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THE DEVICE OF AIR-ASSISTED SIDE DEEP PRECISION FERTILIZATION FOR RICE TRANSPLANTER

Wu Guangwei, Meng Zhijun, Fu Weiqiang, Li Liwei, Wei Xueli, Zhao Chunjiang

National Engineering Research Center for Information Technology in Agriculture, Beijing, 100097, P. R. China

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Abstract. Rice is the most important crop in China, which has the largest plant area. Fertilization is an important process of rice production, which directly affects the yield of crops, reasonable and effective use of chemical fertilizer can improve the yield of crops. At present, the mechanization level of rice fertilization is very low in China, and the artificial fertilization requires a large amount of fertilizer which caused the uneven distribution. The rice side deep fertilizing is an ideal way of fertilization, the fertilizing device will fertilizer (fertilizer for basal and tiller) based on the agronomic requirements one-time positioning and quantitative, it can apply a uniform fertilization to the rice side with a certain depth, which can reduce nitrogen fertilizer amount of 20%-30% compared with the traditional fertilizing operation. The study design a device of air-assisted side deep precision fertilization combined with the agronomic characteristics of side deep fertilization. This device adopted modularization design and riding type rice transplanter supporting the use. In the process of operation, the fertilizer granules falls into the deep trench at a certain amount under the effect of gravity and wind, the trench is drew by fertilizer exports in seedling side 3cm and 5cm depth, and then the fertilizers will be covered in the mud by covering plate. The vehicle control terminal is designed under the embedded Visual C++ integrated development environment in the XP Windows operating system, the interface can display the current operating data, and meanwhile, the user can set the working parameters according to the actual operating requirements. The experiments were done in the field of Heilongjiang seven star farm, the result shows, planting and fertilization can be done completely and independently in one time when fertilization device and riding type rice transplanter supporting the use. When the preset rate of fertilizer was 300 kg/hm2, the vehicle speed was 1m/s fertilization device can realize the precision fertilization, and the deviation of fertilizer is within 5.82%, which can meet the requirement of the actual production.

Keywords. *Rice in cold region Air-assisted Precision fertilization Side deep fertilization Venturi effect*

Introduction

Rice is one of the most important food crops in China, which has the largest plant area and the highest total yield. Fertilization is an important process of rice production, which directly affects the yield of crops(Zeng Xibai,2004). The artificial fertilizer method has been used in process of rice production ,and the mechanization level of rice fertilization is very low at present in China, and the artificial fertilization requires a large amount of fertilizer which caused the uneven distribution. The rice side deep fertilizing is an ideal way of fertilization, it is the way of apply the granular fertilizer to the side of rice seedlings with a certain depth, the granular fertilizer is applied in the topsoil as bandings, which is close to rice roots and improve fertilizer utilization rate, the way can reduce nitrogen fertilizer amount of 20%-30% compared with the traditional fertilizing operation(Xia Yantao,2014; Bai Xue,2014; Miyoko W,2015; Sheng Z,2011).

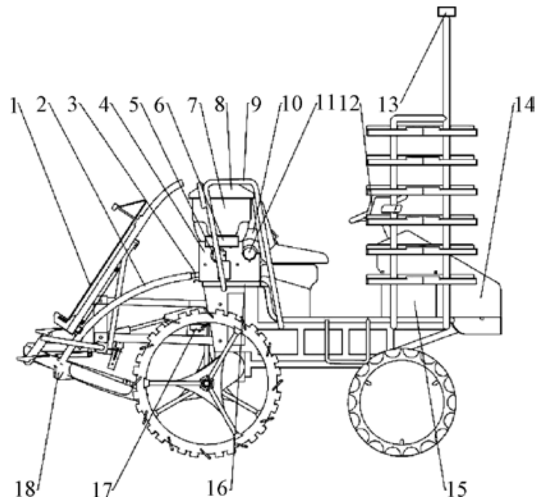
The side deep fertilizing technique has been applied widely in Japan, the products of side deep fertilization were designed by Kubota, Iseki, Yanmar and other companies. The working way of equipment is the mechanical transmission mode and complex in installation, the product of different company has poor matching with the rice transplanter of other companies. At present, most rice transplanters used in China is the products of Kubota, Iseki and Yanmar, another small part is domestic rice transplanter(Kaoru A,2007; Wei Guojian,2014; Wei Guojian,2015). The most rice transplanters are not installed the side deep fertilization device for the reasons of price, poor matching, installation complexity etc. Lack of matching equipment hinder the application of side deep fertilizing technique in China. Rice fertilizer machinery used in China is mainly disc spreader and rotary tillage fertilizing machine, the effect of fertilization is poor and can not achieve the requirements of the side deep fertilization operation(Zhu Song,2015; Chen Changhai,2012; Chen Xiongfei,2014; Zeng Shan,2012). There is a little research on the side deep fertilization device and there is no practical equipment at present in China(Zhang Shuhui,2004; Wang Xiu,2004; Geng Xiangyu,2007).

The study carry out the theory of air-assisted fertilization and the control method of the side deep precision fertilization combined with the agronomic characteristics of side deep fertilization. The device of air-assisted side deep precision fertilization combined was designed for the rice transplanter, its working principle is motor driven fertilizer and air-assisted fertilizer, its fertilization amount was adjusted according to the change of the rice transplanter's speed obtained by GPS. It is in order to achieve the requirements of the side deep precision fertilization operation and improve the fertilizer efficiency and the utilization rate of fertilizer.

STRUCTURE AND WORKING PRINCIPLE OF THE DEVICE

Structure of the device

The device was designed as a modular style, its structure include integrated mounting base, GPS antenna, control terminal, fertilizer application controller, motor, fertilizer box, air blower etc. The device can be used with different brands and types rice transplanters. The device of side deep precision fertilization structural diagram is shown in Fig.1, the main technical parameters are shown in Table.1.



1-Seedling table, 2-Pipeline, 3- Air-assisted fertilizer pipe, 4- Mounting base, 5-Motor, 6-Fertilizer application controller, 7-Fertilizer box, 8-Fertilizer box cover, 9-Armrest, 10-Air blower, 11-Air duct, 12-Vehicle control terminal, 13-GPS antenna, 14-Transplanter, 15-Power supply, 16-Pedal, 17-Job status sensor, 18-Fertilizer export

Fig.1 The device of side deep precision fertilization structural diagram

Table 1 Main technical parameters of the device

Parameters	Values
Dimensions (Length × Width × Height)/ mm×mm×mm	3 000×2 210×2 570
Capacity of fertilizer box/m^3	0.07
Working width/m	1.8
Driving speed/(m·s^{-1})	0～1.62
Rows of fertilization	6
Depth of fertilization/cm	5
Distance from seedling to fertilizer/cm	3
Conveying velocity/(m·s^{-1})	21.16

Working principle

The working principle of device is motor driven fertilizer and air-assisted fertilizer. When the device is fertilizing, the goal amount of fertilizer is set in vehicle control terminal, the fertilizer apparatus is driven by motor to fertilize the granular fertilizer , and the granular fertilizer is carried by airflow from the air blower. Its fertilization amount was adjusted according to the change of the rice transplanter's speed obtained by GPS. The job status sensor is used to judge the rice transplanter's job status in order to control the fertilizer apparatus whether to work. In the time of the device working, the rectangular groove of 5 cm depth is opened in the side of the rice seedling and its distance is 3 cm, the granular fertilizer under the action of gravity and airflow is carried to the bottom of goove through the pipeline, fertilizer export, and the granular fertilizer is covered by the slurry under the action of cover plate(Xia Yantao,2014; Bai Xue,2014; Miyoko W,2015; Sheng Z,2011). Fertilization principle is shown in Fig.2.

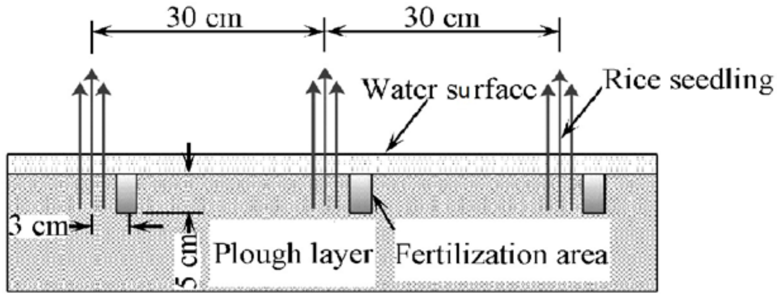


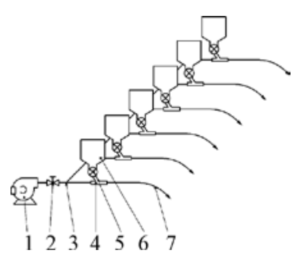
Fig.2 Fertilization principle diagram

PNEUMATIC CONVEYING SYSTEM

Structure and working principle

Pneumatic conveying system is the key to achieve stability of fertilizer in paddy field. The water and mud will affect the granular fertilizer discharged from the fertilizer tube, sometimes the pipeline of the device can be blocked by mud, so the method of air-assisted fertilization can ensure granular fertilizer are delivered to the designated position (Wang Taizhu,2008).

The gas supply pressure of the pneumatic conveying system is lower than 0.1 MPa, and the positive pressure pneumatic conveying system is adopted. The system is mainly composed of air blower, wind speed regulation switch, air duct, air-assisted fertilizer pipe, fertilizer apparatus, pipeline. The system structural diagram is shown in Fig.3, air source is located in the front end of the system, the granular fertilizer is sent to the wind pipe through the fertilizer apparatus when the system works, a certain pressure of compressed air produced by the blower is blown to air supply and transportation through air duct, the air pressure of the feed inlet is negative pressure in the effect of the Venturi effect, the air and granular fertilizer are mixed in the outlet, the granular fertilizer is carried by the airflow to the bottom of goove in the side of rice seedlings with a certain depth through the pipeline(Li Jianian,2012; Wang Miao,2006; Han Qibiao,2013).



1.Air blower 2.Wind speed regulation switch 3.Air duct 4. Air-assisted fertilizer pipe 5.Fertilizer apparatus 6.Hopper 7.Pipeline

Fig.3 Pneumatic conveying system

Air flow rate of the system

In order to ensure the granular fertilizer can be delivered smoothly and not be blocked in lose pipeline, the granular fertilizer and air should maintain proper mixed concentration ratio. Because the system belongs to the low pressure system, productivity is smaller, the value of mixed concentration ratio is 0.6 (Wang Taizhu,2008).The air flow rate is calculated by the Formula 1. *Q* express the air flow rate(m^3/s), *W* express transport mechanism productivity(t/h), γ express air bulk density, γ=1.2 kg/m^3, μ express mixed concentration ratio.

$$Q = \frac{W}{3.6\mu \cdot \gamma} \qquad (1)$$

The working efficiency of rice transplanter is 0.2 ~ 0.61 hm^2/h, when the working efficiency is 0.61 hm^2/h and fertilizing amount is 300 kg / hm^2, *W* is 0.183 T/h, *Q* is 250 m^3/h through calculation.

Conveying air velocity of the system

Conveying air velocity is an important index to evaluate the performance of the system. The air velocity must be guaranteed that the granular fertilizer can be transported in the pipeline（Ma Zheng，2013）. The air velocity is calculated by the Formula 2.

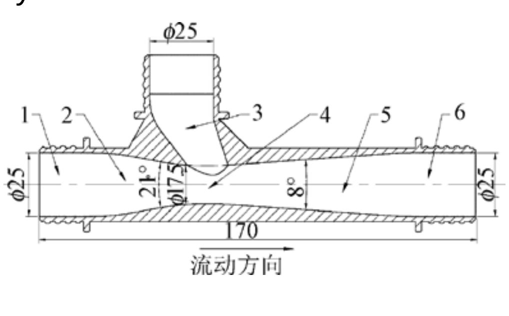
$$V^* = k \cdot V_L \qquad (2)$$

V^* express conveying air velocity(m/s) ,V_L express suspension velocity of the granular fertilizer(m/s), *k* express velocity coefficient(1.5 ~ 2.5). The study

obtained suspension velocity is 10.58m/s through the experiment, the value of *k* is 2 due to the fact of the granular fertilizer and structure of pipeline(Wang Taizhu,2008). V^* is 21.16 m/s through calculation.

Structure design of air-assisted fertilizer pipe

The air-assisted fertilizer pipe is a key component that include inlet, contraction section, feed port, cylindrical throat, diffusion section, outlet(Fig.4). The inner diameter of the pipe is determined by the air consumption and the conveying air velocity（Hu Keji，2013）, the inner diameter is calculated by the Formula 3.



1.Inlet 2.Contraction section 3.Feed port 4.Cylindrical throat 5.Diffusion section 6.Outlet

Fig.4 Structure of the air-assisted fertilizer pipe

$$d_1 = \sqrt{\frac{4Q}{\pi V^*}} \qquad (3)$$

In the formula, d_1 express the inner diameter of the pipe(m), V^* express conveying air velocity(m/s), Q express the air flow rate(m^3/s). d_1 is 26.5 mm through calculation. Because the inner diameter of pipeline connecting with the outlet is 25 mm, the inner diameter of the pipe selected the value of 25 mm. The structure of air-assisted fertilizer pipe was designed by the Venturi effect, the contract angle is 21°. The pressure difference in diffusion section is minimum when the diffusion angle is 8°, and The pressure difference in contraction section is small. The diameter of cylindrical throat is 17.5 mm, the length is generally 0.5 d_2 or d_2, so in order to ensure the fertilizer entrance space, the length of cylindrical throat is 17.5 mm（Tong Feihu，2007；Liu Kai,2015）.

FERTILIZATION CONTROL SYSTEM

System design

The fertilization control system is based on the real-time speed of the rice transplanter to adjust fertilization amount, the system include air blower, vehicle control terminal, GPS antenna, GPS module, fertilization controller, job status sensor, motor（Fig.5）

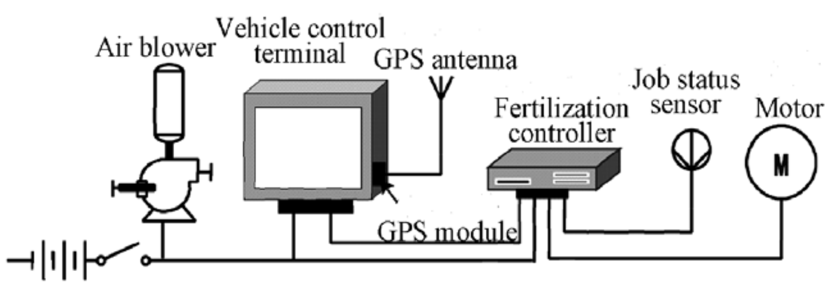


Fig.5 Control system structure diagram

The vehicle control terminal and fertilization controller use shaft speed information, actual fertilizer shaft speed and the speed of the vehicle information for communication（Yu Yingjie,2009；Meng Zhijun,2009）The vehicle control terminal sends vehicle control terminal to fertilization controller as the target speed message, actual fertilizer shaft speed message is feedback to the vehicle control terminal as the current fertilization characterization value. The vehicle speed information is calculated from the data received by the vehicle control terminal through the GPS receiver as the current rice transplanter speed. The vehicle control terminal and the fertilizing controller communicate with the RS485 bus, and adopt the RTU transmission mode according to the definition of the MODBUS protocol on the serial link.In the process of operation, the vehicle control terminal calculates the speed of the rice transplanter by analyzing the GPS data, calculates the target speed of the motor, and realizes the real-time control of the motor speed（Chen Liping，2008）.

The vehicle control terminal

Windows XP operating system is used in the vehicle control terminal. The study designed the fertilizing control software use eMbeddedVisualC++ integrated development environment for the demand of side deep precision application of fertilizer. The vehicle control terminal and fertilization controller using RS485 serial bus communication mode. The software receive the GPS data through the high precision GPS module, to obtain the speed of the rice transplanter. The software interface can display the speed of the motor and the state of the sensor status in real time, and the software allows the user to set the working parameters according to the actual operation requirements.

The fertilization controller

The main task of the fertilizer controller is to collect the current drive motor speed and report the data to the vehicle control terminal, receive the motor target speed of the vehicle control terminal, and drive the motor to achieve the target speed. Fertilization controller using model for AQMD2410NS DC brushless motor driver, set for the self rated speed closed-loop control, motor speed use the internal integration PID regulation to achieve steady speed, which proportional coefficient Kp value is 0.2, integral time constant Ti value is 0.15, differential time constant TD value is 0.15, sampling period TD is 1 ms.

The fertilizing device has 6 working part, transplanter working breadth is 1.8 m, fertilizer amount of every turn is 20 g, the target fertilizer amount, the speed, and motor speed has the relationship as the Formula 4. n_1 express the fertilizer drive motor speed,(r/min), t express the time(s), s express the operating area (hm^2), l express the travel distance(m), v express the speed of travel(m/s), G express the target fertilizer amount(kg/hm^2).

$$\begin{cases} 20\times 6\times \dfrac{n_1\cdot t}{60}=1000\times G\cdot s, \\ t=\dfrac{l}{v}, \\ l==\dfrac{10000s}{1.8}, \\ G=\dfrac{100}{9}\cdot\dfrac{n_1}{v}。 \end{cases} \quad (4)$$

EXPERIMENTAL STUDY AND ANALYSIS OF THE DEVICE

Consistency test of fertilizer amount

When the rice transplanter in static condition, consistency of the each row fertilizer quantity was test in different speed. In the experiment, the fertilizer amount was 1/2 of the volume of fertilizer box, the number of rows was 6, the target fertilizer amount was set to 300 kg/hm^2. The driving motor speed was 10, 20, 30, 40 r/min, the measuring time is 5 min, and the test is repeated for 5 times at each speed, the granular fertilizer from 6 fertilizer export was collected and numbered, and the electronic balance with the accuracy of 0.001g was used for weighing and recording.

The 20 group test results was collected and statistically analyzed, the statistical results were shown in Table 2, and the standard deviation and coefficient of variation was calculated according to Formula 5. xi express the average fertilizer amount of each row(g), *x* express the average value(g), S^* express the standard deviation(g), *V* express the coefficient of variation(%), *n* express the number of rows. In Formula 5, when n<30, the denominator is (n-1), when n=30, the denominator is n.

$$\begin{cases} x = \dfrac{\sum_{i=1}^{n} x_i}{n} \\ S^* = \sqrt{\dfrac{\sum_{i=1}^{n}(x_i - x)^2}{n-1}} \\ V = \dfrac{S}{x} \times 100\% \end{cases} \quad (5)$$

In Table 2, we can see that the each row fertilizer variation coefficient is small at the same speed, the fertilizer amount consistency is good, the fertilizer amount is relatively constant. The average fertilizer amount increases linearly with the increasing of the rotation speed, and the fertilizer amount of every turn is relatively stable in different speed, and which has decreasing trend with the increasing of rotational speed.

Table 2 Statistical results of each row fertilizer quantity consistency determination

speed/ (r·min^{-1})	First row of fertilizer/g	Second row of fertilizer/g	Third row of fertilizer/g	Fourth row of fertilizer/g	Fifth row of fertilizer/g	Sixth row of fertilizer/g	Average/g	Standard deviation	Coefficient of variation/%	Fertilizer amount per turn/g
10	1035.000	1005.000	1010.000	1000.000	1063.350	1031.650	1024.167	23.920	2.3	20.483
20	2036.700	1961.700	2046.700	1965.000	2045.000	2046.700	2016.967	41.709	2.1	20.169
30	2970.000	2901.600	3019.950	3010.050	2953.350	3093.300	2991.375	65.599	2.2	19.943
40	3936.600	3873.400	3998.400	3848.400	3811.600	3 940.000	3901.400	68.986	1.8	19.507

THE FIELD EXPERIMENT

In order to test actual working performance of the device, the field experiment were conducted in seven star farm of Heilongjiang in May 2015. The total area of fertilizer is 0.6 hm^2. In this experiment, the granular fertilizer is compound fertilizer, the vehicle platform is Yanmar VP6 rice transplanter. The field experiment is shown in Fig.6

Fig.6 Field experiment of rice transplanter and fertilizing device

The speed of rice transplanter was 1 m/s, the target fertilizer amount was set to 300 kg/hm2 in the progress of field experiment. The rice transplanter make 4 times reciprocating fertilization progress in fertilization area, he amount of fertilizer was calculated, the statistical results were shown in Table 3, and the fertilizer deviation was calculated according to the Formula 6.

$$\gamma_s = \frac{\left|10\,000(W_q - W_h)/S - F\right|}{F} \times 100\% \qquad (6)$$

In the formula, γ_s express the fertilizer deviation(%), W_q express the fertilizer quality before testing(kg), W_h express the remainder fertilizer quality after testing(kg), S express the fertilizer area(m^2); kg/hm2 for the preset amount of fertilizer, F. F express the target fertilizer amount(kg/hm^2).

As can be seen from Table 3, the fertilizer amount of the device is relatively stable in actual operation process, when the preset amount of fertilizer is 300 kg/hm^2, the speed of the vehicle is 1 m/s, the fertilizer deviation is less than 5.82%.

Table 3 Statistical results of field application

Number	Preset fertilizer/ ($kg \cdot hm^{-2}$)	Actual amount of fertilizer/($kg \cdot hm^{-2}$)	Fertilization deviation/%
1	300	316.425	5.48
2	300	303.69	1.23
3	300	383.160	4.21
4	300	317.445	5.82
5	300	307.980	2.66
6	300	306.690	2.33
7	300	290.370	3.21
8	300	299.340	0.22
9	300	316.890	5.63
10	300	306.825	2.28

Conclusion or Summary

The study design a device of air-assisted side deep precision fertilization, in order to meet the requirement of the production of deep fertilization in cold region, and the fertilization control system was developed for precision fertilization operation .The device can matched with the rice transplanter, its working principle is motor driven fertilizer and air-assisted fertilizer, its fertilization amount was adjusted according to the change of the rice transplanter's speed obtained by GPS. It can achieve continuous strip side deep precision application of fertilizer and improve the fertilizer efficiency and the utilization rate of fertilizer.

Field experiment showed that the device of air-assisted side deep precision fertilization can complete fertilization operation, when the rice transplanter speed is 1 m/s and the preset amount of fertilizer is 300 kg/hm^2, the fertilizer deviation is less than 5.82%, the actual working performance of the device reached design target. The next step is to carry out more field experiments to test the stability and reliability of the device.

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