high yield and a uniform sorting of the tubers at harvest. Field measurements of planting distance in the Netherlands revealed a coefficient of

Received date: 2016-04-20 **Accepted date:** 2016-12-11

Biographies: Niu Kang, PhD candidate, research interest: mechanical design and theory, Email: niukag@163.com; Fang Xianfa, research fellow, research interests: agricultural mechanization, Email: Fangxf@caams.org.cn; Liu Yangchun, PhD, research interests: virtual reality and control. Email: 694000662@qq.com; Lü Chengxu, PhD, research interest: intelligent agricultural machine, Email: lcx@cau.edu.cn.

***Corresponding author:** Yuan Yanwei, research fellow, research interests: virtual reality and control. Chinese Academy of Agricultural Mechanization Sciences, P.O. Box 25, No.1 Beishatan, Dwai St, Beijing 100083, China. Tel: +86-10-64882658; Email: yyw215@163.com.

variation of around 20%. Earlier studies in Canada and the USA showed even higher coefficient of variations up to 69%^[8,11-13].

Based on the drive type, cup style can be divided into cup-chain and cup-belt. Cup-belt is often utilized in large tractors because of its strong demand for power, as demonstrated by the highly reliable German Grimme GL series potato planter that combines mechanical, electrical, hydraulic, and controller features with high reliability^[14,15]. Cup-chain is utilized in small and medium tractors with low power demands. Influenced by polygonal action, the cup-chain metering device has a vibration effect and has higher missing-seeding rate (MSR) and lower double-seeding rate (DSR) than cup-belt metering device^[16,17]. Artificial assistance metering can resolve these problems effectively but with increased labor intensity and potential safety problems^[18-20]. Hongzhu Nongji Co. Ltd. (China) designed a motor vibration device to reduce the double-seeding rate of metering devices and improve metering performance. Lu designed a mechanical vibration device to reduce the double-seeding rate^[21]. PARMA Company designed a stirring cam to solve the seed blocking problem^[22]. Cup size has a significant effect on metering performance. Cup size is generally 1.2 to 1.6 times of the potato size. Hongzhu Nongji Co. Ltd. (China) designed a combination cup to improve device adaptability to different seed sizes. Han Heng conducted research on the belt-cup potato metering device^[23]. In this study, the influence of belt tension, planter working speed, position of the vibration wheel, and seed filling height on misses and multiples indexes was revealed through experiments.

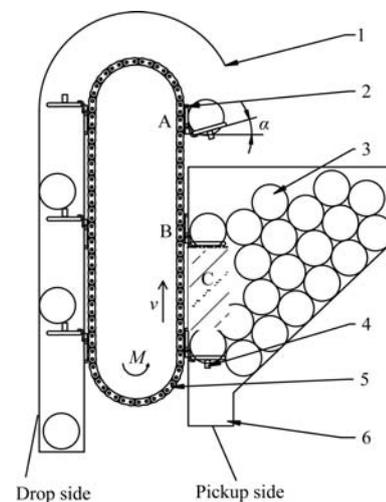
In the current research, a cup-chain potato metering device equipped tilting cups with guard plates are designed and constructed. The difference between the actual center distance and theoretic center distance is defined as chain tightening distance (CTD). This device was laboratory tested with three factors, namely, chain speed (CS), CTD, and cup tilting angle (CTA), and three indicators, namely, MSR, DSR and spacing. A regression experiment was conducted with three factors (CS, CTD and CTA) and two indicators (MSR and DSR).

Based on the regression experiment result, a numerical regression model is built and a multi-objective optimization method is used to get an optimal solution. Subsequently, the optimized device was tested in the field. The device designed presents a tilting seed cup with a guard plate and an electric control system. A control system for metering was developed to resolve the slipping of the ground wheel. The metering chain is driven by a motor, and the driving speed is determined by tractor speed, which is achieved by differential GPS.

2 System design

2.1 Working principle and analysis of factors

The cup-chain potato metering device is shown in Figure 1. The cup-chain device goes through the potato pile and isolates one potato from the others for single grain metering. The metering direction is marked as v in Figure 1. Metering success rate is determined by the number of potato seeds in region C and is influenced by the potato flow behavior and metering speed. Furthermore, the potato can be dropped from the cup because of equipment bumps and chain shaking.



1. Sheet-metal duct 2. Guard plate 3. Potato seeds 4. Seed cup
5. Chain 6. Seed box

Figure 1 Schematic of the cup-chain potato metering device

Point A in Figure 1 shows that the cup tilting angle is defined as the angle between the cup-chain and the normal line of the fixed point. Generally, the cup is placed perpendicular to the chain, with a CTA of 0° . In this condition, the forces acting on the potato in the cup include gravity and the supporting force from the cup. With equipment bumping and chain shaking, the potato

can be dropped from the cup.

Figure 2 shows the forces acting on the potato in the tilted cup. The forces acting on the potato include gravity G , supporting force P from the cup, and supporting force N from the guard plate. While the potato tends to separate from the cup under the conditions of device bumping and chain shaking, the guard plate acts as friction force f on the potato which prevents the shedding phenomenon occurs. Friction force increases and the shaking phenomenon decreases with the increase in CTA. Meanwhile, the effective area that contributes to metering decreases, which leads to an increase in MSR.

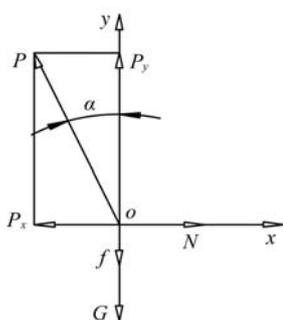


Figure 2 Stress analysis of a potato

The metering chain should neither be too tight nor too loose. A metering chain that is too tight causes a polygonal action, with the results of MSR increase and DSR decrease. A metering chain that is too loose easily causes chain shaking and collision with other components, with the results of MSR increase and DSR decrease.

On the basis of predecessor findings and above analysis, studied factors in this paper are CS, chain tightening tension, and CTA. Chain tightening tension is evaluated by CTD.

Ground wheel slipping is mainly the result of lacking driving capacity, which can be caused by huge load torque or ground drive failed attached to the soil/residue surface. To solve this problem, a motor was employed to drive the metering device instead of the ground wheel. Working speed was measured by differential GPS. A metering control system was developed to control the metering speed according to the ground wheel speed.

2.2 Mechanical system design

The mechanical system is an improvement of the potato planter type 1220 produced by Menoble Company. The structure is shown in Figure 3.

Metering speed was set by driver 4 and implemented by motor 2. The relationship between metering speed v and motor rotational speed n is as follows:

$$n = \frac{1000 \times 60 \cdot i}{z \cdot p \cdot v}$$

where, p is chain pitch, m; i is total drive ratio; z is metering sprocket teeth.

CTD α was adjusted by the distance between the driven and drive sprockets. Center distance α_0 was calculated by the sprocket number, sprocket teeth count, and chain pitch count. The actual center distance is α_1 , so,

$$\alpha = \alpha_1 - \alpha_0$$

Guard plate 9 is replaceable, and CTA can be changed.



1. Collecting box 2. Motor 3. Controller 4. Driver 5. Frame 6. Seed box 7. Chain 8. Seed cup 9. Guard plate 10. Tightener

Figure 3 Structure of the metering test device

2.3 Control system design

The metering control system consists of a microcontroller, a motor control circuit, and a GPS communication circuit. The microcontroller is a microcomputer PIC18F2580 produced by Microchip Company. The control signal was amplified by a D/A translate box through an electrical signal control servo motor to adjust the metering speed. Working speed was measured by the differential GPS and achieved through the RS232 serial port. The main controller implements closed loop control using the PID control algorithm for the feedback signal. Figure 4 shows a block diagram of the control system principle.

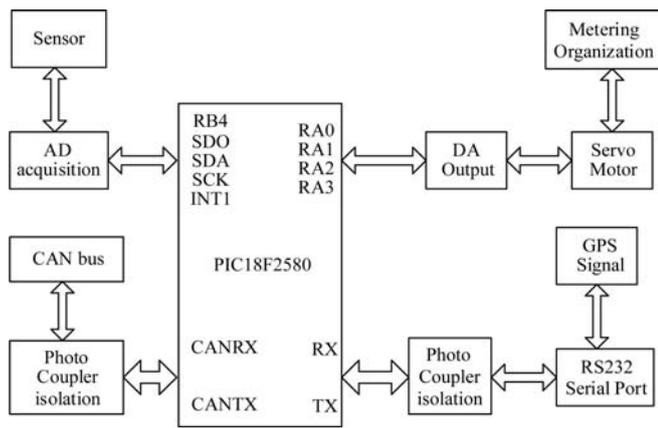


Figure 4 Schematic of the control system

2.4 Tests

2.4.1 Test apparatus

Type PS70 precision planetary gear box (Newstart Gear Transmission Co., Ltd.), type SGMJV-04ADE6S servo motor (Yaskawa Electric Corporation), type SGD V-2R8A01B002000 servo driver (Yaskawa Electric Corporation), and analysis software DPS v7.05 and Matlab R2012A were utilized.

2.4.2 Test materials

The future development trend of potato seeds will utilize entire potatoes rather than diced potatoes^[24]. In this test, the seed material was naturally matured and harvested manually. The species is Holland 15, cultivated by Zhangjiakou Academy of Agricultural Sciences. According to user guide of type 1220 potato planter, the mean diameter of potato seed selection is 56 mm.

2.4.3 Test method

A laboratory test was conducted according to the standard GB/T 6242-2006 Equipment for Planting-Potato Planters-Method of Testing^[25-29]. On the basis of test scheme, each parameter was set. Then, the seed box was filled with the potato seeds.

By mounting two laser sensors on seed discharge hole, the number of missing-seeding can be calculated with logic output. The number of double seeding can be observed. Then, MSR and DSR can be calculated. With the furrow coverer of potato planter removed, the plant spacing can be measured easily.

3 Test results and analysis

3.1 Test model

Test conducted with quadratic general rotary unitized

design regression testing method. Multi-objective optimization method is used to get an optimal solution^[24]. According to the related technical standard and preliminary test results, the value of each factor and range were determined.

The best level of value was encoded as space factor 0 according to the factor value range. Each factor code was determined.

In the test index, y_1 is MSR and y_2 is DSR. Experimental factors x_1 , x_2 , and x_3 are the encoded values of CS v , CTD d , and CTA α . The coding of the regression test is shown in Table 1. The design and results are shown in Table 2.

Table 1 Factors and levels of regression experiment

Coding level	CS $v/m \cdot s^{-1}$	CTD $d/10^{-3}m$	CTA $\alpha(^{\circ})$
1.682	0.71	4	18.7
1	0.61	3.2	16
0	0.46	2	12
-1	0.3	0.8	8
-1.682	0.2	0	5.3

Table 2 Scheme and results of regression experiment

Test number	Test factors			Test indicators	
	x_1	x_2	x_3	$y_1/\%$	$y_2/\%$
1	1	1	1	7	11.3
2	1	1	-1	6	10.9
3	1	-1	1	6.2	6.7
4	1	-1	-1	5.8	6.7
5	-1	1	1	4.9	13.5
6	-1	1	-1	4.7	12.4
7	-1	-1	1	4.6	8.5
8	-1	-1	-1	5	7.9
9	-1.682	0	0	3.6	11.3
10	1.682	0	0	6.1	8.5
11	0	-1.682	0	6.5	5.8
12	0	1.682	0	6.8	13.5
13	0	0	-1.682	4.6	9.4
14	0	0	1.682	5	10.2
15	0	0	0	4.1	10.6
16	0	0	0	4.1	10.7
17	0	0	0	4.3	10.6
18	0	0	0	4.2	10.5
19	0	0	0	4.1	10.4
20	0	0	0	4.2	10.4

The regression equation of MSR is:

$$y_1 = 4.1662 + 0.7326x_1 + 0.1102x_2 + 0.1371x_3 + 0.2447x_1^2 + 0.8811x_2^2 + 0.2271x_3^2 + 0.125x_1x_2 + 0.2x_1x_3 + 0.15x_2x_3 \quad (1)$$

The regression equation of DSR is:

$$y_2 = 10.5333 - 0.8354x_1 + 2.2882x_2 + 0.2523x_3 - 0.224x_1^2 - 0.3124x_2^2 - 0.2593x_3^2 - 0.0875x_1x_2 - 0.1625x_1x_3 + 0.1125x_2x_3 \quad (2)$$

The *F*-tests of regression Equations (1) and (2) are shown in Table 3. The comparison of the calculated result with $F_{0.01}(9,10)=4.94$ shows that both of the regression equations are remarkable. The regression model can reflect actual situations well.

Table 3 F-test for MSR and DSR

Indicators	Source	Sum of squares	Degree of freedom	<i>F</i> -value	Significance
MSR	Regression	20.1554	9	2.2395	525.83
	Residual	0.0426	10	0.0043	
	Sum	20.1980	19		
$R=0.9150 \quad S=0.141 \quad \alpha=0.00$					
DSR	Regression	84.8813	9	9.4313	1229.74
	Residual	0.0767	10	0.0077	
	Sum	84.9580	19		
$R=0.9983 \quad S=0.1255 \quad \alpha=0.00$					

3.2 Factor effect analysis

3.2.1 Main effect analysis

The partial regression coefficients were standardized because the factors were substituted by dimensionless linear. Two factors were fixed on level 0, so the third factor influences were determined.

$$y_1(x_1) = 4.1662 + 0.7326x_1 + 0.2447x_1^2 \quad (3)$$

$$y_1(x_2) = 4.1662 + 0.1102x_2 + 0.8811x_2^2 \quad (4)$$

$$y_1(x_3) = 4.1662 + 0.1371x_3 + 0.2271x_3^2 \quad (5)$$

$$y_2(x_1) = 10.5333 - 0.8354x_1 - 0.224x_1^2 \quad (6)$$

$$y_2(x_2) = 10.5333 + 2.2882x_2 - 0.3124x_2^2 \quad (7)$$

$$y_2(x_3) = 10.5333 + 2.2523x_3 - 0.2593x_3^2 \quad (8)$$

The main effects between each factor and MSR and DSR are shown in Figures 5 and 6. MSR increases with CS; it initially decreases and then increases with CTD and CTA. DSR declines with CS; it increases initially and then decreases afterward with CTD. With CTA, it initially decreases and then increases. CS and CTD have a greater influence on MSR and DSR than CTA.

The test results show that the chances that the potato will fall to the cup decreases with the increase in CS, thus, MSR increases and DSR decreases.

The chain easily slackens and swings during vertical lifting with the decrease in CTD. MSR increases

because a potato can easily fall from the cup. The chain free swinging phenomenon disappears, MSR decreases, and DSR increases with the increase in CTD. As CTR increases, the polygonal action becomes significant, chain shaking intensifies, MSR increases, and DSR decreases.

The chances that a potato will fall from the cup can be improved by increasing CTA appropriately. The MSR rate increases with the increase in CTA. Thus, with the increase in CTA, MSR decreases initially and then increases, which is contrary to DSR.

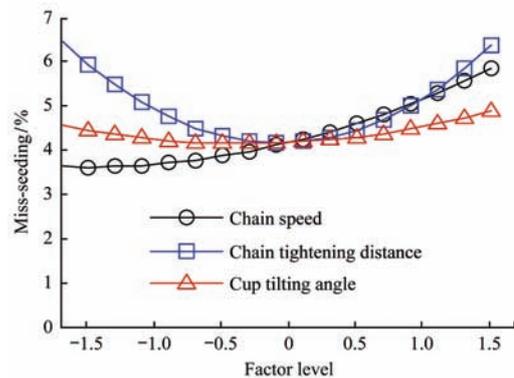


Figure 5 Major effects of factors and MSR

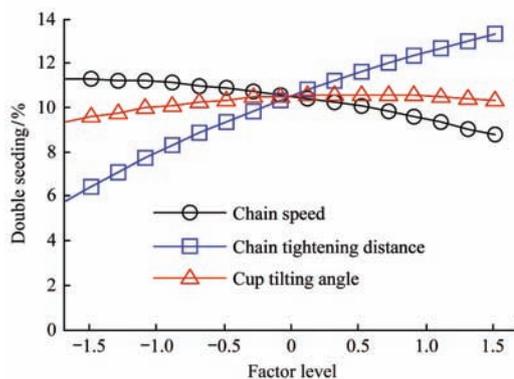


Figure 6 Major effects of factors and DSR

3.2.2 Response surface analysis

When one factor is fixed at level 0, the binary quadratic equation of the other two factors is determined. The interaction equations of MSR and DSR are presented by Equations (1) and (2). The interactive effect of the factors and contour on MSR and DSR are shown in Figures 7 and 8.

Figure 7 shows the interactive influence of factors on MSR is significant. The interactive influence sequence is as follows: CS and CTD, CS and CTA, CTD and CTA. MSR is less than 10% when CS is less than 0.46 m/s, CTD is in the range of 0.81×10^{-3} m to 3.19×10^{-3} m, and CTA is in the range of 8° to 16°.

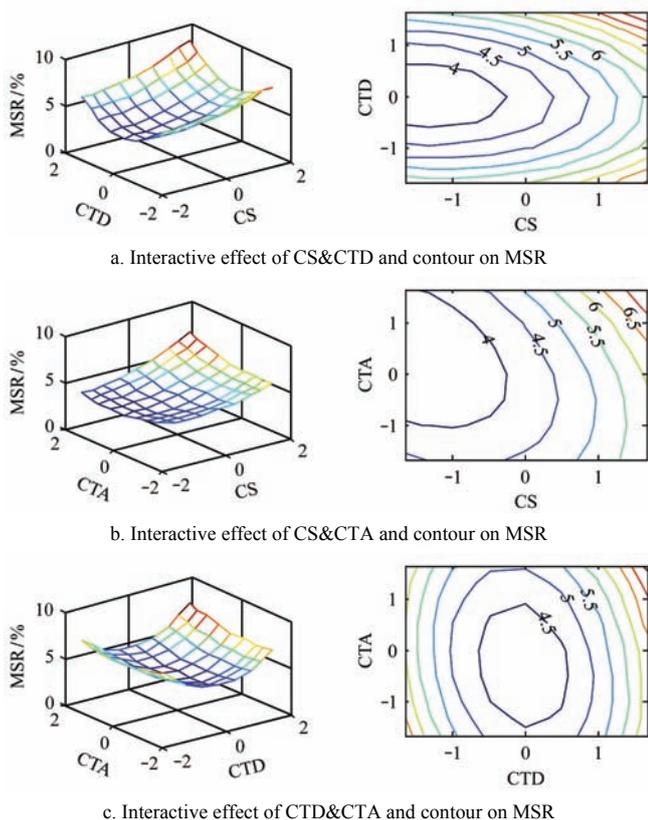


Figure 7 Interactive effect of factors and contour on MSR

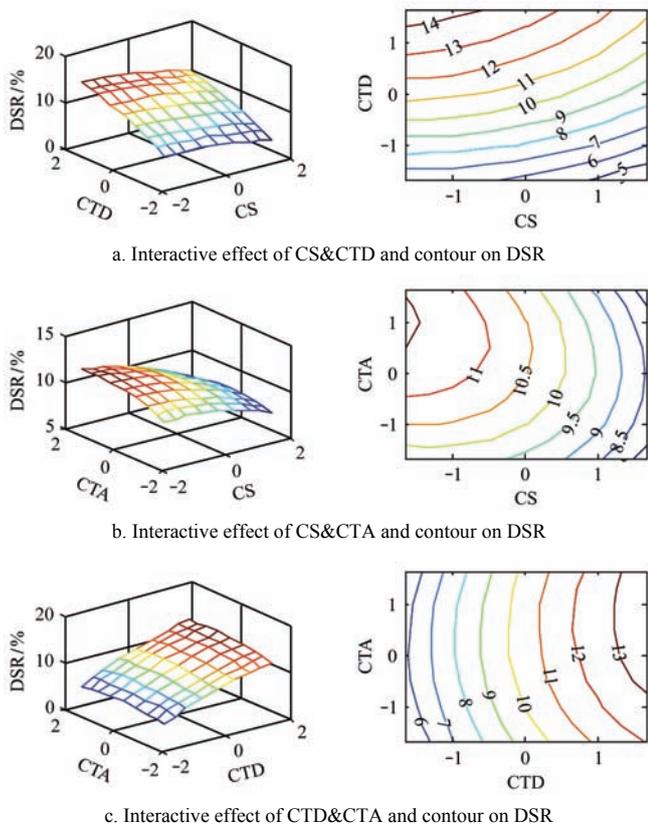


Figure 8 Interactive effect of factors and contour on DSR

Figure 8 shows that the interactive influence of factors on DSR is significant. The interactive influence sequence is as follows: CS and CTD, CS and CTA, CTD and CTA. DSR is less than 20% when CS is greater

than 0.3 m/s, CTD is less than 2×10^{-3} m, and CTA is in the range of 8° to 16° .

3.3 Parameter optimization of the regression model

The national standards for potato planter performance indicators are as follows: MSR of less than 10% and DSR of less than 20%. For DSR and MSR, smaller is better. Based on the above model, the mathematical model for determination is as follows:

$$\begin{aligned} \min F(X_j) &= y_1 \\ \min F(X_j) &= y_2 \\ X_j &\in [-1.682, 1.682] \end{aligned}$$

The model is a multi-objective optimization problem. Sequential quadratic programming method is utilized to solve this problem. The method is accomplished by the “fgoalattain” function of the MATLAB optimization toolbox. By using coded formula back substitution to optimize the variables, the actual values of each optimized factor were determined as follows: CS is 0.32 m/s, CTD is 0.94×10^{-3} m, CTA is 12.5° , MSR is 4.39%, and DSR is 8.78%.

To verify the reliability of the optimized results, a test was conducted. The results are shown in Table 4. The authentication and predicted values are similar. The test results show that the regression model is reliable and can be used to predict and analyze the potato metering device.

Table 4 Experimental scheme and results for prediction verification

Number	Test scheme			Results	
	CS v/m·s ⁻¹	CTD d/10 ⁻³ m	CTA α/(°)	MSR y ₁ /%	DSR y ₂ /%
1	0.32	0.94	12.5	4.6	8.4
2	0.32	0.94	12.5	4.9	9.0
3	0.32	0.94	12.5	4.3	8.6

3.4 Field test

The field test scheme and results are shown in Table 5. Type I is type 1220 potato planter designed by Menoble Corporation. Type II is the planter with optimization parameters.

Field test was conducted on October 18, 2015 in Chinese Academy of Agricultural Mechanization. Field flatness and crop stubble have influenced on sowing precision of potato planter. Major agricultural production process for reference, land preparation was conducted including subsoiling and rotary tilting operation.

Table 5 Field experimental scheme and results

Number	Type	Test results		
		MSR $y_1/\%$	DSR $y_2/\%$	Spacing $y_3/10^{-3}\text{m}$
1	I	8.6	9.3	319
2	I	7.7	8.5	307
3	I	8.2	8.4	312
4	II	4.9	8.1	281
5	II	5.1	7.8	281
6	II	5.2	7.6	282

The test results show that the MSR of type II decreases from 8.2% to 5.1% and DSR drops from 8.7% to 7.8% compared with those of type I. The average intra-row space is $281.3 \times 10^{-3}\text{m}$, which is better than that of type I ($312.7 \times 10^{-3}\text{m}$).

4 Conclusions

(1) Within the scope of the test, the MSR increases with the CS; it initially decreases and then increases with the CTD and CTA. The DSR declines with the CS, increases initially, and decreases afterward with the CTD; meanwhile, it initially decreases and then increases with the CTA.

(2) MSR and DSR are both influenced by CS significantly, which determines the filling time. Chain tightening extent is decided by CTD, which is important to chain shaking and polygonal action. CTA has a large influence on the stability of the potato in the cup.

(3) The optimization results show a MSR of 4.39% and a DSR of 8.78% under the parameters of 0.32 m/s seeding speed, $0.94 \times 10^{-3}\text{m}$ tightening distance, and 12.5° cup tilting angle.

(4) The field test indicates that electric control instead of ground wheel-driven chain enables the increase in seeding speed and precision in intra-row seeding distance.

Acknowledgments

The authors acknowledged the financial support by the State's Key Project of Research and Development Plan (2016YFD0700103) and National Natural Science Foundation of China (31301241).

[References]

- [1] Lv J Q, Tian Z E, Yang Y, Shang Q Q, Wu J E, Li Z H, et al. The development situation, existing problems and development trend of potato machinery. *Journal of Agricultural Mechanization Research*, 2015; 37(12): 258–263. (in Chinese)
- [2] Liu Q W, Wu J M, Wang D, Sun W, Wang G P, Shi L R. Current status and progress of the potato seeder. *Journal of Agricultural Mechanization Research*, 2013; 35(6): 238–241. (in Chinese)
- [3] Yang L, He X T, Cui T, Zhang D X, Shi S, Zhang R, et al. Development of mechatronic driving system for seed meters equipped on conventional precision corn planter. *Int J Agric & Biol Eng*, 2015; 8(4): 1–9.
- [4] Jiang Y Y. Combination of agricultural machinery and agronomy in their scientific and technological innovations. *Transactions of the CSAM*, 2007; 46(3): 163, 179–181. (in Chinese)
- [5] Lü J Q, Yang Y, Li Z H, Shang Q Q, Li J C, Liu Z Y. Design and experiment of an air-suction potato seed metering device. *Int J Agric & Biol Eng*, 2016; 9(5): 33–42.
- [6] Tang H J, Lv Z Q, Liu S F. The design of new potato planter. *Journal of Agricultural Mechanization Research*, 2015; 37(12): 148–151. (in Chinese)
- [7] Ebrahim I Z, Ayman A E, Guidetti R. New small potato planter for Egyptian agriculture. *Journal of Agricultural Engineering*, 2011; 42(3): 7–13.
- [8] Buitenwerf H, Hoogmoed W B, Lerink P, Müller J. Assessment of the behavior of potatoes in a cup-belt planter. *Biosystems Engineering*, 2006; 95(1): 35–41.
- [9] Ilyes S, Popescu S, Voicu E. Experimental device for the researches on the precision of the tubers planting distance within the row for different potato planters. in *Research People and Actual Tasks on Multidisciplinary Sciences/ Proceedings of the Third International Conference*, Lozenc: Bulgaria, 2011; 2: 153–158.
- [10] Szczepaniak J, Pawlowski T, Grzechowiak R, Kromulski J, Rutkowski J. Experimental tests and computer simulations of a combination tractor/potato planter: the identification and optimization of parameters. *Applied engineering in agriculture*, 2015; 31(5): 126–136.
- [11] McPhee J E, Beattie B M, Corkrey R, Fennell F M. Spacing uniformity—yield effects and in-field measurement. *American Potato Journal*, 1996; 73(1): 167–171.
- [12] Siczka J B, Ewing E E, Markwardt E D. Potato planter performance and effects on non-uniform spacing. *American Potato Journal*, 1986; 63: 25–37.
- [13] Liu H J, Liu J F, Li J P. Comprehensive utilization technology of orchard pruning branches. *Journal of Agricultural Mechanization Research*, 2011; 33(2): 214–217, 221.
- [14] Boydas M G, Uygan F. Influence of seed physical properties and speed on the external mechanical damage

- index and in-row spacing uniformity in an automatic potato planter. *Journal of Agricultural Sciences*, 2012; 18(2): 126–136.
- [15] Al-Gaadi K A. Performance evaluation of a cup-belt potato planter at different operation conditions and tuber shapes. *American-Eurasian Journal of Agricultural & Environmental Sciences*, 2011; 10(5): 821–828.
- [16] Al-Gaadi K A, Marey S A. Effect of forward speed and tuber characteristics on tuber spacing uniformity for a cup-belt potato planter. *Middle East Journal of Scientific Research*, 2011; 8(8): 753–758.
- [17] Zheng D H, Chen W, Du W L, Fan M S, Liu G S. The study and analysis of cup seed sowing technology and uniformity. *Journal of Agricultural Mechanization Research*, 2016; 38(7): 106–109. (in Chinese)
- [18] Szczepaniak J. Parameters identification of agricultural combination tractor-potato planter model. *Journal of Research and Applications in Agricultural Engineering*, 2008; 53(2): 16–20.
- [19] Hamid A, Ahmad D, Rukunuddin I H. Performance of sweet potato transplanting machine on mineral and bris soils. *AMA-Agricultural Mechanization, in Asia Africa and Latin America*, 2010; 41(1): 55–59.
- [20] Pawlowski T, Kromulski J. Control theory models of the agricultural set (tractor-potato planter) driver. *4th International Symposium on Applications of Modelling as an Innovative Technology in the Agri-Food-Chain-Model-IT*, 2007; 802(Madrid): 227–331.
- [21] Lu Y F, Sun C Z, Wang F M, Su G L, Shi D Y. The improved design of potato planter seeding-unit. *Journal of Agricultural Mechanization Research*, 2015; 37(12): 140–143. (in Chinese)
- [22] Song Y M, Wang F E. The general development of potato machinery at home and abroad. *Journal of Agricultural Mechanization Research*, 2008; 25(9): 224–227.
- [23] Han H, Chen W, Du W L, Zheng D H, Liu G S. Analysis and test of the factors influence the seeding performance of potato planters. *Journal of Agricultural Mechanization Research*, 2016; 43(3): 209–217.
- [24] Zhang Y, Li L X, Han H Y, Du M J, Dou Y C. Development status and prospect of mechanized planting micro potato. *Journal of Anhui Agri. Sci.* 2015; 43(4): 372–375. (in Chinese)
- [25] GB/T 6242-2006. Equipment for planting-Potato planters-Method of testing.
- [26] Zhang G Z, Zang Y, Luo X W, Wang Z M, Zhang Q, Zhang S S. Design and indoor simulated experiment of pneumatic rice seed metering device. *Int J Agric & Biol Eng*, 2015; 8(4): 10–18.
- [27] 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.
- [28] Ren L Q. Optimization experiment design and analysis. Beijing: Higher Education Press, 2003: 79–84. (in Chinese)
- [29] Qi J T, Jia H L, Li Y, Yu H B, Liu X H, Lan Y B, et al. Design and test of fault monitoring system for corn precision planter. *Int J Agric & Biol Eng*, 2015; 8(6): 13–19.