# Experimental study on performance of pneumatic seeding system

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**Abstract:** The purpose of this study was to promote the development of large-scale agricultural machines in China and meet the demand of air seeder localization.    This study investigated the relationship between the working parameters and the performance of pneumatic seeding system, Cangmai 6004 wheat seed was used.    A test platform for pneumatic seeding systems was developed, and then a series of experiments were performed based on the quadratic general rotary unitized design and response surface methodology (RSM).    The seeding rate and the air flow rate were selected as affecting factors, coefficient of variation (CV) of evenness of feeding rate between rows and CV of seeding stability of total rows were assigned as the test indexes.    Regression models between factors and indexes were established, and finally, an optimal equation based on this pneumatic seeding system were established as well, which can determine the proper air flow rate once the seeding rate was set based on the practical agronomic requirements.    For example, when the seeding rate is set as 250 kg/hm$^2$, the proper air flow rate of 7.53 m$^3$/min can be obtained.    The verification experiment results showed that the predicted working parameters obtained by RSM were feasible, which might provide a theoretical basis for further research of pneumatic seed metering systems.

**Keywords:** pneumatic seeding system, seeding rate, air flow rate, quadratic general rotary unitized design, regression model

## 1    Introduction

With the rapid advance of land concentration and large-scale field operation in China, the new requirement of the large-scale field agricultural machinery development was put forward.    Seeding is one of the key operations of crop production.    Air seeders were designed to meet the demands of large-scale field operation, whose feature is "using one metering device, to drill several rows"[1].    Centralized metering device drops the seeds uniformly, the high pressure airflow produced by an air pump transports the air-seed two-phase flows, which was divided by the distributer and was moved in flexible tubes, to openers finally.    Air seeder can drill several rows with only once metering, it improves the work efficiency, and expand the number of rows to meet the requirements of large-scale field operation.    The air seeder can seed many kinds of seeds, such as soybean, corn, wheat and forage, because it conveys the seeds via air.

It has been over 60 years since the first air seeder was invented.    The air seeder has been a commercial production in foreign markets now.    Air seeder manufacturers include John Deere, Bourgault, New Holland, KUHN, Kverneland, MASCHIO GASPARDO and so on.    Almost all aspects of the machine were patented at abroad[2-21].    The air seeder research in China started from the early 21$^{st}$ century.    Researchers of

Shandong Agricultural University (Tai'an, China)[22-26] studied the working principle of pneumatic seeding system, made the theoretical analysis and optimization design, and designed 2BQ-10 one-step centralized type pneumatic seeding system[25,26]. In China Agricultural University (Beijing, China), Li et al.[27] used computational fluid dynamics (CFD) method to simulate the distribution of airflow field and path curve of the particle phase, and the simulation results were in good agreement with experimental data. Chinese Academy of Agricultural Mechanization (Beijing, China) imported foreign pneumatic seeding systems, and developed 2BMG-24Q[28] and 2BMG-48Q pneumatic no-till planters.

Because the study of air seeder in China was in the initial stage, the above mentioned studies just studied the working principle, components design and simulation, they did not provide available methods for the research of performance of pneumatic seeding system. As a result, in order to improve the performance of air seeder to meet the demands of large-scale field operation in China, this study built a test platform and introduced a method for the study of pneumatic seeding system based on quadratic general rotary unitized design and response surface methodology (RSM), which can provide a basis for further research and performance test of the pneumatic seeding system, and promote the air seeder localization.

## 2    Materials and methods

### 2.1    Experiments devices

The structure schematic of the test platform is shown in Figure 1. It was mainly composed of a console, a metering system, an oil scraping system, a drive system and an oil injection system. All the experimental parameters were set on the console, driving system drives belt conveyor moving, seed metering system seeding, and oil injection system injecting oil, the injected oil will be scrapped evenly by oil scraping system to accept seeds, which will avoid seeds bouncing and rolling, the test platform can test three rows simultaneously, and in this study the seed was collect by using nylon mesh (see details in section 2.3).

The main driving device included a RB75 three-phase vortex pump (ComSat Electric Co., Ltd., FuAn) (max airflow rate: 9 m³/min, power: 5.5 kW/7.5 hp), and a SN 031752002237 alternating current servomotor (Beijing Hollysys Electric Tech Co. Ltd., Beijing) (max speed: 3000 r/min, max torque: 1.27 N·m). The main instrument included a scale, a stopwatch and a graduate.
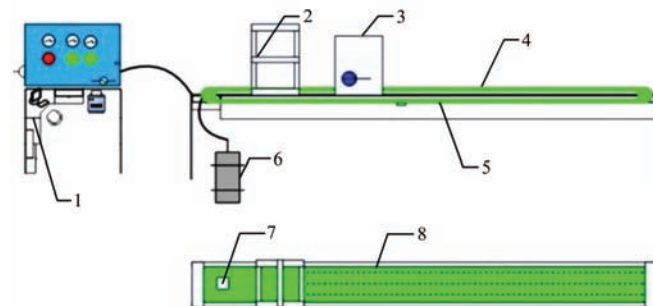


1. Console   2. Seed metering system   3. Oil scraping system   4. Belt conveyor   5. Test platform bracket   6. Driving system   7. Oil injection system   8. Seeds

Figure 1    Structure schematic of pneumatic seeding system test platform

### 2.2    Experiment materials

The pneumatic seeding system in this study is shown in Figure 2. It was mainly composed of an air pump, a seed box, a centralized metering device, an air-seed mixing chamber, a conveying tube, a guide tube, a distributor and final tubes. Seeds were metered from the seeding wheel of the centralized metering device. The high-pressure air from the pump and the seeds met in the mixing chamber, and then mixed into air-seed two-phase flow. They flowed through the conveying tube and the guide tube, and then were distributed into eight pieces by the distributor. The uniform air-seed two-phase flow finally arrived at the opener, and the seeds were planted into the soil. The metering wheel (Figure 3a) was of out-slotted type, within the working length its metering capacity could meet the seeding requirement in terms of seeding quantity per unit area. The tip diameter (Ds) was 100 mm, the root diameter (Dr) was 50 mm, the sheave length was 110 mm, the groove number was 10, the groove arc radius (r) was 6.5 mm, and the tooth groove depth was 25 mm. As shown in Figure 3b, the guide tube had a dimpled structure, the inner diameter was 60 mm, all dimples were distributed uniformly in radial direction, and adjacent two rows were stagger distributed. The total length of the dimpled tube was

379 mm, the bending radius was 160 mm, and the bending angle was 75°. In addition, the distributor had a total of eight outlets, and was equipped with a seed guide cone inside to increase uniformity.
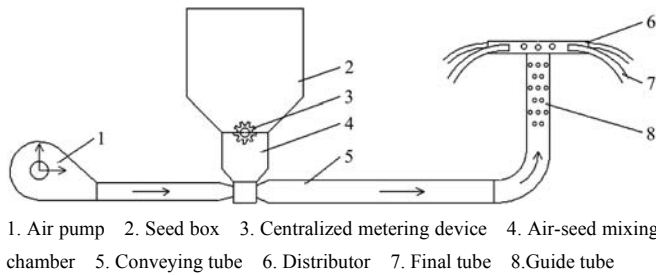


1. Air pump   2. Seed box   3. Centralized metering device   4. Air-seed mixing chamber   5. Conveying tube   6. Distributor   7. Final tube   8. Guide tube

Figure 2    Pneumatic seeding system schematic diagram
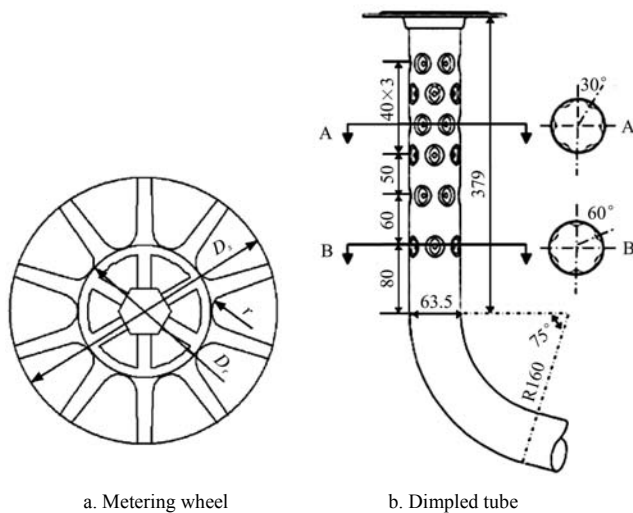


a. Metering wheel                    b. Dimpled tube

Figure 3    Structural diagram of metering wheel and dimpled tube

The wheat variety was Cangmai 6004, according to GB/T 5262-2008 Measuring Methods for Agricultural Machinery Testing Conditions—General Rules[29]. Physical parameters of wheat seeds were measured before experiment and is shown in Table 1.

Table 1    Physical parameters of wheat seeds

| Description | Dimension |
| --- | --- |
| Thousand kernel weight/g | 40.00 |
| Moisture content/% | 8.46 |
| Breakage rate before experiment/% | 1.15 |
| Seed purity/% | 99.94 |
| Angle of repose/° | 24.05 |
| Bulk density/g·L$^{-1}$ | 702.92 |
| Shape size (length×width×height)/(mm×mm×mm) | 6.18×3.26×3.26 |

## 2.3  Experiment methods

Tractor running speed ($v_t$), seeding rate ($q$) and air flow rate ($Q$) are the import factors that influence seeding performance. In actual production, the seed metering system is driven by ground wheels whose speed is determined by tractor running speed, in other words, the metering wheel speed is determined by the tractor running speed, and according to the experience, when the metering wheel speed is over 60 r/min, seed filling rate will significantly decrease, and seed broken rate obviously increase as well. So in this study, the metering wheel speed was set as 40 r/min to make the measurements more convenient and achieve high seed filling rate, and then tractor running speed can get a constant. Finally in this study, the seeding rate ($q$) and the air flow rate ($Q$) were selected as affecting factors. The seeding rate was 90-337.5 kg/hm$^2$ according to the actual agronomic requirements in China. The air flow rate was set as 5.4-9 m$^3$/min by trial experiment. Since the metering wheel speed was constant (40 r/min), the seeding rate seeding rate ($q$) was changed by adjusting the effective length ($z_1$) of the metering wheel and the air flow rate ($Q$) was controlled by adjusting air pump frequency ($z_2$).

According to the requirement of GB/T 9478-2005 Testing Methods of Sowing in Lines[30], coefficient of variation (CV) of evenness of feeding rate between rows ($y_1$), CV of seeding stability of total rows ($y_2$)[29] and seed broken rate should be assigned as the test indexes. Under the condition of 337.5 kg/hm$^2$ seeding rate and 9 m$^3$/min air flow rate which is the maximum level of the study, seed broken rate trial experiments were conducted, the results showed that seed broken rate was 0.23%, less than 0.5% that JB/T 6274.1-2013 Grain drill Part 1: technical conditions[31] required. Because the experiment was conducted under maximum level and the result was very low (0.23%), much less than the standard required, so this study ignore this index, and as a result, CV of evenness of feeding rate between rows ($y_1$) and CV of seeding stability of total rows ($y_2$) were assigned as the test indexes.

Two factorial experiments were adopted in this study, it was designed based on the quadratic general rotary unitized design[32], it is a common design method, which can reduce the testing time and can obtain more consistent multivariate quadratic regression equation with the actual, and get a higher forecasting precision. The factors code was calculated based on the quadratic general rotary unitized design method[32], and coding table is shown in Table 2.

**Table 2　Factors coding table**

| Factors | $q$/kg·hm$^{-2}$ | $Q$/m$^3$·min$^{-1}$ |
|---|---|---|
| Zero level, $z_0$ | 213.8 | 7.2 |
| Variation radius, $\Delta$ | 87.5 | 1.3 |
| −1.414 | 90 | 5.4 |
| −1 | 126.3 | 5.9 |
| 0 | 213.8 | 7.2 |
| 1 | 301.3 | 8.5 |
| 1.414 | 337.5 | 9 |

The experiment was conducted according to GB/T 9478-2005 Testing Methods of Sowing in Lines[30]. Each processing was performed five replicates and lasted 30 s each time. The end of all the eight transporting tubes was sealed with a nylon mesh to hold the wheat seed, 2 min after a processing began (the flow became smooth), the seed of eight transporting tubes was collected by using the nylon mesh for 30 s and then weighted, respectively, and the data was recorded. The experiment device is shown in Figure 4.



Figure 4　Experiment device

# 3　Results and discussion

Experimental plan was developed based on the quadratic general rotary unitized design method and indoor bench experiments were completed, the experimental scheme and results are shown in Table 3.

Where, code is a professional term of "numerical analysis and mathematical statistics", $x_1$ and $x_2$ are the codes, $x_1 = \dfrac{q-213.8}{87.5}$, $x_2 = \dfrac{Q-7.2}{1.3}$. The specific value of $x_1$ and $x_2$ are −1.414, −1, 0 1 and 1.414; $y_1$ is CV of evenness of feeding rate between rows and $y_2$ is CV of seeding stability of total rows.

**Table 3　Experimental results expressed by codes**

| No. | Factors | | Indexes | |
|---|---|---|---|---|
| | $x_1$ | $x_2$ | $y_1$/% | $y_2$/% |
| 1 | 1 | 1 | 0.805 | 0.797 |
| 2 | 1 | −1 | 1.898 | 0.358 |
| 3 | −1 | 1 | 1.310 | 1.038 |
| 4 | −1 | −1 | 0.759 | 1.126 |
| 5 | 1.414 | 0 | 0.937 | 0.227 |
| 6 | −1.414 | 0 | 1.509 | 2.116 |
| 7 | 0 | 1.414 | 1.183 | 0.589 |
| 8 | 0 | −1.414 | 0.697 | 0.808 |
| 9 | 0 | 0 | 1.250 | 0.411 |
| 10 | 0 | 0 | 0.796 | 0.518 |
| 11 | 0 | 0 | 0.755 | 0.417 |
| 12 | 0 | 0 | 1.224 | 0.473 |
| 13 | 0 | 0 | 0.848 | 0.754 |

## 3.1　Mathematical model

Based on the experiment data, the regression equations about CV of evenness of feeding rate between rows and CV of variation of seeding stability of total rows were established. The $F$-test results are shown in Table 4.

**Table 4　$F$-test of CV of evenness of feeding rate between rows $y_1$ and CV of seeding stability of total rows $y_2$**

| Indexes | Source of variation | Variance value | Degree of freedom | $F_{Lf}$ | $F$ | Significance level |
|---|---|---|---|---|---|---|
| $y_1$/% | $S_R$ | 1.0268 | 5 | 2.1777 | 4.9449 | $\alpha=0.05$ |
| | $S_E$ | 0.2907 | 7 | | | |
| | $S_T$ | 1.3175 | 12 | | | |
| | $S_e$ | 0.1104 | 4 | | | |
| | $S_{Lf}$ | 0.1803 | 3 | | | |
| $y_2$/% | $S_R$ | 1.1783 | 5 | 3.0432 | 7.1333 | $\alpha=0.05$ |
| | $S_E$ | 0.2313 | 7 | | | |
| | $S_T$ | 1.4096 | 12 | | | |
| | $S_e$ | 0.0705 | 4 | | | |
| | $S_{Lf}$ | 0.1608 | 3 | | | |

Check relative tables: $F_{0.95}(3,4) = 6.590$, $F_{0.95}(5,7) = 3.970$. For Equation (1), $F_{Lf} = 2.1773 < F_{0.95}(3,4)$ and $F = 4.9449 > F_{0.95}(5,7)$. For Equation (2), $F = 7.1333 > F_{0.95}(5,7)$. Therefore, the regression model can reflect the real situationat a significant level of $\alpha=0.05$.

The regression Equation (1) about CV of evenness of feeding rate between rows $y_1$ is as follows:

$$\hat{y}_1 = 0.7979 + 0.016q - 0.4494Q - 0.0036qQ + 0.00002q^2 + 0.0843Q^2 \tag{1}$$

The regression Equation (2) about CV of seeding stability of total rows $y_2$ is as follows:

$$\hat{y}_2 = 5.8608 - 0.0112q - 1.0327Q - 0.0005qQ + 0.00003q^2 + 0.0779Q^2 \tag{2}$$

## 3.2    Interaction analysis

To investigate the relationship between the working parameters (the seeding rate and the air flow rate) and the test indexes (CV of evenness of feeding rate between rows and CV of seeding stability of total rows) of pneumatic seeding system, MATLAB software[33] was used to simulate the regression Equations (1) and (2) and an influence surface (Figure 5) was generated to illustrate interaction effect of seeding rate ($q$) and air flow rate ($Q$) on CV of evenness of feeding rate between rows $y_1$ and CV of seeding stability of total rows $y_2$.
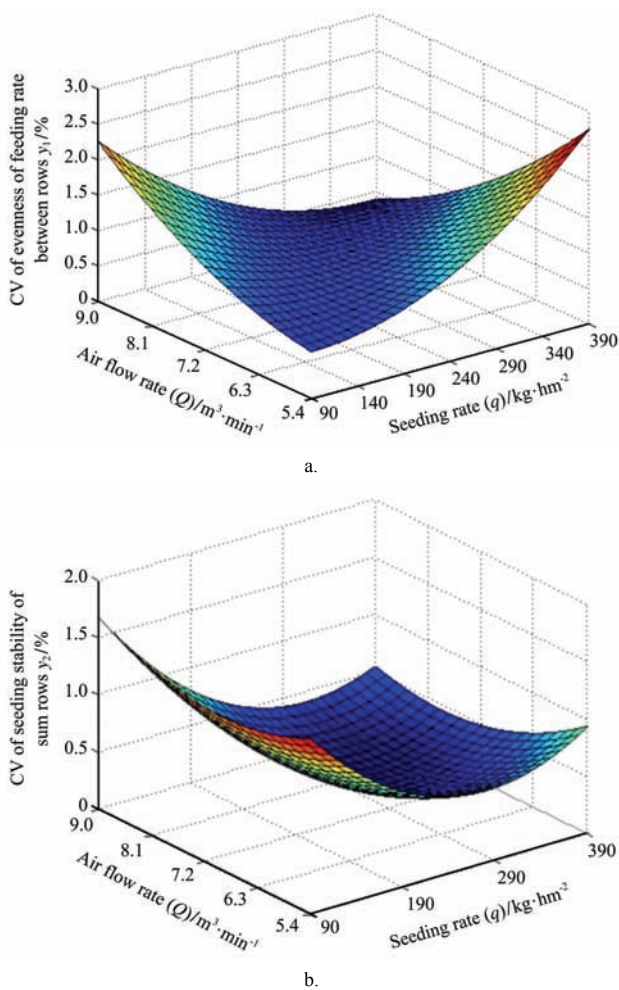


a.



b.

Figure 5    Interaction analysis between factors and test indexes

According to the similar analysis[34-36], it was found from Figure 5a that the surface structure was almost symmetrical, so the seeding rate and the air flow rate played the similar influence on CV of evenness of feeding rate between rows $y_1$.    Under the condition of $q \geq 250$ kg/hm$^2$, $Q \leq 7.2$ m$^3$/min or $q \leq 250$ kg/hm$^2$, $Q \geq 7.2$ m$^3$/min, CV of evenness of feeding rate between rows increased rapidly, so if one of the factors was too small and the other was too big, it would lead to relatively

worse evenness of feeding rate between rows.    It was found from Figure 5b that: the part of $q<190$ kg/hm$^2$ changed greater than the part of $q>190$ kg/hm$^2$, so the seeding rate had more important influence on CV of seeding stability of total rows, the surface changed greatly when the seeding rate was small, so the small seeding rate would lead to relatively worse seeding stability of total rows.

## 3.3    Optimized analysis

To improve the comprehensive performance of the pneumatic metering system, and to reduce CV of evenness of feeding rate between rows and CV of seeding stability of total rows, the study adopted weighted optimization method to get the optimal combination of parameters.    It can be seen from Figure 5, the curvature of Figure 5b is larger than Figure 5a, and the average CV of evenness of feeding rate between rows $y_1$ was 0.76%, it is much less than 3.9% that national standard required. So the weighting coefficient was set as 0.15 and 0.85 for $y_1$ and $y_2$ respectively.    After weighting, comprehensive assessment index $y=0.15y_1+0.85y_2$, the Equation (3) is as follows.

$$\hat{y} = 5.1014 - 0.0071q - 0.9452Q - 0.00097qQ + 0.000029q^2 + 0.0789Q^2 \tag{3}$$

The influence surface (Figure 6) was got based on mathematical software MATLAB, and according to the practical agronomic requirements, once the seeding rate was set, the optimal air flow rate can be received by Equation (3), for example, A farmer in Hebei province asked for the seeding rate as 250 kg/hm$^2$ based on the agronomic requirements, then the proper air flow rate was 7.53 m$^3$/min.
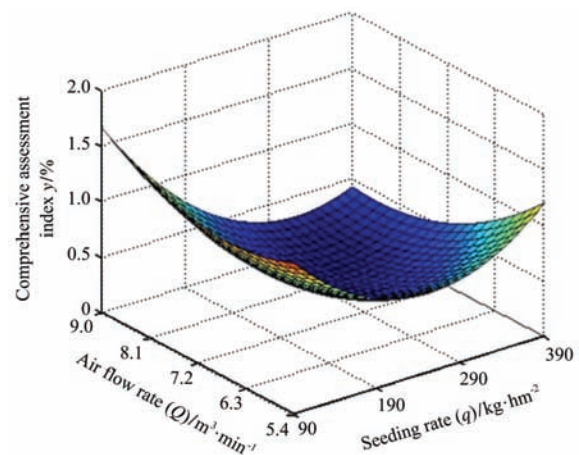


Figure 6    Influence surface between factors and comprehensive assessment index $y$

In order to guarantee the reliability of the optimization results, verification experiment was conducted. Weighted optimization results and experimental results are as shown in Table 5, it can be seen that verification value was close to the predicted, it can offer references for the study and the application of the pneumatic seeding system.

**Table 5　Weighted optimization results and verification experimental results**

| Results | $y_1$/% | $y_2$/% |
|---|---|---|
| Weighted optimization | 0.67 | 0.63 |
| Verification experiment | 0.70 | 0.61 |

## 4　Conclusions

The relationship between the working parameters (the seeding rate and the air flow rate) and the performance (coefficient of variation (CV) of evenness of feeding rate between rows and CV of seeding stability of total rows) of a pneumatic seeding system based on the quadratic general rotary unitized design and response surface methodology (RSM) was investigated. Regression models between factors and indexes were developed, and finally, an optimal equation based on this pneumatic seeding system was established as well. The proper air flow rate can be worked out by the optimal equation once the seeding rate was set based on the practical agronomic requirements. For example, the seeding rate was selected as 250 kg/hm$^2$, and then the proper air flow rate was 7.53 m$^3$/min. The verification experiment showed that the experimental result was close to the predicted results and might provide a basis for the practice and further research of pneumatic seeding systems.

## Acknowledgements

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