STUDY ON THE UNIFORMITY OF SPRAYING SEEDS WITH 4BQD-40C SPRAYING SEEDER MACHINE
/
4BQD-40C 型喷播机喷播落种均匀性研究

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ABSTRACT
The working parameters of the pneumatic sprayer, such as the sprayer's attitude, working airflow, and spraying amount, have an impact on the evenness of seed distribution during the process of vegetation restoration on degraded grasslands. This article focuses on the 4BQD-40C pneumatic sprayer and analyzes the impact of the sprayer's forward speed, the airflow velocity at the sprayer's inlet, and the frequency of the sprayer's swinging nozzle on the spraying quality. The conclusion shows that: 1) the equation of the seed distribution trajectory of the sprayer was obtained, laying the foundation for subsequent research; 2) the swinging frequency of the nozzle is the key factor affecting the spraying quality of the sprayer, and the optimal swinging frequency of the nozzle corresponding to different forward speeds of the sprayer was obtained based on the established trajectory equation; 3) when the sprayer performs spraying operations with the optimized forward speed and swinging frequency, the trajectory of the sprayer's seed distribution was analyzed. It was found that when the nozzle swings at each optimal frequency, the trajectory of the seed distribution is the same, and the sum of the re-sprayed and missed areas in the seed distribution area is equal.

摘要
气力喷播机对退化草地进行植被修复的过程中，喷播机的工作参数，如喷播机姿态、工作气流和喷播量对喷播均匀性均有影响。本文以4BQD-40C 型气力喷播机为研究对象，分析喷播机前进速度、喷筒入口气流速度及喷筒摆动频率对喷播质量的影响。结论表明：1）得到了喷播机的落种轨迹方程，为后续研究奠定基础；2）得出喷筒摆动频率是影响喷播机喷播质量的关键因素，依据建立的轨迹方程对喷播机不同前进速度对应的喷筒摆动频率进行了优化，得到喷播机不同前进速度对应的喷筒最优摆动频率；3）当喷播机以优化后的前进速度与摆动频率进行喷播作业时，对喷播机的落种轨迹进行了分析，发现喷筒在各个最优摆动频率摆动时，种子的落种轨迹相同，且此时在落种区域内，重播、漏播面积之和相等。

INTRODUCTION
From the results of the preliminary spraying experiments, spraying operations are an efficient and fast technique for restoring grassland vegetation under natural climatic conditions. Significant research achievements have been made in the related studies on vegetation restoration on degraded grasslands using pneumatic sprayers *(Jin et al., 2023; Wang et al., 2015; Zhang et al., 2013; Xuan et al., 2016; Grella et al., 2020; Tai et al., 2022; Wang et al., 2023)*. However, in the process of using pneumatic sprayers for vegetation restoration on degraded grasslands, the impact of the sprayer's working parameters, such as the sprayer's attitude, working airflow, spraying amount, and their relationship with the existing vegetation coverage have not been fully considered. Although the reciprocating swinging spraying method of the 4BQD-40C sprayer nozzle can increase the operational range and spraying area, it also has a certain impact on the spraying quality. The spraying quality of the sprayer can be measured by the evenness of seed distribution in the seed distribution area, mainly manifested by the size of the re-sprayed and missed areas in the seed distribution area.

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The term "Replay seeding area" refers to the area where seeds have been sown more than once during the spraying operation, while "Missed seeding area" refers to the area where no seeds have been sown during the spraying operation (*Kang et al., 2019; Wu et al., 2022*). The main factors that affect the uniformity of seed sowing by the sprayer seeding machine are the forward speed of the machine, the air flow velocity at the nozzle inlet, and the oscillation frequency of the nozzle. Changing the air flow velocity and oscillation frequency of the nozzle based on the machine's different posture information is the most convenient and effective method to improve the quality of seed sowing by the sprayer seeding machine. This paper mainly studies the relationship between the forward speed of the 4BQD-40C sprayer seeding machine, the air flow velocity at the nozzle inlet, the oscillation frequency of the nozzle, and the areas of seed sowing with overlapping or missing seeds.

MATERIALS AND METHODS

Establish trajectory equation

The 4BQD-40C pneumatic sprayer seeding machine swings its spray nozzle back and forth around its center from 0 to 180 degrees during the seeding process to increase its coverage area, resulting in a complex seed drop trajectory. To study the seeding area of the machine, it is necessary to establish the seed drop trajectory equation first, and then analyze the seed drop area based on this equation *(Wang et al., 2012; Liu et al., 2020; Xing et al., 2020; Cujbescu et al., 2022).*

The forward travel speed of the sprayer seeding machine is v. The sprayer nozzle swings back and forth around its own center in the horizontal plane, with a swing angle ranging from 0 to 180 degrees. One swing cycle is completed when the nozzle swings back and forth once, and the swing frequency is denoted as n_b. Taking the opposite direction of the forward direction of the sprayer as the positive direction of the y-axis, and the limit position of the nozzle swinging counterclockwise as the positive direction of the x-axis, a coordinate system is established with the swinging center of the nozzle as the origin. The motion state of the seeds at the nozzle outlet is analyzed (*Akhalaya et al., 2021;* Cao *et al., 2023; Liao et al., 2022; Tabeei et al., 2021*).

The initial position of the nozzle is at the counter clockwise limit position, which coincides with the positive direction of the x-axis. The nozzle swings around its own center for one period T, and there are two different trajectories for the seeds, as shown in Fig. 1. In the first half period of swinging, the seed's trajectory is represented by curve AB, while in the second half period, the seed's trajectory is represented by curve BC. If the swinging angular velocity of the nozzle is ω, the spraying time is t, and the velocity of the seed at the nozzle outlet is v_r, then the angle between the nozzle and the positive x-axis during the swinging process is ω_t (*Zhang et al., 2012*).

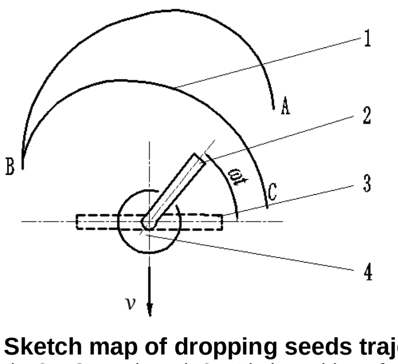


Fig. 1 - Sketch map of dropping seeds trajectory

1 – Trajectories for the seeds; 2 – Spray barrel; 3 – Limit position of spray barrel; 4 – Turntable

The initial position of the spray barrel is aligned with the positive direction of the x-axis, and the spray barrel swings in a counterclockwise direction, forming an acute angle λ with the x-axis. When the swing time is $t \in [\pi/2\omega, \pi/\omega]$, it can be obtained $\lambda=\omega t$, the seed velocity at the outlet of the spray barrel can be analyzed as shown in Fig. 2a. At this time, the partial velocity equation of the seed along the coordinate axis direction is:

$$\begin{cases} v_x = -v_r \cdot sin\omega t \\ v_y = v_r \cdot cos\omega t - v \end{cases} \tag{1}$$

When the swing time $t\in[\pi/2\omega, \pi/\omega]$, it can be obtained $\lambda=\pi-\omega t$, the seed velocity at the outlet of the spray barrel can be analyzed as shown in Fig. 2b. At this time, the partial velocity equation of the seed along the coordinate axis direction is:

$$\begin{cases} v_x = -v_r \cdot sin(\pi - \omega t) \\ v_y = -v_r \cdot cos(\pi - \omega t) - v \end{cases} \tag{2}$$

When the swing time $t\in[\pi/\omega, 3\pi/2\omega]$, it can be obtained $\lambda=\omega t-\pi$, the seed velocity at the outlet of the spray barrel can be analyzed as shown in Fig. 2c. At this time, the partial velocity equation of the seed along the coordinate axis direction is:

$$\begin{cases} v_x = v_r \cdot sin(\omega t - \pi) \\ v_y = v_r \cdot cos(\omega t - \pi) - v \end{cases} \tag{3}$$

When the swing time $t\in[3\pi/2\omega, 2\pi/\omega]$, it can be obtained $2\pi-\omega t$, the seed velocity at the outlet of the spray barrel can be analyzed as shown in Fig. 2d. At this time, the partial velocity equation of the seed along the coordinate axis direction is:

$$\begin{cases} v_x = v_r \cdot sin(2\pi - \omega t) \\ v_y = -v_r \cdot cos(2\pi - \omega t) - v \end{cases} \tag{4}$$

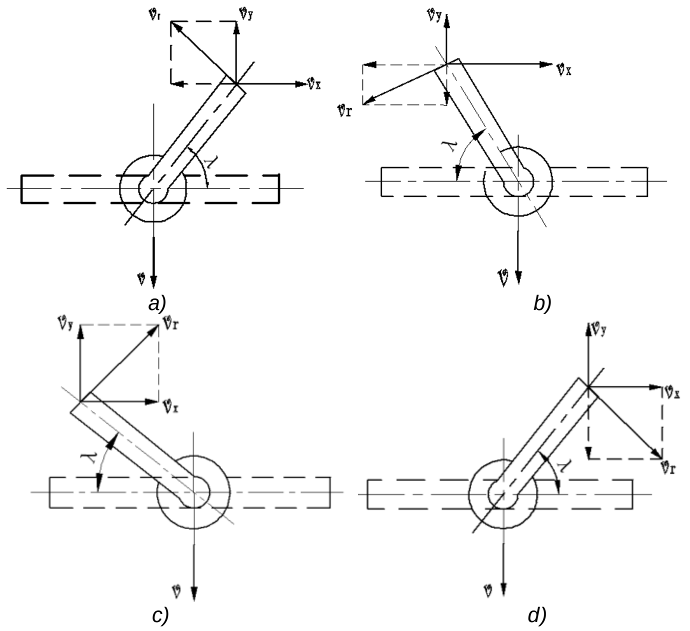


Fig. 2 - Diagram of the velocity analysis of the seed at the outlet of spray pipe

After sorting out Equations (1), (2), (3), and (4), the following equations can be obtained for the velocity of the seed at the outlet of the spray barrel. When $t\in[0, \pi/\omega]$, the trajectory of the nozzle barrel is shown in Section AB in Fig. 1, and the velocity equation of Equation (5) is obtained. When $t\in[\pi/\omega, 2\pi/\omega]$, the trajectory of the nozzle barrel is shown in Section BC in Fig. 1, and the velocity equation of Equation (6) is obtained:

$$\begin{cases} v_x = -v_r \cdot sin\omega t \\ v_y = v_r \cdot cos\omega t - v \end{cases} \tag{5}$$

$$\begin{cases} v_x = -v_r \cdot sin\omega t \\ v_y = -v_r \cdot cos\omega t - v \end{cases} \tag{6}$$

By integrating Equations (5) and (6), the following expression is obtained, where c_1 and c_2 are constants.

$$\begin{cases} x = v_r/\omega \cdot cos\omega t + c_1 \\ y = v_r/\omega \cdot sin\omega t - v \cdot t + c_2 \end{cases} \tag{7}$$

$$\begin{cases} x = v_r/\omega \cdot cos\omega t + c_1 \\ y = -v_r/\omega \cdot sin\omega t - v \cdot t + c_2 \end{cases} \tag{8}$$

Set the spray barrel length of the sprayer to l, while $x=l$, $v_r=\omega l$. At this point, $c_1=c_2=0$, so the trajectory equations for AB and BC segments are shown in Equation (9) and (10).

$$\begin{cases} x = l \cdot cos\omega t \\ y = l \cdot sin\omega t - v \cdot t \end{cases} \tag{9}$$

$$\begin{cases} x = l \cdot cos\omega t \\ y = -l \cdot sin\omega t - v \cdot t \end{cases} \tag{10}$$

Therefore, the trajectory equation of the seed with the spray barrel of the sprayer swinging back and forth for one cycle can be expressed as:

$$\begin{cases} x = l \cdot cos\omega t \\ y = |l \cdot sin\omega t| - v \cdot t \end{cases} \tag{11}$$

Analysis of seed falling area

Upon enlarging the trajectory of the seeds sprayed by the sprayer, it can be seen that the seed distribution area is enclosed by four curves, forming a belt-shaped pattern as shown in Fig. 3. The seed distribution area for one swing cycle of the nozzle barrel consists of eight curves. When the nozzle barrel transitions from counterclockwise swing to clockwise swing, the end curve of the first half cycle coincides with the start curve of the second half cycle, and they are the same curve. Therefore, the actual seed distribution area is composed of seven different curves. Based on Equation (11), the equation of each curve can be obtained as shown in Equations (12)-(18) (*Fan et al., 2013*).

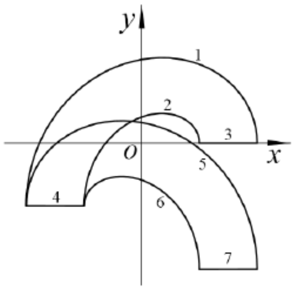


Fig. 3 - Diagram of the falling region

$$\begin{cases} x_1 = R \cdot cos\omega t \\ y_1 = R \cdot sin\omega t - v \cdot t \end{cases} \quad t \in (0, \tfrac{T}{2}) \tag{12}$$

$$\begin{cases} x_2 = r \cdot cos\omega t \\ y_2 = r \cdot sin\omega t - v \cdot t \end{cases} \quad t \in (0, \tfrac{T}{2}) \tag{13}$$

$$y_3 = -v \cdot t \quad t = 0, x \in [r, R] \tag{14}$$

$$y_4 = -v \cdot t \quad t = \tfrac{T}{2}, x \in [-r, -R] \tag{15}$$

$$\begin{cases} x_5 = R \cdot cos(\pi - \omega t) \\ y_5 = R \cdot sin(\pi - \omega t) - v \cdot t \end{cases} \quad t \in (\tfrac{T}{2}, T) \tag{16}$$

$$\begin{cases} x_6 = r \cdot cos(\pi - \omega t) \\ y_6 = r \cdot sin(\pi - \omega t) - v \cdot t \end{cases} \quad t \in (\tfrac{T}{2}, T) \tag{17}$$

$$y_7 = y_3 - v \cdot t \quad t = T, x \in [r, R] \tag{18}$$

In the equation, T is the swing period of the spray barrel, R is the distance from the outer edge of the seed landing area to the center of the spray barrel swing, and r is the distance from the inner edge of the seed landing area to the center of the spray barrel swing.

According to the above analysis, a GUI interface program is designed in Matlab software to draw the seed distribution area of the sprayer, as shown in Fig. 4.

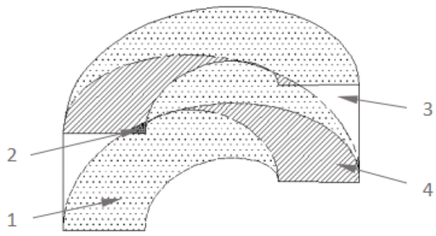


Fig. 4 - Sketch map of missing and broadcast area in seeding area

1 – Normal spraying area; 2 – Secondary spraying area; 3 – Missed spraying area; 4 – One spraying area

Based on the above analysis, a GUI program for designing the spray seeding area was developed in Matlab software, as shown in Fig. 4. To analyze the re-seeding and missed seeding areas in the seeding area, the curve intersection method was used to determine the re-seeding and missed seeding areas in the seeding area. From Fig. 4, it can be seen that in one swing cycle of the nozzle, there are normal seeding areas, re-seeding areas, and missed seeding areas, and these areas appear twice symmetrically in one swing cycle. Since the shapes of the re-seeding and missed seeding areas are irregular, the calculus method of finding the area of a rectangle was used to calculate the re-seeding and missed seeding areas in the spray seeding area.

For ease of calculation, the coordinates of the leftmost and rightmost projections of the seeding area onto the x-axis are [-R, R]. Then, the seeding area is divided into n equal parts, with an integration step size of h is:

$$h = \frac{R-(-R)}{n} \tag{19}$$

The area of replanting and missed seeding in the seed falling area is:

$$S = h\sum_{i=1}^{m}|f_i(x) - f_{i+1}(x)| \tag{20}$$

In the equation, $f_i(x)$ represents the outer boundary curve equation of the seed falling area in the second half of the swing cycle, $f_{i+1}(x)$ represents the inner boundary curve equation of the seed falling area in the first half of the swing cycle, and x represents the horizontal coordinate value of the spray range (*Fan et al., 2013*).

Analysis of seed drop uniformity

As shown in Fig. 4, uneven seeding areas such as replanting and missed seeding appear in the seed falling area, mainly caused by the combined motion of the swinging of the spray barrel and the forward movement of the sprayer. Therefore, the relationship between the frequency of the spray barrel swing and the forward speed of the sprayer has a significant impact on the area of replanting and missed seeding in the seed falling area.

Based on the established trajectory equation and seed falling area of the sprayer, and with the forward speed of the sprayer fixed, the replanting and missed seeding areas were calculated for different swing frequencies of the spray barrel, and the minimum total area of replanting and missed seeding was found. This corresponded to the optimal swing frequency of the spray barrel for the given forward speed, thus achieving optimization of the swing frequency. Before optimization, the relationships between the forward speed of the sprayer, swing frequency of the spray barrel, and the total area of replanting and missed seeding were established separately. Then, a unified relationship was established using optimization methods.

The optimization variables are the nozzle oscillation frequency n_b and the forward speed of the sprayer v, with the minimum total area of replanting and missed seeding in the seed falling area as the optimization objective. During the optimization process, the area of the replanting region is denoted as S_C, and the area of the missed seeding region is denoted as S_L, both in units of square meters. The optimization function is given by equation (21) (*Chen et al., 2018*).

$$S(v, n_b) = S_c + S_L \tag{21}$$

Based on the actual situation, the following constraints are set for the objective function:

● The proportion of replanting area to the total seed falling area should be less than or equal to 20%.

● The proportion of missed seeding area to the total seed falling area should be less than or equal to 20%.

● According to the literature, the maximum speed of a tractor in the field is 20 km/h, which is equivalent to a maximum speed of 5.6 m/s. Therefore, only forward speeds of 0~6 m/s are considered in optimizing the nozzle oscillation frequency.

● The oscillation frequency of the nozzle should be less than or equal to 20 min^{-1}, which is determined by the motor speed and transmission ratio.

For the convenience of optimizing the swing frequency of the nozzle, various parameters are set on the Matlab GUI program interface. At the same time, the calculated optimal swing frequency of the nozzle and the minimum replanting and missed seeding area are displayed on the GUI interface (Fig. 5).

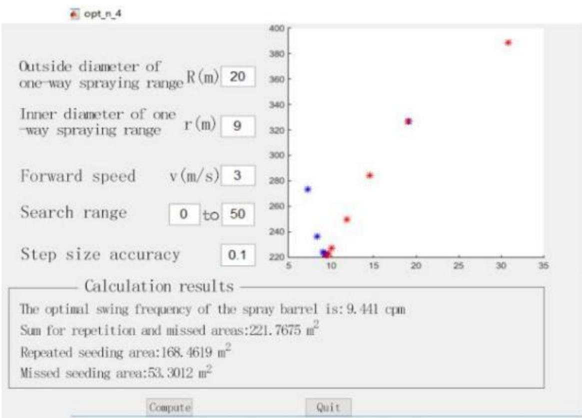


Fig. 5 - Optimization of GUI program interface for swinging frequency of spray cylinder

The optimization of the spraying tube swing frequency was conducted for different forward speeds of the sprayer seeding machine. The relationship between the optimal swing frequency of the spraying tube and different forward speeds of the sprayer seeding machine is shown in Table 1.

Table 1

Optimal swing frequency of spray cylinder corresponding to different forward speeds

Forward speed [m/s]	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6
Swing frequency [rpm]	1.6	3.1	4.7	6.3	7.8	9.4	11.1	12.6	14.2	15.7	17.3	18.9

According to Table 1, the optimal frequency of the nozzle swing is proportional to the forward speed of the sprayer. Furthermore, it was found through analysis of the seed falling trajectory that the optimal frequency corresponding to the optimized seed falling trajectory results in the same area of replanting and missed seeding. Therefore, verification of the spraying swing under a commonly used working speed is sufficient.

Seed falling uniformity test

The experimental site was selected in a relatively flat soil field at Inner Mongolia Agricultural University. The experiment was conducted under the condition of wind speed less than 1 m/s and temperature of 15-20℃. The experimental equipment used in this experiment was 4BQD-40C pneumatic seeder (as shown in Fig. 6), several packages of coated rye grass seeds, a TSI 9565-P multifunctional anemometer, a hot wire anemometer probe, a tape measure, a stopwatch, and several bags of white powder.

Fig. 6 - 4BQD-40C type pneumatic sprayer seeding machine

Check the components of the sprayer to ensure that they are in good condition during operation. Choose a relatively flat soil site for the experiment to ensure that the seeds sprayed land smoothly on the ground and there is minimal splashing, which can reflect the actual working conditions of the sprayer. Count the amount of seeds in the seeding area, record the area of the replay and leakage in the seeding area, and compare the data obtained from the experiment with the simulated data to obtain the optimal swing frequency of the nozzle corresponding to different forward speeds of the sprayer.

Before the experiment, the working area was divided into a grid using a tape measure and white powder. The grid size was: 2m x 2m and the grid size of the total seed drop area was: 40m x 40m. The centerline of the total seeding area was selected as the position of the sprayer, and the grid edges were numbered for later statistical analysis. In this experiment, the sprayer was tested at forward speeds of 0.3 m/s and 0.5 m/s with different optimal nozzle swing frequencies (as shown in Table 2).

Table 2

The sprayer seeding machine speed is 0.3 m/s and 0.5 m/s, corresponding frequency of the spray cylinder swing

Forward speeds [m/s]	**Swing frequencies 1 [rpm]**	**Swing frequencies 2 [rpm]**	**Swing frequencies 3 [rpm]**	**Swing frequencies 4 [rpm]**	**Swing frequencies 5 [rpm]**
0.3	0.75	0.84	0.94	1.02	1.11
0.5	1.25	1.40	1.57	1.70	1.85

Before starting the experiment, the following steps were taken:

● Set the inlet air velocity of the nozzle to 50 m/s using the frequency converter.

● Adjust the seeding rate to 0.63 rpm.

● Set the frequency of the frequency converter according to the corresponding values in Table 3 obtained from Equation (22).

● Adjust the initial position of the nozzle to its counterclockwise limit position.

● Adjust the forward speed of the sprayer to 0.3 m/s.

● Set the distance from the starting position of the sprayer to the edge of the grid behind the sprayer to be 20 m, as the maximum seeding distance is 20 m when the inlet air velocity of the nozzle is 50 m/s.

● Set the centerline of the grid as the predefined path of the sprayer (Fig. 7) and determine the end position of the sprayer according to Equation (23).

$$f = 50 \cdot \frac{n_b}{n_0 \cdot i} \tag{22}$$

$$s = v \cdot T = v \cdot \frac{60}{n_b} \tag{23}$$

The formula is as follows: n_b is the oscillation frequency of the spray nozzle of the sprayer; n_0 is the rated speed of the motor that drives the nozzle oscillation, n_0= 2840 rpm; i is the transmission ratio, and the motor and nozzle are connected by a gear transmission, i = 1/60; T is the oscillation period of the nozzle.

Table 3

Frequency of frequency converter corresponding to different spray cylinder swings

Swing frequencies [rpm]	0.75	0.84	0.94	1.02	1.11	1.25	1.40	1.57	1.70	1.85
Converter frequency [Hz]	0.80	0.89	1.00	1.08	1.18	1.33	1.48	1.66	1.80	1.96

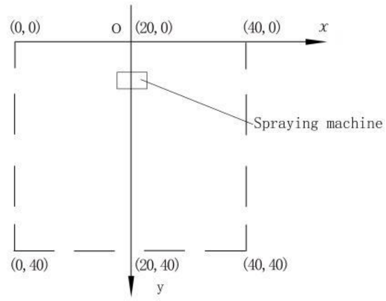


Fig. 7 - Predefined path schematic of a sprayed machine

During the experiment, the sprayer seeding machine traveled at a constant speed along a pre-defined path according to the set forward speed. At the start position for spraying, the aerial sprayer seeding machine was activated, and the seeding motor was started along with the swinging of the nozzle. The sprayer seeding machine stopped working after one cycle of nozzle swinging, and the experimental data was then collected. The ground seeds were cleaned up after the data collection was completed, preparing for subsequent experiments. Five experiments were conducted with varying frequencies of nozzle swinging while the sprayer seeding machine was traveling at a speed of 0.3 m/s. The experimental process at a forward speed of 0.5 m/s was identical to that at a forward speed of 0.3 m/s, except for the change in nozzle swinging frequency.

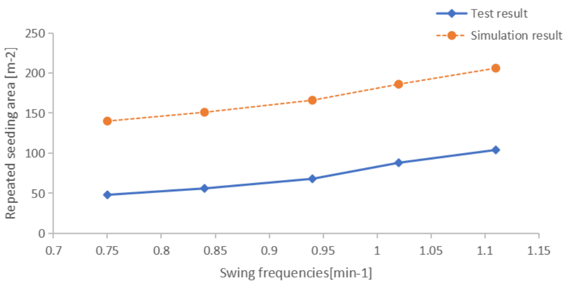
RESULTS

The experimental analysis record table was identical to the ground grid used during the experiment. During the experiment, the seeding amount in each grid was recorded when the sprayer seeding machine was traveling at a speed of 0.3 m/s. The experimental data and simulation results were analyzed and the analysis results are shown in Table 4. During the experiment, the re-seeding and leakage areas of the spraying region were calculated. The leakage area was defined as the grid area with a seeding amount of 0, while the re-seeding area was defined as the grid area with a seeding amount greater than the average seeding amount of the spraying region. The experimental results were compared with the simulation analysis results, as shown in Fig. 8.

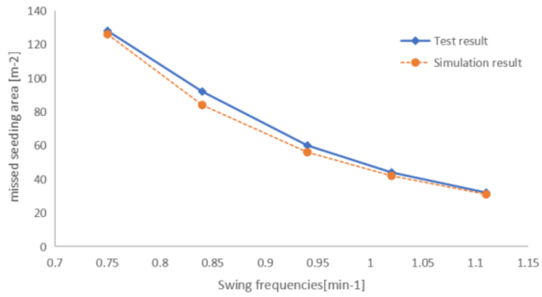
Table 4

Results of reseeded and missed areas at different oscillation frequencies when the sprayer forward speed is 0.3m/s.

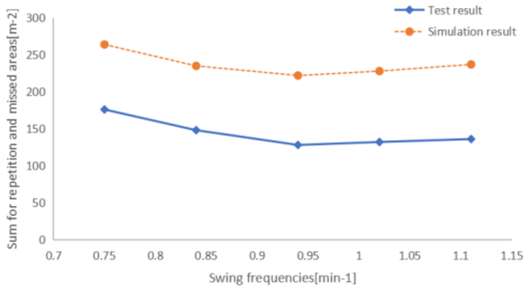
Swing frequencies [rpm]	Repeated seeding area of the test [m^2]	Missed seeding area of the test [m^2]	Sum for repetition and missed areas of the test [m^2]	Repeated seeding area of the simulation [m^2]	Missed seeding area of the simulation [m^2]	Sum for repetition and missed areas of the simulation [m^2]
0.75	48	128	176	140	126	264
0.84	56	92	148	151	84	235
0.94	68	60	128	166	56	222
1.02	88	44	132	186	42	228
1.11	104	32	136	206	31	237



a) Comparison of repeat sowing area



b) Comparison of missed sowing area



c) Comparison of the sum of repeated and missed sowing areas

Fig. 8 - Comparison of rebroadcast and missed area results when the speed is 0.3 m/s

From Fig. 8, it can be observed that as the frequency of nozzle swinging increases, the re-seeding area of the spraying region increases while the leakage area decreases. When the frequency of nozzle swinging is 0.94 rpm, the sum of the re-seeding and leakage areas is minimized. At this frequency, the seed distribution in the spraying region is relatively even. This result is consistent with the simulation analysis, which found that the optimal frequency of nozzle swinging for a sprayer seeding machine traveling at a speed of 0.3 m/s is 0.94 rpm, thus validating the correctness of the simulation analysis. However, Fig. 8 also shows that there is a certain difference between the re-seeding and leakage areas obtained from the experimental data and the simulation analysis results, which is mainly due to statistical errors. Nevertheless, the overall trend of the results is similar.

Simultaneously, the recorded data for the sprayer seeding machine traveling at a speed of 0.5 m/s shows the seed distribution in each grid of the experimental area obtained by changing the frequency of nozzle swinging. The experimental results are analyzed and compared with the simulation results in Table 5. When the sprayer seeding machine travels at a speed of 0.5 m/s, both the simulation and experimental results show that the re-seeding area in the spraying region increases with the increase of nozzle swinging frequency while the leakage area decreases. At the optimal frequency of nozzle swinging, the sum of the re-seeding and leakage areas is minimized. This result is consistent with the analysis results obtained when the sprayer seeding machine travels at a speed of 0.3 m/s.

Table 5

Results of reseeded and missed areas at different oscillation frequencies when the sprayer forward speed is 0.5m/s

Swing frequencies [rpm]	Repeated seeding area of the test [m^2]	Missed seeding area of the test [m^2]	Sum for repetition and missed areas of the test [m^2]	Repeated seeding area of the simulation [m^2]	Missed seeding area of the simulation [m^2]	Sum for repetition and missed areas of the simulation [m^2]
1.25	40	140	180	141	119	260
1.40	44	100	144	151	83	234
1.57	60	64	124	168	54	222
1.70	80	52	132	181	45	226
1.85	100	36	136	200	36	236

Reseeded and missed area after spray canister operation at an optimum oscillation frequency of 0.94 rpm with a sprayer advance speed of 0.3 m/s. This was compared with the reseeded and missed area after the spray barrel was operated at an optimum oscillation frequency of 1.57 rpm at a forward speed of 0.5 m/s of the sprayer. The results are shown in Table 6. Table 6 shows that when the forward speed of the spreader is changed and the spray nozzle is operated at the corresponding optimum oscillation frequency, the sum of the reseeded missed areas obtained statistically in the seed drop area is essentially equal and the seed drop trajectories are similar, which is consistent with the conclusions obtained from the simulation.

Table 6

Comparison of replanting and missing area in the falling area when the forward speed is 0.3 m/s and 0.5 m/s

Forward speeds [m/s]	Repeated seeding area of the test [m^2]	Missed seeding area of the test [m^2]	Sum for repetition and missed areas of the test [m^2]
0.3	68	60	128
0.5	60	64	124

CONCLUSIONS

Spraying quality is an important indicator for evaluating the spraying performance of a sprayer seeding machine. Through simulation analysis, numerical simulation, and experimental analysis, the factors affecting the spraying quality of the sprayer seeding machine were analyzed, and the following conclusions were drawn:

(1) Analyzing the seed trajectory of the spray seeder, an equation for the seed trajectory was obtained, laying the foundation for subsequent research.

(2) By analyzing the influence of the swing frequency of the nozzle on the spray quality of the spray seeder, the optimal swing frequency of the nozzle corresponding to different forward speeds of the spray seeder was obtained through optimization based on the established trajectory equation.

(3) When the spray seeder performs seeding operations at the optimized forward speed and swing frequency of the nozzle, an analysis of the seed trajectory was conducted. It was found that when the nozzle swings at various optimal frequencies, the seed trajectory remains the same, and the sum of the areas of over-seeding and under-seeding is equal within the seeding area.

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