PARAMETER OPTIMIZATION AND EXPERIMENT OF ORCHARD DOUBLE ROW DITCHING-FERTILIZING MACHINE

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果园双行开沟施肥机的参数优化与试验

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ABSTRACT

In order to improve the fertilization uniformity and stability of the orchard double row ditching-fertilizing machine, the design was optimized. Firstly, the factors affecting the movement of the fertilizer particles were analysed in combination with the kinetic model of the fertilizer particles during the falling process. Secondly, the influence of each factor on the fertilization uniformity was analysed by single factor variance. Finally, the Box-Behnken central composite method was used to establish a mathematical model of fertilization uniformity of the orchard double row ditching-fertilizing machine, and regression statistical variance, response surface, and contour lines were used to analyse the influence of each mechanism parameter on the fertilization uniformity. The test results show that: when the test parameters of the conveyer belt speed is within 165~235 $r \cdot min^{-1}$, the advancing velocity is within 0.8~1.2 $m \cdot s^{-1}$, and the guide plate angle is changed within the range of 15~45°, the degree of influence of each factor on the fertilization uniformity from high to low is the conveyer belt speed, advancing velocity, the angle of the guide plate, and the conveyer belt speed; when the conveyer belt speed is 214 $r \cdot min^{-1}$, advancing velocity is 1 $m \cdot s^{-1}$, and the angle of the guide plate is 37°, the fertilizer coverage reaches 100%, and the fertilization uniformity is increased from 86.31% to 90.73%, and the fertilization stability is improved. The research results provide a theoretical basis for the design and optimization of orchard ditching-fertilizing machine.

摘要

为提高果园双行开沟施肥机的施肥均匀度和稳定性，对果园双行开沟机进行优化设计。首先结合肥料颗粒下落过程中的动力学模型，分析影响肥料颗粒运动的各因素。其次通过单因素方差分析各因素对施肥均匀度的影响。最后采用 Box-Behnken 中心组合试验设计方法，建立果园双行开沟施肥机施肥均匀度的数学模型，通过回归统计方差、响应曲面和等高线分析各机构参数对施肥均匀度的影响规律。试验结果表明：在前进速度 0.8～1.2$m \cdot s^{-1}$，传送带转速 165～235$r \cdot min^{-1}$，导板角度 15°～45°的试验参数范围内，各因素对施肥均匀度的影响程度从高到低依次为传送带转速、前进速度、导板角度；当传送带转速为 214 $r \cdot min^{-1}$、前进速度为 1.0$m \cdot s^{-1}$、导板角度为 37°的参数条件下，肥料覆盖率达 100%，施肥均匀度由原来的 86.31%提高到 90.73%，施肥稳定性提高。研究结果为果园开沟施肥机的设计和优化提供了理论依据。

INTRODUCTION

China has superior natural conditions suitable for the growth of fruit trees. It is a large country for fruit growing. After more than 40 years of development, China has become the main supply base and processing base for fruit in the world. Its fruit output and output value are among the highest in the world. Fruit production has become one of the pillar industries of China's agriculture *(Huairui Shu et al, 2018; Jingyan Wang et al, 2019)*. Fertilization of fruit trees is a key operation in the growing of fruit trees. The quality of fertilization directly affects the absorption of nutrients in fruit trees. Reasonable fertilization is an important measure to ensure high yield, stable yield and increased yield of fruit trees *(Dayong Han et al, 2010; Congju Shen et al, 2019; Xiaochun Zheng et al, 2011)*.

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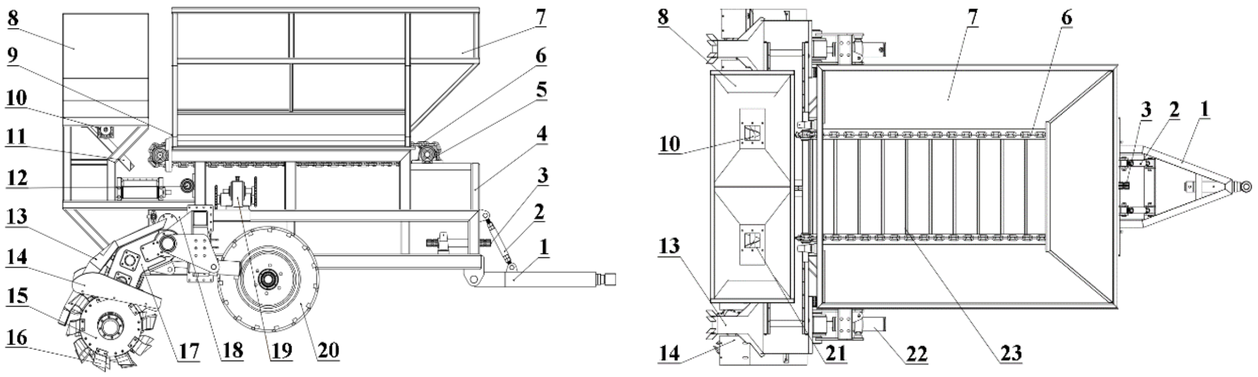
At present, orchards in the full fruit season mostly use ditching-fertilizing machines for stripe fertilization *(Chen Ma et al, 2017)*. Fertilization uniformity is a key factor that affects the effect of fertilization operations, and is an important index for evaluating the performance and effect of working tools *(Junliang Fan et al, 2016; Jing Ma et al, 2016; Rui Wang et al, 2017; Zhou Zhou et al, 2009)*. Overseas, *Hofstee et al (1990, 1992, 1994, 1995)* made in-depth research on fertilization uniformity, including the effect of fertilizer size, friction coefficient and recovery coefficient on the distribution of fertilizer movement. In China, *Yang Qinglu et al. (2019)* carried out numerical analysis of particle motion based on the coupled method of discrete element and hydrodynamics, studied the flow characteristics of fertilizer particles in a pneumatic concentration and distribution type fertilizer separator, and obtained the optimal value of fluidity and uniformity of airflow and fertilizer in the fertilizer separating device. *Qi Xingyuan et al. (2018)* based on the pneumatic variable fertilizer applicator, theoretically analysed the fertilizer movement in its sprayer and simulated the air flow field, and obtained the optimal speed and baffle structure of the fertilizer removal wheel, which has a significant effect on the fertilization uniformity in the fertilization range of a single sprayer. *Wang Jinfeng et al. (2018)* carried out design analysis on key components of the deep-field fertilizing device on the paddy field side, and used a quadrature orthogonal rotation combination design test to obtain the mathematical model of the relationship among the speed of the fertilizer wheel, the advance speed of the rice transplanter, the wind speed of the fan and the uniformity of fertilization.

After comprehensive analysis of research status at home and abroad, it is found that the uniformity of fertilization affects the effect of fertilization. With the advancement of orchard mechanization, the promotion scope of orchard ditching-fertilizing machine has increased, but there are problems such as low fertilization uniformity and poor stability. For this reason, based on the existing orchard ditching-fertilizing machine, the single factor and Box-Behnken central composite experiment was adopted to establish mathematical model of fertilization uniformity, and to analyse the correlation between different structural parameters and fertilization uniformity through regression statistical variance, response surface, and contour lines to provide theoretical basis for the design and optimization of orchard ditching-fertilizing machine.

MATERIALS AND METHODS

Overall structure

At present, the new orchards in Bohai Bay, Northwest Loess Plateau and other main apple producing areas mostly adopt the planting mode of short anvil close planting, the row spacing of orchards is between 3.5~4.0m, and the plant spacing is between 1.5~1.8m. In order to improve the operation efficiency and combine the apple planting mode, the orchard double row ditching-fertilizing machine is designed. The structure of the whole machine is shown in Figure 1, which is mainly composed of traction frame, frame, organic fertilizer box, compound fertilizer box, ditching device, fertilizer discharge device, etc. The main technical parameters of the whole machine are shown in Table 1.



(a) Front view *(b) Vertical view*

Fig. 1 - Orchard double row ditching-fertilizing machine

1) traction frame; 2) adjusting pulling pipe; 3) transmission shaft; 4) frame; 5) fertilizer discharge chain wheel; 6) O-chain; 7) organic fertilizer box; 8) compound fertilizer box; 9) organic fertilizer discharge port; 10) fertilizer discharge auger; 11) fertilizer transport plate; 12) fertilizer discharge transmission box; 13) fertilizer guide plate; 14) soil cover; 15) ditching cutterhead; 16) ditching cutter; 17) ditching transmission box; 18) main transmission box; 19) fertilizer transport transmission box; 20) wheels; 21) fertilizer discharge port; 22) hydraulic cylinder; 23) fertilizer discharge scraper

Table 1

Main technical parameters

Parameter	Value	Units
Structure form	traction type	-
Tractor power	≥58.8	kW
Operation speed	0.8~1.2	$m \cdot s^{-1}$
Overall dimension (length × width × height)	4030×2470×2150	mm
Depth of ditching	0~400	mm
Width of ditching	350	mm
Compound fertilizer application amount	0~9.0	$kg.m^{-1}$
Fertilizer application amount	0~2.2	$kg.m^{-1}$
Compound fertilizer box volume	2450	L
Fertilizer box volume	650	L

Working principle

When working, the orchard double row ditching-fertilizing machine advances under the tractor's traction, the ditching cutter cuts into the soil and throws up the soil. The compound fertilizer and the chemical fertilizer are discharged by the fertilizer discharge scraper and the fertilizer discharge auger respectively, and fall into the opened trench through the fertilizer conveyer belt and the fertilizer guide plate. Meanwhile, the ditching soil cover blocks the soil thrown up by the ditching cutter and makes it fall back into the opened trench, realizing the integration of ditching, fertilization and covering soil. Part of the tractor's power is transmitted to the fertilizer transport transmission box to drive the fertilizer conveyer belt to rotate to realize the fertilizer conveying operation, and other power is transmitted to the main transmission box. Part of the power of the main transmission box is transferred from the first and second output shafts to the ditching transmission box to drive the ditching cutter to rotate and realize ditching operation; other power of the main transmission box is transferred from the third output shaft to the fertilizer discharge transmission box to drive the fertilizer discharge scraper and fertilizer discharge auger to rotate and realize fertilizer discharge operation. The power transmission route is shown in Figure 2.

Through the analysis of the movement of fertilizer particles, we know that there are three factors that affect the fertilizer discharge effect of the orchard double row ditching-fertilizing machine: one is the mechanical structure parameters of the machine; the other is the characteristics of the fertilizer itself; the third is the environmental factors. Under the influence of irresistible environmental factors and the characteristics of fertilizer itself, this study mainly studies the influence of the structural parameters of the machine on the law of fertilizer discharge to solve the problems in practical work.

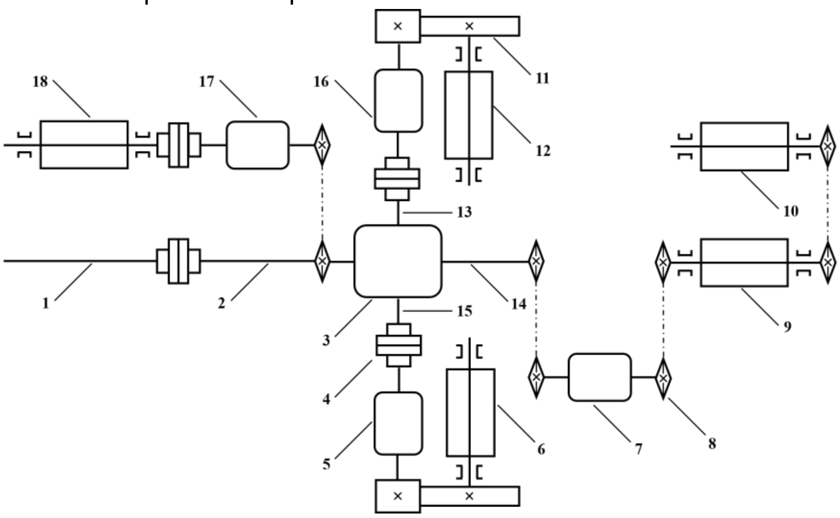


Fig. 2 - Power transmission route

1) tractor rear power output shaft; 2) main transmission box input shaft; 3) main transmission box; 4) coupling; 5) right ditching transmission box; 6) right ditching cutterhead; 7) fertilizer discharge transmission box; 8) chain drive; 9) fertilizer discharge scraper; 10) fertilizer discharge auger; 11) gear drive; 12) left ditching cutterhead; 13) main transmission box first output shaft; 14) main transmission box third output shaft; 15) main transmission box second output shaft; 16) left ditching transmission box; 17) fertilizer transport transmission box; 18) fertilizer conveyer belt

Test conditions

The test was carried out in the test base of Gaomi Yifeng Machinery Co., Ltd. in December 2019. The weather is sunny, the temperature is -4~3ºC, the southwest wind, the wind speed is less than 2 km/h, the air relative humidity is 64%, and the test ground is relatively flat, with an area of about 650 m^2. The fertilizer used in the experiment is spherical compound fertilizer produced by Stanley Agricultural Group Co., Ltd. the N: P_2O_5 ： K_2O is 15:15:15, the total nutrient is more than 45%, the water content is 1.12%, and the average diameter of particles is 4.19 mm. The test method and index refer to GB/T5262—2008 general provisions for the determination of test conditions for agricultural machinery and NY/T1003—2006 standard test method for operation quality evaluation of fertilizing machinery. Figure 3 is the test diagram of orchard double row ditching-fertilizing machine.

Fig. 3 - Test of orchard double row ditching-fertilizer machine

Evaluation of fertilization uniformity

The fertilization operation schedule of the orchard double row ditching-fertilizer machine was tested, and the operation length of a single row is 50m for each double-row operation, of which the length of the measuring area is 30 m and the length of the reserve area at both ends is 10 m. Each row along the travel direction was divided into 30 sections as the measuring area according to the continuous length of 10cm, and a total of 60 sections were tested. During the test, the ditching device will be raised in the preparation area, and the calibration machine will enter the working state. After that, the measuring area will be passed at the normal working speed. The fertilizer dropped in each section was collected separately and weighed by an electronic balance. Under a single operation stroke, the fertilization uniformity was calculated according to formula (1), (2), (3), (4) after the completion of all measurement areas.

$$X = \sum_{i=1}^{n} x_i / n \tag{1}$$

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

$$CV = \frac{\sigma}{x} \times 100\% \tag{3}$$

$$CU = 1 - CV \tag{4}$$

Where, x is the mean value of fertilizer mass, g; x_i is the fertilizer mass of the i^{th} measurement area, g; n is the number of measurement areas selected in the operation area; σ the standard deviation of fertilizer mass, g; CV is the coefficient of variation of fertilizer distribution, %; CU is the stability coefficient of fertilizer distribution, %.

Test design

Granular organic fertilizers fall into the fertilizer guiding mechanism by means of fertilizer discharge mechanism, with a certain initial velocity V_p. After the granular organic fertilizer enters the fertilizer guiding mechanism, it is subjected to gravity G_p, buoyancy F_{fp}, and air resistance F_{zp}. After the interaction, it finally falls into the ditch of the orchard ditching-fertilizer machine.

Gravity: $$G_p = \rho_p V_p \tag{5}$$

Buoyancy: $$F_{fp} = \rho_a V_p g \tag{6}$$

Air resistance: $$F_{zp} = \frac{1}{2}K\rho_p S_p V_p^{\,2} \tag{7}$$

Air resistance coefficient: $$K = \frac{3}{8}C_D\rho_a\frac{1}{\rho_p r_p} \tag{8}$$

There is a correlation between drag coefficient C_D and Reynolds number R_e:

$$R_e = 2\frac{r_p v_p \rho_p}{\eta_a} \tag{9}$$

In equations (5), (6), (7), (8), (9):

ρ_p-granular organic fertilizer density; V_p-volume of granular organic fertilizer; ρ_a-air density;
η_a-aerodynamic viscosity; v_P-granular organic fertilizer velocity;
S_p-granular organic fertilizer frontal area; r_p-granular organic fertilizer radius; g-gravity acceleration;

Assuming that the positive direction of the Z axis is opposite to the direction of gravity of the granular organic fertilizer, the equation of motion of the granular organic fertilizer in the X, Y, and Z directions is:

X direction: $$\frac{d^2x}{dt^2} = -Kv_{Px}\sqrt{v_{Px}^{\,2}+v_{Py}^{\,2}+v_{Pz}^{\,2}} \tag{10}$$

Y direction: $$\frac{d^2y}{dt^2} = -Kv_{Py}\sqrt{v_{Px}^{\,2}+v_{Py}^{\,2}+v_{Pz}^{\,2}} \tag{11}$$

Z direction: $$\frac{d^2z}{dt^2} = -Kv_{Pz}\sqrt{v_{Px}^{\,2}+v_{Py}^{\,2}+v_{Pz}^{\,2}} \tag{12}$$

In equations (10), (11), (12):

v_{Px}-the velocity component in the X direction;
v_{Py}-the velocity component in the Y direction;
v_{Pz}-the velocity component in the Z direction;

Through the analysis of the movement state of fertilizer particles after they leave the fertilizer device, it is found that the conveyer belt speed, advancing velocity and guide plate angle affect the amount of fertilizer applied and the movement state of fertilizer particles. With the fertilization uniformity as the experimental index, the single factor test was conducted with the conveyer belt speed, advancing velocity and guide plate angle as the factors, and the results are shown in Table 2. It can be seen from Table 2 that the speed of conveyer belt has a very significant effect on the fertilization uniformity ($P<0.01$), and the guide plate angle and advancing velocity have a significant effect on the fertilization uniformity ($P<0.05$).

Table 2

Single-factor test results

Project	Conveyer belt speed [r·min^{-1}]	Advancing velocity [m·s^{-1}]	Guide plate angle [°]
P Value	0.00015	0.0138	0.0273

According to the results of single factor analysis, the conveyer belt speed x_1, advancing velocity x_2 and guide plate angle x_3 were selected as the test factors, and the fertilization uniformity was used as the evaluation index. The Box-Behnken composite test design method was adopted. The value range of each factor and the factors and levels in the test are shown in Table 3. The experimental scheme and results of Box-Behnken are shown in Table 4.

Table 3

Factors and levels

Level	Conveyer belt speed x_1 [r·min^{-1}]	Advancing velocity x_2 [m·s^{-1}]	Guide plate angle x_3 [°]
-1	165	0.8	15
0	200	1.0	30
1	235	1.2	45

Table 4

Box-Behnken design scheme and response values of fertilization uniformity

Test serial number	Conveyer belt speed x_1 [r·min^{-1}]	Advancing velocity x_2 [m·s^{-1}]	Guide plate angle x_3 [°]	Fertilization uniformity [%]
1	200	1.0	30	90.10
2	165	1.0	45	85.00
3	200	0.8	15	85.65
4	165	0.8	30	82.65
5	165	1.2	30	84.35
6	200	1.2	15	86.20
7	235	0.8	30	90.40
8	200	1.0	30	91.10
9	200	1.0	30	89.80
10	235	1.2	30	83.30
11	200	0.8	45	85.30
12	165	1.0	15	87.65
13	200	1.0	30	90.40
14	235	1.0	45	88.95
15	235	1.0	15	84.65
16	200	1.2	45	89.15
17	200	1.0	30	90.30

RESULTS AND ANALYSIS

Test analysis results

The Design Expert statistical analysis software was used to perform a polynomial regression analysis on the experimental data in Table 4, the regression equation of the fertilization uniformity of the orchard ditching-fertilizing machine was obtained:

$$Y=90.34+0.96x_1-0.12x_2+0.53x_3-2.20x_1x_2+1.74x_1x_3+0.83x_2x_3-2.59x_1^2-2.58x_2^2-1.19x_3^2 \tag{13}$$

Significance test and variance analysis of mathematical model were carried out, and the results are shown in Table 5. According to the data results, the regression model was significant ($P<0.05$), indicating that the model established was meaningful. The modified determination coefficient of the model is 0.70, and the regression determination coefficient R^2 is 0.87, indicating that the gap between the actual measurement value and the mathematical model is small, that is, the model has a high degree of fit to the data, the regression model is significant, the test error is small, and can better describe the experimental results, so the establishment of this regression equation is correct *(Yuanyu Qian et al, 2018; Zhihong Yu et al, 2018)*.

Table 5

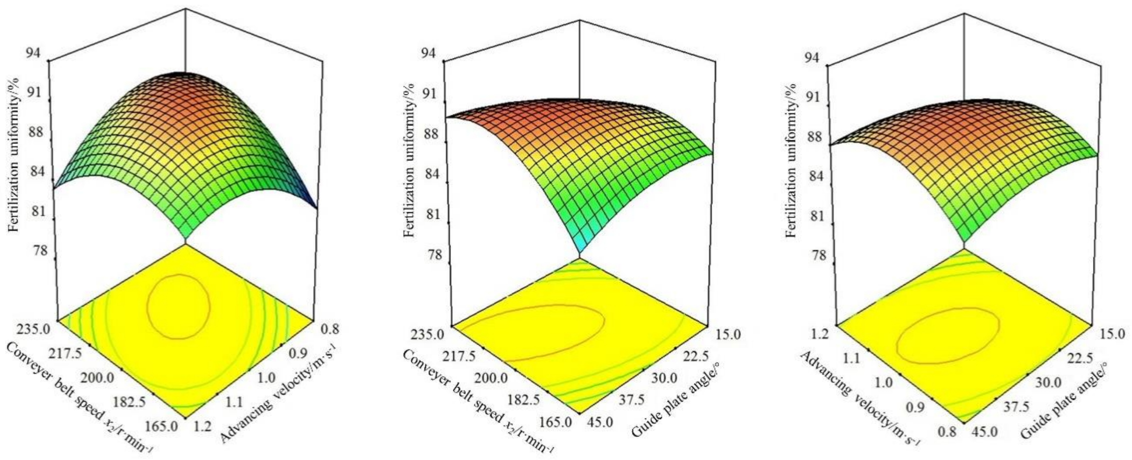
Regression statistical variance analysis results

Project	Freedom	Sum of squares	Mean square	F Value	P Value
x_1	1	7.32	7.32	2.98	0.1279
x_2	1	0.12	0.12	0.05	0.8279
x_3	1	2.26	2.26	0.92	0.3695
x_1^2	1	19.36	19.36	7.89	0.0262
x_1x_2	1	12.08	12.08	4.92	0.0621
x_1x_3	1	2.72	2.72	1.11	0.3273
x_2^2	1	28.22	28.22	11.50	0.0116
x_2x_3	1	27.95	27.95	11.38	0.0119
x_3^2	1	5.95	5.95	2.42	0.1634
Model	9	112.36	12.48	5.09	0.0217
Residual	7	17.18	2.45		
Total	16	129.54			

It can be seen from the results of the regression statistical analysis of variance in Table 5, that x_1 (the conveyer belt speed), x_2 (the advancing velocity) and x_3 (the guide plate angle) have no significant effect on the uniformity of fertilization in the linear term of the model; x_1^2 and x_2^2 have significant effects on the fertilization uniformity, and x_3^2 has no significant effect in the quadratic term of the model. Considering the interaction effects, x_1x_2 and x_2x_3 have significant effects on the fertilization uniformity, and x_1x_3 has no significant effect. According to the analysis of the significance of the impact, it can be known that within the range of the selected factors, the order of influence on the uniformity of fertilization from high to low is as follows: the conveyer belt speed > the advancing velocity > the guide plate angle.

Response Surface Analysis of Fertilization Uniformity

Design-Expert was used to plot the response surface of fertilization uniformity, the effect of various factors on fertilization uniformity can be seen, and the relationship between various variables can be determined and tested *(Jin Yuan et al, 2018)*. One of the conveyer belt speed, advancing velocity and the guide plate angle is fixed at the middle level, and analyse the effect of the other two factors and their interaction on fertilization uniformity. The interaction results are shown in Fig. 4 ~ 6.



a) $Y = (x_1, x_2, 0)$ b) $Y = (x_1, 0, x_3)$ c) $Y = (0, x_2, x_3)$

Fig. 4 - Interactive effects of different experimental factors on fertilization uniformity

In Figure 4a, the fertilization uniformity response surface opens downward, showing the interactive influence of the advancing velocity and the conveyer belt speed on the fertilization uniformity when the guide plate angle is 30°. When the conveyer belt speed is 217.5 r·min^{-1} and the advancing velocity is 1m·s^{-1}, the fertilization uniformity is the highest. It can be seen from the contour map that the effect of the conveyer belt speed on the fertilization uniformity is more significant than that of the advancing velocity. When the angle of the guide plate is 30°, the conveyer belt speed is at any level, and the uniformity of fertilizer application increases first and then decreases with the increase of the advancing velocity. When the conveyer belt speed is low, the effect of the advancing velocity on the fertilization uniformity is obvious, as shown in the figure, the fertilization uniformity curve in the figure is steep. This shows that when the conveyer belt speed is in the range of 165~182.5 r·min^{-1}, properly increasing the advancing velocity can significantly improve the fertilization uniformity. When the angle of the guide plate is 30°, the advancing velocity is at a low level, and the uniformity of fertilization shows an increasing trend with the increase of the conveyer belt speed, and the influence of the conveyer belt speed on the uniformity of the fertilization is obvious, as shown in the steep curve in the figure. This shows that when the advancing velocity is within the range of 0.8~0.9 m·s^{-1}, increasing the conveyer belt speed can significantly improve the uniformity of fertilization; when the advancing velocity is at a medium and high level, the uniformity of fertilization increases first as the conveyer belt speed and then decreases, it shows that when the advancing velocity is in the range of 0.9~1.2m·s^{-1}, maintaining the conveyer belt speed at 200 r·min^{-1} can improve the fertilization uniformity. When the conveyer belt speed (the advancing velocity) is low, the amount of fertilization is small, and part of the trench is not covered by fertilizer, which reduces the uniformity of fertilization. Increasing the conveyer belt speed (the advancing velocity) appropriately can speed up the fertilizer movement rate and increase fertilization amount, reducing the area in the trench that is not evenly covered by fertilizer, and improving the uniformity of fertilization.

In Figure 4b, the fertilization uniformity response surface opens downward, showing the interactive effect of the conveyer belt speed and the guide plate angle on the fertilization uniformity when the advancing velocity is 1.0 m·s^{-1}, and when the conveyer belt speed is 217.5 r·min^{-1}, and the angle of the guide plate is 45°, the fertilization uniformity is the highest. It can be seen from the contour map that the effect of the conveyer belt speed on the fertilization uniformity is more significant than that of the guide plate angle. When the advancing velocity is 1.0 m·s^{-1}, the conveyer belt speed is low, and the amount of fertilizer applied is small. As the angle of the guide plate increases, the movement time of the fertilizer on the guide plate becomes longer, and the amount of fertilizer per unit time becomes smaller. Part of the area is not evenly covered by fertilizer, which leads to a decrease in the uniformity of fertilizer application with the increase of the angle of the guide plate; when the conveyer belt speed is at medium and high levels, the amount of fertilization is large. There are more areas covered by the fertilizer repeatedly in the trench. As the angle of the guide plate increases, the movement time of the fertilizer on the guide plate becomes longer, and the amount of fertilizer per unit time becomes smaller. The area covered by fertilizers repeatedly decreases, leading to an increase in the uniformity of fertilization as the angle of the guide plate increases. When the advancing velocity is 1.0 m·s^{-1}, the angle of the guide plate is at any level, and the fertilization uniformity increases first and then decreases with the increase of the conveyer belt speed, and the angle of the plate is at a high level, the effect of the conveyer belt speed on uniformity is more significant. The curve shown in the figure is steeper. With the increase of the conveyer belt speed, the amount of fertilizer applied per unit time becomes larger, and the area not covered by the fertilizer uniformly in the trench decreases. This means that when the angle of the guide plate in the range of 37.5~45°, increasing the conveyer belt speed can significantly improve the fertilization uniformity.

In Fig.4c, the response surface of the fertilization uniformity opens downward, showing the interactive effect of the advancing velocity and the guide plate angle on the fertilization uniformity when the conveyer belt speed is 200r·min^{-1}, and when the advancing velocity is 1.0m·s^{-1} and the angle of the guide plate is 30°, the fertilization uniformity is the highest. It can be seen from the contour map that the influence of the advancing velocity on the fertilization uniformity is more significant than that of the guide plate angle. When the conveyer belt speed is 200 r·min^{-1}, the advancing velocity is at any level, and the fertilization uniformity increases first and then decreases with the increase of the angle of the guide plate. When the advancing velocity is at a high level, the influence of the guide plate angle on fertilization uniformity is obvious, as shown in the figure, the fertilization uniformity curve is steeper, indicating that when the advancing velocity is in the range of 1.1~1.2 m·s^{-1}, appropriately increasing the angle of the guide plate can significantly improve the fertilization uniformity; when the advancing velocity is at a medium and low levels that in the range of 0.8~1.1m·s^{-1}, maintaining the guide plate angle at a medium level can improve the fertilization uniformity. When the conveyer belt speed is 200r·min^{-1}, and the angle of the guide plate is at any level, the uniformity of fertilization increases first and then decreases with the increase of the advancing velocity. When the advancing velocity is low (the angle of the guide plate is high), the amount of fertilization is small, and some areas in the trench are not covered by fertilizer, which reduces the uniformity of fertilization. Increasing the angle of the guide plate or the advancing velocity appropriately can speed up the fertilizer movement rate and increase fertilization amount, reducing the area in the trench that is not evenly covered by fertilizer, and improving the uniformity of fertilization.

Optimization of fertilization uniformity response surface

According to the analysis of the measured data, it can be known that the conveyer belt speed, the advancing velocity and the guide plate angle have a certain effect on the uniformity of fertilization. The best condition for fertilization uniformity is obtained by overlapping three response surface graphs. The conveyer belt speed is within 165~235 r·min^{-1}, the advancing velocity is within 0.8~1.2 m·s^{-1}, and the guide plate angle is changed within the range of 15~45°. When the conveyer belt speed is 214 r·min^{-1}, the advancing velocity is 1.0 m·s^{-1}, and the angle of the guide plate is 37°, the fertilization uniformity is the best, reaching 90.66%.

Field test

In December 2019, an apple gardening test was conducted at Yishui Henghe Farm. The test garden is standardized for planting with a row spacing of 4m and a plant spacing of 1.5 m. The terrain is flat, the soil quality is loam, and the soil pH is 6.7.

Before optimization, the conveyer belt speed is 180r·min^{-1}, the advancing velocity is 0.8 m·s^{-1}, the angle of the guide plate is 20°. After optimization, the conveyer belt speed is 214 r·min^{-1}, the advancing velocity is 1.0 m·s^{-1}, the angle of the guide plate is 37°, and the verification test was repeated three times. The results are shown in Table 6.

The test results show that the uniformity of fertilizer release after optimization is 90.73%, which indicates that the test results after optimizing the parameters of the equipment are consistent with the actual values of the response surface analysis. At the same time, the suitability of the established mathematical model is verified. After optimization, the machine fertilization depth reaches 35 cm, the fertilization uniformity is 90.73%, and the average depth of ditching is 40 cm, which meets the technical requirements for ditching and fertilizing in orchards.

Table 6

Field test results.

Project	Tractor power [kW]	Amount of work	Depth of ditching [mm]	Depth of Fertilization [mm]	Fertilization uniformity [%]
Before optimization	44.13	2	400	350	86.31
After optimization	44.13	2	400	350	90.73

CONCLUSIONS

(1) Establish a fertilization uniformity model. A single-factor and Box-Behnken central composite test is used to establish a mathematical model of fertilization uniformity. It is found through experiments that the mathematical model of fertilization uniformity is accurate and reliable, which provides a theoretical basis for the design and improvement of the orchard ditching-fertilizing machine.

(2) There are optimal values for the technical parameters of the orchard ditching-fertilizing machine. The structural parameters of the fertilizer device have a significant effect on the uniformity of fertilization. Under the conditions when the conveyer belt speed is 214.

$r \cdot min^{-1}$, the advancing velocity is $34 r \cdot min^{-1}$, and the angle of the guide plate is 37°, the uniformity of fertilization is optimal, increasing from 86.31% to 90.73%, and the fertilization stability was improved.

(3) Although the effects of structural parameters on fertilization uniformity have been completed, the effects of shapes of fertilizers on fertilization uniformity have not been studied. The effects of different shapes of fertilizers on fertilization uniformity will be the next research object.

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