

Development of mechatronic driving system for seed meters equipped on conventional precision corn planter

Yang Li, He Xiantao, Cui Tao, Zhang Dongxing^{*}, Shi Song, Zhang Rui, Wang Mantao

(College of Engineering, China Agricultural University, Beijing 100083, China)

Abstract: Precision planters are more and more widely used for planting corn in China. Seed meters of conventional precision corn planters are usually driven by ground wheel and chain and sprocket system at present. Because of the slippage of ground wheels and vibration of chains, planting accuracy cannot be ensured, especially at higher forward speed. To improve the planting performance of precision planters, a mechatronic driving system was designed and its field working performance was evaluated in this research. A two-row pneumatic precision planter was modified to allow simultaneously using two different driving systems, i.e., with one row unit equipped with the newly designed mechatronic driving system and the other row unit equipped with conventional mechanical driving system, and used for planting at three forward speeds (9, 11 and 12 km/h) on no-tillage and rotary-tillage lands. The distances between adjacent seeds in each plot were measured and the indices of uniformity in seed spacing, quality of feeding index (QFI), missing-seeding index and precision index were analyzed. With the average 4.70% increase of QFI and 3.54% decrease of missing-seeding index, the mechatronic driving system performed better than the mechanical driving system both on no-tillage and rotary-tillage lands at each forward speed. The values of QFI, missing-seeding index and precision index of the mechatronic driving system on rotary-tillage land are comparable to those on no-tillage land, by contrast, these indices of the mechanical driving system on rotary-tillage land are significantly worse than those on no-tillage land. The result indicates that the mechatronic driving system can eliminate the effect of ground wheel slippage on planting quality and maintain the uniformity of seed distribution. Although the QFI, missing-seeding index and precision index become worse with the increase of forward speed, with the worst values of QFI of 89.93%, missing-seeding index of 5.08% and precision index of 18.92% at the highest forward speed of 12 km/h, the mechatronic driving system can reduce the effect of forward speed on planting accuracy effectively. The result indicates that planters equipped with the mechatronic driving system are suitable for high speed planting. As compared to the mechanical driving system, the advantage of the mechatronic driving system is more noticeable especially when the forward speed is more than 11 km/h.

Keywords: precision planter, seed meter, mechatronic driving system, control, motor, wheel slippage

DOI: 10.3965/j.ijabe.20150804.1717

Citation: 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.

1 Introduction

Corn has become the No.1 crop in China since 2012 and its planting acreage is more than 36 million hm² at

present, most of which was planted by precision planters due to their ability to save seeds and keep uniform seed spacing. Precision planters were developed and more and more widely used for planting corn in recent years^[1-4].

Received date: 2015-02-07 **Accepted date:** 2015-07-06

Biographies: **Yang Li**, PhD, Associate Professor, Research interests: modern agricultural machinery and corn precision planting technology. Email: yl_hb68@126.com. **He Xiantao**, PhD student, Research interests: corn precision planter and its control system. Email: hxt@cau.edu.cn. **Cui Tao**, PhD, Research interests: corn planting and harvesting technology. Email: cuitao850919@163.com. **Shi Song**, PhD student, Research interests: corn precision planting technology. Email:

shisongfox@163.com. **Zhang Rui**, PhD student, Research interests: corn precision planting technology. Email: zhr27@163.com. **Wang Mantao**, Master, Research interests: corn precision planter and control system. Email: wangmtgs@163.com.

*** Corresponding author: Zhang Dongxing**, Professor, Research interests: corn planting and harvesting technology. College of Engineering, China Agricultural University, Beijing 100083, China. Email: zhangdx@cau.edu.cn; Tel: +86- 10-62737765.

Seed meter is the key component of precision planter and its performance affects the uniformity of seed distribution directly^[5-9]. However, seed meters of conventional precision corn planters are usually driven by ground wheel and chain and sprocket system, and as a result, planting accuracy cannot be ensured because of the existence of ground wheel slippage and chain vibration, especially at higher forward speeds. Moyer et al.^[10] reported that planters lost their efficiency and planting accuracy in rugged fields due to the inappropriate interaction between ground wheel and soil which resulted in non-uniform seed placement. Some studies showed that non-uniform seed placement would reduce final crop yield^[11-15].

To solve the problems mentioned above, an alternative power transmission method which adopted electrical motor replacing mechanical driving system to drive seed meters was developed. CNH and John Deere, the top two American agricultural machinery companies, have developed new technologies for driving seed meters of precision planter by using DC motors^[16,17]. Horsch, a famous Germany planter company, also owned the technology for driving seed meters by using DC or hydraulic motors^[18]. Precision Planting and Ag Leader, the two hi-tech agricultural machinery companies of America, have developed intelligent control system for precision planters equipped with motor-driven seed meters^[19,20]. According to these researches, seed meters driven by electrical or hydraulic motors can effectively eliminate non-uniformity of seed spacing caused by slippage of ground wheel and vibration of sprocket chain, and therefore increase working speed and improve planting accuracy. Moreover, Singh et al.^[21] developed an electronically controlled metering mechanism for okra seed. Chaney et al.^[22] developed an automatic control system for a sugarcane planter. In China, there are also some studies focused on motor-drive seed meters in recent years. He et al.^[23] designed a kind of seed meter based on electromagnetic vibrating mode and developed its PLC controller. Yang et al.^[24] developed a controller based on PIC16C57 single chip for precision planter which was used for planting vegetable seeds into plastic seedling tray. Li et al.^[25] adopted stepper motor to drive

seed meter and developed a control system based on Intel 8031 to control the planting process. Tang et al.^[26] designed a driving mechanism for seed meters which controlled the rotary speed of seed meter according to the forward speed of tractor. Zhai et al.^[27] developed an automated seed metering driving system based on sensor signal. Yang et al.^[28] optimized the structure schema of flexible comb-type grass seeder. Yi et al.^[29] optimized the parameters of bowl-tray rice precision seeder and improved its performance. But all these researches were just at laboratory test stage and were not used in production, and the axles of seed meters, in these researches, were directly driven by motors, which needed high torque motors and could not ensure the seed plate stability.

In this study, a mechatronic driving system which combined an electrical motor and an edge-driven mechanism to drive seed meter was developed and the performance of a planter equipped with seed meters driven by the mechatronic driving system was evaluated through field test.

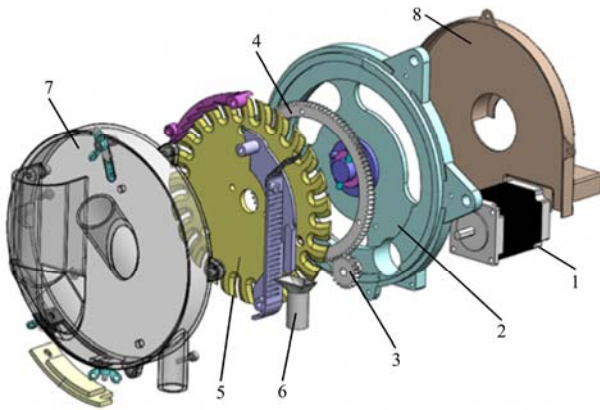
2 Materials and methods

2.1 Design of the mechatronic driving system

2.1.1 Edge-driving mechanism for seed meter

A kind of air-pressure precision meter^[30] which was designed by corn mechanization laboratory at China Agricultural University was selected to be modified in this study. The meter was modified to be driven by motor instead of ground wheel and chain. In order to minimize the torque on motor axle and enable the seed plate to run smoothly, an edge-driving mechanism was designed. The mechanism mainly consisted of four parts, i.e., a motor, a small gear, a gear ring and a seed plate (Figure 1). When the motor works, it will drive the seed plate to rotate through the gear set. The reduction gear ratio from the small gear to the gear ring was set at 5 according to the structure of the seed plate. The advantage of this edge-driving mechanism is that it can reduce the rotational inertia of the seed plate and as a result can ensure the seed plate to rotate smoothly, especially when the motor speeds up and slows down. Moreover, the reduction gear ratio from the small gear to

the gear ring is also helpful to reduce the requirement for the torque on motor.

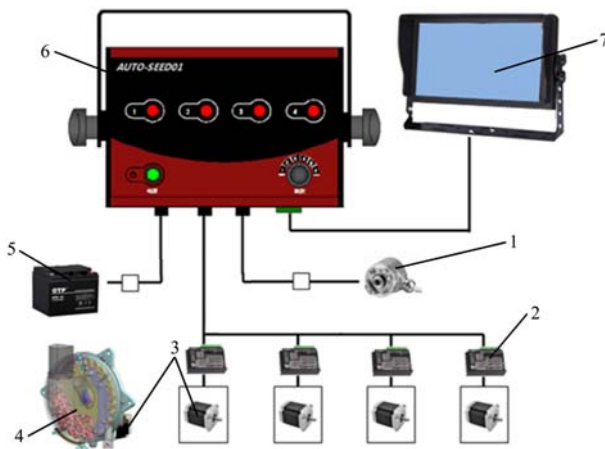


1. Motor 2. Base 3. Small gear 4. Gear ring 5. Seed plate 6. Seed tube
7. Front cover 8. Back cover

Figure 1 Schematic diagram of the precision meter and its edge-driving mechanism

2.1.2 Control system

The control system for the mechatronic driving mechanism consisted of six components: motor and its driver module, forward speed sensor, touchscreen display, microcontroller and power source (Figure 2).



1. Forward speed sensor 2. Driver module 3. Motor 4. Seed meter
5. Power source 6. Microcontroller 7. Touchscreen

Figure 2 The structural diagram of the control system

1) Motor and driver module

The torque requirement for driving a seed plate was calculated to be 4.6 N·m, therefore a 1.5 N·m stepper motor was selected. The torque was increased to be 7.5 N·m after the transmission of gear set, and it is enough for driving the seed plate.

The electrical power was supplied by tractor battery (12 V/150 A·h), so the voltage of the stepper motor was determined to be 12 V.

The step angle is a crucial parameter for a stepper

motor to guarantee its working accuracy. Smaller values of step angle indicate higher accuracy than bigger ones. Hence, in this system a small step angle of 1.8° was chosen for the motor.

Based on the parameters mentioned above, a two-phase hybrid stepper motor (57HBP76AL4-TF0, Times Brilliant Electrical Company, Beijing, China) with the rated current of 2.0 A was used in this study.

The speed and rotation direction of the stepper motor was adjusted by a driver module. The driver module was from the same Company as the stepper motor and its model was 2HD403. The input signals were isolated through optical system inside the driver module to obtain strong anti-interference ability for adapting hard work environments.

2) Sensor of forward speed

When planting, the rotational speed of seed plate should be adjusted in time according to the forward speed of planter, so as to achieve desired seed spacing as planned. To measure the planter forward speed, a rotary shaft encoder (TRD-2T500BF, Koyo Electrical Company, Japan) with the precision of 500 pulse/rev was selected to install on the hub of the ground wheel. The forward speed of planter could be calculated from Equation (1).

$$v = \frac{N_e}{500} \cdot \pi \cdot 2R \quad (1)$$

where, v is the forward speed of planter, m/s; N_e is the number of pulses given by encoder per second, pulse/s; R is the radius of ground wheel, m.

3) Interface of data input/output

A data input/output interface was developed to enter planter structure and working parameters such as seed spacing and number of holes on seed plate and display performance index of planter (Figure 3). A touchscreen named MT4414T was selected to be the display, which was collected to the microcontroller by RS485. The touchscreen was mounted in tractor cab. So it is very convenient for driver to change planting parameters according to different requirements.

4) Microcontroller

A microcontroller based on STM32F103VCT6 single chip microcomputer was designed to receive input data from forward speed sensor and touchscreen and provide

appropriate pulses to the motor driver module (Figure 4).

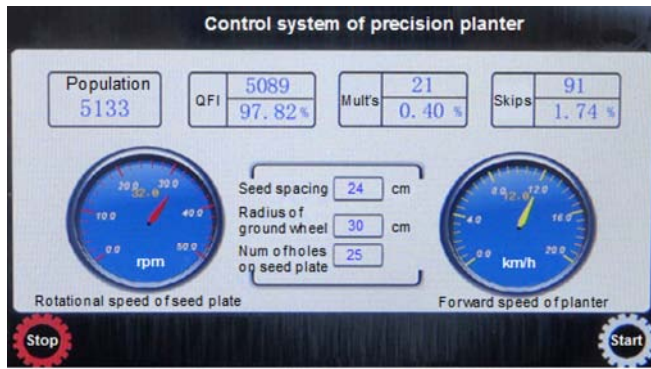


Figure 3 Touchscreen display of the control system

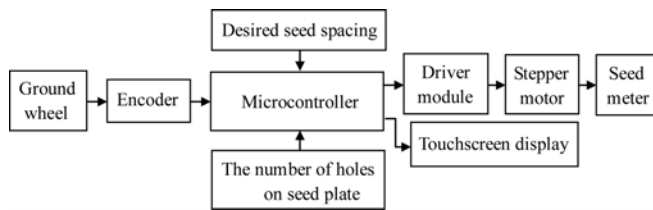


Figure 4 The schematic diagram of the control system

As mentioned above, the inputs of the microcontroller were pulses of encoder, the number of holes on seed plate and desired seed spacing. The output of the microcontroller was the pulses corresponding to these inputs.

The frequency of the pulses which would be sent to the motor driver module could be calculated from Equation (2).

$$n_s = N_e \cdot \frac{360 / \theta}{c_e} \cdot \frac{2\pi R}{mS} \quad (2)$$

where, n_s is the frequency of pulses which would be sent to motor driver module, pulse/s; N_e is the number of pulses given by encoder per second, pulse/s; θ is the step angle of stepper motor; c_e is the precision of the encoder, pulse/rev; m is the number of holes on seed plate; R is the radius of ground wheel, m; S is desired seed spacing, m.

2.2 Test methods

A two-row pneumatic precision planter was modified to allow simultaneous using two different driving systems to drive seed meters, with one row unit equipped with the new designed mechatronic driving system and the other row unit with conventional driving system (Figure 5). Each row unit was independently mounted on a four-bar parallel linkage system. The same types of seed meters are used on the two row units except the different driving system. The planter was calibrated in laboratory before

field operation.



1. Mechatronic driving system 2. Ground wheel and chain-sprockets driving system

Figure 5 The modified precision corn planter with different power transmission systems to drive seed meters

Field experiment was conducted in October 2014 on a research field at Gu'an County (39°19'N, 116°18'E), Hebei Province, North China Plain. Gu'an is located in a typically semi-arid region and has a continental climate. Average annual temperature for this area is 11.5°C with 188 frost-free days. Annual total rainfall is 548 mm with 80% falling in corn growing season, from June to mid-September. The soil composed of 18.7% clay, 44.9% silt, and 36.4% sand, was classified as light loam.

The study was arranged in a randomized complete block design as a 2 by 3 by 2 factorials with 12 treatments and three replications. The variables were two types of driving system, three planting speeds (9, 11 and 12 km/h, respectively) and two types of land condition (no-tillage land and rotary-tillage land). Size of each experimental plot was 100 m in length and 1.5 m in width. Corn seed (Zhengdan 958) with 1000-kernel weight of 330 g was planted at 69 444 seeds per hectare in 600 mm row space with a theoretical seed spacing of 240 mm and a nominal depth of 50 mm.

After sowing, 250 seeds in each row of each plot were dug out and the distances between adjacent seeds were measured in the field (Figure 6). The sowing uniformity of seed distribution along the length of the row was analyzed using the methods described by Kachman and Smith^[31]. Missing-seeding index (MI) is the percentage of seed spacings that are greater than 1.5 times the nominal seed spacing and indicates the percentage of missed seed locations or skips. Quality of feeding index

(QFI) is the percentage of seed spacings that are more than half but no more than 1.5 times the nominal spacing and indicates the percentages of single seed drops. Precision (PREC) is the coefficient of variation of the spacings (length) between the nearest seeds in a row that are classified as singles after omitting the outliers consisting of missing-seedings and multiples. The calculation formulas for MI, QFI and PREC are as follows:

$$1) \text{ Missing-seeding index: } M = \frac{n_0}{N} \times 100\%$$

$$2) \text{ Quality of feeding index: } A = \frac{n_1}{N} \times 100\%$$

$$3) \text{ Precision index: } C = \frac{S}{\bar{x}} \times 100\%$$

where, N is the total number of seed spacing and x_i is the n^{th} seed spacing;

$$\bar{x} \text{ is the average seeds spacing: } \bar{x} = \frac{1}{N} \sum_{i=1}^N x_i ;$$

$$n_0 \text{ is the number of missing seeding: } n_0 = \sum n_i \{x_i \in (1.5\bar{x}, +\infty)\} ;$$

$$n_1 \text{ is the number of qualified spacing: } n_1 = \sum n_i \{x_i \in (0.5\bar{x}, 1.5\bar{x})\} ;$$

S is the standard deviation of seed spacing:

$$S = \sqrt{\frac{1}{N} \sum_{i=1}^N (x_i - \bar{x})^2}$$



Figure 6 Measuring the distances between seeds in field

Data were analyzed statistically using the SPSS analytical software package (2003) to test differences among treatments. ANOVA was used for assessing treatment effects on the measured variables. Means were declared significantly different using a protected *LSD* (0.05) value.

3 Results and discussion

The quality of feeding index, missing-seeding index and Precision index of each planting unit with different driving system working at three forward speeds in the rotary-tillage and no -tillage plots were shown in Table 1.

Table 1 Uniformity of seed spacing as affected by driving systems, forward speeds and land conditions

Land condition	Forward speed /km·h ⁻¹	Mechanical driving system			Mechatronic driving system		
		QFI /%	Missing-seeding index/%	Precision index/%	QFI /%	Missing-seeding index/%	Precision index/%
Rotary-tillage	9	90.05	3.95	17.94	94.21	2.66	17.86
	11	89.20	6.90	18.77	94.18	3.19	17.90
	12	82.43	12.32	20.27	89.93	5.08	18.80
No-tillage	9	91.33	3.41	17.83	94.23	2.43	17.85
	11	90.86	5.42	18.14	93.80	2.94	17.83
	12	84.81	10.15	19.52	90.50	4.59	18.92

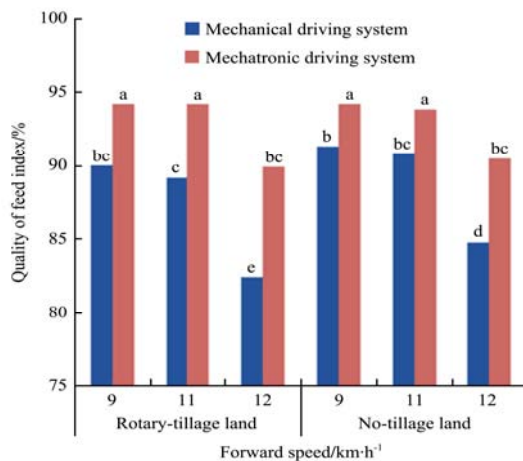
3.1 Evaluation of quality of feeding index

The QFI indicates how often the spacings are close to the nominal spacing. Larger values of QFI indicate better performance than smaller ones.

Comparison of means of QFI showed that the mechatronic driving system resulted in significant increasing of QFI as compared to the mechanical driving system at each forward speed (Figure 7). Further comparison revealed that the QFI value on rotary-tillage land is comparable to that on no-tillage land at each forward speed when using the mechatronic driving system. By contrast, for the mechanical driving system, the QFI value on rotary-tillage land is significantly lower than that on no-tillage land at each forward speed, which is because the ground wheel slippage on rotary-tillage land is bigger than that on no-tillage land. The result indicates that the mechatronic driving system can eliminate the effect of ground wheel slippage on planting quality and increase the uniformity of seed distribution.

Comparison of the QFI values, as affected by forward speed, showed that the QFI values decrease with the increase of forward speed for both driving systems. With the forward speed increasing from 9 km/h to 12 km/h, the QFI values of the mechatronic driving system decreased from 94.23% to 90.50% on no-tillage land and from 94.21% to 89.93% on rotary-tillage land, meanwhile the QFI values of the mechanical driving system

decreased from 91.33% to 84.81% on no-tillage land and from 90.05% to 82.43% on rotary-tillage land. The difference between the QFI values of mechatronic and mechanical driving systems changed from 2.90% to 5.69% on no-tillage land and from 4.16% to 7.50% on rotary-tillage land, which means that QFI values of the mechatronic system decreased less rapidly than those of the mechanical driving system with the increase of forward speed on both lands. The result indicates that the mechatronic driving system is effective for reducing the effect of forward speed on QFI, which means planters equipped with the mechatronic driving system are more suitable for high speed planting.



Note: Columns with the same letters are not significantly different ($p < 0.05$).

Figure 7 Comparison of means of QFI for various driving systems, land conditions and forward speeds

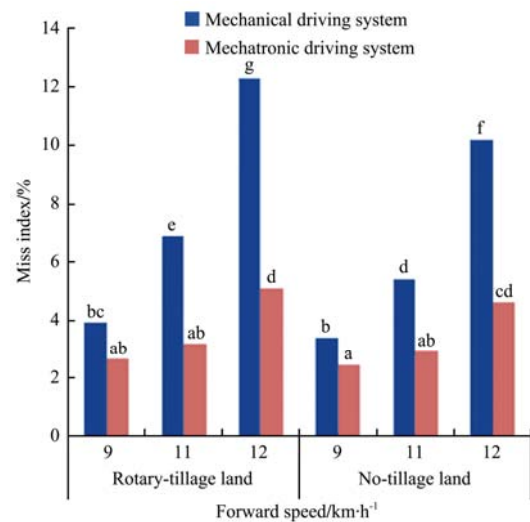
The range of QFI values for the planting unit with the mechatronic driving system working at forward speeds of 9, 11 and 12 km/m and on both no-tillage and rotary-tillage lands was 89.93%-94.23%, which is much better than the China National Standard of Test Method of Single Seed (Precision) Planter ($\geq 85\%$) and therefore is desirable.

3.2 Evaluation of missing-seeding index

With the theoretical spacing of 240 mm in this study, the missing-seeding index is the percent of seed spacings bigger than 360 mm. Smaller values of this index indicate better performance than larger ones.

Comparison of means of missing-seeding index showed that the data for the mechatronic driving system was significantly smaller than that for the mechanical driving system at each forward speed on both rotary-tillage and no-tillage lands (Figure 8). For the

mechatronic driving system, there is no significant difference between the missing-seeding index values on rotary-tillage land and no-tillage land. But for the mechanical driving system, the missing-seeding index on rotary-tillage land is significantly higher than that on no-tillage land at each forward speed. The result indicates that the mechatronic driving system is effective for improving the missing-seeding index of planters.



Note: Columns with the same letters are not significantly different ($p < 0.05$).

Figure 8 Comparison of means of missing-seeding index for various driving systems, land conditions and forward speeds

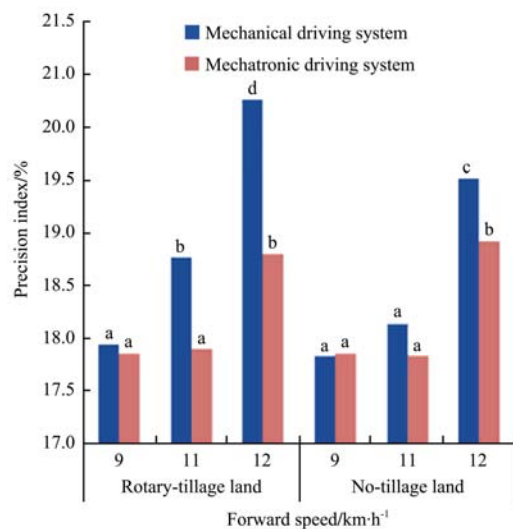
Figure 8 revealed that the missing-seeding index values increase with the increase of forward speed for both mechatronic and mechanical driving systems. With the forward speed increasing from 9 km/h to 12 km/h, the missing-seeding index values of the mechatronic driving system increased from 2.49% to 4.59% on no-tillage land and from 2.66% to 5.08% on rotary-tillage land, meanwhile the missing-seeding index values of the mechanical driving system increased from 3.41% to 10.15% on no-tillage land and from 3.95% to 12.32% on rotary-tillage land. The data indicated that the missing-seeding index values of the mechatronic driving system increased less rapidly than those of the mechanical driving system with the increase of forward speed on both land conditions. Moreover, missing-seeding index values of the mechanical driving system were higher than China national standard of precision planter (missing-seeding index should be lower than 5%) when forward speed was over 11 km/h, however the missing-seeding index values of the mechatronic

driving system were lower than 5%. The result indicated that the mechatronic driving system is effective for reducing the effect of forward speed on missing-seeding index.

3.2.3 Evaluation of precision index

Precision index is a measure of the variability in spacings between seeds after accounting for variability due to both multiples and skips. A practical upper limit for precision index is 29%. Smaller values of precision index indicate better performance than larger values.

Comparison of data on average precision index showed that the mechatronic driving system resulted in lower values of the precision index than the conventional mechanical driving system (Figure 9). Further comparison revealed that there is no significant difference between the precision indices on rotary-tillage land and no-tillage land at each forward speed for the mechatronic driving system. By contrast, for the mechanical driving system, the precision index on rotary-tillage land is significantly higher than that on no-tillage land when forward speed is faster than 9 km/h. The result indicates that the mechatronic driving system is helpful to reduce precision index and ensure planting accuracy.



Note: Columns with the same letters are not significantly different ($p < 0.05$).

Figure 9 Comparison of means of precision index for various driving systems, land conditions and forward speeds

Comparison of the precision values, as affected by forward speed, revealed that the precision values increase with the increase of forward speed for both driving systems. With the forward speed increasing from 9 km/h to 12 km/h, the precision values of the

mechatronic driving system increased from 17.85% to 18.92% on no-tillage land and from 17.86% to 18.80% on rotary-tillage land, meanwhile the precision values of the mechanical driving system increased from 17.83% to 19.52% on no-tillage land and from 17.94% to 20.27% on rotary-tillage land. The difference between the precision values of mechatronic and mechanical driving systems changed from 0.02% to 0.60% on no-tillage land and from 0.08% to 1.47% on rotary-tillage land, which means that precision values of the mechatronic driving system increased less quickly than those of the mechanical driving system with the increase of forward speed on both lands. The result indicates that the mechatronic driving system is also effective for reducing the effect of forward speed on precision.

The range of precision index for the planting unit with the mechatronic driving system working at forward speeds of 9, 11 and 12 km/m and on both no-tillage and rotary-tillage lands was 17.85%-18.92% which is far below 29% and therefore is acceptable^[31].

4 Conclusions

A practical solution to improve the performance of precision corn planter by using mechatronic driving system for seed meter instead of using ground wheel and chain sprocket driving system was outlined. On the basis of this research the specific conclusions can be drawn as follows:

1) Values of QFI, missing-seeding index and precision index of the mechatronic driving system on rotary-tillage land are comparable to those on no-tillage land. By contrast, these indices of the mechanical driving system on rotary-tillage land are significantly worse than those on no-tillage land. The result indicates that the mechatronic driving system can eliminate the effect of ground wheel slippage on planting quality and maintain the uniformity of seed distribution.

2) Although the QFI, missing-seeding index and precision index become worse with the increase of forward speed, the mechatronic driving system, with the worst values of QFI of 89.93%, missing-seeding index of 5.08% and precision index of 18.92% even at the highest forward speed of 12 km/h, can reduce the effect of

forward speed on planting accuracy effectively. The result indicates that planters equipped with the mechatronic driving system are more suitable for high speed planting.

3) With the average 4.70% increase of QFI and 3.54% decrease of missing-seeding index, the mechatronic driving system performed better than the ground wheel and chain sprocket driving system on both no-tillage and rotary-tillage lands at each forward speed. The advantage of the mechatronic driving system is more obvious especially when the forward speed is more than 11 km/h.

4) The new developed mechatronic driving system can reduce the effect of forward speed on planting accuracy effectively. Precision planters equipped with this system are more suitable for high speed planting (≥ 11 km/h) as compared to conventional mechanical driving system.

Acknowledgements

This study was supported by the 948 Program (2014-S8), the National Science and Technology Research Program (2013BAD08B01-3) and the Soil-Machine-Plant Key Laboratory of Ministry of Agriculture of PR China. The financial supports from above funds and organizations are gratefully acknowledged. Also thanks to all the postgraduate students working in the Soil-Machine-Plant Key Laboratory of MOA, who provided their input to this study.

References

- [1] Li F H, Diao P S, Du R C, Cui Q, Zhang Y P, Li T. Development and test of no-tillage fertilization planter with embedded spoon disc helm wheel. *Transactions of the CSAE*, 2013; 29(19): 16–23. (in Chinese with English abstract)
- [2] Zhang J C, Yan X L, Xue S P, Zhu R X, Su G Y. Design of no-tillage maize planter with straw smashing and fertilizing. *Transactions of the CSAM*, 2012; 43(12): 51–55. (in Chinese with English abstract)
- [3] Liu L J, Li C R, Zhou J P. Design and experiment on 2BQX-6 no-till corn precision seeder. *Chinese Agricultural Mechanization*, 2011; 5: 76–79. (in Chinese with English abstract)
- [4] Zhang X R, He J, Li H W, Wang Q J, Wu S S. Design and experiment on no-till planter in horizontal residue-throwing finger-wheel type for maize. *Transactions of the CSAM*, 2010; 41(12): 39–43. (in Chinese with English abstract)
- [5] Miller E A, Rascon J, Koller A, Porter W M, Taylor R, Raun W R. Evaluation of corn seed vacuum metering systems. *American Society of Agricultural and Biological Engineers Annual International Meeting*, 2012; 1: 815–825.
- [6] Searle C L, Kocher M F, Smith J A, Blankenship E E. Field slope effects on uniformity of corn seed spacing for three precision planter metering systems. *Applied Engineering in Agriculture*, 2008; 24(5): 581–586.
- [7] Yazgi A, Degirmencioglu A. Measurement of seed spacing uniformity performance of a precision metering unit as function of the number of holes on vacuum plante. *Journal of the International Measurement Confederation*, 2014; 56: 128–135.
- [8] Shearer S A, Holmes R G. Precision seed metering with a submerged turbulent air-jet. *Transaction of the ASAE*, 1991; 34(3): 781–786.
- [9] Yang L, Shi S, Cui T, Zhang D X, Gao N N. Air-suction corn precision metering device with mechanical supporting plate to assist carrying seed. *Transactions of the CSAM*, 2012; 43(s1): 48–53. (in Chinese with English abstract)
- [10] Moyer J R, Roman E S, Lindwall C W, Blackshaw R E. Weed management in conservation tillage systems for wheat production in North and South America. *Crop Protection*, 1994; 13(4): 243–259.
- [11] Kaspar T, Crosbie T M, Cruse R, Erbach D C, Timmons D R, Potter K N. Growth and productivity of four corn hybrids as affected by tillage. *Agronomy Journal*, 1987; 79: 477–481.
- [12] Kaspar T C, Erbach D C, Cruse R M. Corn response to seed-row residue removal. *Soil Science Society of America Journal*, 1990; 54: 1112–1117.
- [13] Kaspar T C, Erbach D C. Improvement stand establishment in no-till with residue-clearing planter attachments. *Transactions of ASAE*, 1998; 71: 301–306.
- [14] Griffith D R, Kladvko E J, Mannerling J V, West T D, Parsons S D. Long-term tillage and rotation effects on corn growth and yield on high and low organic matter, poorly drained soils. *Agronomy Journal*, 1988; 80: 599–605.
- [15] Raoufat M H, Mahmoodieh R A. Stand establishment response of maize to seedbed residue, seed drill coulters and primary tillage systems. *Biosystems Engineering*, 2005; 90: 261–269.
- [16] Case planter brochure. http://www.caseih.com/en_us/Products/PlantingSeeding-/Documents/Brochures/PL309014_Planter_ProdGd_Jumpstart2014_Final. Accessed on [2014-05-08]

- [17] John Deere planter brochure. http://www.deere.com/en_US/products/equipment-/planting_and_seeding_equipment/planters/row_units/row_units.page?int_cmp=BAC_Ag_enUS_emerge_rowunit_plantseedhero1. Accessed on [2014-06-12]
- [18] Horsch planter brochure. Maestro 12/24 SW. <http://www.horsch2.com/de>. Accessed on [2014-02-19]
- [19] Precision planting control system. <http://www.precisionplanting.com/products/vset>. Accessed on [2013-11-23]
- [20] Ag Leader seed command. <http://www.agleader.com/solutions/planting/>. Accessed on [2013-11-21]
- [21] Singh T P, Mane D M. Development and laboratory performance of an electronically controlled metering mechanism for okra seed. *Agricultural Mechanization in Asia, Africa and Latin America*, 2011; 42(2): 63–69.
- [22] Chaney P P, Parish R L, Sistler F E. Automatic control system for a sugarcane planter. *Applied Engineering in Agriculture*, 1986; 2(2): 51–54.
- [23] He P X, Yang M J, Chen Z H. Study on photoelectric controlled precision seeder. *Transactions of the CSAM*, 2003; 34(1): 47–49. (in Chinese with English abstract)
- [24] Yang M J, Yang L, He P X. Development of a precision seeder control system. *Journal of Southwest Agricultural University*, 2002; 24(3): 286–288. (in Chinese with English abstract)
- [25] Li J F, Gao X Y. Systematic design of the drill's speed automatic monitor. *Journal of Gansu Agricultural University*, 2007; 2: 92–95. (in Chinese with English abstract)
- [26] Tang Y H, Zhang J G. Research on the planting drive system based on a tractor front-wheel speed. *Journal of Agricultural Mechanization Research*, 2009; 3: 21–23. (in Chinese with English abstract)
- [27] Zhai J B, Gao H Z, Zheng X L. Research on automatic seed metering drive system based on sensor technology. *Hubei Agricultural Sciences*, 2011; 50(17): 3619–3621, 3646. (in Chinese with English abstract)
- [28] Yang S, Zhang S M. Design and parameter optimization of flexible comb-type grass seed metering device. *Int J Agric & Biol Eng*, 2015; 8(1): 9–16. 10.3965/j.ijabe.20150801.002
- [29] Yi S J, Liu Y F, Wang C, Tao G X, Liu H Y, Wang R H. Experimental study on the performance of bowl-tray rice precision seeder. *Int J Agric & Biol Eng*, 2014; 7(1): 17–25. 10.3965/j.ijabe.20140701.002
- [30] Shi S, Zhang D X, Yang L, Cui T, Zhang R, Yin X W. Design and experiment of pneumatic maize precision seed-metering device with combined holes. *Transactions of the CSAE*, 2014; 30(5): 10–18. (in Chinese with English abstract)
- [31] Katchman S D, Smith J A. Alternative measures of accuracy in plant spacing for planter using single seed metering. *Transactions of the ASAE*, 1995: 38, 379–387.