DESIGN AND TEST OF KEY COMPONENTS OF 3ZFS-520 INTERTILLAGE DEEP FERTILIZER APPLICATOR
/
3ZFS-520 型中耕深施肥机施肥铲仿真分析与试验

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ABSTRACT

Considering the problems of current intertillage deep fertilizer applicators such as insufficient topdressing depth and poor adaptability in ridge forming, this paper designs a 3ZFS-520 intertillage deep fertilizer applicator by making some improvements to the deep application shovel and hiller. With a lengthened and narrowed deep application shovel and optimized penetration angle, clearance angle and curvature radius, this applicator experiences reduced working resistance and soil disturbance while increasing the fertilizing depth, and has enhanced adaptability in ridge forming and achieves better ridge forming effects through the integration of the hilling shovel and the hiller with adjustable extent. Test results show that, the 3ZFS-520 intertillage fertilizer applicator can reach a fertilization depth of 20cm with good ridge forming effects, strong applicability and adaptability, and stable working performance, and thus can meet the requirements set by the national standard.

摘要

针对现有中耕施肥机追肥深度不足和起垄适应性差的问题，研制了 3ZFS-520 型中耕深施肥机，并就深施铲和培土器进行了改进设计。采用增加深施铲长度、减小深施铲宽度，优化入土角、入土隙角和曲率半径的方法解决了在增加施肥深度的同时降低工作阻力和土壤扰动量的问题；采用培土铲和张度可调的培土器相结合的方式增加起垄适应性并提高起垄效果。经试验测试，3ZFS-520 型中耕深施肥机各项作业性能指标满足国家标准要求，通用性及适应性强，施肥深度可达 20cm，起垄效果好，作业性能稳定。

INTRODUCTION

Intertillage and fertilizing are important steps in crop planting. Intertillage is to loosen soil, increase soil temperature, speed up decomposition of organic matters, weed and preserve moisture; and fertilizing is to supplement nutrition in soil to meet the demand of crop growth *(Baimba et al., 2014; Hamdi et al., 2018; Pedrazzi et al., 2018; Wu et al., 2011).*

At present, although mechanization has been widely applied in intertillage and fertilizing, there are still some deficiencies in current machines, especially the following two problems that require prompt solution.

The first is insufficient depth of topdressing. Compared with the working performance of other fertilizing methods, deep fertilization can apply a given amount of fertilizers uniformly to areas with concentrated roots to ensure full absorption of fertilizers by roots, so as to enhance their development and increase their abilities to absorb nutrients and water and their drought resistance. In this way, the utilization rate of fertilizers can be improved, and the volatilization and loss of active ingredients in fertilizers can be reduced, which will promote production *(Engel et al., 2003; Morrison et al., 1988; Fujii et al., 2015).*

The second problem is the poor adaptability of the integrated ridging plough in ridge forming. The ridging plough of a common intertillage fertilizer applicator is made up of a shovel head, a soil separating board, a soil covering board and a plowtail through rigid coupling and fixation. The plowtail spacing can be adjusted, depending on different crops and different agronomic requirements, but such working method is complicated and cannot meet all spacing requirements, and its ridge forming effects are poor.

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By referring to the working principles of intertillage deep fertilizer applicators in China and abroad and by adopting virtual prototype technology and performing field performance tests, this study designed and tested the key components of an intertillage fertilizer applicator. This shortened the development cycle of intertillage deep fertilizer applicator supported by high-horsepower, and achieved the integration of technology advancement and practicability.

MATERIALS AND METHODS

• *OVERALL STRUCTURE AND WORKING PRINCIPLE*

Basic structure

As shown in Fig.1, the 3ZFS-520 intertillage deep fertilizer applicator is made up of a ground wheel assembly, a transmission system, a fertilization system, a hilling and ridge forming mechanism, a traction frame and a depth wheel. The transmission system is composed of transmission chain I, intermediate support, transmission chain II and a drive shaft of the fertilizer distributor; the fertilization system is composed of a fertilizer tank, a fluted wheel fertilizer distributor, a deep application shovel and a fertilizer pipe; the hilling and ridge forming mechanism is mainly composed of a hilling shovel and a hiller with adjustable extent and spacing.

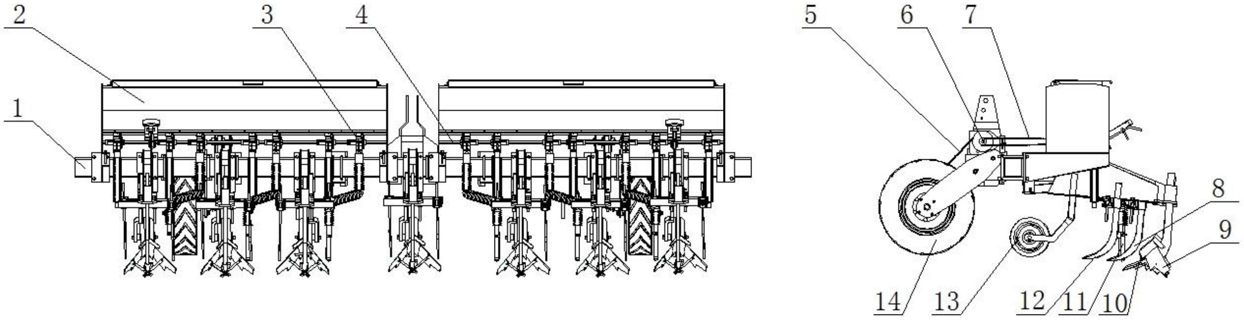


Fig. 1 - Overall structure of the 3ZFS-520 intertillage deep fertilizer applicator

1-Main beam; 2-Fertilizer tank; 3-Fertilizer distributor; 4-Drive shaft of the fertilizer distributor; 5-Transmission chain I; 6-Intermediate support; 7-Transmission chain II; 8-Soil loosening and weeding shovel; 9-Hiller; 10-Hilling shovel; 11-Fertilizing pipe; 12-Deep application shovel; 13-Depth wheel; 14-Ground wheel

Working principle

The 3ZFS-520 intertillage deep fertilizer applicator is compatible with large tractors. It can complete the operations of sub-soiling, sounding and topdressing, and ridge repairing at one time. It works in 6-8 rows in suspension connection with a tractor. The accompanying guide depth-controlled technology is adopted in intertillage and fertilization. Thanks to the great tilling depth of the deep application shovel, it can meet perform sub-soiling and side deep fertilization at the same time, and also achieve drag reduction. During operation, the two ground wheels, as the driver, convey the power symmetrically via transmission chain I to the intermediate support, and to the drive shaft of the fertilizer distributor through transmission chain II. The depth wheel limits the depth of sounding and fertilization. After hilling by the ridge forming mechanism, the entire intertillage fertilization is completed. Table 1 shows the main parameters of the 3ZFS-520 intertillage deep fertilizer applicator.

Table 1

Main parameters of the 3ZFS-520 deep intertillage fertilizer applicator

Items	Parameters
Size (Length * width * height)/(mm × mm × mm)	5380×2390×1370
Total weight/kg	1274
Matched power/kw	75~90
Number of rows	7
Ridge spacing/cm	35~75
Working speed, km·h^{-1}	6.2~7.5
Fertilization depth/cm	15~20
Fertilizer amount/(kg·hm^{-2})	65~110

• DESIGN OF KEY COMPONENTS

Design of the deep application shovel

The deep application shovel is of an integrated structure, as shown in Fig. 2. Its main parameters are penetration angle α, clearance angle β and radius of curvature R. In order to ensure the fertilization depth, the shovel length is 600 mm; the acute angle of the ditching part can ensure the penetration ability of the fertilizing shovel, and the shovel has a thickness of 15 mm; the curving part of the shovel can reduce the working resistance from soil *(Alagusundaram et al., 1990)*.

(1) Penetration angle of the deep application shovel α. IF the shovel is penetrating into the soil, the angle between the working surface of the fertilizing shovel and the ditch underneath is the penetration angle α. When α is large, there will be more soil disturbance, causing more mixture of dry and wet soil, which is not good for dissolution of fertilizers. Experts both in China and abroad made a great deal of in-depth studies on the penetration angle, and it is found that when the penetration angle α is between 0°~20°, the working resistance from soil to the deep application shovel is low; when α>20°, the working resistance increases with the increase of α. During intertillage, the soil disturbance should be controlled; therefore, the penetration angle α should not be excessively large; otherwise, dry and wet soil will be severely mixed. Considering the strength of the shovel tip and the narrowness of the shovel, the penetration angle α is set at 20°. With a smaller width, the shovel will have a stronger soil penetration power. The shape of the shovel tip also affects the working quality of the fertilizing shovel. In this study, the shovel tip is arc-shaped, so that after the shovel penetrates into the soil, the soil may be elevated a little and becomes flat. This design can reduce soil disturbance as much as possible *(Li et al., 2016)*. Then the shaft of the deep application shovel squeezes away the soil to form a fertilizer ditch. Loose soil is left in the ditch by the deep application shovel, allowing the hilling and ridge forming mechanism to cover fertilizer and soil on the ridge.

(2) Clearance angle β. The angle between the deep application shovel and the soil surface is the clearance angle β. This angle can increase the soil penetration ability of the fertilizing shovel. If β is too small, the fertilizing shovel will have a poor soil penetration ability, which will speed up the wearing of the shovel tip; if it is too big, the penetration angle should also be increased, and in this way, the disturbed soil will quickly drop to the ditch bottom, affecting the ditching depth and thus leading to insufficient fertilizing depth. According to some in-depth studies by agricultural technicians, the clearance angle β should be within the range of 5°~10°. Based on the requirements of topdressing in intertillage, the clearance angle is finally set as β=7°*(Shi et al., 2015)*.

(3) Radius of curvature R. The tip of the deep application shovel is arc-shaped, and there is a certain linear relationship between its radius of curvature R and penetration angle α. If the radius of curvature R is too big, the total structure of the shovel tip will be too large; if it is too small, the penetration angle α will be too small to have enough strength in penetration. After comprehensive consideration, the radius of curvature is finally set as R=120 mm.

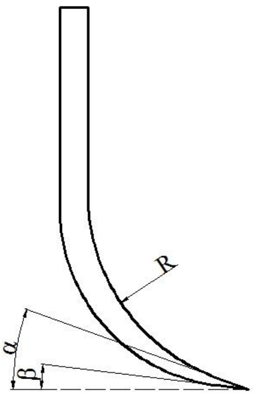


Fig. 2 - Structure of the deep application shovel

R- Radius of curvature; α-Penetration angle; β-Clearance angle

Design of the hilling and ridge forming mechanism

The hilling and ridge forming mechanism has two parts – the hilling shovel and the hiller. The former mainly performs ditching, and the latter mainly performs ridge forming. The hilling shovel is fixed by bolting the L-shaped shovel shaft and the shovel tip. The hiller is composed of the hilling wall and the adjusting plate, with its extent adjustable. With a certain curvature, the hilling wall has a very strong soil turning ability. With a narrow shovel tip, the hilling shovel opens a narrow ditch. It is also good at weeding on both sides of the ridge. Therefore, the hilling shovel can be designed based on the row spacing of crops and size of ridge *(Shi et al., 2017; Wohab et al., 2017)*.

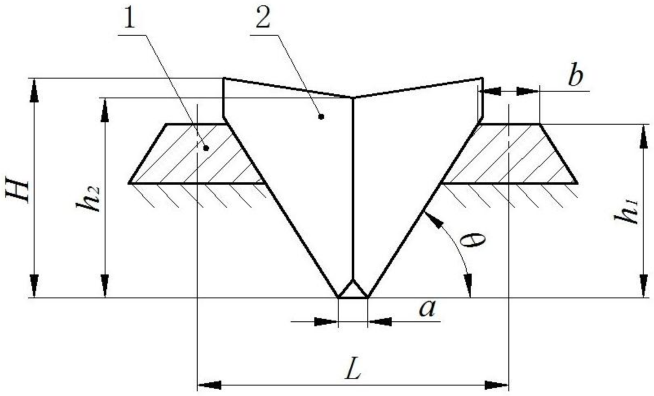


Fig. 3 - Working process of the hiller

1-Ridge; 2-Hiller wall; H-Total height of the hiller; h_1-Total height of the ridge; h_2-The height of hilling wall; α-Ditch width; b-Width of ridge top; θ-Natural angle of repose of soil

Take the intertillage and fertilization of potato for example. The row spacing L=700 mm, ditch width α=100 mm, ridge top width b=400 mm, and the total height of the ridge h_1=1/2 (L-a-b)tan θ=100 mm, where θ is the soil natural angle of repose of the ridge wall, and θ=45°. Based on the requirements for actual operation, the height of the hilling wall h_2 is designed as h_2=(1.1~1.2)h_1. In order to ensure the soil amount of the ridge, and h_2=1.2h_1=120 mm, the total height of the hiller H=1.1h_2=132 mm. The extent of the hiller can be adjusted and controlled by the adjusting plate, with an adjustment range of 325-480 mm, which can meet the requirements of ridging of normal row spacing and ditching *(Shimonasako, 2010).*

• FIELD TEST

Test conditions

The test instruments including the *SM150 High-Precision Soil Moisture Meter* with measuring range of 0~100%, volume content precision of 0.5% under 5~40°C; the *SC900 Soil Compaction Meter, and* the measuring range of which is 0~700kPa, measuring precision is ±103 kPa; the *KTC1-200mm Linear Displacement Sensor* which can be used to measure soil work components operation depth variation, its effective range is 200mm, maximum permissible DC voltage is 42V; the *National Instruments USB-6008 Data Acquisition Board(DAQ)* which has basic data acquisition function, wide application, easy to use and portable data measurement with high mobility, in addition the lead-acid battery, tape, locking tape measure, straight edge and balance etc. are needed.

The field performance test was carried out in the experimental base in Dafeng District of Yancheng, Jiangsu Province, China. The test field was a corn ridge plotted field with average row spacing of 650 mm and a soil moisture content of 17.36% (0-100 mm). The soil compactness of the ridge platform was 0.92 MPa (0~150), the compactness of the ditch soil 1.32 MPa (0~150 mm), the working area 3hm^2, the working depth of the deep application shovel 200 mm, and the ridging height of the hilling shovel 230 mm. There was no case of seedling pressing by soil during the test, and the machine exhibited a good passability.

Test methodology

According to the machinery industry standard of the People's Republic of China *JB/T7864-2013 Cultivator-Fertilizer Machinery Industry Standard* and relevant agricultural machinery test methods, this study tested and analyzed pulverization rate, seeding damage rate, variable coefficient of tilling depth in each row and variable coefficient of consistency in ridge forming spacing (JB/T7864-2013, 2013).

Pulverization rate

After intertillage fertilization operation, a 0.25 m^2 field was selected in any row, and the soil block can be divided into two parts with diameter or length more or less than 25 mm and the ratio of the mass of soil blocks less than 25 mm to the total mass of crushed soil in the survey area was calculated as the pulverization rate. Six plots of land were randomly measured and averaged values were obtained.

Seeding damage rate

The seeding damage rate is the ratio of damaged seedings to the total plants in the tillage area of 1 m in length, which can be calculated by the following formula (1):

$$Y = \frac{X}{N} \times 100\% \tag{1}$$

Where:

X is the number of damaged seedings, plant;
N is the total number of corn seedings after machine operation, plant;
Y is the seeding damage rate, %.

Variable coefficient of tilling depth in each row

The tilling depth data was obtained from the *KTC1-200mm Linear Displacement Sensor* and the *National Instruments USB-6008 Data Acquisition Board (DAQ)*, the variable coefficient was calculated using the following formula (2), (3), (4).

$$\overline{D} = \frac{\sum D}{n} \tag{2}$$

$$S_D = \sqrt{\frac{\sum (D - \overline{D})^2}{n-1}} \tag{3}$$

$$V_D = \frac{S_D}{\overline{D}} \times 100 \tag{4}$$

Where:

D is single tilling depth, mm;
$\overline{D}$ is average tilling depth, mm;
S_D is tilling depth standard deviation, mm;
V_D is tilling depth variable coefficient, %.

Variable coefficient of consistency in ridge forming spacing

In the test area, a test point was selected every 1m along the direction of the machine, and each row distance was measured with 6 test points, the variable coefficient being calculated using the following formula (5), (6), (7):

$$\overline{B} = \frac{\sum B}{n} \tag{5}$$

$$S_B = \sqrt{\frac{\sum (B - \overline{B})^2}{n-1}} \tag{6}$$

$$V_B = \frac{S_B}{\overline{B}} \times 100 \tag{7}$$

Where:

B is row between each test point, mm;
n is row test times;
$\overline{B}$ is average row, mm;
S_B is row standard deviation, mm;
V_B is row variable coefficient, %.

RESULTS

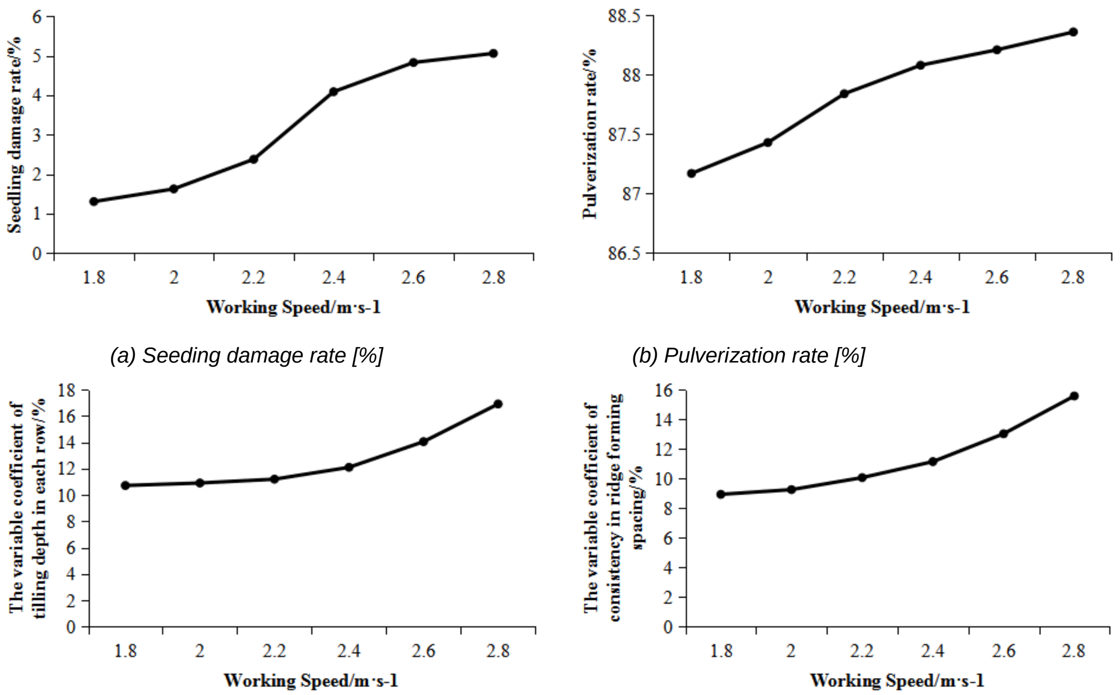
In order to find the proper speed of fertilization, ensure the low seeding damage rate and improve the pulverization rate, maintain the stability tilling depth and ridge forming spacing. In this study, the experiment was carried out in the designated field at different operation speed, and the operation speed of the prototype of 3zfs-520 deep plough fertilizer applicator was set to 6 levels from 1.8m•s^{-1} to 2.8m•s^{-1}, after measuring the test data, using the test methodology to calculate the seeding damage rate, the pulverization rate, the variable coefficient of tilling depth in each row and the variable coefficient of consistency in ridge forming spacing.The test results are shown in Table 2.

Table 2

Field test results of the 3ZFS-520 intertillage deep fertilizer applicator

Working speed ($m \cdot s^{-1}$)	Seeding damage rate [%]	Pulverization rate [%]	The variable coefficient of tilling depth in each row [%]	The variable coefficient of consistency in ridge forming spacing [%]
1.8	1.31	87.17	10.73	8.94
2.0	1.63	87.43	10.92	9.26
2.2	2.38	87.84	11.21	10.07
2.4	4.09	88.08	12.11	11.15
2.6	4.83	88.21	14.06	13.03
2.8	5.06	88.36	16.92	15.58

The seeding damage rate, the pulverization rate, the variable coefficient of tilling depth in each row and the variable coefficient of consistency in ridge forming spacing with the change of working speed were generated in scatter gram, shown in Fig. 4.



(a) Seeding damage rate [%] *(b) Pulverization rate [%]*

(c) The variable coefficient of tilling depth in each row [%] *(d) The variable coefficient of consistency in ridge forming spacing [%]*

Fig. 4 - The test result scatter gram

After analyzing the test results and observing the scatter gram, we noticed that:

(1) The seeding damage rate, the pulverization rate, the variable coefficient of tilling depth in each row and the variable coefficient of consistency in ridge forming spacing were significantly affected by the working speed, and increased with the working speed, and the change tended to be gentle after the working speed was greater than 2.4 $m \cdot s^{-1}$, the percentage of pulverization rate increased with the increase of working speed, and the variation tended to be gentle after the working speed was more than 2.2 $m \cdot s^{-1}$; the variable coefficient of tilling depth in each row and the variable coefficient of consistency in ridge forming spacing increased significantly with the increase of the working speed. In order to ensure that the seeding damage rate meets the standard (less than 5%), and the stability of the ploughing depth and the row spacing between ridges (JB/T7864-2013) are maintained, considering the operation efficiency, the appropriate working speed range is selected as: 2.0~2.4$m \cdot s^{-1}$.

(2) The pulverization rate could reach 87% at a low seeding damage rate. There were mostly small clods and only few big ones, it was proved that the deep application shovel and the hiller combined together had good soil breaking rate; the rate satisfied the agronomic requirement of intertillage operation and there was no damage of the plants *(Kumar et al., 2013)*.

(3) Table 2 shows that, within the range of appropriate operation speed, the variable coefficient of tilling depth in each row and the variable coefficient of consistency in ridge forming spacing could meet the national standards; it was proved that during the operation, both the deep application shovel and the hiller did not have large amount of vibration and deformation under soil resistance, demonstrating good stability in tilling depth and ridge forming. In fertilization, the fertilizing depth had no obvious variation, and thus it could meet the agronomic requirements.

CONCLUSIONS

In this paper, the author designed an intertillage deep fertilizer applicator that could accomplish intertillage, fertilization, soil cultivation and ridging in one-time operation. Considering the current problems of intertillage deep fertilizer applicators, the length of the deep application shovel was increased to 600 mm, so as to ensure that the fertilizer could be applied evenly and quantitatively to the dense part of the crop root system, and the fertilizer could be fully absorbed by the root of the crop, so as to improve the utilization rate of the fertilizer, reduce the volatilization and loss of the effective ingredients of the fertilizer, and achieve the purpose of making full use of the fertilizer efficiency, saving fertilizer and increasing production. In order to prevent the working resistance from increasing with the increase of fertilization depth and soil disturbance, the width of the deep application shovel was decreased to 15 mm, and the penetration angle, clearance angle and radius of curvature were optimized. In light of the poor adaptability of the current intertillage deep fertilizer applicators in ridge forming at present, the hilling and ridge forming mechanism is applied, which consists of a hilling shovel and a hiller. The hilling shovel mainly performs ditching, and the hiller mainly completes ridge forming. The extent of the hiller can be adjusted and controlled by the adjusting plate, with an adjustment range of 275~430 mm, which meets the requirements of ridging and ditching at normal row spacing. In order to find a suitable speed for the application of fertilizer, the experiment was carried out at different speeds in the designated experimental field. After measuring the statistics of the experimental data, the seeding damage rate, the pulverization rate, the variable coefficient of tilling depth in each row and the variable coefficient of consistency in ridge forming spacing were calculated, and the results of the experiment were generated in a scatter gram. Through the analysis of the experimental results and observation of the scatter gram, the suitable operating speed range of low seedlng damage rate and stability of ploughing depth and ridge spacing is 2.0~2.4 m•s-1.

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