DESIGN OF DEEP-FERTILIZATION MECHANISM WITH DEFORMED GEARS AND PERFORMANCE TESTS

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变形齿轮式深施机构设计与施肥性能试验

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ABSTRACT

Deep-fertilization mechanism is a key part of deep-fertilization liquid fertilizer applicator. To obtain a good-performance deep-fertilization mechanism, this study developed a deep-fertilization mechanism with deformed gears and designed a deformed gear fertilization test bench. Single-factor and central composite design tests were performed with the planet carrier, spray hole size and pump pressure as the test factors, and the fertilizer amount as the test index. The results of the single-factor test showed a linear functional relationship between fertilizer amount and pump pressure, an exponential functional relationship between planet carrier velocity and fertilizer amount, and an exponential relationship between spray hole size and fertilizer amount. The rotating and perpendicular test data were analyzed and optimized using Design-Expert 8.0.5 software. The result of the optimization is: 10.5 ml of fertilizer amount with pump pressure 0.36 MPa, planet carrier velocity 82 r/min, and spray hole size 2 mm. The test result can meet the agronomic requirements.

摘要

深施机构是深施型液态施肥机的关键部件，为得到具有较好施肥性能的深施机构，设计了变形齿轮式深施机构，研制了变形齿轮施肥试验台。采用单因素和正交旋转试验方案，以行星架转速、喷孔直径和泵的压力为试验因素，以施肥量为试验指标。单因素试验结果表明，施肥量与液泵压力呈线性函数关系，行星架转速与施肥量呈指数函数关系，喷孔直径与施肥量呈指数关系。运用 Design-Expert 8.0.5 软件对正交旋转试验数据进行分析和优化。最优结果：液泵压力 0.36MPa，行星架转速 82r/min，喷孔直径为 2mm 时，施肥量 10.5ml。试验结果满足农艺要求。

INTRODUCTION

Liquid fertilizer deep-fertilization technology is an agricultural technology which applies fertilizer at the root of crops by means of deep-fertilization mechanism. This method can directly deliver the nutrient composition of liquid fertilizer to the root system of crops, promote their absorption of nutrients, improve the utilization and reduce the run-off of fertilizer, which can lower the cost of agricultural production and protect the environment *(da Silva et al., 2017; Jagvir et al., 2018; Zhou et al., 2016)*. Deep-fertilization mechanism is a key part of liquid fertilizer deep-fertilization applicator; hence it is very necessary to develop a liquid fertilizer deep-fertilization applicator suitable for Chinese situations. Currently there are mainly three types of deep-fertilization applicators, namely crank rocker mechanism, planetary elliptic gear mechanism, and all planetary elliptic gear mechanism. For crank rocker mechanism, the trajectory of the pricking is too forward, making it hard to control the inertia of the mechanism, enlarging the hole in the soil, and causing a waste of fertilizer *(Zhang et al., 2018a).* The planetary elliptic gear mechanism and all planetary elliptic gear mechanism can optimize the mechanism parameters by writing visual aids and using human-machine interaction method, which can improve the entering and exiting trajectory of the hole pricking mechanism, reducing the hole size and the waste of fertilizer (*Zhang et al., 2018b; Wang et al., 2013; Zhao et al., 2005*).

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However, the fertilizer loss of the above deep-fertilization applicators is still very high. Therefore, this paper proposed a liquid fertilizer injection deep-fertilization mechanism with deformed gears. As deformed gears can realize the vertical and horizontal changes of transmission ratio *(Da Silva et al., 2017; Jin et al., 2018; Thomas, 2002),* this type of deep-fertilization mechanism can improve the perpendicularity to the soil and further reduce the fertilizer loss. Then, bench test was performed on the deep-fertilization mechanism with deformed gears. By identifying a reasonable combination of working parameters, this study aimed to provide reference for the design and optimization of liquid fertilizer deep-fertilization applicator.

MATERIAL AND METHODS

STRUCTURE AND WORKING PRINCIPLE OF DEEP-FERTILIZATION MECHANISM WITH DEFORMED GEARS

Deep-fertilization mechanism is an important executive component of deep-fertilization liquid fertilizer applicator. According to the working characteristics of deep-fertilization liquid fertilizer applicator, the deep-fertilization mechanism was designed with deformed gears, which include five congruent deformed gears, one gearbox (planet carrier), two pairs of rocker arms and spray fertilizer needles, as shown in Fig. 1. The planet carrier is coaxially arranged with the central deformed gear. The planetary deformed gear is consolidated with the rocker arm with screw to be one component. When the mechanism is working, the central deformed solar gear stays fixed (similar to the sun wheel in epicyclic gear train), the planet carrier rotates and drives two intermediate deformed gears through meshing transmission to revolve around the central deformed solar gear, and meanwhile the planetary deformed gears at two sides would make cyclical movements through the meshing transmission with the intermediate deformed gears. The compound motion of the rocker arms and spray fertilizer needles, the clockwise rotational movement of the planetary deformed gears and the swing with the planetary deformed gears have constituted the special trajectory of the spray fertilizer needles and a whole process of fertilization is thus completed. According to agronomic requirements, the fertilization depth of liquid fertilizer should be around 80 mm. Therefore, a 20 mm long needle tip was welded at the lower part of the spray part to facilitate the entering of the spray fertilizer needles into the soil and avoid attaching soil when the mechanism is working. Each spray needle is designed with two liquid hole to reduce the number of sprays needs and improve the working efficiency.

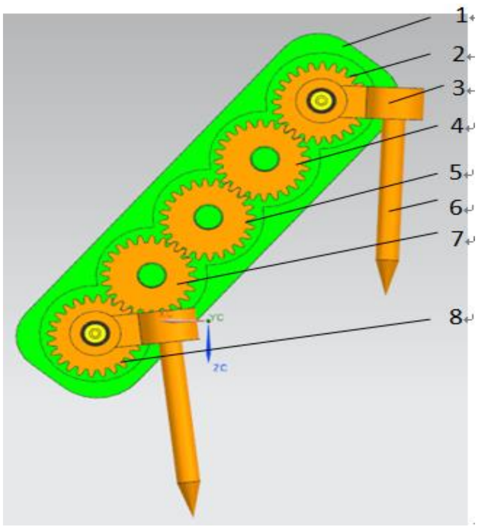

Fig. 1 - Structure of deep-fertilization mechanism with deformed gears

1. Planet carrier 2. Upper planetary deformed gear 3. Rocker arm 4. Upper intermediate deformed gear 5. Deformed solar gear 6. Spray fertilizer needle 7. Lower intermediate deformed gear 8. Lower planetary deformed gear

FERTILIZATION PERFORMANCE TESTS OF DEEP-FERTILIZATION MECHANISM WITH DEFORMED GEARS

Test equipment

In order to study the fertilization quality of deep-fertilization mechanism with deformed gears under certain combination of working parameters, a fertilization performance test was conducted on a self-built test bench of deep-fertilization mechanism with deformed gears. The structure of the test bench is shown in Fig. 2.

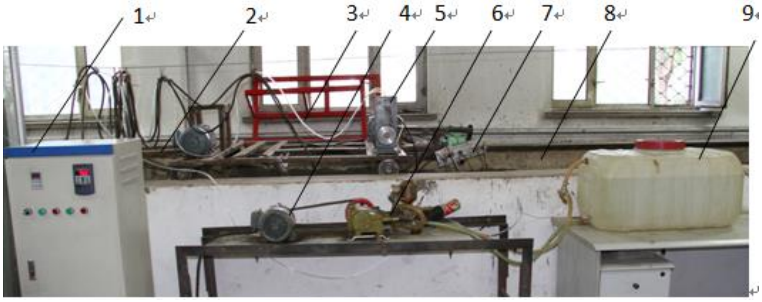

Fig. 2 - Test bench of deep-fertilization mechanism

1. Frequency converter; 2. Trolley; 3. Fertilization line; 4. Motor; 5. Distributor; 6. Liquid fertilizer pumps; 7. Deep-fertilization mechanism; 8. Test soil bin; 9. Liquid fertilizer container

As shown, the test bench mainly consists of frequency converter, trolley, fertilization line, motor, distributor, liquid fertilizer pump, deep-fertilization mechanism, test soil bin, and liquid fertilizer container, of which the deep-fertilization mechanism with deformed gears is the major working part. The working process is as follows: (1) Adjust the frequency converter to make the planet carrier speed and the executive mechanism movement satisfy the requirement; (2) Start the three-phase asynchronous motor to drive the liquid pump; (3) When the liquid pump works under a stable pressure, the trolley would be driven into the test area and the spray fertilizer needles of the deep-fertilization mechanism would prick into the soil in the test soil bin; (4) The distributor delivers certain liquid fertilizers with proper pressure into the spray fertilizer needles, which were sprayed into the soil from the spray hole; (5) The trolley keeps moving, the distributor stops delivering liquid fertilizer and the spray fertilizer needle stops fertilizing; (6) The deep-fertilization mechanism drags the spray fertilizer needles from the soil, and a deep-fertilization application of liquid fertilizer is therefore completed. As for the measurement of fertilizer amount, we start the liquid pump, adjust the planet carrier speed through the frequency converter, wait until the liquid pump becomes stable, and take the mean value of sprayed fertilizer as the fertilizer amount. A measuring cylinder was applied to get 10 times of fertilizer amount, and the average amount was used as the single-factor test data.

Test design

Fertilizer amount is an index to evaluate the fertilizing performance of deep-fertilization mechanism. The major working parameters that affect the fertilization performance include planet carrier speed, spray hole size and pump pressure. These three parameters were defined as the test factors of fertilization performance. A three-factor, five-level quadric rotating perpendicular test design was adopted. Table 1 shows the coding of factor levels. Design expert 8.0.1 software was adopted to process the test data and analyze the influence law of different factors on the fertilizer amount of the deep-fertilization mechanism *(Wang et al., 2017; Wang et al., 2018; Viei et al., 2015)*.

Table 1

Coding of factor levels

Coded value	Planet carrier speed ($r \cdot min^{-1}$)	Liquid pump pressure (MPa)	Spray hole size (mm)
1.68	63	0.23	1
1	70	0.3	1.5
0	80	0.4	2
-1	90	0.5	2.5
-1.68	96	0.57	3

RESULTS AND ANALYSIS

Single-factor test

Impact of pump pressure on fertilizer amount

Single-factor test was performed on the pump pressure under the condition of 2.5 mm spray hole size and 80 r/min planet carrier speed with fertilizer amount as the index. Results were shown as Fig.3.

The curve regression fitting of pump pressure and fertilizer amount showed a nice goodness of fit of the linear functional relationship. The fitted equation and coefficient of determination were shown in Fig. 3. The results showed that the fertilizer amount and the pump pressure presented a significant linear functional relationship. As shown, the fertilizer amount satisfies the agronomic requirement of 5-20 ml when the pump pressure is controlled in the range of 0.3-0.5MPa. Therefore, the 0.3-0.5MPa pump pressure is initially defined as the reference pressure of subsequent tests.

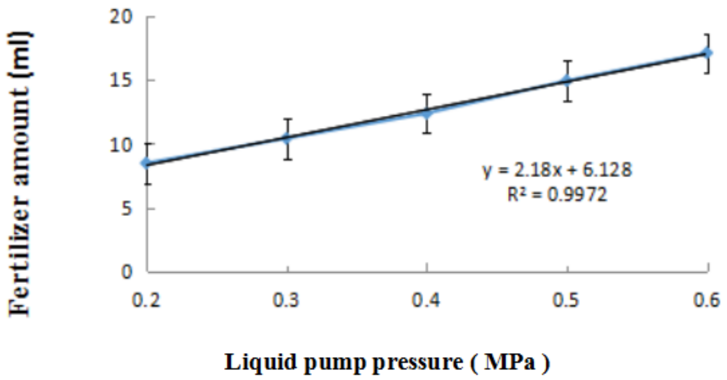

Fig. 3 - Impact of pump pressure on fertilizer amount

Impact of planet carrier speed on fertilizer amount

Single-factor test was performed on the planet carrier speed under the condition of 2 mm spray hole size and 0.4 MPa pump pressure with fertilizer amount as the index. Results were shown as Fig.4.

The curve regression fitting of planet carrier speed and fertilizer amount showed a nice goodness of fit of the linear functional relationship. The fitted equation and coefficient of determination were shown as Fig. 4. The results showed that the fertilizer amount and the planet carrier speed presented a significant logarithmic functional relationship. As shown, the fertilizer amount satisfies the agronomic requirement of 5-20 ml when the planet carrier speed is controlled in 70–90 r/min. Therefore, the 70–90 r/min of planet carrier speed is initially defined as the reference speed of subsequent tests.

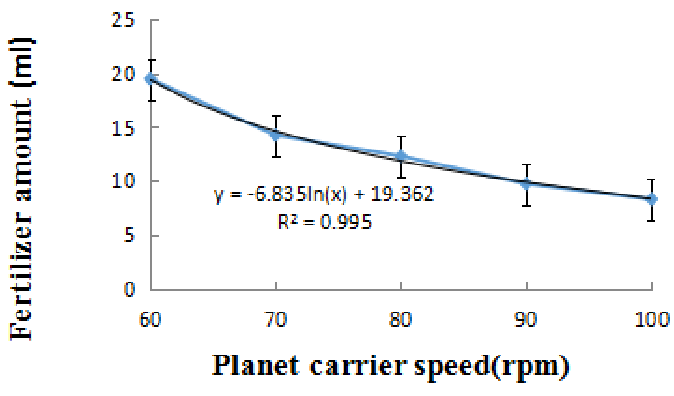

Fig. 4 - Impact of planet carrier speed on fertilizer amount

Impact of spray hole size on fertilizer amount

Single-factor test was performed on the spray hole size under the condition of 80r/min planet carrier speed and 0.4 MPa pump pressure with fertilizer amount as the index. Results were shown as Fig.5.

The curve regression fitting of spray hole size and fertilizer amount showed a nice goodness of fit of the power functional relationship. The fitted equation and coefficient of determination were shown as Fig. 5. The results showed that the fertilizer amount and the spray hole size presented a significant power functional relationship. As shown, the fertilizer amount satisfies the agronomic requirement of 5-20 ml when the spray hole size is controlled in 1.5-2.5 mm. Therefore, the 1.5-2.5 mm of spray hole size is initially defined as the reference size of subsequent tests.

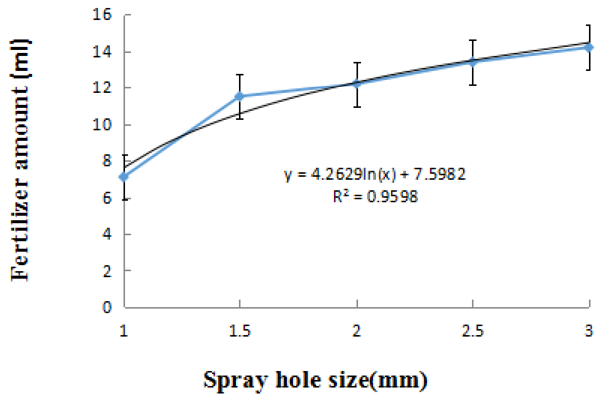

Fig. 5 - Impact of spray hole size on fertilizer amount

Multi-factor test

An orthogonal rotation test was performed on the basis of a single factor. The test scheme and results are shown in Table 2. Design-Expert 8.05 software is applied to analyze the test data in Table 2 to obtain the hydraulic pump pressure and the nozzle-hole diameter.

Table 2

Test plan and results

Number	Test factors			Performance index	
	Planet carrier speed x_1 (r·min^{-1})	Liquid pump pressure x_2 (MPa)	Spray hole size x_3 (mm)	Fertilizer amount y_1 (ml)	Fertilizer loss rate y_1 (%)
1	-1	-1	-1	10.6	1.6
2	-1	1	-1	17.2	3.3
3	-1	-1	1	12.5	1.6
4	-1	1	1	21.1	4.9
5	1	-1	-1	6.2	4.7
6	1	1	-1	6.8	3.6
7	1	-1	1	7.8	2.2
8	1	1	1	13.1	5
9	0	-1.68	0	6.5	3.2
10	0	1.68	0	18.4	6.5
11	0	0	-1.68	4.3	1.5
12	0	0	1.68	13.5	4.5
13	-1.68	0	0	25.7	1.5
14	1.68	0	0	7.3	5.5
15	0	0	0	12.3	2.9
16	0	0	0	12.3	3.1
17	0	0	0	12.3	2.9
18	0	0	0	12.4	2.9
19	0	0	0	12.4	3
20	0	0	0	12.3	3.1
21	0	0	0	12.4	2.9
22	0	0	0	12.3	3
23	0	0	0	12.3	2.9

The response surfaces are depicted in Figure 6, Figure 7 and Figure 8 to reflect the influences of the hydraulic pump pressure and the rotational speed of the planet carrier, as well as the nozzle-hole diameter and the rotational speed of the planet carrier, on the fertilization amount, and the multi-factor analysis of variance is shown in Table 3. Also, the response surfaces are depicted in Figure 9, Figure 10, and Figure 11, to reflect the influences of the hydraulic pump pressure and the nozzle-hole diameter, the hydraulic pump pressure and the rotational speed of the planet carrier, as well as the nozzle-hole diameter and the rotational speed of the planet carrier on the loss rate of fertilizer, and the multi-factor analysis of variance is exhibited in Table 4 *(Otto et al., 2014; Fan et al., 2006; Xu et al., 2010)*.

At the significance level of $F_{0.05}$, it can be seen from Table 3 that x_2, x_3, x_1, x_1x_2, x_3^2 and x_1^2 have a significant influence on the fertilization amount and are the significant terms of the model. After removing insignificant terms, the fitted regression equation is:

$$y_1 = 51.68 - 2.08x_1 + 123.1x_2 + 26.08x_3 - 1.16x_2x_1 - 5.45x_3^2 + 0.01x_1^2 \quad (1)$$

Table 3

Analysis of variance for the influence of factors to the fertilization amount

Source	Sum of squares (ml)	Degree of freedom (ml)	F-value (ml)	Significance level (P>F) (ml)
Model	511.13	9	32.9	<0.0001
x_2	123.77	1	71.70	<0.0001
x_3	62.32	1	36.10	<0.0001
x_1	250.12	1	144.90	<0.0001
x_2x_3	5.61	1	3.25	0.0946
x_1x_2	10.81	1	6.26	0.0265
x_1x_3	0.55	1	0.32	0.5816
x_2^2	0.19	1	0.11	0.7476
x_3^2	29.54	1	17.11	0.0012
x_1^2	27.84	1	16.13	0.0015
Error	22.44	13		
Sum	533.57	22		

It is clear from Table 3 that the F value reflecting the effect of hydraulic pump pressure on the fertilization amount y_1 is 71.7, while the F value reflecting the effect of nozzle-hole diameter on the fertilization amount y_1 is 36.1. As thus, compared to nozzle-hole diameter, hydraulic pump pressure has a greater effect on fertilization amounts.

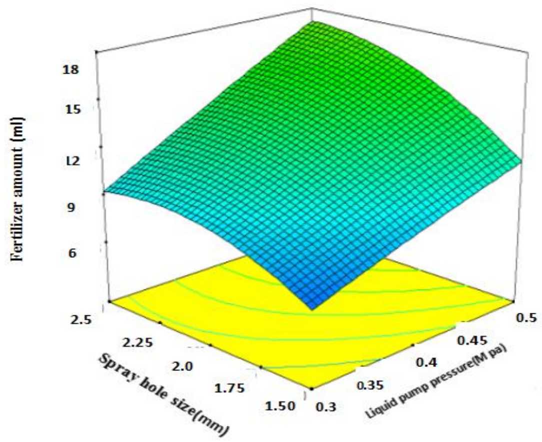

Fig. 6 - Impact of liquid pump pressure and spray hole size on fertilizer amount

Figure 6 shows that when the nozzle-hole diameter remains constant and the hydraulic pump pressure varies in the range 0.3-0.5 MPa, the fertilization amount will gradually increase with increasing hydraulic pump pressure; on the other hand, when the pressure at the hydraulic pump remains constant and the nozzle-hole diameter varies in the range 1.5-2.5 mm, the fertilization amount gradually increases with increasing nozzle-hole diameter. The response surface changes faster in the direction of hydraulic pump pressure than in the direction of nozzle-hole diameter.

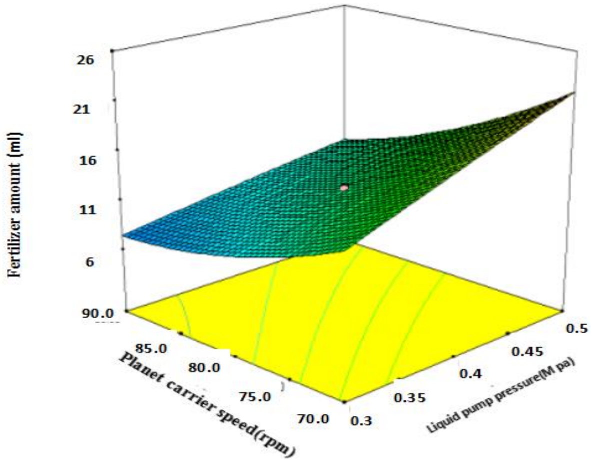

Fig. 7 - Impact of liquid pump pressure and planet carrier speed on fertilizer amount

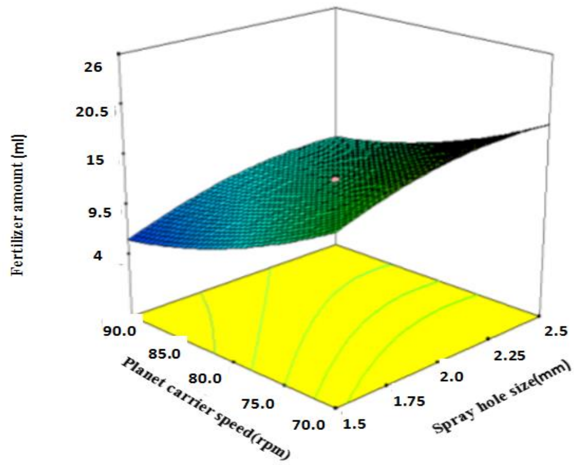

Fig. 8 - Impact of spray hole size and planet carrier speed on fertilizer amount

Figure 7 visibly demonstrates that when the pressure at the hydraulic pump remains constant and the rotational speed of the planet carrier varies in the range 70-90 r/min, the fertilization amount will gradually decrease with an increase in rotational speed; on the other hand, when the rotational speed of the planet carrier remains constant and the pressure at the hydraulic pump varies in the range 0.3-0.5 MPa, the fertilization amount will gradually increase with an increase in pressure. The response surface changes faster in the direction of the rotational speed of the planet carrier than in the direction of the pressure at the hydraulic pump. As per Table 3, the F value reflecting the effect of the rotational speed of the planet carrier on the fertilization amount y_1 is 144.90, while the F value reflecting the effect of the pressure at the hydraulic pump on the fertilization amount y_1 is 71.7. As thus, compared to the pressure at the hydraulic pump, the rotational speed of the planet carrier has a greater effect on fertilization amounts.

It can be seen from Figure 8 that when the nozzle-hole diameter remains constant and the rotational speed of the planet carrier varies in the range 70-90 r/min, the fertilization amount will gradually decrease with increasing rotational speed; on the other hand, when the rotational speed of the planet carrier remains constant and the nozzle-hole diameter varies in the range 1.5-2.5 mm, the fertilization amount will gradually rise with declining diameter.

The response surface changes more slowly in the direction of the rotational speed of the planet carrier than in the direction of the nozzle-hole diameter. According to Table 3, the F value reflecting the effect of the rotational speed of the planet carrier on the fertilization amount y_1 is 112.56, while the F value reflecting the effect of the nozzle-hole diameter on the fertilization amount y_1 is 36.10. As thus, compared to the nozzle-hole diameter, the rotational speed of the planet carrier has a greater effect on fertilization amounts.

At the significance level of $F_{0.05}$, it can be seen from Table 4 that x_2, x_3, x_1, x_1x_2, x_3^2 and x_1^2 have a significant influence on the fertilization loss rate and are the significant terms of the model. After removing insignificant terms, the fitted regression equation is:

$$y_2 = 30.37 - 0.77x_1 + 13.71x_2 + 1.69x_3 - 0.55x_1x_2 + 51.9x_2^2 + 0.0053x_1^2 \tag{2}$$

Table 4

Analysis of variance for the influence of factors on fertilization loss rate

Source	Sum of squares (ml)	Degree of freedom (ml)	F-value (ml)	Significance level (P>F) (ml)
Model	62.03	9	22.10	< 0.0001
x_2	17.25	1	55.34	< 0.0001
x_3	9.84	1	31.55	< 0.0001
x_1	22.38	1	71.77	< 0.0001
x_2x_3	0.72	1	2.31	0.1525
x_1x_2	2.42	1	7.76	0.0154
x_1x_3	0.60	1	1.94	0.1870
x_2^2	4.28	1	13.72	0.0026
x_3^2	0.013	1	0.043	0.8384
x_1^2	4.57	1	14.67	0.0021
Error	4.05	13		
Sum	66.08	22		

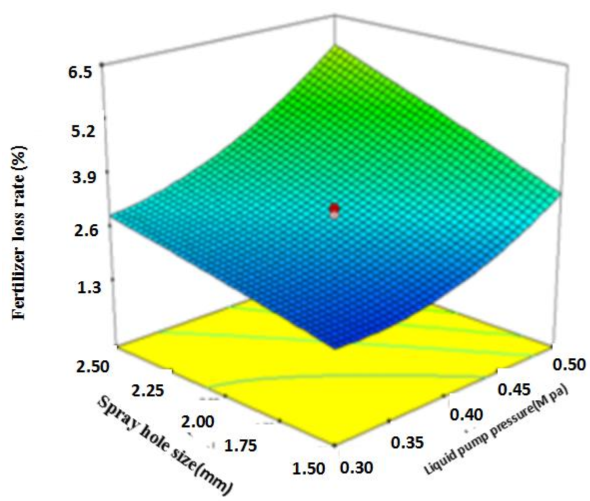

Fig. 9 - Impact of liquid pump pressure and spray hole size on fertilizer loss rate

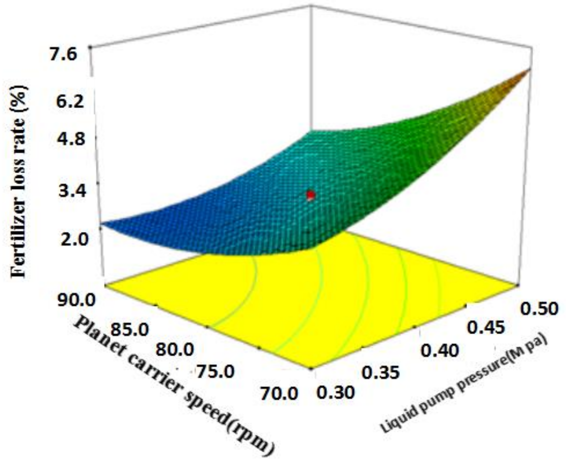

Fig. 10 - Impact of liquid pump pressure and planet carrier speed on fertilizer loss rate

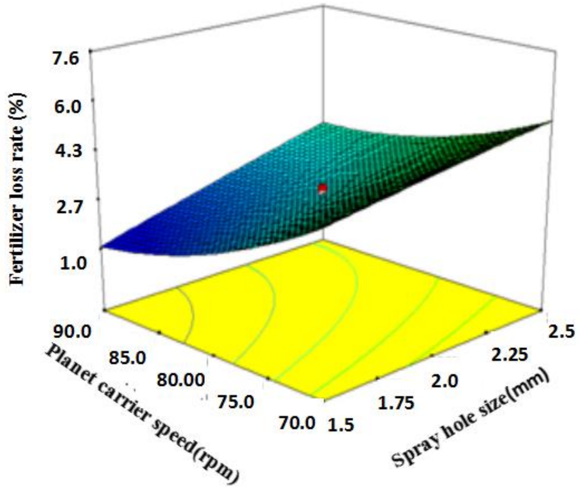

Fig. 11 - Impact of spray hole size and planet carrier speed on fertilizer loss rate

Figure 9 shows that when the nozzle-hole diameter remains constant and the pressure at the hydraulic pump varies in the range 0.3-0.5 MPa, the fertilization loss rate will gradually increase with increasing hydraulic pump pressure; on the other hand, when the pressure at the hydraulic pump remains constant and the nozzle-hole diameter varies in the range 1.5-2.5 mm, the fertilization loss rate gradually increases with increasing nozzle-hole diameter. The response surface changes faster in the direction of hydraulic pump pressure than in the direction of nozzle-hole diameter. Table 4 indicates that the F value reflecting the effect of hydraulic pump pressure on the fertilization loss rate y_2 is 55.34, while the F value reflecting the effect of nozzle-hole diameter on the fertilization loss rate y_2 is 31.55. Hence, compared to nozzle-hole diameter, the pressure at the hydraulic pump has a greater effect on the fertilization loss rate.

Figure 10 exhibits that when the pressure at the hydraulic pump remains constant and the rotational speed of the planet carrier varies in the range 70-90 r/min, the fertilization loss rate will gradually decrease with increasing rotational speed; on the other hand, when the rotational speed of the planet carrier remains constant and the pressure at the hydraulic pump varies in the range 0.3-0.5 MPa, the fertilization loss rate will gradually increase with increasing pressure. The response surface changes fast in the direction of the rotational speed and it changes slowly in the direction of the hydraulic pump pressure. As per Table 4, the F value reflecting the effect of the rotational speed of the planet carrier on the fertilization loss rate y_2 is 71.77, while the F value reflecting the effect of the pressure at the hydraulic pump on the fertilization loss rate y_2 is 55.34. Hence, compared to the pressure at the hydraulic pump, the rotational speed of the planet carrier has a greater effect on fertilization loss rates.

In accordance with Figure 11, when the nozzle-hole diameter remains constant and the rotational speed of the planet carrier varies in the range 70-90 r/min, the fertilization loss rate will gradually decrease with increasing rotational speed; on the other hand, when the rotational speed of the planet carrier remains constant and the nozzle-hole diameter varies in the range 1.5-2.5mm, the fertilization loss rate will gradually rise with an increase in the nozzle-hole diameter. The response surface changes fast in the direction of the rotational speed of the planet carrier and it changes slowly in the direction of the nozzle-hole diameter. It is clear from Table 4 that the F value reflecting the effect of the rotational speed of the planet carrier on the fertilization loss rate y_2 is 71.77, while the F value reflecting the effect of the nozzle-hole diameter on the fertilization loss rate y_2 is 31.55. Hence, compared to the nozzle-hole diameter, the rotational speed of the planet carrier has a greater effect on fertilization loss rates.

Test optimization and verification

In order to find the optimal combination of parameters for hydraulic pump pressure, nozzle-hole diameter and rotational speed of the planet carrier, this study uses fertilization amount and fertilization loss rate as performance indicators, and the constraint conditions of agronomic requirements as boundary conditions in order to analyze the regression equation of fertilization amount and fertilization loss rate and get a mathematical model of nonlinear programming:

$$\begin{cases} y_1 \in (10,20) \\ y_2 \in (0,2.5) \\ s.t. 70 \le x_1 \le 90 \\ 03 \le x_2 \le 0.5 \\ 1.5 \le x_3 \le 2.5 \end{cases} \tag{3}$$

where the objective function for parameter optimization is

$$\begin{cases} y_1 = 51.68 - 2.08x_1 + 123.1x_2 + 26.08x_3 - 1.16x_1x_2 - 5.45x_3^2 + 0.01x_1^2 \\ y_2 = 30.37 - 0.77x_1 + 13.71x_2 + 1.69x_3 - 0.55x_1x_2 + 51.9x_1^2 + 0.0053x_1^2 \end{cases} \tag{4}$$

In this study, Design-Expert 8.05 software is applied for parameter optimization, and the optimal combination of parameters for hydraulic pump pressure, nozzle-hole diameter and rotational speed of the planet carrier is gained: the rotational speed of the planet carrier at 82.15 r/min, the pressure at the hydraulic pump at 0.36 MPa, the nozzle-hole diameter at 2.04 mm, the output fertilization amount at 10.5 mL and the fertilization loss rate at 2.3%, and this combination has met the fertilization performance requirements.

Table 5

Verification of testing results

Factor			**Performance indicators**	
Rotational speed of the planet carrier x_1 / r·min $^{-1}$	Hydraulic pump pressure x_2 / MPa	Nozzle-hole diameter x_3 / mm	Fertilization amount y_1 /mL·s^{-1}	Fertilization loss rate y_2 / %
			10.5	2.31
			10.6	2.35
82	0.36	2	10.4	2.33
			10.4	2.28
			10.6	2.36

Five sets of verification testing were carried out based on the optimal value optimal combination of parameters, i.e. the rotational speed of the planet carrier at 82 r/min, nozzle-hole diameter at 2mm and hydraulic pump pressure at 0.36 MPa.

The verification testing results are illustrated in Table 5. It can be seen from Table 6-13 that as per the test results, for the fertilization amount, the maximum is 10.6 mL, the minimum is 10.4 mL, the average is 10.5 mL; for the fertilization loss rate, the maximum is 2.36%, the minimum is 2.28%, and the average is 2.33%. These results have proved that the optimal combination of parameters can meet the performance standards required by fertilization.

CONCLUSIONS

(1) A test bench of deep-fertilization mechanism with deformed gears was established. Single-factor test showed that the fertilizer amount presented a linear function increase trend with the increase of the pump pressure, an exponential function decrease trend with the increase of planet carrier speed, and an exponential function increase trend with the increase of spray hole size.

(2) A quadric rotating perpendicular test design was adopted to establish a mathematical model of fertilization performance index and test factors, and the impacts of interaction relationship on the fertilization index were analyzed.

(3) The test results were analyzed and optimized using Design-Expert 8.0.5 software. Results show that an optimal fertilizing performance can be achieved with following parameter combination: liquid pump pressure: 0.36 MPa; spray hole size: 2 mm; planet carrier speed: 82r/min. The fertilizer amount was 10.5 mL and fertilizer loss rate was 2.33%, with this combination, which can meet the agronomic requirement of fertilization.

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