Journal of Engineering Science and Technology Review 16 (3) (2023) 165 - 172

Research Article

JOURNAL OF
Engineering Science and Technology Review

www.jestr.org

# Study on Fertilizer Spreading Performance of a Sieve Bucket-Type Fertilizer Spreader for Orchards

**Zhang Liping[1], Li Kuiduo[1], Luo Haowei[1], Zheng Weiqiang[1,*] and Ge Yuanyue[2]**

*[1]College of Mechanical Engineering, Xinjiang University, Urumchi 830046, China*
*[2]Faculty of Science and Techonogy, Norwegian University of Life Sciences, Aas, 1432, Norway*

Received 22 March 2023; Accepted 15 June 2023

***Abstract***

Orchard fertilization, as a key link in fruit tree planting, plays an important role in improving the cultivation quality, fruit yield, and fruit quality of trees. At present, manual and mechanical furrowing (hole) fertilization methods are dominant for orchard fertilization, leading to high labor intensity of fruit farmers, low production efficiency, and poor fertilization quality. Meanwhile, these methods fail to solve the quality problem of orchard fertilization due to root burning induced by non-uniform drill seeding and spreading. In this study, a sieve bucket-type fertilizer spreader was proposed, the influencing factors of the key mechanisms in this sieve bucket-type fertilizer spreader were analyzed, and the prototype was built. The correlation models of the coefficient of variation (CV) of fertilizer spreading with influencing factors, such as the shape and quantity of sieve pores and the advancing speed, were established via EDEM. Finally, verification was completed through a bench test. Results demonstrated that the influencing factors for the CV are successively the advancing speed and the shape and quantity of sieve pores, consistent with the simulation results. The proposed algorithm provides evidence for implementing the research and development of orchard furrowing fertilization equipment and promoting the rapid development of orchard economy.

*Keywords:* Fertilizer spreading mechanism, Sieve bucket device, CV, Orchard fertilization

## 1. Introduction

China is a large fruit producer and consumer, and it ranks first in terms of cultivation area and fruit production. Orchard fertilization, a key link in the process of fruit tree planting, plays an important role in the cultivation quality, yield, and quality improvement of fruit trees [1-3]. At present, in China, especially in the concentrated planting areas of characteristic fruits, the levels of mechanization and automation of orchard fertilization are low [4, 5], where the methods of surface spreading, manual furrowing (hole digging), and mechanical furrowing (artificial fertilization) are mainly adopted [6]. Such methods lead to shortcomings, such as high labor intensity, low operation efficiency, fertilizer accumulation at the bottom of the furrow, burning of fruit tree roots, and low fertilization quality, thereby restricting the rapid and healthy growth of characteristic fruits in concentrated planting areas.

The existing orchard fertilization machinery mainly include drill fertilization machinery, and centrifugal fertilization machinery, the drill fertilization machinery can improve the uniformity of fertilization to a certain extent, but the spreading area of fertilizers is small [7]. The fertilizer spreading area and working width of centrifugal fertilizer Spreading machinery is extremely large, leading to non-uniform fertilizer spreading and low fertilizer utilization rate. Moreover, the quality requirements of orchard fertilization cannot be satisfied, and adaptability is relatively poor [8, 9]. Meanwhile, on the basis of drill fertilization machinery, the experts and scholars of China and other country have put forward some other orchard fertilization methods, such as offset-type orchard fertilization, layered fertilization, and gas explosion subsoiling fertilization [4, 10-12]. These fertilization methods have, to some extent, reduced the intensity of fertilization operations for fruit farmers, improved the fertilization efficiency, and promoted the development of drill fertilization machinery in orchards. However, they still failed to solve problems, such as fertilizer accumulation at the furrow bottom and root damage of fruit trees. Therefore, a type of machinery suitable for furrowing drill fertilization of orchards is urgently needed.

## 2. State of the Art

Early studies orchard mainly included fertilizer spreading and furrowing fertilization in the world. From the 1950s to the 1970s, fertilization machinery had developed from the plowshare-type simple-structure furrow openers with high efficiency but poor adaptability to rotary furrow openers with a neat furrow pattern but low efficiency and high labor intensity, and then to chain-type furrow openers with good furrowing performance and high efficiency. Since the 1970s, the functions of foreign fertilizer spreaders have been continuously improved, with a high level of automation and intelligence, typically in Japan, France, Germany, and Italy [13, 14]. The RT24 ride-on furrow opener developed by American Ditch Witch Company is hydraulically driven, with a standard furrowing depth of 600 mm and a maximum furrowing depth of 920 mm, suitable for small orchards and

*E-mail address: zhlp@xju.edu.cn
ISSN: 1791-2377 
doi:10.25103/jestr.163.20

family farms, its furrowing power can reach 14.9 kw. In addition, the machinery can slip, steer, and complete operations in small and narrow plots by virtue of high flexibility. The Japanese MT-900 chain-type furrow opener, which is equipped with a crawler base, is small, simple, and has high automation level. It is applicable to furrowing application of liquid fertilizers in orchards [15]. Relevant studies show many types of orchard fertilization machinery in the world. However, they fail to complete multiple working procedures at the same time, have a low level of functional integration, high cost, and cannot effectively adapt to the situation in China.

In recent years, the rapid development of fertilization machinery in orchards has been vigorously boosted in China by the increase in the planting area and yield of orchards and the vigorous national support in agriculture. Xie et al. [16] from Southwest University put forward an annular furrowing fertilization device for orchards in hilly and mountainous areas. The device is mainly composed of furrowing fertilization parts, overload protection parts, control modules, a transmission system, and other key parts. It could complete the combined operation of annular furrowing, fertilization, and covering soil. The furrow depth of the device can reach more than 30 cm, and the stability coefficients of furrowing and fertilization were 93.5% and 94.6%, respectively. Zhang et al. [17] from Shandong Agricultural University designed and developed a double-row ditching fertilizer machine for apple orchards, mainly consisting of a furrowing device, a fertilization device, a furrowing depth automatic adjusting device, and other key components. The furrowing depth stability coefficient was greater than 95.25%, the furrow bottom width consistency coefficient was greater than 95.59%, and the covering soil rate was higher than 81.09%. The distribution stability coefficients of organic, chemical, and mixed fertilizers reached over 91.92%, 92.40%, and 94.02%, respectively. Wang et al. [18] from Nanjing Agricultural University put forward an electric-driven orchard furrowing fertilization machine, which was mainly composed of a fertilization assembly, a furrowing cutter head assembly, and a transmission block body, with a furrowing depth of 200 mm and a furrow width of 150 mm. Zang et al. [19] from Northwest Agriculture & Forestry University raised an organic fertilizer furrowing and fertilizer mixing device, which mainly consisted of a furrowing and fertilizer mixing mechanism, a fertilizer discharge system, and a curve control mechanism, with the root depth of stable operation reaching 30 cm. In addition, orchard fertilization machinery had been investigated by universities and research institutes, such as Agricultural Mechanization Research Institute of Xinjiang Academy of Agricultural Sciences, Machinery and Equipment Research Institute of Xinjiang Academy of Agricultural Reclamation, Huazhong Agricultural University, Hebei Agricultural University, and Shihezi University.

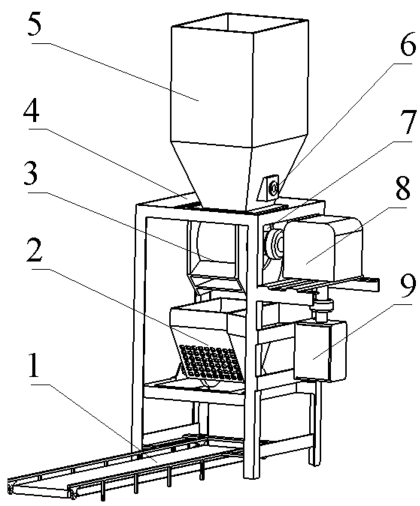
In summary, many types of orchard fertilization machinery are available all over the world. Moreover, the automation and intelligence level of orchard fertilization machinery is relatively high, which can satisfy various depths, but the functions are relatively simple with high costs, resulting in a certain gap from the agricultural requirements of Chinese orchards. The existing orchard fertilization machinery can complete several processes in China, such as furrowing, fertilization, covering soil, and compaction at one time, with a certain degree of integration. However, the level of automation and intelligence is relatively low, failing to guarantee the uniformity of fertilizers at a certain depth. Moreover, the fertilization quality is low, and no mature and promotable products are formed.

The remainder of this study is organized as follows: in Section III, the influencing factors of fertilizer spreading quality of the sieve bucket-type fertilizer spreader were analyzed and modeled, and the fertilizer spreading process simulation and bench test were carried out. In Section IV, the simulation and bench test results of fertilizer spreading performance of the sieve bucket-type fertilizer spreading mechanism were analyzed to verify the theoretical research findings. In the final section, the findings were summarized and relevant conclusions were drawn.

## 3. Methodology

### 3.1 General framework System composition and principle of the sieve bucket-type fertilizer spreade

The sieve bucket-type fertilizer spreader is mainly composed of a fertilizer box, a fertilizer discharging mechanism, a sieve bucket-type fertilizer spreading mechanism, and a simulated ground conveying mechanism (Fig.1).




Note: 1.simulated ground conveyer mechanism 2.fertilizer spreading mechanism 3.fertilizer feeding box 4.frame 5.fertilizer box 6.arch-breaking mechanism 7.spiral grooved-wheel 8.speed adjustment mechanism 9.servo motor

**Fig. 1.** Sieve bucket-type fertilizer spreader

Driven by the driving motor, the fertilizer is discharged at a certain speed by the fertilizer discharging device, and falls into the sieve bucket-type fertilizer spreading mechanism, the driving member of which drove the sieve bucket to start swinging at a certain angle and frequency under the driving action of the driving motor. Finally, the fertilizer in the sieve bucket is scattered on the simulated ground conveyer belt through sieve pores.

### 3.2 Influencing factor analysis and performance evaluation

#### 3.2.1 Influencing factor analysis of fertilizer spreading quality

The structural dimensions and parameters of the sieve bucket, which is a key component of the fertilizer spreader, influence the performance of the fertilizer spreading mechanism. In the previous research, the relationship between the basic dimension of the sieve pores and the size of the fertilizer particles and the effective area of the distribution of the sieve holes on the sieve surface were determined. In addition, single-factor tests were carried out on the factors affecting the fertilizer spreading uniformity of the sieve bucket device, such as the advancing speed of the sieve bucket, the shape of the sieve pores, and the quantity of sieve pores. The influencing law of each parameter on the fertilizer spreading uniformity of the sieve bucket-type fertilizer spreader was determined, but many factors that affect the fertilizer spreading performance were identified in the actual working process of the sieve bucket-type fertilizer spreader. Moreover, the spreading uniformity results from the combined action of such factors. Therefore, the results of the combined action of factors, such as the advancing speed, the shape of the sieve bucket, and the quantity of sieve pores in the sieve bucket-type fertilizer spreader, were explored to perfect the previous study.

**3.2.2 Evaluation of the fertilizer spreading performance**

To ensure the consistency between the theoretical design and the bench test, the uniformity of fertilizer spreading in the sieve bucket-type fertilizer spreader is evaluated by a unified standard, that is, the coefficient of variation (CV) of fertilizer spreading amount is used (Formula 3) [20].

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

$$s = \sqrt{\frac{\sum_{i=1}^{n} (x_i - x)}{n-1}} \tag{2}$$

$$c_v = \frac{s}{x} \times 100\% \tag{3}$$

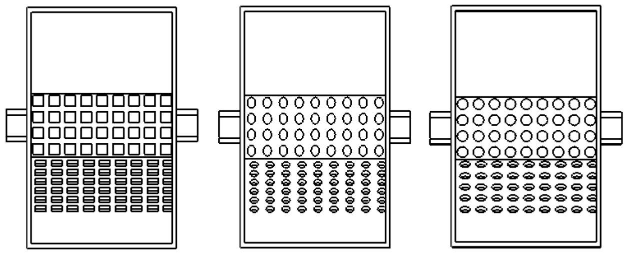
where $x_i$ is the total amount of fertilizer discharged each time, g; $x$ is the average value of the total amount of fertilizer discharged each time, g; $s$ is the standard deviation of the stability of total fertilizer discharge, g; $CV$ is the CV of the stability of total fertilizer discharge, %; $n$ is the number of tests, times.

**3.3 Fertilizer spreading process simulation**

**3.3.1 Establishment of a sieve bucket model under different sieve pore parameters**

(1) Modeling of the fertilizer spreading mechanism of sieve buckets with different sieve pore structures.

On the basis of the design of the structural parameters of the sieve bucket fertilizer spreader and on the premise that all other parameters were the same, the fertilizer spreading performance of the sieve bucket-type fertilizer spreading mechanisms with three different sieve pore structures was investigated. Therein, the side length of the square holes, the diameter of the circular hole, and the long axis size of the elliptical holes were identical, and the three fertilizer spreading mechanisms were modeled (Fig.2).

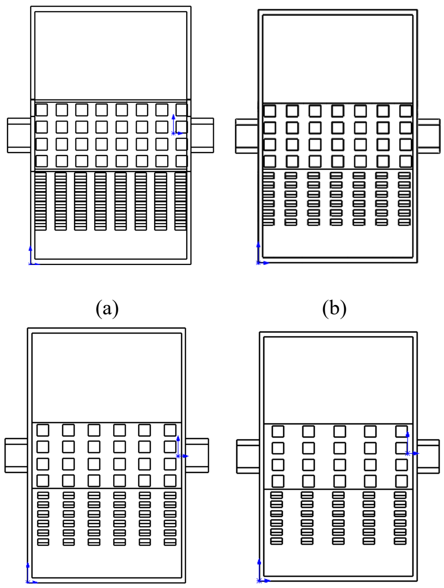


(a) (b) (c)

**Fig. 2.** Structural representation of fertilizer spreading mechanisms.(a) Square hole. (b) Elliptical hole. (c) Circular hole

(2) Modeling of sieve bucket-type fertilizer spreading mechanisms with different quantities of sieve pores.

Under a fixed shape of sieve pores, the influence of the quantity of sieve pores on the fertilizer spreading performance of sieve bucket-type fertilizer spreading mechanisms was mainly studied, and the performance was investigated under $k$ =0.75, $k$ =1.0, $k$ =1.25, and $k$ =1.5 (Fig. 3), where $k$ is the hole spacing ratio, that is, the ratio of the hole spacing to the hole size. The large value of $k$ indicates large hole spacing and small hole quantity.



(a) (b) (c) (d)

**Fig. 3.** Modeling of sieve bucket mechanisms with different quantities of sieve pores. (a) $k$=0.75. (b) $k$=1. (c) $k$=1.25. (d) $k$=1.5

**3.3.2 Setting of simulation parameters**

During the simulation, the material and contact mechanical parameters between different materials in the test system were obtained by actual measurement and consulting relevant literature, and the parameter settings are listed (Table 1) [21, 22].

**Table 1.** Material characteristic parameters

| Property | Parameter | Value |
|---|---|---|
| Fertilizer | Particle size $d/(mm)$ | 2.97 |
| | Density $\rho/(kg.m^{-3})$ | 1333 |
| | Poisson's ratio $\upsilon$ | 0.25 |
| | Elasticity modulus $G/(Pa)$ | $9.2\times10^{6}$ |
| Sieve Bucket | Density $\rho/(kg.m^{-3})$ | 7850 |
| | Poisson's ratio $\upsilon$ | 0.24 |
| | Elasticity modulus $G/(Pa)$ | $8.2\times10^{10}$ |
| Ground | Density $\rho/(kg.m^{-3})$ | 2500 |

| | | |
|---|---|---|
| | Poisson's ratio $\upsilon$ | 0.3 |
| | Elasticity modulus $G/(Pa)$ | $1\times10^6$ |
| | Static friction coefficient between fertilizer and sieve bucket $\mu_1$ | 0.278 |
| | Dynamic friction coefficient between fertilizer and sieve bucket $v_1$ | 0.152 |
| | Static friction coefficient between Fertilizers $\mu_2$ | 0.906 |
| Interaction | Dynamic friction coefficient between fertilizers $v_2$ | 0.495 |
| | Static friction coefficient between fertilizer and ground $\mu_3$ | 1.25 |
| | Dynamic friction coefficient between fertilizer and ground $v_3$ | 1.22 |
| | Recovery coefficient between fertilizer and sieve bucket $e_1$ | 0.2026 |
| | Recovery coefficient between fertilizer and ground $e_2$ | 0.02 |
| Others | Gravitational acceleration $g/(m/s^2)$ | 9.8 |

**3.3.3 Simulation process and test design**

The differently structured fertilizer spreading mechanisms were imported into the discrete element simulation software, and the relevant parameters were set. A simulated ground (length $\times$width = $800mm\times1000mm$ ) was set to verify the fertilizer spreading performance after the fertilizer passed through the fertilizer spreading mechanism. It was located under the fertilizer spreading mechanism and moved in the actual fertilizer spreading direction at different speeds after the simulation started for 0.2 s. In addition, Grid Bin Group was set in the longitudinal direction (direction $Y$ ) of the ground using the selection module in EDEM, and the size of each grid was $600mm\times800mm$ . A particle factor was assigned, fertilizer particles were filled in the fertilizer box during simulation, and the motion characteristics of the assembly were finally set. The fertilizer discharging device started discharging the fertilizer at a certain rotational speed, and the relevant parameters of the fertilizer spreading mechanism were changed for fertilizer spreading simulation for 4 s.

**3.4 Bench test of the fertilizer spreading performance**

**3.4.1 Test conditions**

The test was performed with the self-made sieve bucket-type fertilizer spreader as the testing equipment (Fig. 4). The test fertilizer was diammonium phosphate commonly used in Xinjiang. According to the previous measurement results, the average particle size of diammonium phosphate was 2.97 mm, and the density was 1.333 $g/cm^3$ . For the fertilizer spreading mechanism, an optimized sieve bucket structure was adopted for the fertilizer spreading performance test. To simulate the actual fertilization accurately, mitigate the difficulty, and reduce the test cost, a simulated ground operating device with a reference length of 2000 mm and a bandwidth of 400 mm was set under the sieve bucket-type fertilizer spreading mechanism, and the conveyer belt of the simulated ground operating device was subjected to grid division in advance, with a grid division area of 2000 mm×300 mm and 40 grids formed along the length direction.

**3.4.2 Test method**

The static test was carried out in accordance with the test methods specified in Chinese national standard GB/T20346.1-2006 and China machinery industrial standard JB/T7864-2013. As the fertilizer spreading mechanism started swinging at a certain frequency, the conveyer belt of the simulated ground operating device also started to move at a certain speed. The sampling analysis area was measured when the fertilizer spreading mechanism was in a stable state. During the whole fertilizer spreading process, the sampling area was 600 mm×300 mm. The entire sampling area was divided into 12 equal parts, each of which was a sampling interval. The fertilizers in the 12 sampling intervals were collected, and the fertilizer quantity in each sampling interval was measured and counted.

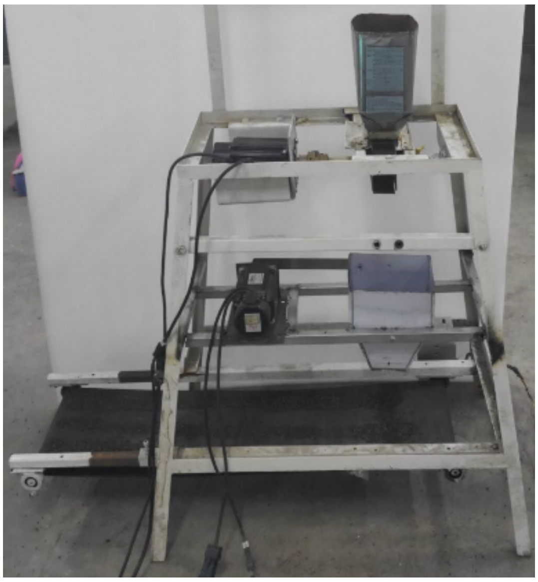


**Fig. 4.** Sieve bucket-type fertilizer spreader

**4. Result analysis and discussion**

**4.1 Simulation result analysis**

In the previous study, the single-factor (e.g., sieve pore structure, quantity of sieve pores, and advancing speed) simulation test of the fertilizer spreading process of the sieve bucket-type fertilizer spreading mechanisms with different sieve pore structures was completed via EDEM. Results showed that the structure and advancing speed of the sieve bucket greatly influenced the fertilizer spreading performance, however, the quantity of sieve pores influenced slightly. To study the influencing law of the interaction of the three factors on the fertilizer spreading accuracy of the sieve bucket-type fertilizer spreading mechanism, the general rotary combination design was selected, a three-factor three-level (the structure and quantity of sieve pores, and advancing speed) experiment was arranged, and the coding level of each factor is shown in Table 2.

**Table 2.** The coding level of factor

| Coding | Factor | | |
|---|---|---|---|
| | **Structure of sieve pores $x_1$** | **Quantity of sieve pores $x_2$** | **Advancing speed $x_3$/(m/s)** |
| -1 | Circular hole | 0.5 | 0.4 |
| 0 | Square hole | 1.0 | 1.0 |
| 1 | Elliptical hole | 1.5 | 1.2 |

The test scheme and results are shown in Table 3.

**Table 3.** The test scheme and results

| Serial number | Test factor | | | Performance index | |
|---|---|---|---|---|---|
| | Sieve pore | Sieve pore | Advancing speed | Amount of | CV of fertilizer spreading |
| 1 | Square hole | 0.8 | 0.8 | 102 | 23.14% |
| 2 | Square hole | 1.5 | 1.2 | 77 | 22.07% |
| 3 | Elliptical hole | 1.5 | 0.8 | 7 | 28.66% |
| 4 | Circular hole | 1.5 | 0.8 | 31 | 27.516 |
| 5 | Square hole | 1.5 | 0.4 | 212 | 4.67% |
| 6 | Circular hole | 0.5 | 0.8 | 42 | 28.02% |
| 7 | Circular hole | 1.0 | 1.2 | 16 | 30% |
| 8 | Circular hole | 1 | 0.4 | 62 | 5.2% |
| 9 | Square hole | 1 | 0.4 | 192 | 2.5% |
| 10 | Square hole | 1 | 1.2 | 60 | 25.01% |
| 11 | Elliptical hole | 1 | 1.2 | 6 | 31.26% |
| 12 | Elliptical hole | 1 | 0.4 | 24 | 5.8% |
| 13 | Square hole | 0.5 | 1.2 | 68 | 28.36% |
| 14 | Elliptical hole | 0.5 | 0.8 | 12 | 29.19% |

The analysis of variance of experimental data was performed using Design-Expert 8.0.5b, and the variance data of fertilizer spreading amount and CV are displayed in Tables 4 and 5, respectively. Furthermore, the regression equations of the shape and quantity of sieve pores, and advancing speed for the fertilizer spreading amount and CV of the sieve bucket-type fertilizer spreading mechanism were determined, followed by the significance analysis.

(1) Regression model and significance analysis of fertilizer spreading amount.

By regression fitting of data, the quadratic polynomial regression model between the fertilizer spreading amount of the fertilizer spreading mechanism and various influencing factors was obtained, as follows:

$$y_1 = 105.36 + 15.17x_1 + 3.27x_2 - 54.36x_3 - 30.14x_1x_2 - 26.52x_1x_3 - 10.32x_2x_3 - 75.96x_1^2 - 2.17x_2^2 + 30.23x_3^2 \quad (4)$$

where $y_1$ is the coded value of the fertilizer spreading amount.

The analysis of variance of the fertilizer spreading amount in Table 4 shows that the significant level of the model item was $P$ =0.0143<0.05, indicating that the regression equation of the fertilizer spreading amount with the shape and quantity of sieve pores, and traveling speed was extremely significant and usable. The significance level of lack-of-fit items was $P$=0.1021>0.05, reflecting that the abnormal errors in this equation and those in actual fitting accounted for a small proportion, and the fertilizer discharging amount was reasonably associated with the shape and quantity of sieve pores and the advancing speed as manifested in the regression equation.

**Table 4.** The variance analysis of the fertilizer spreading amount

| Source | Quadratic sum | Freedom | F | Significance Level P |
|---|---|---|---|---|
| Model | 52808.87 | 9 | 12.09 | 0.0143 |
| $X_1$ | 340.78 | 1 | 0.7 | 0.4492 |
| $X_2$ | 12.44 | 1 | 0.026 | 0.8805 |
| $X_3$ | 7029.04 | 1 | 14.49 | 0.019 |
| $X_1X_2$ | 873.6 | 1 | 1.8 | 0.2508 |
| $X_1X_3$ | 852.87 | 1 | 1.76 | 0.2556 |
| $X_2X_3$ | 124.48 | 1 | 0.26 | 0.6392 |
| $X_1^2$ | 7920.99 | 1 | 16.32 | 0.0156 |
| $X_2^2$ | 6.11 | 1 | 0.013 | 0.9161 |
| $X_3^2$ | 1853.19 | 1 | 3.82 | 0.1224 |
| Residual error | 1940.97 | 4 | | |
| Lack-of-fit | 1928.47 | 3 | 51.43 | 0.1021 |
| Error | 12.5 | 1 | | |
| **Total** | 54749.85 | 13 | | |

(2) Regression model and significance analysis of CV of fertilizer spreading.

The quadratic polynomial regression model between the CV of fertilizer spreading mechanisms and various influencing factors was obtained by regression fitting of the data, as follows:

$$y_2 = 22.15 + 1.56x_1 - 1.98x_2 + 11.46x_3 - 1.36x_1x_2 - 1.17x_1x_3 - 1.88x_2x_3 + 5.7x_1^2 + 2.98x_2^2 - 8.78x_3^2 \quad (5)$$

Where $y_2$ is the coded value of the CV of fertilizer spreading.

**Table 5.** The variance analysis of the CV of fertilizer spreading

| Source | Quadratic sum | Freedom | F | Significance Level P |
|---|---|---|---|---|
| Model | 1555.33 | 9 | 58.95 | 0.0007 |
| $X_1$ | 3.62 | 1 | 1.23 | 0.3288 |
| $X_2$ | 4.54 | 1 | 1.55 | 0.2813 |
| $X_3$ | 312.65 | 1 | 106.65 | 0.0005 |
| $X_1X_2$ | 1.77 | 1 | 0.6 | 0.4807 |
| $X_1X_3$ | 1.66 | 1 | 0.56 | 0.4942 |
| $X_2X_3$ | 4.13 | 1 | 1.41 | 0.3008 |
| $X_1^2$ | 44.58 | 1 | 15.21 | 0.0175 |
| $X_2^2$ | 11.5 | 1 | 3.92 | 0.1187 |
| $X_3^2$ | 156.31 | 1 | 53.32 | 0.0019 |
| Residual error | 11.73 | 4 | | |
| Lack-of-fit | 11.55 | 3 | 22.12 | 0.1547 |
| Error | 0.17 | 1 | | |
| **Total** | 1567.06 | 13 | | |

The analysis of variance of the CV of fertilizer spreading in Table 5 indicates that the significance level of the model item was $P$=0.0007<0.01, manifesting that the regression equation of the CV with the shape and quantity of sieve pores and the advancing speed was extremely significant and usable. The significance level of the lack-of-fit item was $P$=0.1547>0.05, indicating that the abnormal errors in this equation and those in actual fitting accounted for a small proportion, and the regression relationships of the CV of fertilizer spreading with the shape and quantity of sieve pores and the advancing speed were reasonable.

(3) Response surface analysis corresponding to the fertilizer spreading performance test factors of fertilizer spreading mechanism.

To more clearly reflect the relationships of each parameter with the indexes measuring fertilizer discharging performance, such as the fertilizer spreading amount and the CV of fertilizer spreading, a 3D response surface diagram was drawn using the model graph function of Design-Expert 8.0.5b. Moreover, the response surface diagrams (Fig.5 and 6) of the fertilizer spreading amount and CV were generated, according to the established quadratic polynomial regression model for the fertilizer spreading amount and CV of the fertilizer spreading mechanism. In addition, the relationships of the shape and quantity of sieve pores and the advancing speed with the fertilizer spreading amount and CV were analyzed.

Fig.5 shows that the fertilizer spreading amount of the fertilizer spreading mechanism decreased evidently with the increase in the advancing speed, because the falling height of the fertilizer is greater than the traveling displacement of the fertilizer spreader when the advancing speed increases. As a result, the fertilizer decreases in the same sampling interval. Therefore, the advancing speed of the fertilizer spreading mechanism should be controlled to ensure the fertilizer spreading amount. The fertilizer spreading amount by square sieve pores was the largest, because the compressive force of fertilizer particles is the smallest when they pass through square sieve pores. Under the largest quantity of sieve pores, the probability for fertilizer particles to pass through the sieve pores evidently increased. When the advancing speed was low, the fertilizer spreading amount was the largest.

Fig. 6(a) shows that the shape of sieve pores exerted a greater influence on the CV of fertilizer spreading than the quantity of sieve pores. In Fig. 6(b), the advancing speed had a greater influence on the CV of fertilizer spreading than the shape of sieve pores. In Fig. 6(c), the advancing speed had a greater influence on the CV of fertilizer spreading than the quantity of sieve pores. Therefore, the advancing speed generated the greatest influence on the CV of fertilizer spreading, followed by the shape and quantity of sieve pores successively.

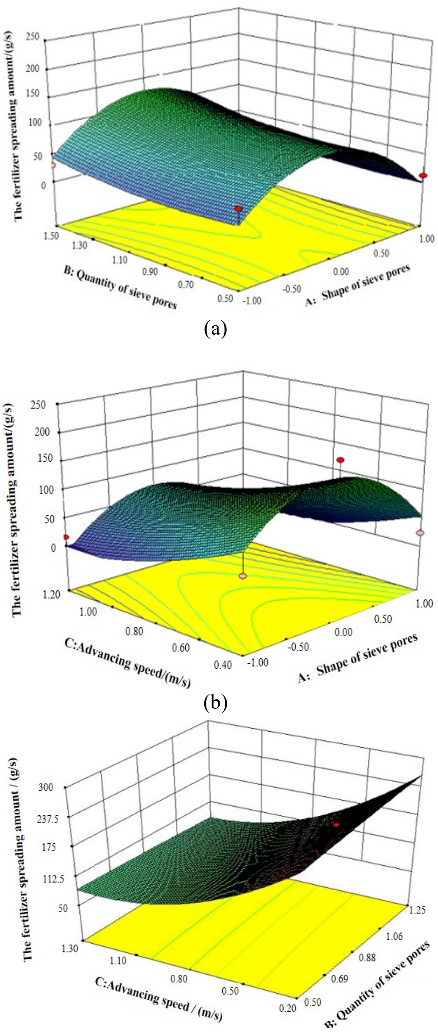



**Fig. 5.** The response surface diagrams of the fertilizer spreading amount. (a) S ($x_1$, $x_2$, 0). (b) S ($x_1$, 0, $x_3$). (c) S (0, $x_2$, $x_3$)

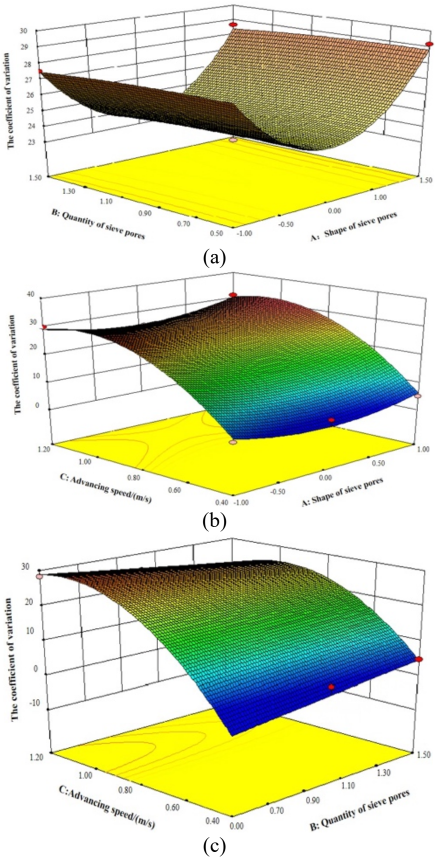



**Fig. 6.** The response surface diagrams the CV of the fertilizer spreading amount. (a) S ( $X_1$, $X_2$, 0). (b) S ( $X_1$, 0, $X_3$). (c) S(0, $X_2$, $X_3$)

### 4.2 Analysis of bench test results

An orthogonal bench test of fertilizer spreading was arranged through $L_9$ ( $3^3$ ), in which the main factors considered were the shape and quantity of sieve pores and the advancing speed, and each factor and their level were finally determined. The main sieve pore shapes considered were square, elliptical, and circular hole. According to the change laws of theoretical design, the quantity of sieve pores was selected as $K$ =0.5, 1.0, and 1.5. The advancing speed was 0.4, 0.8, and 1.2 m/s as per the change laws. The levels of test factors and test data analysis are listed in Tables 6 and 7, respectively.

**Table 6.** The levels of test factors

| Level | Factor | | |
|---|---|---|---|
| | **Sieve pore shape** | **Sieve pore quantity ( $K$ )** | **Advancing speed(m/s )** |
| 1 | Square hole | 0.5 | 0.4 |
| 2 | Elliptical hole | 1 | 0.8 |
| 3 | Circular hole | 1.5 | 1.2 |

**Table 7.** Test data analysis

| Test number | Factor | | | CV |
|---|---|---|---|---|
| | **A** | **B** | **C** | |
| 1 | 1 | 1 | 1 | 3.33% |
| 2 | 1 | 2 | 2 | 23.14% |
| 3 | 1 | 3 | 3 | 21.65% |
| 4 | 2 | 1 | 2 | 28.02% |
| 5 | 2 | 2 | 3 | 30.06% |
| 6 | 2 | 3 | 1 | 5.60% |
| 7 | 3 | 1 | 3 | 34.03% |
| 8 | 3 | 2 | 1 | 4.80% |
| 9 | 3 | 3 | 2 | 27.52% |
| $K_1$ | 48.12% | 65.38% | 13.73% | |
| $K_2$ | 63.68% | 58.00% | 78.68% | |
| $K_3$ | 66.35% | 54.77% | 85.74% | |
| $K_1$ | 16.04% | 21.79% | 4.58% | |
| $K_2$ | 21.23% | 19.33% | 26.23% | |
| $K_3$ | 22.12% | 18.26% | 28.58% | |
| Range | 6.08% | 3.54% | 24.00% | |

Table 7 shows that the ranges of the three factors were 6.08%, 3.54%, and 24%. Evidently, the range of the advancing speed was the maximum at 24%, reflecting that the change in the advancing speed exerted the greatest influence on the CV. Therefore, the advancing speed was the main factor to be considered. The average values of the CV corresponding to the three levels of the advancing speed were 4.58%, 26.23%, and 28.58%. The value corresponding to the first level was the minimum, so the first level was the best. The range of the sieve pore structure was 6.08%, which was second only to that of the advancing speed. The average values of the CV corresponding to its three levels of the sieve pore structure were 16.04%, 21.23%, and 22.12%, and the CV of the first level was the smallest, so the first level was the best. The range of the quantity of sieve pores was 3.54%, which was the smallest among these factors, indicating that the change in quantity had the smallest influence on the CV of fertilizer spreading. The average values of the CV corresponding to the three levels were 21.79%, 19.33%, and 18.26%, and the CV of the third level was the smallest, so the level of third was the best.

## 5. Conclusions

To improve the uniformity of fertilizer spreading in the process of furrowing fertilization in orchards, on the basis of the previous study, the uniformity of fertilizer spreading under the combined action of various factors affecting the sieve bucket-type fertilizer spreader was investigated and verified through the simulation and bench tests. The following conclusions could be drawn:

(1) Under the same shape of sieve pores of the sieve bucket-type fertilizer spreading mechanism, with the increase in the quantity of sieve pores, the fertilizer spreading amount of the fertilizer spreading mechanism and the CV of fertilizer spreading slightly changed. The fertilizer spreading amount reduced evidently as the advancing speed accelerating, presenting a decreasing trend. The CV increases continuously, showing an increasing trend in general, indicating that the advancing speed exerts a greater influence on the fertilizer spreading amount and CV than the quantity of sieve pores.

(2) Under the same advancing speed of the sieve bucket-type fertilizer spreading mechanism, the fertilizer spreading amount tended to increase with the increase in the quantity of sieve pores, and the CV decreased but not significantly. However, with the change in the shape of sieve pores, the fertilizer spreading amount initially increased and then decreased, consistent with the CV, manifesting that the shape of the sieve pores generates a greater influence on the fertilizer spreading amount and the CV than the quantity of sieve pores.

(3) Under the same quantity of sieve pores in the sieve bucket-type fertilizer spreading mechanism, with the change in the shape of sieve pores, the fertilizer spreading amount initially increased and then decreased, whereas the CV of fertilizer spreading showed an opposite trend. As the advancing speed increase, the fertilizer spreading amount

presented an overall declining trend, and the CV displayed an overall increasing trend. This finding indicates that the advancing speed generates a greater influence on the fertilizer spreading amount and CV of fertilizer spreading than the shape of the sieve pores.

(4) For the sieve bucket-type fertilizer spreader, the factors influencing the CV are sorted as the advancing speed, the sieve pore structure, and the quantity of sieve pores successively, consistent with the simulation conclusions. Therefore, the results verify the simulation reliability and the design accuracy.

Based on the previous single-factor study, the results of the combined action of various factors on the uniformity of fertilizer spreading were comprehensively considered through the discrete element method, and the findings were verified through the bench test. The results can improve the uniformity and quality of furrowing fertilization in orchards, to some extent, and provide reference for optimizing the machinery and exploring the control algorithm for fertilizer discharging parameters.

**Acknowledgements**

This work was supported by Doctoral Startup Fund of the Xinjiang University, Key R & D Projects of Xinjiang Uygur Autonomous Region (No. 2022B02028-4) and the National Natural Science Foundation of China (No. 52265039).



## References

1. Kilic, N., Burgut, A., Gundesli, M. A., Nogay, G., Ercisli, S., Kafkas, N.E., Ekiert, H., Elansary, H. O., Szopa, A., "The Effect of Organic, Inorganic Fertilizers and Their Combinations on Fruit Quality Parameters in Strawberry". *Horticulturae*, 7(10), 2021, pp. 354, doi: 10.3390/horticulturae7100354.
2. Sete, P. B., Comin, J. J., Ciotta, M. N., Salume, J. A., Thewes, F., Brackmann, A., Toselli, M., Nava, G., Rozane, D. E., Loss, A., Lourenzi, C. R; Couto, RdR; Brunetto, G., "Nitrogen fertilization affects yield and fruit quality in pear". *Scientia Horticulturae*, 258, 2019, pp.108782, doi:10.1016/j.scienta.2019.108782.
3. Maraa-Santacruz, J. N., Castellanos-Pérez, E., Vázquez-Vázquez, C .,Martinez-Rios, J. J., Trejo-Escareno, H. I., Gallegos-Robles, M. N., "Solarized manure and two irrigation methods on fruit yield of jalapeno chili (Capsicum annuum L. var. annuum)". *Revista de la Facultad de Ciencias Agrarias*, 50(2), 2018, pp. 105-117.
4. Shen, C. J., Zhang, L. X., Zhou, Y., Dai, Y. M., Li, F., Zhang, J., "Kinematic analysis and tests of the insertion mechanism of a self-propelled orchard gas explosion subsoiling and fertilizing machine". *Transactions of the Chinese Society of Agricultural Engineering*, 38(01), 2022, pp. 44-52, doi:10.11975/j.issn.1002-6819.2022.01.005.
5. Xia, R. H., Wu, D. J., Meng, H. W., "Design and experiment of 2FPG-40 grape ditching fertilizer combined machine". *Journal of Chinese Agricultural Mechanization*, 39(12), 2018, pp.36-40, doi: 10.13733/j.jcam.issn.2095-5553.2018.12.06.
6. Liu, S. X., Xu, C. B., Zhang, H. J., Jiang, H., Quan, Z. K., Wang, J. X., "Research Status and Development Analysis of Base-fertilizer Application Equipment of Orchard". *Transactions of the Chinese Society for Agricultural Machinery*, 51(S2), 2020, pp. 99-108, doi: 10.6041/ j. issn.1000-1298.2020.s2.012.
7. Sugirbay, A. M., Zhao, J., Nukeshev, S. O., Chen, J., "Determination of pin-roller parameters and evaluation of the uniformity of granular fertilizer application metering devices in precision farming ".*Computers and Electronics in Agriculture*, 179, 2020, pp.105835, doi:10.1016/j.compag.2020.105835.
8. Zinkeviciene, R., Jotautiene, E., Juostas, A., Comparetti, A., Vaiciukevicius, E., "Simulation of Granular Organic Fertilizer Application by Centrifugal Spreader". *Agronomy*, 11(2), 2021, pp. 247, doi:org/10.3390/agronomy11020247.
9. Fulton, J. P., Thaper, R. K., Virk, S. S., McDonald, T., Fasina, O., "Effect of Vane Shape on Fertilizer Distribution for a Dual-Disc Spinner Spreader". *Applied Engineering in Agriculture*, 36(5), 2020, pp. 743-751, doi:10.13031/aea.13634.
10. Wang, Z. Q., Liu, F. Z., Wang, X. D., Zhang, J. G., Shi, X. B., Wang, H. B., "Design and Experiment on the Offset Fertilization Machine for Orchard". *Journal of Agricultural Mechanization Research*, 45(06), 2023, pp. 115-119, doi:10.13427/j.cnki.njyi.2023.06.011.
11. Yuan, Q. C., Xu, L. M., Niu, C., Ma, S., Yan, C. G., Zhao, S. J., "Design and Test of Layered Variable Rate Fertilizer Discharge Control System for Organic Fertilizer Deep Applicator". *Transaction of the Chinese Society for Agricultural Machinery*, 51(S1), 2020, pp. 195-202, doi: 10.6041/j.issn.1000-1298.2020.S1.022.
12. Wang, W. W., Song, J. L., Zhou, G. A., Quan, L. Z., Zhang, C. L., Chen, L. Q., "Development and Numerical Simulation of a Precision Strip-Hole Layered Fertilization Subsoiler While Sowing Maize". *Agriculture*, 12(7), 2022, pp. 938, doi:org/10.3390/agriculture12070938.
13. Banđur, Đ., Jakšić, B., Banđur, M., Jović, S., "An analysis of energy efficiency in Wireless Sensor Networks (WSNs) applied in smart agriculture". *Computers and Electronics in Agriculture*, 156, 2019, pp. 500-507, doi:10.1016/j.compag.2018.12.016.
14. Batte, M. T., "Factors influencing the profitability of precision farming systems". *Journal of Soil and Water Conservation*, 55(1), 2000, pp. 12-18.
15. Morinaga, K., Sumikawa, O., Kawamoto, O., Yoshikawa, H., Nakao, S. J., Shimazaki, M., Kusaba, S., Hoshi, N., "New technologies and systems for high quality citrus fruit production, labor-saving and orchard construction in mountain areas of Japan". *Journal of Mountain Science*2, 2005, pp. 59, doi:org/10.1007/s11629-005-0059-4.
16. Xie, C., Yang, J. W., Wang, B. S., Zhuo, P., Li, C. S., Wang, L. H*., "Parameter calibration for the discrete element simulation model of commercial organic fertilizer". *International Agrophysics*, 35(1), 2021, pp. 107-117, doi:10.31545/intagr/134141.
17. Zhang, H. J., Xu, C. B., Liu, S. B., Jiang, H., Zhang, C. F., Wang, J. X., "Design and Experiment of Orchard Double Row Ditching-fertilizer Machine with Automatic Depth Adjustment". *Transaction of the Chinese Society for Agricultural Machinery*, 52(01), 2021, pp.62-72, doi:10.6041/j.issn.1000-1298.2021.01.007.
18. Wang, X. Y., "Development of electric driver orchard ditching fertilizer applicator". Master thesis of Nan Jing Agricultural University, China, 2020, doi:10.27244/d.cnki.gnjnu.2020.001194.
19. Zhu, X. H., Li, X. D., Gao, X., Tan, C., Deng, H. T., "Design and Test of Self-propelled Orchard Organic Fertilizer Strip-spreader". *Transaction of the Chinese Society for Agricultural Machinery*, 53(05), 2022, pp. 136-146, doi:10.6041/j.issn.1000-1298.2022.05.014.
20. Villette, S., Piron, E., Miclet, D., "Hybrid centrifugal spreading model to study the fertiliser spatial distribution and its assessment using the transverse coefficient of variation". *Computers and Electronics in Agriculture*, 137, 2017, pp. 115-129, doi:10.1016/j.compag.2017.03.023.
21. Ahmad, F., Qiu, B. J., Ding, Q. S., Ding, W. M., Khan, Z. M., Shoaib, M., Chandio, F. A., Rehim, A., Khaliq, A .,"Discrete element method simulation of disc type furrow openers in paddy soil". *International Journal of Agriculture and Biological Engineering*, 13(4), 2020, pp. 103-110, doi:10.25165/j.ijabe.20201304.4800.
22. Ucgul, M., Fielke, J. M., Saunders, C., "Three-dimensional discrete element modelling (DEM) of tillage: Accounting for soil cohesion and adhesion". *Biosystems Engineering*, 129, 2015, pp. 298-306, doi:10.1016/j.biosystemseng.2014.11.006.