DESIGN AND EXPERIMENTAL STUDY ON FERTILIZATION PERFORMANCE OF CRANK ROCKER DEEP APPLICATION MECHANISM
/
曲柄摇杆式深施机构的设计与施肥性能试验研究

Jinlong FENG[1*)], Dongxue CHEN[2)], Qichao LI[1)], Hua LI[1)]
[1)] College of Mechanical and Electrical Engineering, Lingnan Normal University; Zhanjiang 524048, China
[2)] Teacher education college, Lingnan Normal University; Zhanjiang 524048, China
*Corresponding author's E-mail: 37002165@qq.com
DOI: https://doi.org/10.35633/inmateh-73-44

Keywords: *crank rocker arm; deep implementation institutions; spray hole diameter; experimental research; pump pressure; fertilizer*

ABSTRACT
In response to the poor fertilization performance of the deep application mechanism of the deep application liquid fertilizer applicator under multiple parameters, the fertilization variation of the crank rocker deep application mechanism under multiple working parameters is explored. To obtain the fertilization variation of the crank rocker deep application mechanism, a fertilization performance test bench for the crank rocker deep application mechanism is developed. On this test bench, the crank speed, liquid pump pressure, and spray hole diameter are used as experimental factors, and fertilizer application rate is used as experimental indicators. A composite design scheme of rotation center is adopted to establish a relationship model and response surface diagram between experimental influencing factors and influencing indicators. Design Expert 8.0.10 software is used to analyze and optimize the experimental data. The optimal results are a crank speed of 145.80 r/min, a liquid pump pressure of 0.25 MPa, a spray hole diameter of 3.02 mm, a fertilizer application rate of 28.6 mL, and a fertilizer loss rate of 1.95%. At this time, the fertilization performance of the mechanism is optimal. This parameter combination is applied for testing and verification to verify its rationality. The results can ensure that the crank rocker deep application mechanism has good working performance when working under multiple parameters, providing theoretical reference for designing deep application liquid fertilizer machines with simple structure and optimal fertilization performance.

摘要
针对深施型液态施肥机的深施机构多参数下施肥性能差等问题，探索了多工作参数下的曲柄摇杆式深施机构施肥变化规律，为了得到曲柄摇杆式深施机构的施肥变化规律，研制了曲柄摇杆式深施机构的施肥性能试验台。在该试验台上以曲柄转速、液泵压力和喷孔直径为试验因素，施肥量为试验指标，采用旋转中心复合设计方案，建立试验影响因素和影响指标的关系模型及响应曲面图，并运用 Design-Expert 8.0.10 软件对试验数据进行分析和优化，最优结果：曲柄转速为 145.80 r/min、液泵压力为 0.25 MPa、喷孔直径 3.02 mm、施肥量为 28.6 mL 和施肥损失率为 1.9%，此时机构施肥性能最优，应用此参数组合进行测试验证，验证了其合理性。该研究结果可保证曲柄摇杆式深施机构在多参数下工作时，机具具有良好的工作性能，为设计结构简单且具有较好施肥性能的深施型液态施肥机提供理论参考。

INTRODUCTION
With the promotion and popularization of liquid fertilizers, deep application liquid fertilizing machines with high fertilizer efficiency have been widely recognized and applied. The deep application mechanism is an important working component of the deep application liquid fertilizer applicator, which is the executing component of deep application of liquid fertilizer into the soil. Its fertilization directly affects the quality and efficiency of fertilization *(da Silva and Magalhães, 2019; Sharma and Khar, 2022; Ramarao et al., 2024).* A well performing deep application mechanism can reduce the impact of soil on the deep application mechanism, thereby ensuring the trajectory posture of the fertilizer spraying needle entering the soil and improving the fertilization performance of the mechanism.

Jinlong Feng, Lecturer, Ph.D.; Dongxue Chen, assistant engineer, Ph.D.; Qichao Li, Associate professor, Ph.D.; Hua Li, professor, Ph.D.

At present, the deep application mechanism of the deep application liquid fertilizer applicator mainly proposes three forms of deep application mechanisms: elliptical gear planetary system, fully elliptical gear planetary system, and non-circular gear planetary system *(Wafiqah et al., 2024; Gilvan et al., 2023; Wang et al., 2022).* Kinematic and simulation analysis, structural optimization, and corresponding bench tests have been conducted on the three mechanisms. After optimization, although the inertia force of the three mechanisms has decreased and the number of punctures per unit time has increased, the machining accuracy requirements are high, especially for the relative position between the planetary carrier and the gear shaft. This has resulted in an increase in the machining cost of the deep application mechanism, and the fertilizer loss rate is still high *(Wang et al 2022; Chen et al 2023; Zhou et al 2023)*. Therefore, on the premise of further reducing the fertilizer loss rate, a crank rocker deep application mechanism is proposed. It uses the insertion mechanism of the transplanting machine as the research and development basis of the crank rocker deep application mechanism. Utilizing the trajectory characteristics of the crank rocker mechanism, the verticality of the deep application mechanism into the soil is further improved, thereby reducing fertilizer loss and processing costs. Indoor bench tests were conducted on the deep application mechanism device, using response surface design method to fit the functional relationship between factors and response values, and analyzing the regression equation to seek the optimal process parameters, providing a reference for the design and optimization of deep application liquid fertilizer equipment.

MATERIAL AND RESEARCH METHODS

The overall structure of the crank rocker depth application mechanism

The deep application mechanism is an important executing component of the deep application liquid fertilizer applicator. Based on the operating characteristics of the deep application liquid fertilizer applicator, the deep application mechanism is designed in the form of a crank rocker, consisting of a front swing arm spindle seat *2*, a crank *4*, a fertilizer spray needle *5*, and other parts. The structure is shown in Fig. 1.

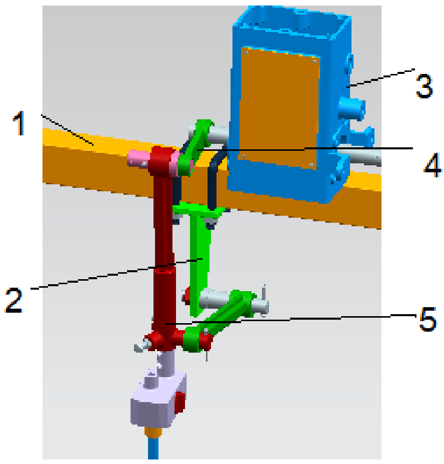

Fig. 1 - Schematic diagram of deep application mechanism
1.Main beam, 2. Front swing arm spindle seat, 3. Spray automatic control valve, 4. Left crank arm, 5. Fertilization spray needle assembly

The rotation of the shaft of the spray control valve *3* drives the rotation of the crank *2*, which in turn drives the movement of the fertilizer spraying needle. The trajectory of the fertilizer spraying needle meets the requirements of deep fertilization. The movement of the fertilizer spraying needle causes the front swing arm spindle seat *2* to swing slightly, and the fertilizer spraying needle deeply applies liquid fertilizer to the soil, thereby achieving the deep application of liquid fertilizer. The power of the crank rocker deep application mechanism is transmitted to the crank through the transmission system. Through the rotational motion of the crank, the reciprocating motion of the rocker is driven to achieve the up and down movement of the spray needle, completing piercing and fertilizing. According to agricultural requirements, the depth of liquid fertilizer application is around 100-130 mm. Therefore, the deep application mechanism is designed to ensure that the spraying point of the needle is within the spraying zone of 70-120 mm below the surface. Due to the ease of penetration of the fertilizer spraying needle into the soil, a 30 mm needle tip is welded below the spraying area, which not only facilitates penetration into the soil but also reduces the risk of clay formation when the needle moves upward. Each nozzle has two liquid outlet holes, reducing the number of spray needles and improving work efficiency.

Test equipment

To study the fertilization performance of the crank rocker deep application mechanism under the combinations of certain performance parameters, a liquid fertilizer deep application test bench is designed. The test bench is shown in Fig. 2.

The liquid fertilization test device mainly consists of components such as *1*: the motor that drives the pump, *2*: the piston pump, *3*: the fertilizer spraying needle, *4*: the crank, *5*: the self-control spraying system, 6: the fertilizer tank, *7*: the motor that drives the small sprocket, and *8*: the frequency converter. The deep construction mechanism is the main working component. The working process is as follows: after the three-phase asynchronous motor that drives the pump starts, the liquid pump begins to work. At this time, the flow path of liquid fertilizer is from the liquid fertilizer tank through the outlet pipe to the liquid pump. After being pressurized by the liquid pump, it becomes a high-pressure liquid and passes through the pipeline system to the automatic spraying system. After passing through the automatic spraying system, the liquid fertilizer is finally applied to the soil through the crank rocker hole digging fertilization mechanism.

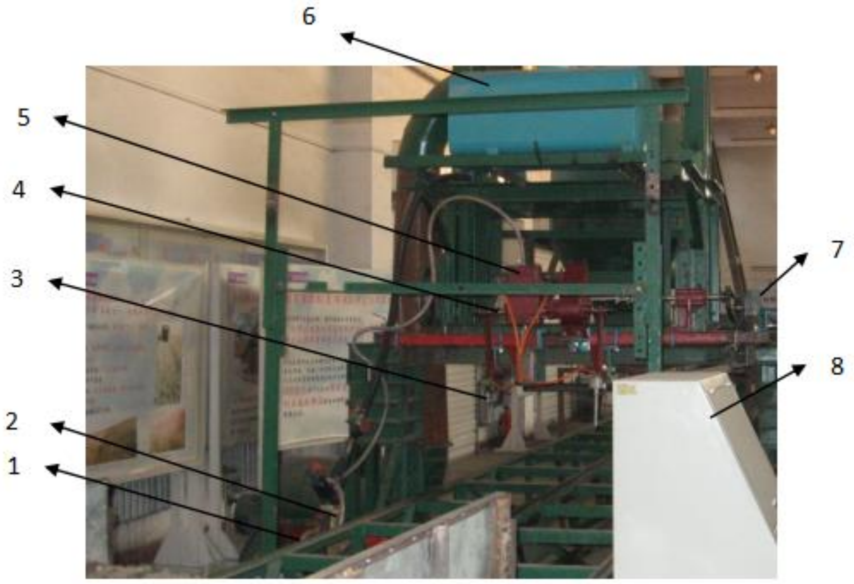

Fig. 2 - Test bench of the crank rocker deep application mechanism

1. Motor that drives the pump, 2. Piston pump, 3. Fertilizer spraying needle, 4. Crank, 5. Self-controlled spray system, 6. Fertilizer box, 7. Motor that drives the sprocket, 8. Frequency converter

Test design

The fertilization amount and fertilization loss rate are indicators for evaluating the fertilization performance of deep application mechanisms. The main working parameters that affect fertilization include liquid pump pressure, spray hole diameter, and crank speed. The above three factors are determined as experimental factors of fertilization. Single-factor and three-factor five level quadratic rotation orthogonal experimental designs are adopted, and the experimental coding table is shown in Table. 1. Design expert 8. 0. 10 is used to process experimental data and analyze the impact of various factors on the fertilizer application rate and fertilizer loss rate of deep application mechanisms *(Wang et al., 2023; Zhang et al., 2021; Yang et al., 2023).*

Table 1

Test level coding table

Coding value	Pump pressure / MPa	Spray hole diameter / mm	Crank speed / r/min
Upper star arm (1.68)	0.23	4.6	167
Higher level (1)	0.3	4	150
Zero level (0)	0.4	3	125
Lower level (-1)	0.5	2	100
Lower level (-1.68)	0.57	1.3	83

RESULTS AND ANALYSIS

Single-factor experiment

When the crank speed is 125 r/min and the nozzle diameter is 3 mm, the effect of liquid pump pressure on fertilizer application rate is studied. The five levels of experimental factors are 0.2 MPa, 0.3 MPa, 0.4 MPa, 0.5 MPa and 0.6 MPa, respectively.

Five repeated experiments at each level are conduced, totaling 25 experiments. Design expert 8. 0. 10 is used to analyze the experimental data, and the relationship curve between liquid pump pressure and fertilizer application rate is shown in Fig. 3.

As shown in Fig. 3, when the crankshaft speed and nozzle diameter are constant and the liquid pump pressure varies in the range of 0.2 - 0.6 MPa, the applied fertilizer increases as the pressure increases. The reason is that the crankshaft speed and the key component cam speed of the distributor are the same during the fertilization. Therefore, when using the deep injection mechanism for fertilization, the opening and closing duration of the distribution valve remains unchanged, and the fertilizer gradually increases as the liquid pump pressure increases.

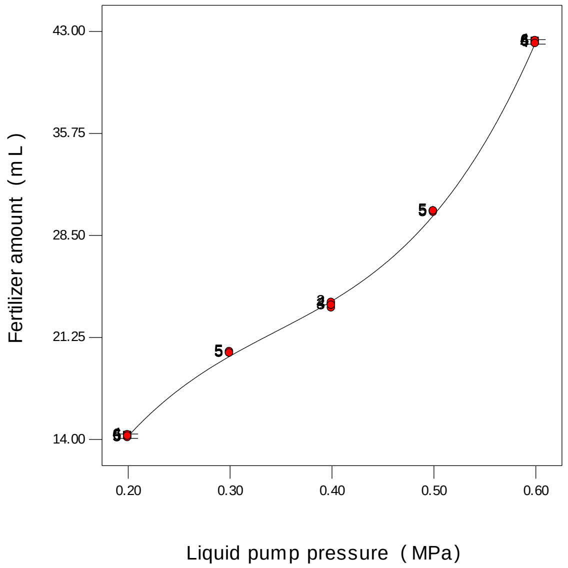

Fig. 3 - The effect of liquid pump pressure on fertilizer application rate

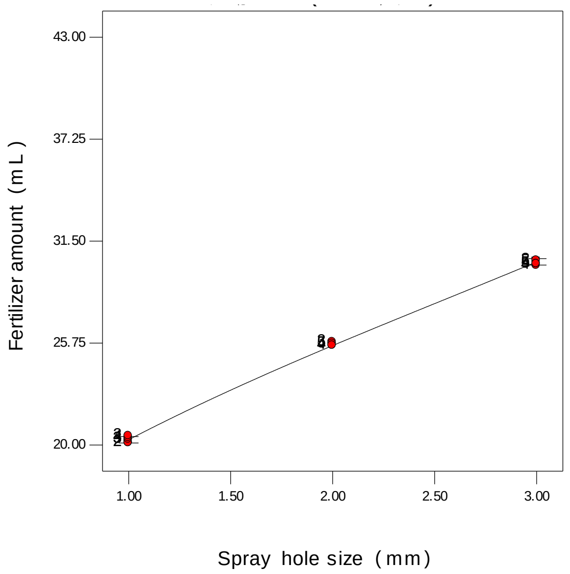

Fig. 4 - The influence of spray hole diameter on fertilizer application rate

When the crank speed is 125 r/min and the liquid pump pressure is 0.4 MPa, the influence of spray hole diameter on fertilizer application rate is studied. The five levels of experimental factors are 1 mm, 2 mm, 3 mm, 4 mm and 5 mm, respectively. 5 repeated experiments at each level are conducted, totaling 25 experiments. Design expert 8. 0. 10 is used to analyze the experimental data, and the relationship curve between the diameter of the spray hole and the fertilizer application rate is shown in Fig. 4.

As shown in Fig. 4, when the crank speed and liquid pump pressure are constant and the spray hole diameter varies in the range of 1-5 mm, the applied fertilizer increases with the increase of diameter. The reason is that the pressure of the liquid pump and the opening and closing duration of the distribution valve remain unchanged, and the fertilizer gradually increases with the increase of the spray hole diameter.

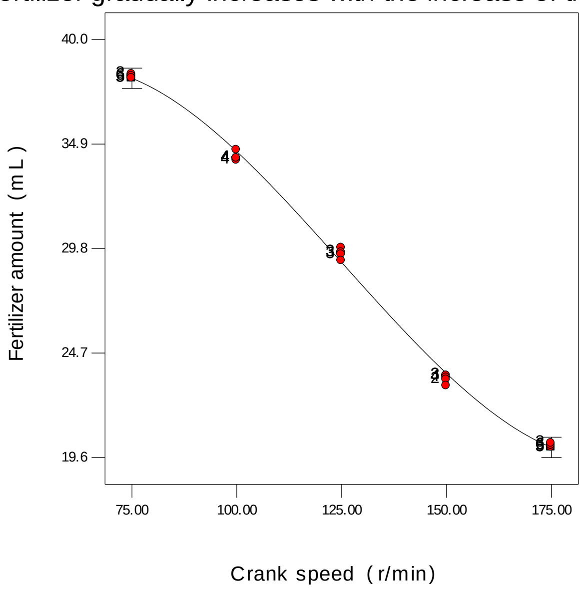

Fig. 5 - The influence of crank speed on fertilizer application rate

When the spray hole diameter is 3 mm and the liquid pump pressure is 0.4 MPa, the effect of crank speed on fertilizer application rate is studied. The five levels of experimental factors are 100 r/min, 125 r/min, 150 r/min, 175 r/min, and 200 r/min, respectively. 5 repeated experiments at each level are conducted, totaling 25 experiments. Design expert 8. 0. 10 is used to analyze the experimental data, and the relationship curve between crank speed and fertilizer application rate is shown in Fig. 5.

From Fig. 5, it can be seen that when the spray hole diameter and the liquid pump pressure are constant and the crankshaft speed varies in the range of 75-175 r/min, the applied fertilizer decreases with the increase of the speed. The reason is that the pressure of the liquid pump and the diameter of the spray hole remain unchanged. As the crankshaft speed increases, the opening and closing duration of the distribution valve will gradually decrease, and the fertilizer will also gradually decrease.

Multi-factor experiment

On the basis of a single factor, an orthogonal rotation experiment is conducted, and the experimental scheme and results are shown in Table. 2. Design expert 8. 0. 10 is used to analyzed the experimental data in Table. 2, and the response surfaces of the effects of liquid pump pressure and spray hole diameter, liquid pump pressure and crank speed, and spray hole diameter and crank speed on fertilizer application rate are shown in Figs. 6, 7, and 8, respectively. The response surfaces of the effects of liquid pump pressure and spray hole diameter, liquid pump pressure and crank speed, and spray hole diameter and crank speed on fertilizer loss rate are shown in Figs. 9, 10, and 11, respectively. The multi-factor variance analysis is shown in Tables. 3 and 4 *(Rubeis et al., 2024; Sommermann and Cartmell, 2024; Riess, 2023).*

When the significance level is $F_{0.05}$, as shown in Table 3, the effects of x_1, x_2, x_3, x_1^2 and x_2^2 on fertilizer are significant, and are the effective items of the model. After removing insignificant terms, the fitted regression equation is as follows:

$$y_1 = 59.735 - 140.546x_1 - 4.849x_2 - 0.3742x_3 + 311.06x_1^2 + 4.098x_2^2 \quad (1)$$

When the significance level is $F_{0.05}$, as shown in Table 4, the effects of x_1, x_2, x_3, x_1^2 and x_2^2 on fertilizer are significant, and are the effective items of the model. After removing insignificant terms, the fitted regression equation is as follows:

$$y_2 = 28.37 + 10.92x_1 + 1.67x_2 - 0.72x_3 - 0.50x_1x_3 + 50.15x_1^2 + 0.0051x_3^2 \quad (2)$$

Table 2

Secondary rotation orthogonal experiment scheme and results

No.	Experimental factors			Performance indexes	
	Pump pressure x_1 / MPa	Spray hole diameter x_2 / mm	Crank speed x_3 / r·min^{-1}	Fertilizer y_1 / mL^{-1}	Fertilizer loss rate y_2 / %
1	-1	-1	-1	22.2	1.2
2	1	-1	-1	42.9	2.9
3	-1	1	-1	31.4	1.2
4	1	1	-1	56.4	4.5
5	-1	-1	1	16.2	4.3
6	1	-1	1	36.9	3.2
7	-1	1	1	25.3	1.8
8	1	1	1	50.3	4.2
9	-1.68	0	0	20.6	2.7
10	1.68	0	0	54.2	5.4
11	0	-1.68	0	21.5	1.1
12	0	1.68	0	41.5	4.1
13	0	0	-1.68	36.8	1.1
14	0	0	1.68	20.8	5.2
15	0	0	0	30.5	2.3
16	0	0	0	29.5	2.7
17	0	0	0	30.5	2.2
18	0	0	0	29.5	2.3
19	0	0	0	29.5	2.9
20	0	0	0	30.0	2.8
21	0	0	0	29.5	2.4
22	0	0	0	30.5	2.5
23	0	0	0	31.0	2.6

Table 3

Variance analysis of the influence of various factors on fertilizer application rate

Sources	Square sum	Degree of freedom	F-value	Significance (P>F)
Model	2427.33	9	88.87	<0.0001
x_1	455.09	1	149.96	<0.0001
x_2	1601.90	1	527.84	<0.0001
x_3	191.27	1	63.03	<0.0001
x_1x_2	9.24	1	3.05	0.1045
x_1x_3	0.01	1	0.000	0.0946
x_2x_3	0.0.3	1	0.003	10.9682
x_1^2	153.79	1	50.68	<0.0001
x_2^2	16.70	1	5.50	0.0355
x_3^2	0.079	1	0.026	0.8743
Errors	39.45	13		
Sum	2466.78	22		

Table 4

Analysis of variance on the impact of various factors on fertilizer loss rate

Sources	Square sum	Degree of freedom	F-value	Significance (P>F)
Model	56.72	9	19.96	< 0.0001
x_1	16.67	1	52.78	< 0.0001
x_2	9.50	1	30.09	0.0001
x_3	19.16	1	60.69	< 0.0001
x_1x_2	0.61	1	1.92	0.1896
x_1x_3	0.85	1	6.33	0.0258
x_2x_3	0.85	1	2.68	0.1258
x_1^2	4.01	1	12.65	0.0035
x_2^2	0.019	1	0.063	0.9378
x_3^2	4.0	1	12.65	0.0035
Errors	4.10	13		
Sum	60.82	22		

As shown in Fig. 6, when the spray diameter is constant and the liquid pump pressure varies in the range of 0.1-0.6 MPa, the applied fertilizer gradually increases with the increase of liquid pump pressure. When the pressure of the liquid pump is constant and the diameter of the spray hole varies in the range of 1-5 mm, the applied fertilizer gradually increases with the increase of the spray hole diameter. The response surface changes faster in the direction of the spray hole diameter than the liquid pump pressure. According to Table. 3, the F value of the effect of liquid pump pressure on fertilizer application y_1 is 149.96, and that of spray hole diameter on fertilizer application y_1 is 527.84. Therefore, the influence of spray hole diameter on fertilizer application is greater than that of liquid pump pressure.

From Fig. 7, it can be seen that when the liquid pump pressure is constant and the crank speed varies in the range of 100-150 r/min, the applied fertilizer gradually decreases with the increase of crank speed. When the crankshaft speed is constant and the liquid pump pressure varies in the range of 0.1-0.6 MPa, the fertilizer application rate gradually increases with the increase of pressure. The response surface changes faster in the direction of pump pressure than the crankshaft speed.

According to Table 3, the F value of the effect of crank speed on fertilizer application y_1 is 63.03, and that of liquid pump pressure on fertilizer application y_1 is 149.96. Therefore, the influence of liquid pump pressure on fertilizer application is greater than that of crank speed.

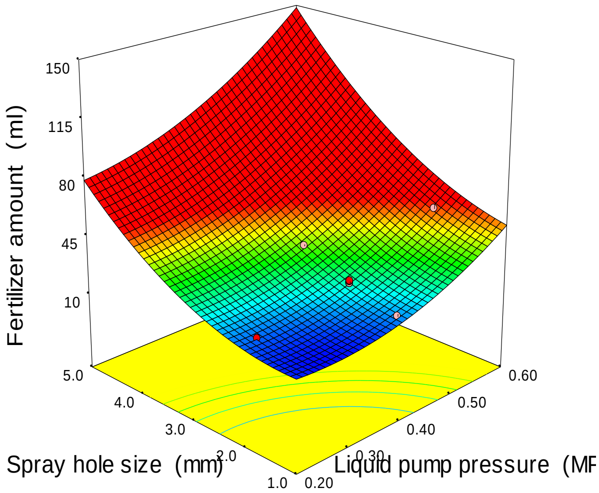

Fig. 6 - Response surface diagram of the influence of spray hole diameter and liquid pump pressure on fertilizer application rate

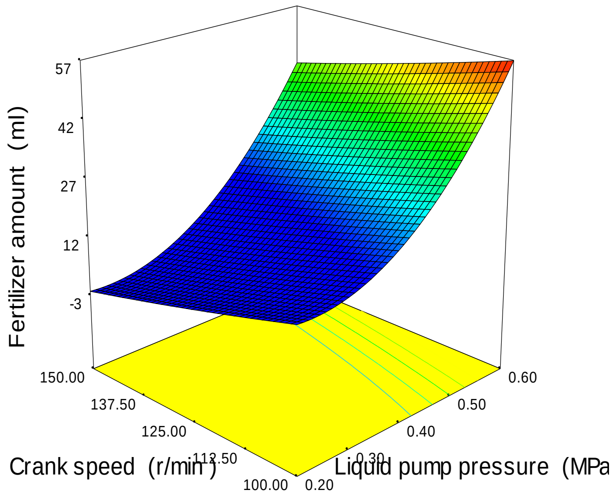

Fig. 7 - Response surface diagram of the influence of crank speed and liquid pump pressure on fertilizer application rate

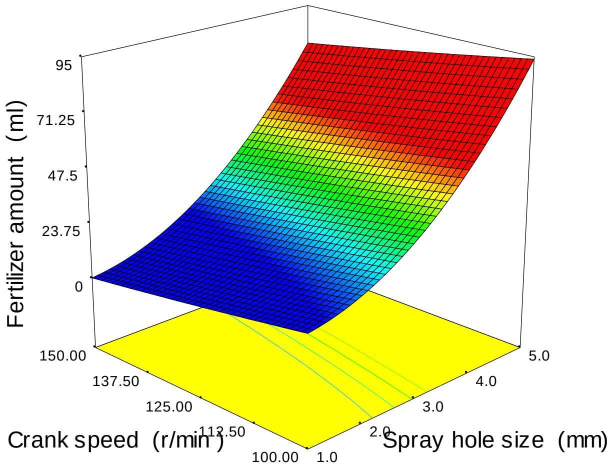

Fig. 8 - Response surface diagram of the influence of crank speed and spray diameter on fertilizer application rate

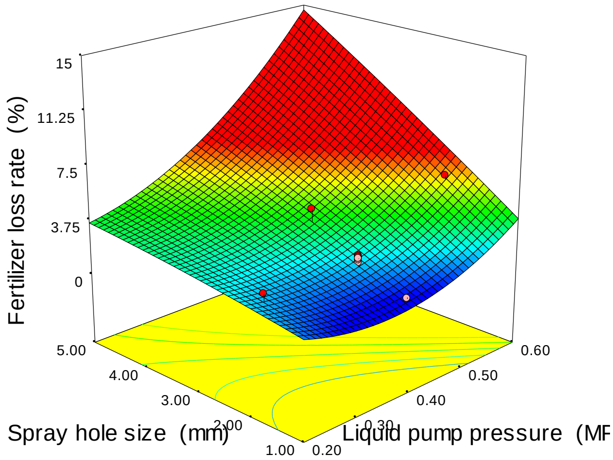

Fig. 9 - Response surface graph of the influence of spray hole diameter and liquid pump pressure on fertilizer loss rate

As shown in Fig. 8, when the spray hole diameter is constant and the planetary carrier speed varies in the range of 100-150 r/min, the applied fertilizer gradually decreases with the increase of the planetary carrier speed. When the crankshaft speed is constant and the spray hole diameter varies in the range of 1-5 mm, the applied fertilizer gradually increases with the increase of spray hole diameter. The response surface changes faster in the direction of the spray hole diameter than the crank speed. According to Table. 3, the F -value of the effect of crank speed on the fertilizer application y_2 is 63.03, and that of spray diameter is 527.84. Therefore, the influence of spray hole diameter on fertilizer application is greater than that of crank speed.

According to Fig. 9, when the nozzle diameter is constant and the liquid pump pressure varies within the range of 0.1 - 0.6 MPa, the fertilizer loss rate gradually increases with the increase of liquid pump pressure. When the liquid pump pressure is constant and the spray hole diameter varies in the range of 1-5 mm, the fertilizer loss rate gradually increases with the increase of spray hole diameter. The response surface changes faster in the direction of liquid pump pressure than the spray hole diameter. According to Table 4, the F value effect of liquid pump pressure on fertilizer loss rate y_2 is 52.78, and that of spray hole diameter on fertilizer loss rate y_2 is 30.09. Therefore, the influence of liquid pump pressure on fertilizer loss rate is greater than that of spray hole diameter.

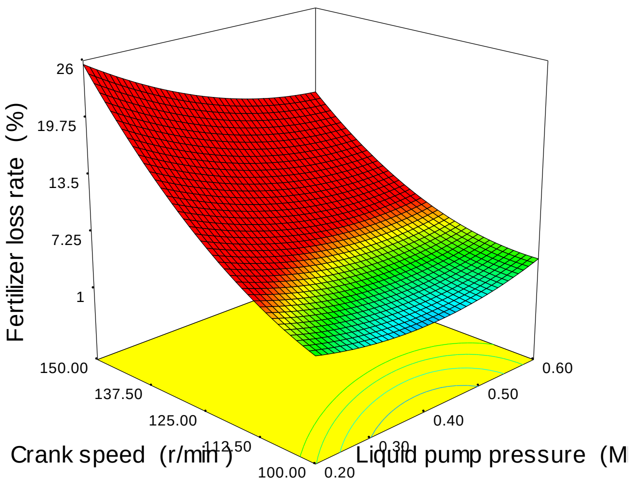

Fig. 10 - Response surface diagram of the influence of crank speed and liquid pump pressure on fertilizer loss rate

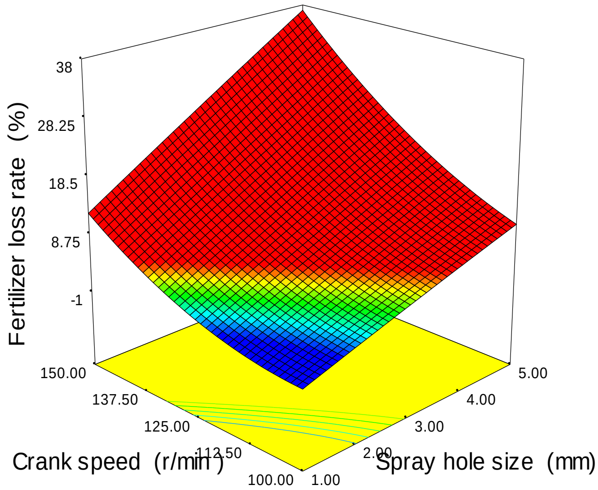

Fig. 11 - Response surface graph of the influence of crank speed and spray hole diameter on fertilizer loss rate

As shown in Fig. 10, when the liquid pump pressure is constant and the crank speed varies in the range of 100-150 r/min, the fertilizer loss rate gradually increases with the increase of crank speed. When the crankshaft speed is constant and the liquid pump pressure varies in the range of 0.1 - 0.6 MPa, the fertilizer loss rate gradually increases with the increase of pressure. The response surface changes rapidly in the direction of crank speed and slowly in the direction of liquid pump pressure. According to Table 4, the F value of the effect of crank speed on fertilizer loss rate y_2 is 60.69, and that of liquid pump pressure on fertilizer loss rate y_2 is 52.78. Therefore, the influence of crank speed on fertilizer loss rate is greater than that of liquid pump pressure.

As shown in Fig. 11, when the spray hole diameter is constant and the crank speed varies in the range of 100-150 r/min, the fertilizer loss rate gradually increases with the increase of crank speed. When the crankshaft speed is constant and the spray hole diameter varies in the range of 1-5 mm, the fertilizer loss rate gradually increases with the increase of spray hole diameter. The response surface changes rapidly in the direction of crank speed and slowly in the direction of spray hole diameter. As shown in Table. 4, the F-value of the effect of crank speed on fertilizer loss rate y_2 is 60.69, and that of nozzle diameter on fertilizer loss rate y_2 is 30.09. Therefore, the influence of crank speed on fertilizer loss rate is greater than that of spray hole diameter.

Experimental optimization and validation

To obtain the optimal parameter combination of liquid pump pressure, spray hole diameter, and crank speed, with fertilizer application rate and fertilizer loss rate as performance indicators and agronomic requirements as boundary conditions, the regression equations of fertilizer application rate and fertilizer loss rate are analyzed, and a nonlinear programming mathematical model is obtained as follows:

$$\begin{cases} y_1 \in (20{,}30) \\ y_2 \in (0{,}3) \\ s.t. 0.1 \le x_1 \le 0.6 \\ 1 \le x_2 \le 5 \\ 100 \le x_3 \le 150 \end{cases} \tag{3}$$

where the objective function used in parameter optimization is as follows (1) and (2):

$$\begin{cases} y_1 = 59.735 - 140.54x_1 - 4.849x_2 - 0.3742x_3 + 311.060x_1^2 + 4.0980x_2^2 \\ y_2 = 28.37 + 10.92x_1 + 1.67x_2 - 0.7x_3 - 0.5x_1x_3 + 50.15x_1^2 + 0.005x_3^2 \end{cases} \tag{4}$$

Application Software Design Expert 8 .0.10 pairs of (3) and (4) are optimized for parameter solving, the optimal parameter combination of hydraulic pump pressure, spray hole diameter and crank speed, that is, the crank speed is 145.80 r/min; the hydraulic pump pressure is 0.25 MPa; the nozzle diameter is 3.02 mm; the output fertilizer amount is 28.6 mL, and the fertilizer loss rate is 1.95%, which meet the requirements of fertilization performance.

Five sets of validation tests were conducted with the optimal crank speed of 145.80 r/min, liquid pump pressure of 0.25 MPa, and spray hole diameter of 3.02 mm. The validation results are shown in Table. 5. The verification results are consistent with the optimization results of Design expert 8. 0. 10. The error mainly refers to the error caused by equipment accuracy and human operation during the experimental process. The validation test results are close to the predicted results under the optimal combination, with good consistency, indicating that the optimization model is feasible, the research results are available and provide reference for the design of fertilization equipment.

Table 5

Verification test results

Factors			**Performance indexes**	
Pump pressure x_1 / r·min^{-1}	**Spray hole diameter x_2 / MPa**	**Crank speed x_3 / mm**	**Fertilizer y_1 / mL**	**Fertilizer loss rate y_2 / %**
0.25	3.02	145.8	28.6	1.95
			28.5	2.01
			28.5	2.33
			28.4	2.12
			28.4	2.10

CONCLUSIONS

(1) A crank rocker fertilization performance test bench was established, and a single factor experiment was designed. The results showed that as the crank speed increased, the fertilization amount gradually decreased; as the spray hole diameter increased, the fertilization gradually increased; as the liquid pump pressure increased, the fertilization amount gradually increased.

(2) A quadratic orthogonal rotation combination design experiment was adopted to establish a mathematical model for the performance indicators and experimental factors of fertilizer application rate, and the influence of interaction relationship on dynamic characteristics was analyzed.

(3) Design Expert 8 0.10 software was used to analyze and optimize the experimental results. When the crank speed was 145.80 r/min, the liquid pump pressure was 0.25 MPa, and the nozzle diameter was 3.02 mm, the fertilization of the crank rocker deep application mechanism was optimal. That is, the crank speed was 145.80 r/min; the liquid pump pressure was 0.25 MPa; the nozzle diameter was 3.02 mm; the output fertilization amount was 28.6 mL, and the fertilization loss rate was 1.95%.

ACKNOWLEDGMENTS

The work was supported by the Postdoctoral Science Foundation of Heilongjiang Province of China (Grant No. LBH-Z18254), Guangdong basic and applied basic research fund project (2021A1515011790), Special project for doctoral talents of Lingnan Normal University (ZL2021019).

REFERENCES

[1] Chen, J.N., Zhang, X.W., Liu, L.M., Ma, X.X., Yao, K., Cheng, D. (2023). Design and experiment of a non-circular gear corn bowl seedling transplanting mechanism with clamped stem (夹茎式非圆齿轮玉米钵苗移栽机构设计与试验). *Journal of Agricultural Engineering*, *39*(18), 30-40. (In Chinese) https://dx.doi.org/10.11975/j.issn.1002-6819.202306011

[2] da Silva, M.J., Magalhães, P.S.G. (2019). Modeling and design of an injection dosing system for site-specific management using liquid fertilizer. *Precision Agriculture, 20,* 649-662. https://doi.org/10.1007/s11119-018-9602-5

[3] Gilvan, M. B., José, F. S., Rovian, B., Alfran, T. M., Marcelo, S. d. F. (2023). Pollutant emissions from a tractor towing a seeder-fertilizer in an area with controlled machinery traffic. *Ciência Rural, 53*(6), 1-6. http://doi.org/10.1590/0103-8478cr20230173

[4] Ramarao, S., Azman, E. A., Tajidin, N. Ismail, R., Yahya, B. (2024). Characterization of Liquid Organic Fertilizer (LOF) Derived from Unmarketable Vegetables and Fruits. *Pertanika Journal of Tropical Agricultural Science, Vol. 47*(2), 559-573. DOI:10.47836/pjtas.47.2.15

[5] Riess, I. (2023). Analysis of Experimental Results of Defect Concentrations in the Surface Layer of Acceptor Doped Ceria. *Russian Journal of Electrochemistry, 59*(3), 169-172. http://dx.doi.org/10.1134/S1023193523030114

[6] Rubeis, T. d., Ciccozzi, A., Paoletti, D., Ambrosini, D. (2024). Experimental analysis of insulating materials using Guarded Hot Box - Preliminary results. *Journal of Physics: Conference Series, 2685,* 012033. Doi:10.1088/1742-6596/2685/1/012033

[7] Sharma, A., Khar, S. (2022). Current developments in vegetable transplanters in developing countries: a comprehensive review. *International Journal of Vegetable Science, 28*(5), 417-440. https://doi.org/10.1080/19315260.2022.2046672

[8] Sommermann P., Cartmell. M.P., (2024). Dynamics of an omnidirectional pendulum energy harvester: A comparative analysis between numerical and experimental results. *International Journal of Non-Linear Mechanics, 159, March 2024, 104588.* https://doi.org/10.1016/j.ijnonlinmec.2023.104588

[9] Wafiqah, A., Retnaningtyas, E., Wahyuni, D.S.C., Andini. A., Anjarsari, Y., Khotimah, R. A. N., Abdulaziz, U., Ansari, A. S., Rochman, N. T. (2024). Jamu waste as liquid organic fertilizer (LOF) and its quality analysis. *Materials Today: Proceedings, March 2024*, 1-6. https://doi.org/10.1016/j.matpr.2024.03.057

[10] Wang, J.F, Liu, Y.F., Weng, W.X., Wang, J.W., Fu, Z.D., Wang, Z.T. (2022). Design and experiment of sliding groove rotary deep fertilization device for paddy field side (滑槽回转式水田侧深施肥装置设计与试验). *Journal of Agricultural Machinery, 53*(10), 76-85. (In Chinese) http://dx.doi.org/10.6041/j.issn.1000-1298.2022.10.008

[11] Wang, J.F., Fu, Z.D., Weng, W.X., Wang, Z.T., Wang, J.W., Yang, D.Z. (2023). Design and Experiment of Double row Fertilizer Discharger for Deep Fertilization on the Side of Conical Plate Pushing Plate in Paddy Fields(圆锥盘推板式水田侧深施肥双行排肥器设计与试验). *Journal of Agricultural Machinery*, *54*(02), 53-62. (In Chinese) http://dx.doi.org/10.6041/j.issn.1000-1298.2023.02.005

[12] Wang, J.W., Liu, Z.M., Sun, X.B., Tang, H., Wang, Q., Zhou, W.Q. (2022). Design and Experiment of Fertilizing Device for Deep Application of Liquid Fertilizer with Target Fertilizing System (深施型液肥对靶点施装置设计与试验). *Journal of Agricultural Machinery, 53*(11), 152-162. (In Chinese) http://dx.doi.org/10.6041/j.issn.1000-1298.2022.11.015

[13] Wang, J.W., Yan, D.W., Wang, Q., Tang, H., Wang, J.F., Zhou, W.Q. (2021). Design and Experiment of Jet Type Inter Plant Weeding Device in Paddy Fields (射流式水田株间除草装置设计与试验). *Journal of Agricultural Machinery, 52*(11), 78-85+94. (In Chinese) http://dx.doi.org/10.6041/j.issn.1000-1298.2021.11.008

[14] Yang, X.L., Chen, B., Xing, H., Zhen, W.B., Qi, L. (2023). Design and Experiment of Sliding Knife Trenching Pneumatic Injection Liquid Fertilizer Atomization Side Deep Fertilization Device (滑刀开沟-气力引射式液肥雾化侧深施肥装置设计与试验). *Journal of Agricultural Engineering, 39*(16), 13-25. (In Chinese) http://dx.doi.org/10.11975/j.issn.1002-6819.202212124

[15] Zhang, L.Y., He, Y.C., Yang, H.J., Tang, Z.H., Zheng, X., Meng, X.J. (2021). Analysis of the Relationship between the Development Status of Liquid Fertilization Machinery and Modern Agriculture (液体施肥机械发展现状与现代农业关系分析). *Journal of Chinese Agricultural Mechanization, 42*(04), 34-40. (In Chinese) https://doi.org/10.13733/j.jcam.issn.2095-5553.2021.04.06

[16] Zhou, H.L., Liu, J.G., Yu, G.H., Qi, P., Wang, L., Zheng. J. (2023). Research on the seedling picking mechanism of vegetable transplanter with helical gear non-circular gear planetary gear system (蔬菜移栽机斜齿轮-非圆齿轮行星轮系取苗机构研究). *Journal of Agricultural Machinery, 54*(08), 77-86. (In Chinese) http://dx.doi.org/10.6041/j.issn.1000-1298.2023.08.007