DESIGN AND EXPERIMENTAL RESEARCH ON DISTRIBUTION MECHANISM OF LIQUID MANURE SPREADER

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液态粪肥施肥机分配机构设计与试验研究

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ABSTRACT

To solve the problems of high error on both sides and high coefficient of variation during liquid manure distribution, this work designed a distribution mechanism integrating conveying, stirring and distribution functions, combined with the physical properties of selected liquid manure. Taking rotor speed, inlet flow and moving cutter structure as test factors, the Design-Expert 8.0.6 software was used to design "three-factor three-level quadratic regression" orthogonal test and establish response surface regression model. Through observing relative error and coefficient of variation, uniform distribution characteristics test and parameter optimization of liquid manure were performed. The results showed that the primary and secondary order of influencing factors on the relative error is rotor speed> inlet flow > moving cutter structure; the primary and secondary order of influencing factors on the coefficient of variation is inlet flow > moving cutter structure> rotor speed. Further, the optimization test indicated that 170 r/min rotor speed, 80 m³/h inlet flow, combined with arc-shaped moving cutter structure could output 10.50% relative error and 9.30% variation rate, which was less than 5% relative to the model predicted value.

摘要

针对液态粪肥在分配过程中存在两侧分配误差高、变异系数高等问题，结合选取液态粪肥的物理特性，设计了一种兼具输送、搅拌、分配组合式液态粪肥分配机构,并进行了液态粪肥均匀分配特性试验与参数优化。以转子转速、入口流量和动刀结构为试验因素,以两侧相对误差和变异系数为试验指标，运用 Design-Expert 8.0.6 软件设计三因素三水平二次回归正交试验,建立了响应面回归模型，并进行优化与试验验证。结果表明：各因素对相对误差影响的主次顺序为: 转子转速、 入口流量、动刀结构；各因素对变异系数影响的主次顺序为: 入口流量、动刀结构、转子转速。对优化结果进行了试验验证，当转子转速为 170 r/ min、入口流量转速为 80 m3/ h、 动刀结构为弧形，此时，相对误差为 10.50%,变异系数为 9.30%。验证试验结果与模型预测值相对误差小于 5%。

INTRODUCTION

With the development of biogas industry, China produces more than 200 million tons of biogas slurry annually (*Shi et al., 2019; Zhang, 2018*). Biogas slurry is rich in organic matter, which can improve the quality and efficiency of green growth of crops. The biogas slurry after solid-liquid separation directly enters the oxidation pond and is fermented with an appropriate amount of straw. After fermentation, the liquid manure is returned to the field for application. At present, the application of liquid manure is mainly based on the combination of planting and breeding, and is used through the farmland pipeline network. However, this model is not yet widespread, which restricts the utilization of liquid manure, and liquid manure needs to be returned to the field manually or by machine to improve its utilization value (*Ge et al., 2012; Wang et al., 2021; Zhang et al., 2019; Liu et al., 2010*).

There are inherent deficiencies in "manual return to fields", such as "lack of labor force and high labor intensity", thus this method is now rarely used. Most of the "machine returning to the field" is to spray the liquid manure in the tank directly to the field through pressure, which has problems such as environmental pollution and loss of organic nitrogen. It is urgent to add a distribution link with the functions of removing impurities and cutting, to achieve the uniform distribution of liquid manure to each outlet, and then directly apply it into the soil. There are two types of uniform distribution modes of liquid manure, namely "vertical" and "horizontal".

The technology of "returning biogas slurry or biogas residue to the field" in foreign countries is relatively mature (*Pullen et al., 2004; Pullen et al., 2005; Gioelli et al., 2014; Rena et al., 2019*); however, such research is relatively rare in China (*Hui et al., 2019; Xie et al., 2020*). Northeast Agricultural University has developed equipment that uses biogas fertilizer as a base fertilizer, and applied biogas fertilizer to the fields in the form of dark irrigation (*Liu et al., 2015; Li et al., 2014*). However, undegraded straw, miscellaneous stones and other substances remain in the liquid manure, resulting in poor circulation during the transportation process and high difficulty in uniform distribution. Therefore, studying the uniform distribution characteristics of liquid manure, optimizing the liquid manure separation mechanism, and improving the distribution uniformity are the key issues to be solved urgently in the current "equipment for uniform application of liquid manure".

In this study, combined with the physical properties of liquid manure, a distribution mechanism that integrates "cutting" and "impurity removal" was designed, and a uniform distribution test of liquid manure through a test bench was carried out to explore the effect of structure, motion parameters of "distribution mechanism" on uniformity. This study can provide a theoretical reference for the structural design and parameter optimization of liquid manure distribution mechanism.

MATERIALS AND METHODS

Overall structure and working principle

The liquid manure application equipment is composed of power tractor, tank, distribution mechanism, pump and trenching-burying-soil covering mechanism, which can complete pumping, discharging, distributing, conveying, applying and covering soil at one time. The main working principles of this equipment are as follows: a. tractor pulling and outputting power; b. negative pressure of vacuum pump attracts the biogas slurry into the tank; c. vacuum pump sends biogas slurry into the distribution mechanism under positive pressure once the tank is full, and evenly distributes it to each hose through the rotor mechanism; d. biogas in the hose enters the ditch for simultaneous ditching along the forward direction of the machine; e. covering soil.

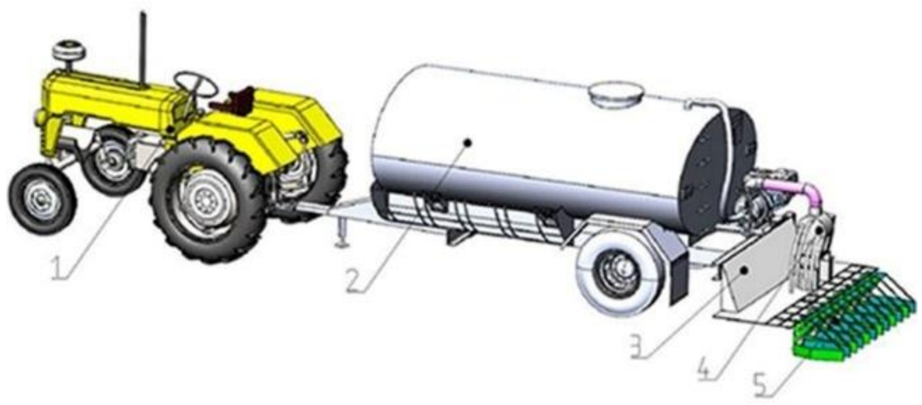
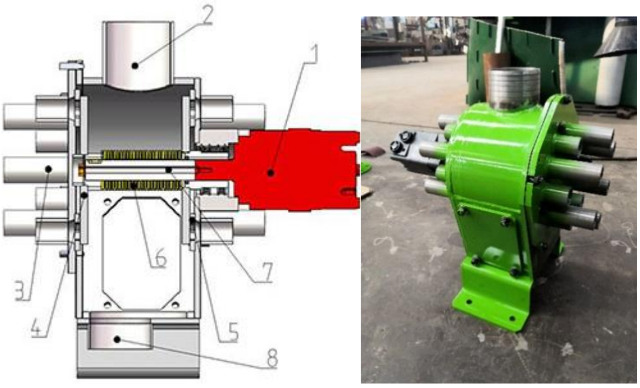


Fig. 1 - Overall structure diagram of liquid manure spreader
1-Tractor; 2-Tank; 3-Machine frame; 4-Distribution device; 5-Trench covering device

Structural design of key components

Overall structure of liquid manure distribution mechanism

The liquid manure distribution mechanism is mainly composed of rotor mechanism, cutting mechanism and impurity removal mechanism, which includes key parts of fixed cutter, moving cutter and compression spring. The end faces of both sides of the mechanism are evenly distributed with circular through holes. One end of these holes is connected with the fixed cutter, which has regular hexagonal through-holes evenly distributed around the circumferential direction, and the other end is connected with the hose, all of which are concentric. After the liquid manure enters the distribution mechanism, the built-in rotor mechanism rotates to stir it evenly. At the same time, the undegraded straws in liquid manure are sheared by moving cutter, so that the liquid manure can be output stably and evenly along the hose. In addition, during the rotation process, part of the miscellaneous stones contained in the liquid manure can directly fall into the bottom collection mechanism by means of gravity, and some of them fall into the collection mechanism after colliding with the shell wall.



(a) Structure diagram **(b) Real diagram**

Fig. 2 - Distribution device

1 - Hydraulic motor; 2- Fluid inlet; 3- Fluid outlet; 4- Moving cutter; 5- Fixed cutter; 6- Compression spring; 7- Power shaft; 8- Miscellaneous stone collection hole

Design of rotor and cutting mechanism

The cutting mechanism is one of the key components of the distribution mechanism, and the cutting effect will directly affect the uniform distribution of liquid manure. How to make the liquid manure containing undegraded straw smoothly and stably through each hole is an important issue. Three different moving cutters and one fixed cutter were designed in this study. The three moving cutters are triangular, rectangular, and arc-shaped, and the side inclination angle is 70°; the fixed cutters are evenly distributed with 12 regular hexagonal through holes. As the undegraded fibers adhere to the sides of the regular hexagon, the moving cutter cuts them.

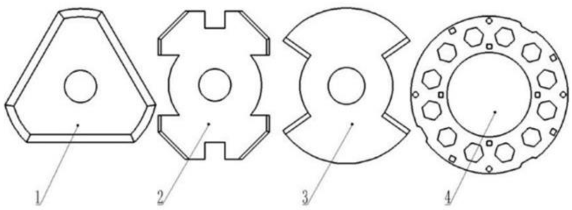


Fig. 3 - Moving and fixed cutter

1-Triangle moving cutter; 2- Rectangle moving cutter; 3- Arc-shaped moving cutter; 4- Fixed cutter

With the extension of working time of the rotor mechanism, the gap between the moving cutter and the fixed cutter is gradually formed due to friction and wear. In order to realize continuous and effective operation of the mechanism, it is necessary to increase the axial force on the movable cutter and the fixed cutter synchronously, thus the worn moving and fixed knives could be kept in close contact at all times by pressing to both sides. A cylindrical helical compression spring with a rectangular section was selected in this study. When the spring reaches the maximum wear value of 1.5 cm between the blades, the moving and fixed cutters would be replaced.

The spring selection is calculated by the following formula: the known outer diameter D_2, the maximum working load P_n, the maximum deformation F_n, the load category is Class II, the ends are tightened and ground, and the support ring is 1 circle (*Cheng, 2016*).

$$\begin{cases} P_n = \frac{b\sqrt{ab}}{\beta C}\tau_p \\ F_n = \gamma\frac{P_n C^2 n D}{G b^2} \\ n = \frac{G F_n a\left(\frac{b}{a}\right)^2}{\gamma P_n C^3} \\ P' = \frac{G a^2 b^2}{\gamma D^3 n} \\ P_j = \frac{ab\sqrt{ab}}{\beta D}\tau_j \end{cases}; \qquad \begin{cases} \tau = \beta\frac{P_n C}{b\sqrt{ab}} \\ F_j = \frac{P_j}{P'} \\ H_0 = nt + 1.5b \\ h = F_n - F_1 \\ a = \frac{D_2}{C+1} \\ D = D_2 - a \\ D_1 = D_2 - 2a \end{cases} \tag{1}$$

pitch $t = (0.28{\sim}0.5)D_2$, minimum working load $P_1 = \left(\frac{1}{3}{\sim}\frac{1}{2}\right)P_j$

In the formula, spring diameter is D, spring inner diameter is D_1, γ and β are coefficients, which can be obtained by looking up the table. n is the effective number of turns, H_0 is the free length of the spring, h is the work form, a is the side length of the rectangular section material perpendicular to the spring axis.

According to the formula, the outer diameter of the spring is 60 mm, the inner diameter is 32 mm, and the length is 125 mm.

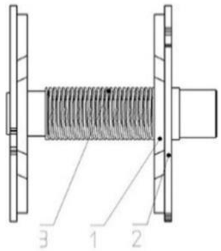


Fig. 4 - Rotor device
1-Moving cutter; 2- Fixed cutter; 3- Compression spring

Mechanics and kinematic analysis of moving and fixed cutter

In order to verify that the undegraded straw can be cut efficiently, the "cut plane" was simplified as a prototype, the cutting force on the straw during the cutting process is recorded as T, and the normal forces perpendicular to the two cutting edges are N_1, N_2 and N_3, respectively. The frictional forces parallel to the two cutting edges are f_1, f_2 and f_3 respectively, and the straw cross section is equivalent to a mass point, thus a straw clamping mechanics model is established (*Xu et al., 2018; Wang et al., 2020*). The circular motion is maintained by the centripetal force to ensure the straw is cut at one time when it enters the cutting area without slippage (Eq.2).

$$\begin{cases} T + N_1 cos\gamma + f_1 sin\gamma > N_2 sin\frac{\beta}{2} + f_2 cos\frac{\beta}{2} + N_3 sin\frac{\beta}{2} + f_3 cos\frac{\beta}{2} \\ m\frac{v^2}{l} = N_1 sin\gamma + N_2 cos\frac{\beta}{2} + f_3 sin\frac{\beta}{2} - f_1 cos\gamma - f_2 sin\frac{\beta}{2} - N_3 cos\frac{\beta}{2} \\ f_1 = \mu N_1 \\ f_2 = \mu N_2 \\ f_3 = \mu N_3 \\ N_2 = N_3 \end{cases} \tag{2}$$

In the formula 2, β is the inner angle of the regular hexagon, γ is the cutting angle of the movable cutter, v is the rotor speed, μ is the friction factor between the cutter and the undegraded straw, and L is the rotation radius of the undegraded straw.

It can be found from the formula that the rotor speed is related to the shear force. When the speed is greater, the shear force is greater; at the same time, as the rotational speed increases, the fluid morphology passing through the inner hexagon is more affected. Therefore, the rotor speed was selected as the test factor, and the orthogonal rotation combination test was conducted in this study, in order to obtain the best working combination parameters.

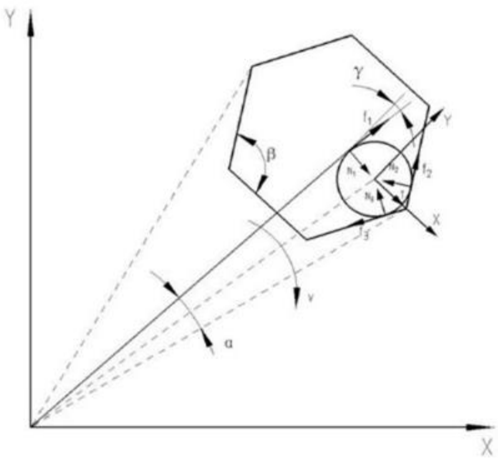


Fig. 5 - Force analysis diagram

Design of other structures and parameters

When the liquid manure enters the distributor, the inlet flow, namely the flow rate, has a great influence on the uniform distribution effect in the later stage. According to the design requirements, the liquid manure application process needs to reach the standard of more than 60 m^3/h. In this study, the diameter of the inner wall of the inlet pipe of the distributor mechanism is 100 mm, and the single factor test showed that the inlet flow of 60-80 m^3/h is suitable.

Liquid manure commonly contains a small amount of miscellaneous stones, and the smaller one is discharged directly from each hose after entering the distributor; the larger size hits the inner wall of the distributor with the rotation of the rotor mechanism and gradually falls into the impurity removal mechanism at the bottom of the distributor. That is, the connection pocket at the outlet, which is then cleaned regularly.

RESULTS

Performance test of uniform distribution of liquid manure

Test materials and equipment

The uniform distribution test was carried out in Yimeite Machinery Manufacturing Co., Ltd. in Tai'an, Shandong Province. The test material was liquid manure containing certain miscellaneous rocks and undegraded straw. A 6-cubic tank, a vacuum pump pressing liquid manure into the distributor, and a solenoid valve adjusting the flow were used in this study. The main equipment and instruments of the test also included plastic barrel with scale, speedometer, electromagnetic flowmeter DN100, electromagnetic valve DN100-24.

Single factor test

When the moving cutter was arc-shaped and the rotation speed was 200 r/min, the single factor test of the inlet flow was carried out. With the increase of the inlet flow, the relative error and the coefficient of variation on both sides first gradually decreased, and then increased. When the moving cutter was arc-shaped and the inlet flow was 80 m^3/h, the rotor speed single factor test was performed. As the rotor speed increases, the relative error and variation coefficient on both sides gradually decreased first, then increased (See the figure below for details).

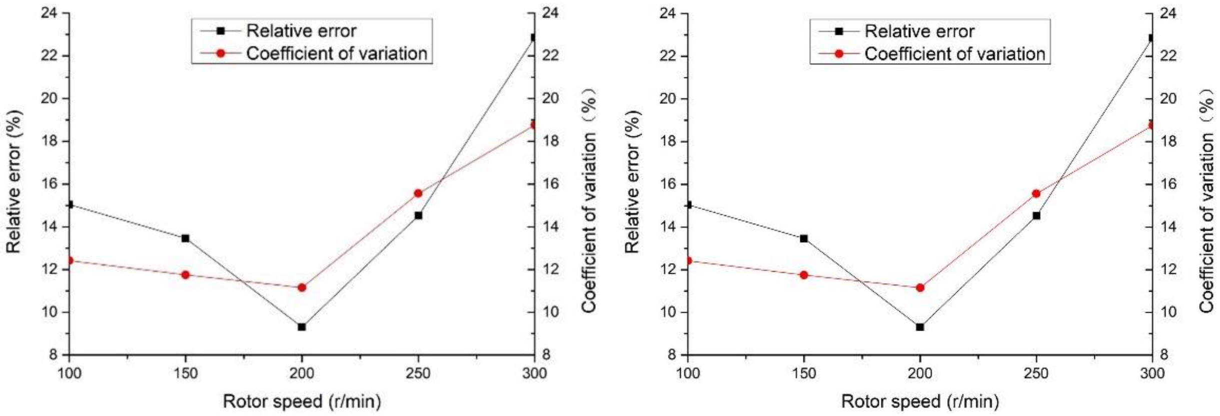


Fig. 6 - Single factor test results

Test factors and indicators

There are many factors that affect work performance during liquid manure distribution. Our preliminary design and single-factor test results showed the inlet flow, the moving cutter shape and the rotor speed can significantly affect mechanism performance. Therefore, in this study, these three parameters were selected as the test factors, and the coefficient of variation and relative error were used as the test indicators to conduct a test on the uniform distribution of liquid manure. In view of the large variation range of parameters, it is necessary to accurately and effectively adjust the level of each operating parameter when carrying out the test. During the distribution test, the rotor speed was hydraulically adjusted through a throttle valve, and the distributor inlet flow was controlled through a solenoid valve.

The relative error calculation formula was:

$$R = \frac{V_a - V_b}{V_a} \times 100\% \tag{3}$$

In the formula, R is the relative error, V_a is the average volume of liquid manure discharged by each hose at the non-motor end, and V_b is the average volume of liquid manure discharged by each hose at the motor end.

The formula for calculating the coefficient of variation was:

$$CV = \frac{S}{\bar{X}} \times 100\% \tag{4}$$

In the formula, CV is the coefficient of variation, S is the standard deviation, $\bar{X}$ is the average volume of liquid manure in all containers in each experiment, X_i is the volume of liquid manure corresponding to each hose, and n is the number of containers corresponding to all hoses.

$$S = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(X_i - \overline{X})^2} \tag{5}$$
$$\overline{X} = \frac{1}{n}\sum_{i=1}^{n} X_i$$

Experimental design and methods

According to the Box-Behnken three-factor and three-level experimental design scheme in the Design-Expert 8.0.6 software, an experiment on the uniform distribution of liquid manure was carried out in this study. Combined with preliminary design and results, here the relative error R and CV were taken as the response values, and three-factor and three-level experimental research on the inlet flow, rotor speed, and moving cutter structure was conducted. The coding of each test factor was shown in Table 1.

Table 1

Codes of test factors

Code	Factors		
	Rotor speed （r/min）	Inlet flow（m^3/h）	Moving cutter structure
-1	120	60	Arc-shaped
0	200	70	Rectangle
1	280	80	Triangle

The orthogonal test scheme has 17 test points, including 12 analysis factors and 5 zero-point estimation errors. The experimental design scheme and results were shown in Table 2 (A, B, and C were the coded values for rotor speed, inlet flow, and moving cutter structure).

Establishment and significance analysis of regression model

Combined with the orthogonal test data (Table 2), the Design-Expert 8.0.6 software was used to perform multiple regression fitting analysis on the test data, and was established a Quadratic Polynomial Regression Model of the relative error R and the coefficient of variation on the three independent variables of rotor speed, inlet flow, and moving cutter structure (*Yang et al., 2020*).

$$L = 14.14 + 1.18A - 1.55B + 1.53C - 0.7AB - 2.85AC + 0.25BC + 4.73A^2 - 2.42B^2 + 1.53C^2$$
$$R = 12.26 + 1.53A - 1.36B + 0.76C - 0.18AB - 2.03AC + 0.25BC + 2.07A^2 - 0.61B^2 + 2C^2 \tag{6}$$

Table 2

Test design scheme and results

Test factors	A	B	C	Relative error (R %)	Coefficient of variation (L %)
1	-1	0	-1	12.1	14.0
2	0	0	0	12.5	14.7
3	1	-1	0	16.8	18.4
4	0	0	0	11.8	13.0
5	-1	0	1	16.8	22.5
6	0	1	-1	11.2	9.3
7	0	0	0	12.0	14.0
8	0	-1	-1	13.7	13.9

Table 2
(continuation)

9	1	0	1	16.5	21.1
10	-1	1	0	11.0	15.9
11	0	1	1	14.1	13.1
12	0	0	0	12.1	14.0
13	1	1	0	13.0	14.9
14	1	0	-1	19.9	24.0
15	-1	-1	0	14.1	16.6
16	0	-1	1	15.6	16.7
17	0	0	0	12.9	15.0

Table 3

Variance and analysis of regression model

Source	Coefficient of variation L				Relative error R			
	Sum of squares	df	F-value	P-value	Sum of squares	df	F-value	P-value
Model	209.32	9	13.43	0.0012	92.22	9	16.55	0.0006
A	11.04	1	6.38	0.0395	18.61	1	30.05	0.0009
B	19.22	1	11.10	0.0126	14.85	1	23.98	0.0018
C	18.6	1	10.74	0.0135	4.65	1	7.51	0.0289
AB	1.96	1	1.13	0.3227	0.12	1	0.20	0.6699
AC	32.49	1	18.76	0.0034	16.40	1	26.49	0.0013
BC	0.25	1	0.14	0.7152	0.25	1	0.40	0.5454
A^2	94.20	1	54.40	0.0002	18.04	1	29.14	0.0010
B^2	24.66	1	14.24	0.0070	1.54	1	2.49	0.1587
C^2	9.86	1	5.69	0.0485	16.76	1	27.06	0.0012
Residual	12.12	7			4.33	7		
Lack of fit	9.73	3	5.42	0.0680	3.56	3	6.15	0.0558
Pure error	2.39	4			0.77	4		
Cor total	221.44	16			96.56	16		

The analysis of variance results of the regression model showed that the relative error and coefficient of variation were extremely significant (Table 3, P<0.01), the significance levels of the missing-fit items were all greater than 0.05 (0.0680 and 0.0558, respectively), indicating that the coefficient of variation and the relative error regression model had a high degree of fit, and the fitting effect was good. Given this, the operating parameters of liquid manure distribution mechanism can be optimized by this model, and the optimized regression model was as follows:

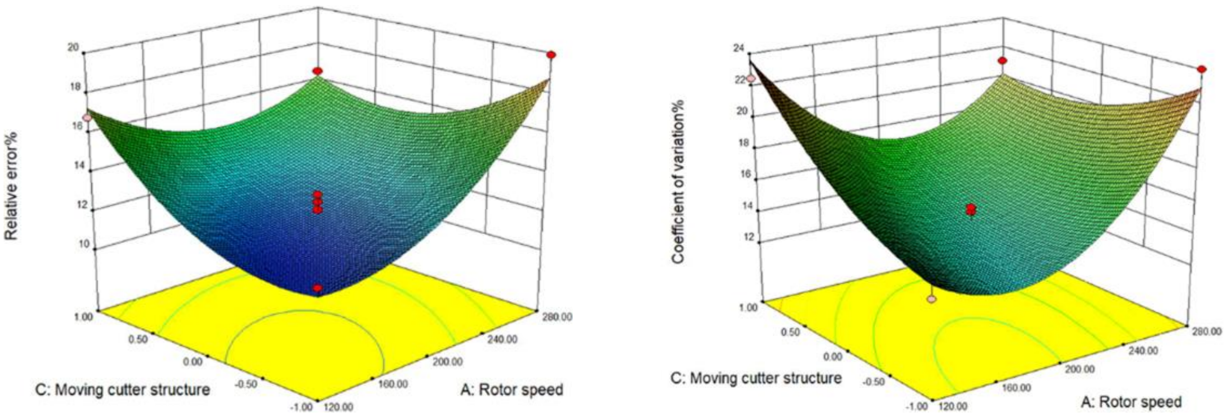
$$R = 14.14 + 1.18A - 1.55B + 1.53C - 2.85AC + 4.73A^2 - 2.42B^2 + 1.53C^2$$
$$L = 12.26 + 1.53A - 1.36B + 0.76C - 2.03AC + 2.07A^2 + 2C^2$$

After analyzing the optimized model, it could be found that the P value of relative error was less than 0.0001, the P value of missing-fit items was 0.1022 and 0.0772, and model determination coefficient R^2 was 0.9453 and 0.9551, respectively, indicating that the optimized model can explain more than 94% of the evaluation. Therefore, the optimized model was extremely significant and the fitting effect was good, and the model was reliable.

The influence degree of parameters on the regression model equation could be evaluated by the P value. The significance order of the three test factors to the relative error was rotor speed> inlet flow> moving cutter structure; the significance order of them to the coefficient of variation was inlet flow> moving cutter structure> rotor speed.

Response surface analysis

The Model Graphs module of the Design-Expert 8.0.6 software was used to analyze the 3D Surface response surface graph (Figure 7). Figure 7a showed the response surface diagram of the interaction between the moving cutter structure and the rotor speed on the relative error when the inlet flow was at the center level of 70 m^3/h. It can be found from the Figure 7a that when the moving cutter structure interacted with the rotor speed, the relative error gradually decreased and the change range was more obvious when the moving cutter structure was replaced by triangle, rectangle and arc-shaped in turn. When the rotor speed gradually increased, the relative error gradually increased, and the change range was more obvious. The response surface curve of the relative error showed that the rotor speed has a more obvious change than the different structures of the moving cutter, which showed that when the inlet flow is at the center level of 70 m^3/h, the effect of the rotor speed is more significant than that of the moving cutter structure. It can be found from the Figure 7b that when the inlet flow was at the center level of 70 m^3/h, and the moving cutter structure interacted with the rotor speed, the relative error gradually decreased and the change range was more obvious when the moving cutter structure was replaced by triangle, rectangle and arc-shaped in turn. However, when the rotor speed gradually increased, the relative error first decreased and then increased, and the change range was relatively gentle. The relative error response surface curve has obvious changes along the different structures of the moving cutter, indicating that when the inlet flow was at the center level of 70 m^3/h, the effect of the moving cutter structure was more obvious than that of the rotor speed.



(a) (b)

Fig. 7 - Response surface of test factors to relative error and coefficient of variation

Parameter optimization and experimental verification

Parameter optimization

In order to obtain the best distribution effect, it is necessary to control the relative error and the CV to be at a small value. Analysis of the response surface map showed that a lower relative error can be achieved when the moving cutter structure is arc-shaped, the rotor speed is in the middle position, and the inlet flow is moderate, and a lower coefficient of variation can be achieved when the moving cutter structure is arc-shaped, the rotor speed is low, and the inlet flow is moderate. Considering the different effects of the interaction among the factors, it is necessary to carry out multi-objective optimization for the regression model.

Using the Optimization module of Design-Expert 8.0.6 software, the multi-objective optimization design of the regression model was carried out, and the relative error and variation coefficient of the response value were analyzed. As liquid manure needs to be applied uniformly to ensure the uniform nutrition of subsequent crops when distributed to the field, it is necessary to first ensure the coefficient of variation is low, and the second is to ensure that the relative error is low. In order to comprehensively evaluate the operation performance of the distribution mechanism, this study added weights to the two experimental indicators in the calculation of the objective optimization, in which the coefficient of variation accounted for 60% and the relative error accounted for 40%.

According to previous results and the distribution operation conditions for the distribution mechanism, in the Optimization module of the Design-Expert 8.0.6 software, the rotor speed was set to 120-280 r/min, the inlet flow was 60-80 m^3/h, and the moving cutter structures were arc-shaped, rectangle and triangle respectively.

The relative error R takes the maximum value of the objective function as 100%, and the coefficient of variation L takes the minimum value of the objective function as 0. The optimization results obtained by the software analysis indicated that when the rotor speed is 169.95 r/min, the inlet flow speed is 80 m^3/h, and the moving cutter structure is arc-shaped, the surface response value of the regression model is the smallest, and the relative error of the model prediction value is 10.50%, the coefficient of variation is 9.30%.

Test verification

In order to verify the model reliability, the researchers conducted 6 verification tests using the optimized model in the test field of Yimeite Machinery Manufacturing Co., Ltd. in Tai'an, Shandong Province in November 2021. According to the actual operation situation, the optimized parameters were fine-tuned, namely, the rotor speed is 170 r/min, the inlet flow speed is 80 m^3/h, and the moving cutter structure is arc-shaped, and the results are shown in Table 4 (all results are averaged).

Table 4

Comparison of model prediction and validation test results

Type	Coefficient of variation L / %	Relative error R / %
Test value	9.04	10.16
Predictive value model	9.30	10.50
coefficient of variation	2.80	3.24

Fig. 8 - Bench test

It can be seen from Table 5 that the relative error between the verification test results of the uniform distribution and the prediction results of the regression model is less than 5%, and the test results are relatively close to the predicted values of the model, which showed that the above parameter optimization regression model is highly reliable.

CONCLUSIONS

(1) In view of the errors on both sides and the difference in the flow rate of each outlet in the process of liquid manure distribution, combined with the agronomic requirements of fertilization, this study designed a liquid manure distribution mechanism, and determined the design and main components of the distribution mechanism. The value range of the parameters is that the rotor speed is 120~280 r/min, the inlet flow is 60~80 m^3/h, and the moving cutter structure is arc-shaped, rectangle and triangle.

(2) The significance order of the three test factors to the relative error was rotor speed> inlet flow> moving cutter structure; the significance order of them to the coefficient of variation was inlet flow> moving cutter structure> rotor speed. The interaction effect of each factor is as follows: the relative error of the moving cutter structure and the rotor speed is significant, the moving cutter structure and the rotor speed are significant to the coefficient of variation, and the direct interaction of other factors has no significant effect on the relative error and the coefficient of variation.

(3) Design-Expert 8.0.6 software was used to conduct orthogonal test and result analysis, and optimize the regression model. The optimized parameter combination of the liquid manure distribution mechanism is as follows: the rotor speed is 170 r/min, the inlet flow speed is 80 m^3/h, and the moving cutter structure is arc-shaped. At this time, the relative error is 10.50%, and the coefficient of variation is 9.3%.

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