# PERFORMANCE TEST OF THE 2BDE-2 TYPE MILLET FINE AND SMALL-AMOUNT ELECTRIC SEEDER
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# 2BDE-2 型谷子精少量电动播种机性能试验

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## ABSTRACT
*This work designed a 2BDE-2 type millet fine and small-amount electric seeder to solve certain problems, such as difficult cultivation and large workload of millet in hilly and mountainous areas. This seeder can finish the sowing operations, such as ditching, fine and small-amount of seed discharging, covering soil and suppressing at one time. The central composite design method was used to test the seeding performance of the seeder along with the factors of the seed metering plate amplitude and operating speed. This task was undertaken to determine the optimal working parameters of the seeder. The mathematical model of the average number of seeds in each 100 mm section and the variation coefficient of seeding uniformity were established. The influence of single factor effects and interaction on the seeding performance was also analysed. The optimum combination after parameter optimisation was determined as follows: seed metering plate amplitude of 109 μm and seeder operating speed of 0.76 m/s. The field sowing experiment was conducted according to the parameter combination. Results showed that the average number of seeds in each 100 mm section was 7.8, and the variation coefficient of seeding uniformity was 19.64%. The relative errors with the predicted values were 1.28% and 4.98%. The research can be used for sowing a small amount of millet in the hilly mountain area.*

## 摘要
*针对丘陵山区谷子播种难、间苗工作量大等问题，本文设计了 2BDE-2 型电磁振动式谷子精少量播种机，该机可一次性完成开沟、精少量排种、覆土和镇压等播种作业。为确定播种机最佳工作参数，采用中心组合试验的方法，以排种盘振幅和作业速度为因素，对播种机进行了播种性能试验，建立了每 100mm 区段内种子的平均粒数、播种均匀性变异系数的数学模型，分析了单因素效应和交互作用对播种性能的影响规律。经参数优化，确定最优组合为排种盘振幅 109μm、播种机作业速度 0.76m/s，根据该参数组合进行田间播种试验验证，得到每 100mm 区段内种子的平均粒数为 7.8 粒，播种均匀性变异系数为 19.64%，与预测值相对误差分别为1.28%、4.98%。该研究可用于丘陵山区谷子精少量播种。*

## INTRODUCTION
Millet is a traditional food crop that originated in China. Such food crop is rich in nutrients and has high edible and medicinal value. Millet is widely planted in the arid and semi-arid hills and mountains of Asia and Africa, with small and scattered planting plots *(Saleh et al., 2013; Li et al., 2018).* Millet seeds are small in size and mostly sown traditionally with large sowing amount, thereby resulting in seed waste. Artificial thinning of seedlings is also required to reduce the competition amongst seedlings and ensure a stable yield; however, this process is time consuming and troublesome *(Zhang et al., 2017; Zhang et al., 2014)*.

Many achievements have been attained in the research and development of millet seeders. Most domestic millet seeders use various mechanical seed metering devices, such as socket type, reciprocating and grooved wheel type seed metering devices. Majority of the foreign millet seeders use pneumatic seed metering devices, such as SN series air suction seeders (MFC Company, United States) and Aeromat II air blowing seeders (Baker Company, Germany). The majority of the above-mentioned seeders are large-scale machines that are unsuitable for operation in hilly and mountainous areas.

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These seeders are also towed by fuel tractors, thereby causing large energy consumption and serious pollution *(Tian et al., 2013; Tao et al., 2011)*. The mechanical seed metering device often experiences seed injury and jamming. Meanwhile, the pneumatic seed metering device has a complex structure and high requirements for air tightness *(Li et al., 2007; Lv et al., 2018; Zheng et al., 2018)*. The electromagnetic vibration seed metering technology is used for seeding because of its low seed injury rate, simple structure and easy operation. A small electromagnetic vibrating wheat seeder was designed to solve the drawbacks of the traditional wheat seeder *(Li et al., 2016)*. The influencing rule of the working performance of the electromagnetic vibration seeder for field seed raising of rice bud-seed was studied to determine the optimal working parameters *(Yang et al., 2012)*. The use of electric agricultural machinery reduces carbon emission and noise pollution, labour intensity and field operation cost *(Tao et al., 2011)*. Numerous scholars worldwide have also attained many achievements in the development of electric croppers for different crops. The Yazaki SYV series electric vegetable planter produced in Japan can realise multi-row sowing of various crops, such as rapeseed and Chinese cabbage. An electric planter for vegetables with small particle size was designed using the hollow-eye wheel seed metering device to reduce the labour intensity of farmers and save the production cost *(Du et al., 2017)*. Moreover, an electric double-row carrot seeder was developed to realise mechanised carrot sowing *(Wang et al., 2016)*. However, the electromagnetic vibration electric seeder used for sowing millet has not been reported.

Considering the difficulty in planting millet in hilly and mountainous areas, a millet fine and small-amount electric seeder was designed according to the agronomic requirements of a small amount of millet seeds, combined with the topographical features of the main production areas. Taking the seeder operating speed and the seed metering plate amplitude as factors and the average number of seeds in each 100 mm section and the variation coefficient of seeding uniformity as evaluation indices, the optimal parameter combination of the seeder is obtained by using the central combination test method. The test verification is also conducted to provide a reference for the design and parameter optimisation of the seeder with a small amount of millet.

## MATERIALS AND METHODS

### Test materials and equipment

The variety of millet used in the experiment is Jingu 21, with 1000 grain weight of 3.3 g and moisture content of 11.5%. Jingu 21 has a high yield and strong drought resistance. The test equipment includes 2BDE-2 type millet fine and small-amount electric seeder, hand-held vibration tester (accuracy of 1 μm), ruler, steel tape and brush.

### Overall structure and working principle

The entire machine mainly comprises various parts, such as electromagnetic vibration millet seed metering device, power transmission system, control system, battery pack (48 V/20 Ah), runner coulter, scraper type soil coverer, rack and ground and pressing wheels. The power transmission system comprises a one-stage reduction chain drive of DC reduction motor (48 V/600 W). The control system comprises two parts: speed and seed metering control systems. The speed control system mainly comprises a DC deceleration motor governor and digital display meter, whilst the seed metering control system is mainly composed of thyristor voltage regulator and inverter. Both systems are powered by a battery pack.

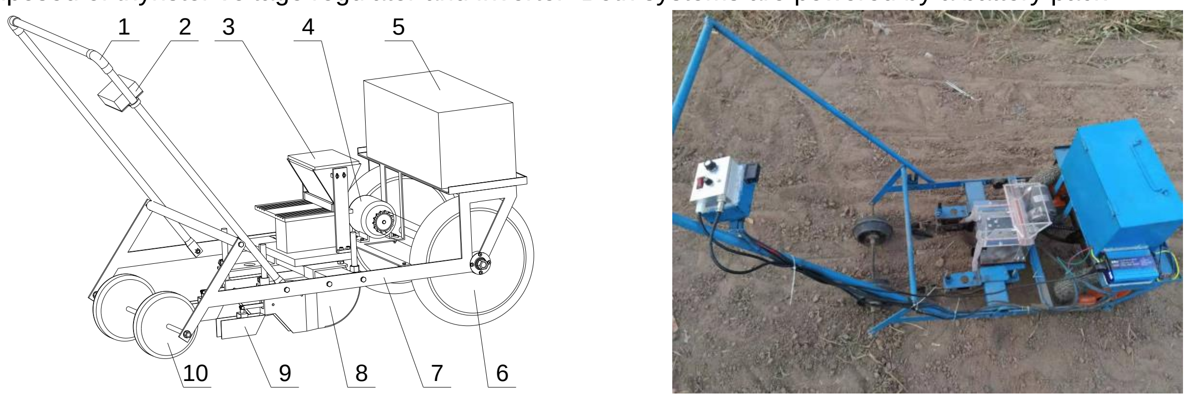



**Fig. 1 - Overall structure of seeder**

*1 – Hand support bracket; 2 – Control system; 3 – Electromagnetic vibration type millet fine seed metering device; 4 – Power transmission system; 5 – Battery pack; 6 – Ground wheel; 7 – Rack; 8 – Runner coulter; 9 – Scraper type soil coverer; 10 – Pressing wheel*

The 2BDE-2 type millet fine and small-amount electric seeder adjusts the motor speed through the speed control system and transmits the power to the ground wheel shaft to drive the planter through the first speed reduction chain drive. The seed metering plate amplitude is adjusted by the seed metering control system, and the metering device is used for metering. The seed falls into the seed ditch already opened by the opener through the seed guide tube. The soil coverer will cover the soil on both sides of the seed ditch evenly back to the original position. The pressing wheel will suppress the covered soil and complete the seeding operation. During operation, the ditch depth can be adjusted by changing the installation height of the opener thread support column in the range of 0 cm to 10 cm. The opener and coverer can be raised to the height of the bottom off the ground when transporting. The row spacing of the seeding can be adjusted by changing the distance between two sowing units. The operating speed can be adjusted to 0–1.2 m/s through the speed control system. The seed metering plate amplitude can be adjusted to 0–1 mm through the seed metering control system.

## Experiment design

The preliminary test results showed that the operating speed is 0.4–1.2 m/s, and the seed metering plate amplitude is 60–140 μm. The central composite design (CCD) method was used to determine the optimal combination of the above-mentioned factors *(Wang, 2012; Wang et al., 2019)*. The operating speed and the seed metering plate amplitude are regarded as the factors, whilst the average number of seeds in each 100 mm section and the variation coefficient of seeding uniformity are regarded as the indicators. The quadratic regression equation was established through the test, and the effects and interactive effects of every single factor were studied. Table 1 shows the corresponding relationship between the coded and the actual values of the two-factor centre combination test.

**Table1**

**Coding schedule of experimental factors**

| **Coding values** | **Operating speed A [m/s]** | **Seed plate amplitude B [μm]** |
|---|---|---|
| **-1.414** | 0.40 | 60 |
| **-1** | 0.52 | 72 |
| **0** | 0.8 | 80 |
| **1** | 1.08 | 128 |
| **1.414** | 1.2 | 140 |

## Performance evaluation of seeding

The test was performed in accordance with the Chinese standard GB/T 9478-2005. The key factors affecting the seeder performance, including the operating speed and the seed metering plate amplitude, were selected in the experiment. Each row was divided lengthwise into several sections (100 mm each) during the test and the number of seeds measured in each section. Each row is continuously taken for 30 sections. The seeding performance can be evaluated by the average number of seeds in each 100 mm section and the variation coefficient of seeding uniformity. The calculation methods are presented in Formulas (1) and (2). Each group of tests is performed fivefold to reduce the test error, and the average value is considered *(China National standardizing committee, 2005).*

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \tag{1}$$

$$a = \frac{100}{\bar{x}}\sqrt{\frac{1}{n}\sum (x_i - \bar{x})^2} \quad [\%] \tag{2}$$

where: $x_i$ is the number of seeds in section I;

$\bar{x}$ is the average number of seeds in each 100 mm section;

*n* is the total number of test sections, 30 sections;

*a* is the variation coefficient of seeding uniformity, [%].

## RESULTS

### Test results and analysis

The design requirements of the two-factor CCD method indicate that 13 groups of experiments were conducted, and each group was repeated fivefold. The mean value was taken as the test result, and the indices were calculated according to Equations (1) and (2). Table 2 shows the test results.

**Table 2**

**The test results**

| NO. | Operating speed A | Seed plate amplitude B | the average number of seeds in each 100 mm section $Y_1$ | the variation coefficient of seeding uniformity $Y_2$ |
|---|---|---|---|---|
| | [m/s] | [μm] | / | [%] |
| **1** | 0 | 0 | 6.6 | 19.69 |
| **2** | -1 | 1 | 13.6 | 19.52 |
| **3** | -1.414 | 0 | 12.5 | 22.05 |
| **4** | 1.414 | 0 | 4.1 | 25.55 |
| **5** | 0 | 0 | 6.7 | 19.07 |
| **6** | -1 | -1 | 5 | 26.80 |
| **7** | 1 | 1 | 7.5 | 21.34 |
| **8** | 1 | -1 | 2.7 | 35.22 |
| **9** | 0 | 0 | 5.9 | 21.46 |
| **10** | 0 | 1.414 | 10.3 | 19.87 |
| **11** | 0 | 0 | 6.5 | 20.83 |
| **12** | 0 | -1.414 | 2.6 | 32.66 |
| **13** | 0 | 0 | 6 | 19.16 |

*Analysis of variance and regression model*

The test results were analysed by variance, and the results are presented in Table 3. The regression models were obtained as Formulas (3) and (4). The variance analysis indicated that the quadratic regression models of the average number of seeds in each 100 mm section $Y_1$ and the variation coefficient of seeding uniformity $Y_2$ were extremely significant ($P < 0.01$), and the misfit terms of the regression model were insignificant ($P > 0.05$). The $R^2$ values of the quadratic regression equation were 0.978 and 0.969. The order of influence of the average number of seeds in each 100 mm section and the variation coefficient of seeding uniformity is as follows: the seed metering plate amplitude B > the operating speed A. The above-mentioned results show that a high correlation exists between the predicted and the actual values. Moreover, the model has a good fitting degree, which can be used to predict and analyse the effects of operating speed and seed metering plate amplitude on the average number of seeds in each 100 mm section and the variation coefficient of seeding uniformity.

$$Y_1 = 6.34 - 2.53A + 3.05B - 0.96AB + 0.94A^2 + 0.012B^2 \tag{3}$$

$$Y_2 = 20.05 + 1.9A - 4.93B - 1.67AB + 2.07A^2 + 3.3B^2 \tag{4}$$

Where:

$A$ is the operating speed, [m/s]; $B$ is the seed metering plate amplitude, [μm]

$Y_1$ is the average number of seeds in each 100mm section; $Y_2$ is the variation coefficient of seeding uniformity, [%].

**Table3**

**The results of variance analysis**

| Item | Degree of freedom | Mean square | F Value | P Value | Item | Degree of freedom | Mean square | F Value | P Value |
|---|---|---|---|---|---|---|---|---|---|
| **Model 1** | 5 | 26.97 | 63.51 | <0.0001** | **Model 2** | 5 | 65.11 | 43.62 | <0.0001** |
| **A** | 1 | 51.41 | 121.04 | <0.0001** | **A** | 1 | 28.84 | 19.32 | 0.0032** |
| **B** | 1 | 73.67 | 173.45 | <0.0001** | **B** | 1 | 192.39 | 128.89 | <0.0001** |
| **AB** | 1 | 3.61 | 8.50 | 0.0225* | **AB** | 1 | 10.89 | 7.30 | 0.0306* |
| **$A^2$** | 1 | 6.09 | 14.34 | 0.0068** | **$A^2$** | 1 | 29.68 | 19.88 | 0.0029** |
| **$B^2$** | 1 | 0.001 | 0.002 | 0.9618 | **$B^2$** | 1 | 74.81 | 50.11 | 0.0002** |

*Note: P < 0.01 (extremely significant, **), P < 0.05 (very significant, *);*
*Model 1 is the average number of seeds in each 100mm section;*
*Model 2 is the variation coefficient of seeding uniformity.*

## Single factor effect analysis

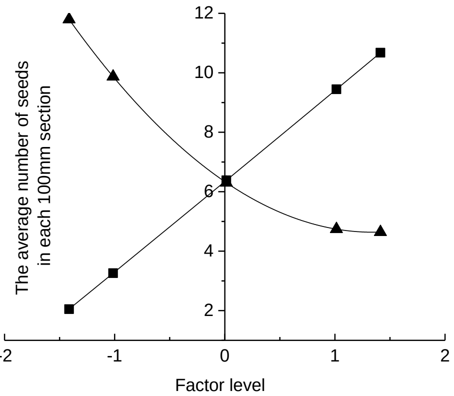
1) Analysis of the influence of test factors on the average number of seeds in each 100 mm section

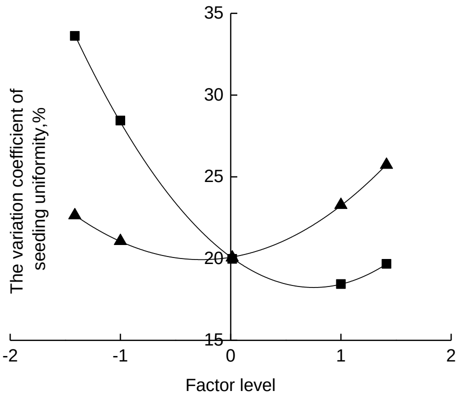
When the operating speed or the seed metering plate amplitude is fixed at zero level, the influencing model of every single factor can be obtained as follows:

Operating speed: $Y_{11} = 6.34 - 2.53A + 0.94A^2$

Seed metering plate amplitude: $Y_{12} = 6.34 + 3.05B + 0.012B^2$

The influencing curve of each factor is shown in Fig. 2. When other factors are fixed at the zero level, the single-factor effect curve of the operating speed is a parabola, and single factor effect of the seed metering plate amplitude is approximately a straight line. As shown in Fig. 2, the average number of seeds in each 100 mm section tends to gradually decrease with the increase in operating speed. The main reason is that the seed broadcasted in each section is thin and the number of particles is small when the operation speed is high. In the single-factor effect curve of seed metering plate amplitude, the average number of seeds in each 100 mm section increases with the seed metering plate amplitude. This phenomenon is attributed to the increase in the number of seeds falling in each section with the increase in the seed metering plate amplitude, seed rate and displacement.




The operating speed
The seed metering plate amplitude

**Fig. 2 - Effect of single factor on the average number of seeds in each 100mm section**

**Fig. 3 - Effect of single factor on the variation coefficient of seeding uniformity**

2) Analysis of the influence of experimental factors on the variation coefficient of seeding uniformity.

When the operating speed or the seed metering plate amplitude is fixed at zero level, the influence model of every single factor can be obtained as follows:

Operating speed: $Y_{21} = 20.05 + 1.9A + 2.07A^2$

Seed metering plate amplitude: $Y_{22} = 20.05 - 4.93B + 3.3B^2$

The influence curve of each factor is shown in Fig. 3. When the other factors are fixed at the zero level, the single-factor effect curves of the operating speed and the seed metering plate amplitude are parabolic. The figure shows that the parabolic extreme value of the operating speed curve is close to the zero-horizontal point, and the variation coefficient of seeding uniformity is small when the seeder operating speed is 0.8 m/s. The variation coefficient of seeding uniformity has an increasing trend when the speed is higher or lower than 0.8 m/s. This phenomenon is attributed to the easy accumulation of the planted seeds when the operating speed is <0.8 m/s. Accordingly, seeding uniformity is affected. When the operating speed is larger than 0.8 m/s, the sowing machine generates a certain degree of vibration during the operation, resulting in an increased variation coefficient of seeding uniformity. The extreme point for the one-factor effect curve of the seed metering plate amplitude is approximately near the +1 level, and the variation coefficient of seeding uniformity is firstly decreased and then increased. The main reason is that the seeding speed is small, the seed in the seed groove is sparse and the variation coefficient of seeding uniformity is large when the seed metering plate amplitude is small. When the seed metering plate amplitude is large, the seed movement mode changes from slip to throwing motion, the seeding speed increases. Such situations result in an increase in the variation coefficient of seeding uniformity.

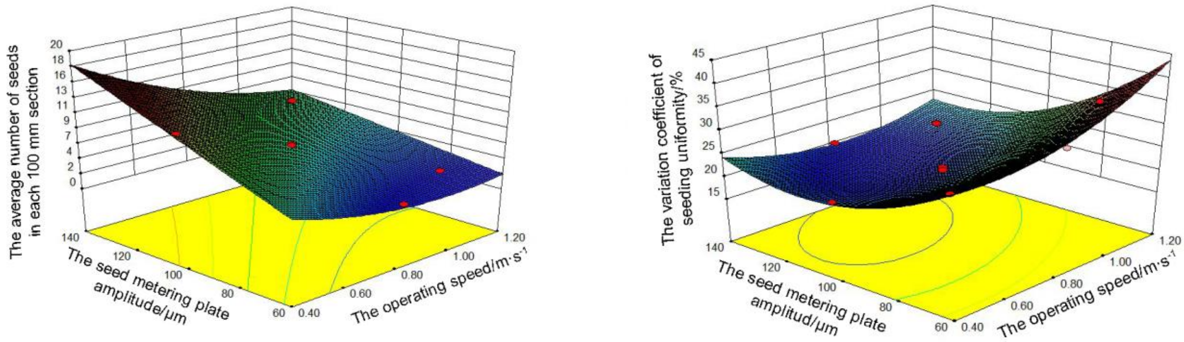
## Analysis of the influence of interaction factors on seeding performance

A 3D surface response surface map was generated according to the CCD method. The effects of operating speed A and seed metering plate amplitude B on the seeder performance were analysed according to the response surface results.

1) Analysis of the influence of test factors on the average number of seeds in each 100 mm section

The response surface of the operating speed A and the seed metering plate amplitude B to the average number of seeds in each 100 mm section is shown in Fig. 4a. The average number of seeds in each 100 mm section decreased with increased operating speed. Moreover, the average number of seeds in each 100 mm section increased with the seed metering plate amplitude.

The change of response value affected by test factors on the average number of seeds in each 100 mm section showed that the overall influence trend of test factors on the average number of seeds in each 100 mm section is as follows: the seed metering plate amplitude is relatively large, the operating speed of the seeder is comparatively small and the average number of seeds in each 100 mm section is increased. This phenomenon is attributed to the high seed metering speed and displacement when the seed metering plate amplitude is large. At this time, the seeding is concentrated, and the average number of seeds in each 100 mm section is high when the operating speed of the seeding machine is small. When the speed is high, the seeding is dispersed and the average number of seeds in each 100 mm section is reduced.




***a.Y₁(A,B)*** ***b.Y₂(A,B)***

**Fig. 4 - Response surface result**

2) Analysis of the influence of experimental factors on the variation coefficient of seeding uniformity

The response surface of operating speed A and seed metering plate amplitude B to the variation coefficient of seeding uniformity is shown in Fig. 4b. The variation coefficient of seeding uniformity firstly decreased and then increased with the increase in operating speed. The variation coefficient of seeding uniformity gradually decreases with the increase in the seed metering plate amplitude.

The change of the response value of test factors on the variation coefficient of seeding uniformity demonstrated that the overall influence trend of the test factors on such variation coefficient is as follows: moderate operating speed, large seed metering plate amplitude, enhanced seeding uniformity and small variation coefficient. The main reasons were as follows: when the operating speed was low, seed accumulation easily occurs. The planting opportunity produces a certain degree of vibration when the operating speed is fast. Such a situation has a certain impact on seeding. When the operating speed is moderate, the planter runs smoothly, which is beneficial to planting. At this time, the seed metering plate amplitude is large, and the seeds in the planter are difficult to jam, easy to disperse and evenly distributed. Thus, the seeding uniformity is satisfactory.

## Parameter optimization and validation

The agronomic requirements of millet sowing combined with those of the national standard grain planter Part 1: Technical conditions indicated that meeting the requirements of the average number of seeds (6–8) in each 100 mm section and the minimum variation coefficient of seeding uniformity is necessary to optimise the performance of the planter *(Zhang et al., 2011; Ministry of Industry and Information Technology.2013)*. The effect of interaction factors on the average number of seeds in each 100 mm section and the variation coefficient of seeding uniformity showed that the seeder must operate at a moderate speed and the seed metering plate amplitude must also remain moderate to attain the above-mentioned average number of seeds in each 100 mm.

The operation speed of the seeding machine is moderate and the seed metering plate amplitude is large to minimise the variation coefficient of seeding uniformity. In the range of 60–140 μm seed metering plate amplitude and 0.4–1.2 m/s seeder operating speed, the average number of seeds in each 100 mm section was set at 6–8 and the variation coefficient of seeding uniformity was also set as the minimum by using design-expert software to find the optimal parameter combination satisfying the above-mentioned objective function simultaneously. Combined with the actual situation, the optimal results are as follows: when the seed metering plate amplitude is 109 μm and the operating speed of the seeder is 0.76 m/s, the comprehensive response value of the model curved surface is optimal, the average number of seeds in each 100 mm section is 7.7 and the variation coefficient of seeding uniformity is 18.66%.

A field verification test is performed on the optimised parameter combination to test the prediction model accuracy. The seed metering plate amplitude t and the speeder operating speed are set to 109 μm and 0.76 m/s, respectively. The test is repeated fivefold, and the average value is obtained. The results showed that the average number of seeds in each 100 mm section was 7.8, and the variation coefficient of seeding uniformity was 19.64%. These findings *satisfied the technical requirements of the grain seeder in the national standard*. The relative errors of the predicted values were 1.28% and 4.98%.

## CONCLUSIONS

1. The 2BDE-2 type millet fine and small-amount electric seeder designed in this work adopts the electromagnetic vibration type millet fine and small-amount seed metering device. Each parameter is easy to adjust, and its performance is stable. The seeder can be used for millet and other small seed crop fine and small-amount of sowing.

2. The quadratic regression equation of the operating speed, the seed metering plate amplitude and the average number of seeds in each 100 mm section and the variation coefficient of seeding uniformity were established through the CCD method. The variance of the test results was analysed to obtain the influence. The order of the average number of seeds in each 100 mm section and the variation coefficient of seeding uniformity is as follows: the seed metering plate amplitude B > the operating speed A.

3. The CCD method is used to optimise the analysis. The optimal parameters of the planter operation are as follows: the seed metering plate amplitude is 109 μm, the operating speed is 0.76 m/s and the predicted result is the average number of seeds in each 100 mm section was 7.7 capsules. The variation coefficient of seeding uniformity was 18.66%. The field verification test was conducted under the condition that the seed metering plate amplitude was 109 μm and the operating speed was 0.76 m/s. The experimental results showed that the average number of seeds in each 100 mm section was 7.8, and the variation coefficient of seeding uniformity was 19.64%. The requirements of the national standard are met; the errors with the predicted value are 1.28% and 4.98%. This finding is consistent with the optimisation result, and the regression model is reliable.

## ACKNOWLEDGEMENTS

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