DESIGN AND EXPERIMENT OF CAM-LINKAGE SELF-CLEANING FERTILIZER APPARATUS
/
凸轮顶板自清式排肥器的设计与试验

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ABSTRACT
Aiming at the poor performance and low efficiency of moist fertilizers, a cam-linkage self-cleaning fertilizer apparatus is designed. The cam-linkage mechanism matched with the self-cleaning device is applied to scrape off the residuals, and the structural parameters of flute cam in the wheel are obtained by using the polar equations. The physical characteristics of Stanley compound fertilizer, Kingenta compound fertilizer and Kingenta dual-effect nitro-fertilizer are analyzed to build the discharging model and obtain the key parameters, such as the wheel diameter, the groove number. The trajectory of fertilizer is introduced for the scraper plate. To evaluate the performance, a full factorial experiment including fertilizer types, moisture content and rotating speed is conducted, taking the discharging and coefficient of variation as the evaluation indicators. The results show that in the rotation of 10-50 r/min, the cam-linkage self-cleaning fertilizer apparatus could discharge compound fertilizers with a moisture content less than 8%, and the coefficient of variation is 0.12% -8.21%. In addition, the relationship between the rotating speed and the discharging has the linear relationship, and the determination coefficient R^2 are more than 0.974. This study helps promoting the deep fertilization technology and equipment in southern rice region.

摘要
针对高湿南方稻区肥料颗粒吸湿粘附堵塞排肥器，影响深施肥作业效果及效率的问题，基于凸轮顶板自清的技术思路，设计了一种凸轮顶板自清式排肥器。建立了凹槽凸轮的极坐标方程及排肥速率数学模型，明确了该排肥轮直径、料槽数量等结构参数；通过开展颗粒肥料运动轨迹分析，获得了清肥刮板结构参数；借助人工气候箱模拟江西省早、中、晚稻种植的温度和湿度，开展了排肥器内颗粒肥料吸湿试验，获得了颗粒肥料含水率的范围；并以史丹利复合肥、金正大复合肥和金正大硝基双效肥为试验材料，肥料类型、肥料含水率和排肥轮转速为试验因素，以排肥量及其变异系数为评价指标，开展了排肥器工作性能试验。试验结果表明：排肥器转速在 10~50r/min 条件下，不同含水率（2%、4%、6%、8%）的 3 种供试肥料的排肥速率与排肥轮转速均呈线性关系，决定系数 R^2 大于 0.974，3 种供试肥料随着含水率增加，排肥速率变异系数均呈增大趋势，变化范围为 0.12~8.21%；影响排肥性能的显著因素由大到小为排肥轮转速、含水率、肥料种类、肥料种类和含水率的交互作用、含水率和排肥轮转速的交互作用。因此，该排肥器在 10~50r/min 转速条件下可适用于含水率不高于 8% 的吸潮颗粒肥料稳定排施，可为高湿南方稻区水稻种植同步深施肥机具的研制提供核心部件。

INTRODUCTION
The average discharging of nitrogen fertilizer in rice planting is 180 kg/hm^2 in China *(Bai, 2018, Randive et al., 2021),* which is more than 75% of the worldwide average *(Tajamul et al., 2022; Ludemann et al., 2022)*. However, the utilization rates of nitrogen, phosphorus and potassium fertilizers is low, which are 30%~35%, 10%~25% and 35%~50%, respectively *(Sichul, 2021, Yu et al., 2022)*. Studies show that the deep fertilization is a great method of increasing efficiency and decreasing cost *(Jelle et al., 2018; Kakar et al., 2019)*. Compared with the scattering fertilization on the soil surface, *(Alameen et al., 2019; Siddique et al., 2020)*, it can also reduce the environmental pollution *(Jabbar et al., 2022; Paul et al., 2022),* promote the utilization rate

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and rice product *(Rebecca et al., 2022; Tang et al., 2019),* and reduce the volatilization and loss*.* Deep fertilization is achieved by fertilization equipment *(Liu et al., 2022).* Researchers of agricultural companies, such as Kubota Agricultural Machinery (Suzhou) Co, Ltd, Yanmar Agricultural Machinery (China) Co, and Ltd and Huanan Agricultural University are researching deep fertilization equipment for rice planting and are manufacturing many agricultural machines.

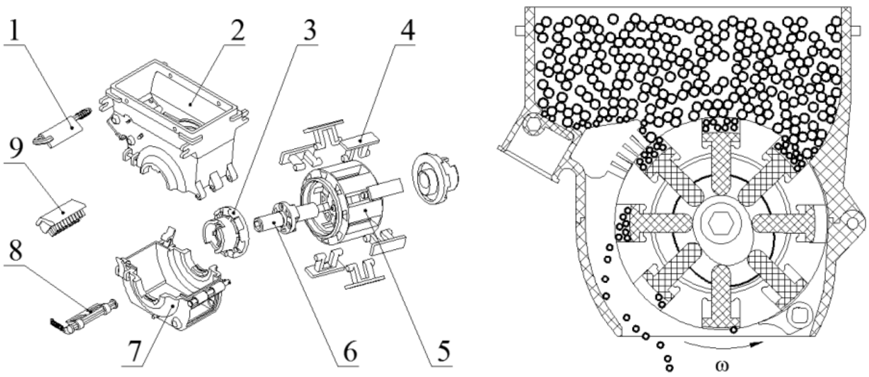
Fertilizer apparatus is the key to develop deep fertilization for rice planting, and its performance will influence the uniformity, stability and adaptability of fertilization. Most fertilizer apparatuses such as outer-fluted wheel fertilizer apparatus perform well in northern drylands *(Tan et al., 2020; Liu et al., 2021),* and poorly with bonding and blockage in southern paddy field *(Uspensky et al., 2021; Xiao et al., 2021)*. The reasons may be that: the granular fertilizer is a pore structure with a great surface energy, which is easy to absorb moisture and bond in the fertilizer apparatus *(Liu et al., 2021.* Once the fertilizer powder blocks the fertilization wheel and stops running, the efficiency would be affected. To solve this problem, many fertilizer apparatuses are studied *(Sugirbay et al., 2020; Liu et al., 2021; Du et al., 2021),* and few applications are found in rice planting.

Aiming to the blockage and bonding of fertilizer apparatuses in the southern region, a cam-linkage self-cleaning fertilizer apparatus is designed. The structure of cam-linkage self-cleaning is analyzed, and then the experiment is carried out to perform the discharging of moist fertilizer. The results show that the fertilizer apparatus could promote the application of deep fertilization in rice planting.

MATERIALS AND METHODS

Cam-Linkage Self-Cleaning Fertilizer Apparatus

The structure of cam-linkage self-cleaning fertilizer apparatus is composed of the upper shell, lower shell, flute cam, linkage, wheel, transmission shaft, discharging plate, cleaning brush and scraper plate, as shown in Figure 1. The wheel with two flute cams is installed in the transmission shaft, and the linkage with the top plate is fixed into the flute cam. Then the cleaning brush is located to clean the extra fertilizer out of the grooves, and the plate discharges the fertilizer into the shell after work. The scraper plate is installed in the lower shell to clean the residues sticking in the wheel, and the lower shell is locked with the upper shell.



a. Structure of the fertilizer apparatus b. Fertilization process

Fig. 1 - Structural diagram of the cam-linkage self-cleaning fertilizer apparatus

1. Discharging plate 2. Upper shell 3. Flute cam 4. Linkage 5. Fertilization wheel 6. Transmission shaft 7. Lower shell 8. Scraper plate 9. Cleaning brush

The transmission shaft rotates to drive the wheel, and then the linkage moves with the flute cam. When the top plate of linkage moves down to change the volume of grooves in the wheel, the fertilizers in the box will be filled. When the linkage moves the deepest, the cam-linkage mechanism is in the near angle of repose stage, and the extra fertilizers out of grooves are cleaned by the brush. In this way, the grooves are full of fertilizers, and the cam-linkage mechanism is in the far angle of repose stage. The top plate of linkage pushes out the fertilizers, and the apparatus discharges the fertilizers, and then the cam-linkage mechanism runs into the lift stage. Finally, the scraper plate cleans the residuals, and the cam-linkage mechanism keeps running in the return stage. Thus, he fertilizer apparatus works with "filling-transporting-discharging-cleaning" as shown in Figure 2, and the cam-linkage mechanism works as "near angle of repose-far angle of repose-lift-return".

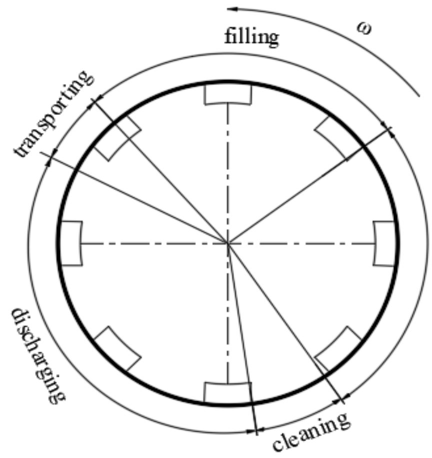


Fig. 2 - Operating process of the flute cam

Parameters of Cam-Linkage Mechanism

Flute cam: The performance of fertilizer apparatus would be influenced by the structural parameters, and the discharging would be influenced by the filling process. Figure 3 shows the near angle of repose θ_1, and θ_1 i 3π/4. The scraper plate is installed in the far angle of repose θ_3 to cover the single groove, and θ_3 is π/9. The wheel discharges the fertilizers in the return stage θ_2 with 5π/9, and the lift stage θ_4 is 7π/12 to prepare for filling.

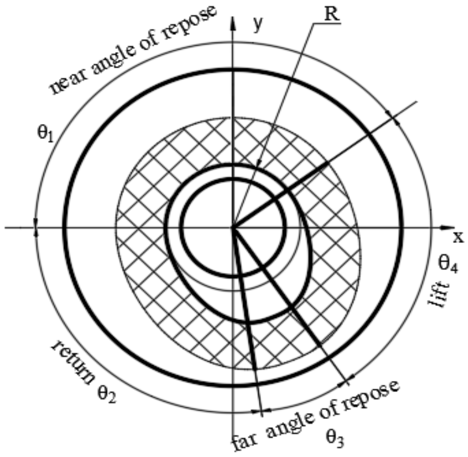


Fig. 3 - Structural parameters of the cam-linkage mechanism

A four-stage analysis of the structure of the flute cam is conducted to analyze the movement without impact. The semi-diameter of the base circle in the flute cam *R* is 15 mm, and the width *d* is 10 mm, the curve of the flute cam is thus established with quantic polynomial equations (1).

$$\begin{cases} \rho_1 = 25 & \theta_1 \in \left(0, \frac{3}{4}\pi\right) \\ \rho_2 = -131.58\theta_2^5 + 410.23\theta_2^4 - 346.21\theta_2^3 & \\ \quad -59.638\theta_2^2 + 191.12\theta_2 - 62.318 + 25 & \theta_2 \in \left(\frac{3}{4}\pi, \frac{47}{36}\pi\right) \\ \rho_3 = 33 & \theta_3 \in \left(\frac{47}{36}\pi, \frac{17}{12}\pi\right) \\ \rho_4 = 33 - (59.516\theta_4^5 - 764.64\theta_4^4 + 3559.2\theta_4^3 & \\ \quad -7777.7\theta_4^2 + 8106.2\theta_4 - 3245.7) & \theta_4 \in \left(\frac{17}{12}\pi, 2\pi\right) \end{cases} \tag{1}$$

where ρ_1 is the displacement between the origin and the point of near angle of repose, mm; θ_1 is the near angle of repose of the cam, rad; ρ_2 is the displacement equation between the origin and the point of the lift stage, mm; θ_2 is the motion angel of the lift in the cam, rad; ρ_3 is the displacement between the origin and the point of the far angle of repose, mm; θ_3 is the far angle of repose of the cam, rad; ρ_4 is the displacement equation between the origin and the point of the return stage, mm; θ_4 is the motion angel of return in the cam, rad.

Fertilization wheel: The theoretic discharging speed required by agronomy and the real discharging speed of fertilizer apparatus are calculated as follows:

$$\begin{cases} Q_s = \dfrac{Q_t B v}{10} \\ Q_s = \dfrac{\rho \lambda w h l Z N n}{60} \end{cases} \tag{2}$$

where Q_s is the theoretic discharging speed, g/s; Q_t is the theoretic quantity of fertilization in a unit area, kg/hm^2; v is the forward speed of tractor, m/s; B is the operating width of fertilization, m; Q_m is the real discharging speed in a unit area, g/s; ρ is the bulk density of granular fertilizer, kg/m^3; λ is the filling coefficient; w is the width of the groove, m; h is the depth of the groove, m; l is the length of the groove, m; Z is the groove number of the fertilization wheel; N is the number of fertilizer apparatuses in the tractor, and n is the rotation of the fertilization wheel, r/min.

Q_t can be obtained by Eq. (3).

$$Q_t = \frac{\rho \lambda w h l Z N n}{6Bv} \tag{3}$$

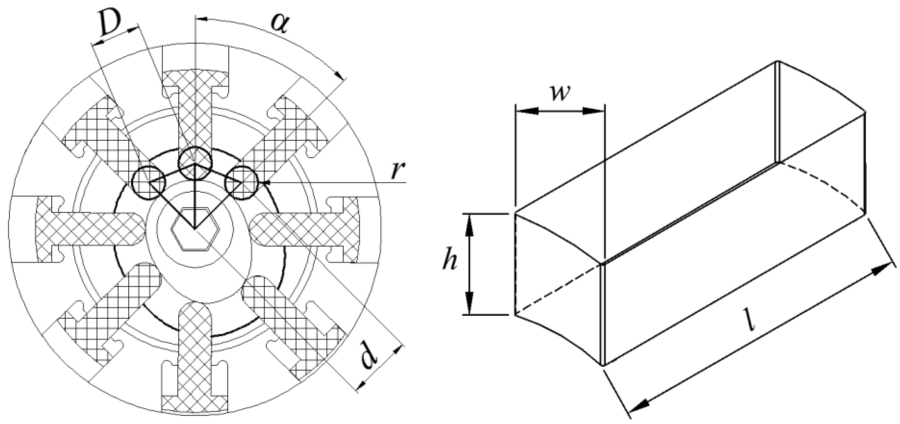
The operating width B and the forward speed v are determined by the tractor, thus the groove length l, the groove number Z, the fertilizer apparatus number N, and the filling coefficient λ have an inverse ratio relationship with the rotating speed n. Since n and Z are influenced by the wheel diameter D, and Z would increase when enlarging D. In the same operational conditions, λ can increase by lowering n.

Stanley compound fertilizer, Kingenta compound fertilizer and Kingenta dual-effect nitro-fertilizer are selected as the experimental materials, and the test parameters as shown in Table 1. The results show that the average size of the fertilizer granular is 4.24mm×3.82mm×3.45mm, and the angle of repose is 30.02° with 90.46% sphericity. The bulk density of Stanley compound fertilizer is the greatest with 867.86 kg/m^3, and Kingenta compound fertilizer has a small bulk density with 819.11 kg/m^3. Therefore, the filling volume of grooves is obtained, and D is 113 mm. To make the linkage move fluently, the width and depth of straight grooves are 20 mm and 8 mm, respectively.

Table 1

Physical and mechanical characteristics of different fertilizers

Name	Length/ mm	Width/ mm	Depth/ mm	Sphericity/ %	bulk density/ kg·m^3	angle of repose/ °
Stanley compound fertilizer	4.25	3.82	3.29	89.12	867.86	29.41
Kingenta compound fertilizer	4.20	3.72	3.34	89.08	819.11	28.84
Kingenta dual-effect nitro-fertilizer	4.27	3.92	3.73	93.19	832.62	31.82



a. Diagram of fertilization wheel b. Groove structure

Fig. 4-Structure of the fertilizer groove

Since the groove number Z had a relationship with the bottom radius of the linkage r, Z was 8 according to Eq. (4):

$$\begin{cases} D = 2d\sin\dfrac{\alpha}{2} \\ \alpha = \dfrac{2\pi}{Z} \\ 2r < \mathrm{D} \\ \mathrm{Z}\arcsin\dfrac{r}{d} < \pi \end{cases} \tag{4}$$

where D is the distance between the two bottom balls of linkage, mm; α is the angle between two linkages, rad; d is the central distance between the ball and transmission shaft, mm; r is the bottom radius of linkage, mm.

Scraper plate: To clean the residual fertilizers in the top plate of the wheel, the scraper plate is installed on the lower shell with a spring, and the hollow curve surface is designed to reduce the bonding of moist fertilizer as shown in Fig. 5. When the linkages push the moist fertilizers out from the grooves, the scraper plate scrapes the residuals to stop the blockage. When the residuals are cleaned and dropped into the outlet, the discharging is uniform, and the filling performance is stable in the next operation.

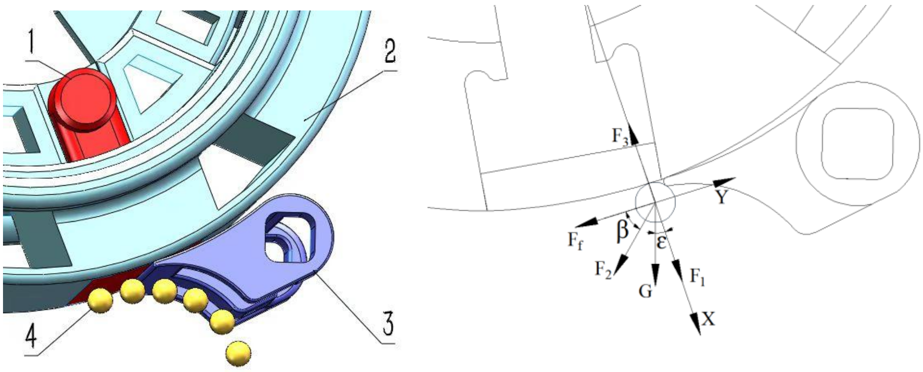


Fig. 5 - Force analysis of bonding fertilizer on the self-cleaning device

1. Linkage 2. Fertilization wheel 3. Scraper plate 4. Bonding fertilizers

To acquire the structural parameters of scraper plate, the force analysis of moisture fertilizer in the top plate is conducted, including the gravity G, the support force from the top plate F_1, the force from the scraper plate F_2, the adhesion force between the bonding fertilizer and the top plate F_3, and the frictional force between the top plate and fertilizers F_f. The following formula can be obtained:

$$\begin{cases} F_1 = \mathrm{m}\omega^2\mathrm{r} \\ F_\mathrm{f} = F_3 - G\cos\varepsilon - F_1 - F_2\sin\beta \end{cases} \tag{5}$$

where:

F_1 is the support force from the top plate, N; F_2 is the force from the scraper plate, N; F_3 is the adhesion force between the bonding fertilizer and the top plate, N; F_f is the frictional force between the top plate and fertilizers, N; ε is the angle between G and F_1, °, and β is the angle between F_f and F_2, °.

To reduce the second adhesion of the scraper plate, the trajectory of the bonding fertilizer is conducted according to Eq. (6). The curve surface of self-cleaning device is designed as Fig. 6.

$$\begin{cases} \mathrm{x}_0 = V_1\cos\varepsilon * \mathrm{t} + \dfrac{1}{2\mathrm{m}}F_2\cos(\varepsilon+\beta) * \mathrm{t}^2 \\ \mathrm{y}_0 = V_1\sin\varepsilon * \mathrm{t} + \dfrac{1}{2\mathrm{m}}F_2\cos(\varepsilon+\beta) * \mathrm{t}^2 + \dfrac{1}{2}\mathrm{g}\mathrm{t}^2 \end{cases} \tag{6}$$

where:

x_0 is the horizontal displacement of fertilizer, m; y_0 is the vertical displacement of fertilizer, m; t is the dropping time, s; m is the mass of fertilizers, kg; V_1 is the velocity of fertilizers, m•s^{-1}, F_2 is the force from the scraper plate, N; ε is the angle between G and F_1, °, and β is the angle between F_f and F_2, °.

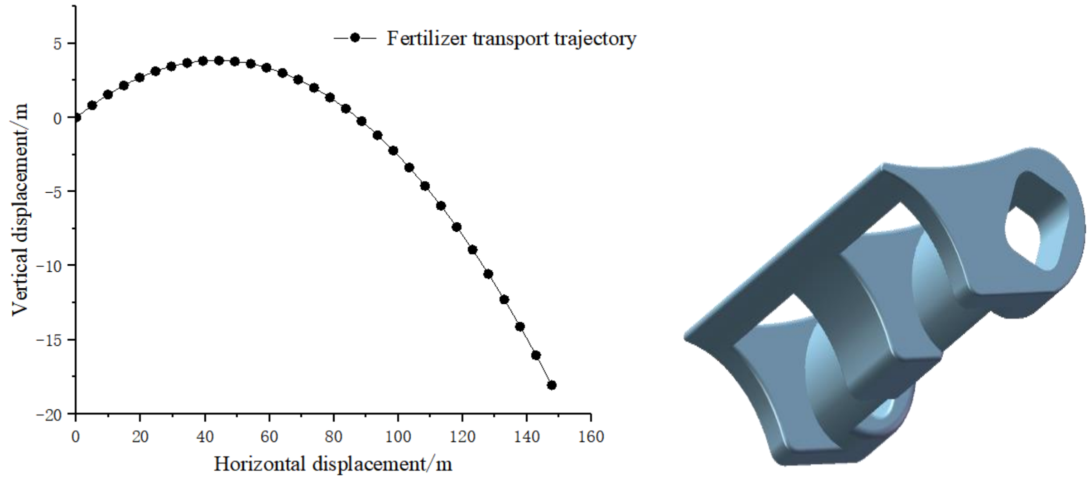


Fig. 6 - Structure of self-cleaning device

Moisture content: To require the moisture content of fertilizers during working, the temperature and humidity parameters of Jiangxi province from 2010-2019, and the data of nine counties including Poyang, Nanchang, Guixi, Yichun, Nancheng, Yongfeng, Gi'an, Suichuan and Ningdu from March to August are collected as shown in Table 2.

Table 2

Average temperature and humidity from March to August in Jiangxi Province's counties (2010-2019)

	March		April		May		June		July		August	
	Temperature /ºC	Humidity /%	Temperature /ºC	Humidity /%	Temperature /ºC	Humidity /%	Temperature /ºC	Humidity /%	Temperature /ºC	Humidity /%	Temperature /ºC	Humidity /%
Poyang	12.9	76.3	18.6	75.8	23.4	76.1	26.7	79.0	29.8	74.6	29.9	72.0
Nanchang	13.0	78.8	19.0	77.3	23.7	77.6	27.0	78.6	30.3	70.2	29.9	70.0
Guixi	13.2	77.6	18.7	78.5	23.4	78.9	26.6	81.7	29.7	75.1	29.5	74.8
Yichun	12.7	81.8	18.4	80.8	22.7	82.0	26.4	80.7	28.8	78.1	28.5	77.2
Nancheng	13.2	78.6	18.9	77.5	23.4	78.3	26.8	79.1	29.3	72.2	29.1	72.9
Yongfeng	13.0	82.5	19.0	80.7	23.3	81.5	26.8	80.1	29.3	74.7	28.9	75.7
Gi'an	13.8	82.3	19.8	80.2	24.0	81.6	27.5	79.1	30.1	72.0	29.7	73.4
Suichuan	14.2	79.8	20.0	77.8	24.0	80.1	27.3	80.2	29.6	72.1	28.8	75.2
Ningdu	14.2	78.6	19.6	77.9	23.8	79.6	27.1	77.6	28.9	73.3	28.5	73.6
Average value	13.36	79.59	19.11	78.50	23.52	79.52	26.91	79.57	29.53	73.59	29.20	73.87

The sowing times of early, middle and late rice are from March to April, May to June and July to August, respectively. The acquired average temperatures are 16.30ºC, 25.20ºC and 29.30ºC respectively, and the average humidity of early, middle and late rice are 79.10%, 79.60% and 73.80% respectively.

To this end, the moist fertilizers in the apparatus are obtained by setting the average temperature and humidity in the growth chamber for 24 hours. The moisture content is tested by using the Karl-Fischer titration method with three republications, as shown in Table 3.

The results show that the initial moisture content of fertilizers from the nylon bag has a great difference between 0.553%~2.307%, while the moisture content still increases in different sowing temperatures and humidity. The moisture content of fertilizers below the surface 0-1cm and in the cleaning brush is higher than other fertilizers. The greatest moisture content is 4.166% below the surface 0-1cm, at the temperature of 29.30ºC and the humidity 73.80%, thus the moisture content of fertilizers is introduced experimentally.

Moisture content of fertilizers in different positions of box **Table 3**

Mass of fertilizers	Sample position	Moisture Content %		
		Temperature 16.30°C and Humidity79.10%	Temperature 25.20°C and Humidity 79.60%	Temperature 29.30°C and Humidity73.80%
Full Box (20kg)	Initial value	1.633~2.307	1.098~2.033	1.544~2.022
	Below the surface 0~1 cm	3.300	3.291	4.166
	Below the surface 1~3 cm	1.912	2.389	3.561
	Below the surface more than 3 cm	2.063	1.394	2.911
	Cleaning brush	1.894	1.368	3.735
Half Box (10kg)	Initial value	1.808~2.224	0.998~1.406	0.764~1.534
	Below the surface 0~1 cm	3.220	1.282	1.830
	Below the surface 1~3 cm	2.478	1.358	1.367
	Below the surface more than 3 cm	2.233	1.169	0.859
	Cleaning brush	2.107	1.196	0.985
Shallow Box (0.85kg)	Initial value	0.553~1.230	0.875~1.098	1.265~1.651
	Below the surface 0~1 cm	1.394	2.275	2.272
	Below the surface 1~3 cm	0.946	1.241	1.769
	Below the surface more than 3 cm	0.934	1.19	1.675
	Cleaning brush	0.988	0.994	1.877

Stanley compound fertilizer, Kingenta compound fertilizer and Kingenta dual-effect nitro-fertilizer are introduced to test the performance of the cam-linkage self-cleaning fertilizer apparatus, and JYC-412 growth chamber, WKT-C20 Karl-Fischer titration equipment and the weighing system are conducted in the experiments, as shown in Figure 7.

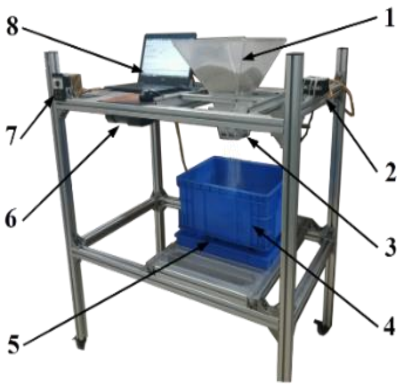


Fig. 7 - Test platform of the fertilizer apparatus
1. Fertilizer box 2. Hall speed sensor 3. Cam-linkage self-cleaning fertilizer apparatus 4. Collecting case 5. Weighing sensor 6. Adjustable speed motor 7. Frequency converter 8. Weighing system

To test the performance and application of fertilizer apparatus, three kinds of fertilizers in different moisture contents and the rotating speeds are used in the full-factor experiment, as shown in Table 4. The above fertilizers were treated with four moisture contents of 2%, 4%, 6% and 8%. Karl Fischer titration is introduced to test the moisture content, and the discharging of fertilizer apparatus in the weighing system was obtained in 1 minute with 4 repetitions.

Test factors and levels **Table 4**

No.	Factors		
	A Types	B Moisture content , %	C Rotating speed , $r{\cdot}min^{-1}$
1	Stanley compound fertilizer	2.00	10.00
2	Kingenta compound fertilizer	4.00	20.00
3	Kingenta dual-effect nitro-fertilizer	6.00	30.00
4	——	8.00	40.00
5	——	——	50.00

According to GB/T9478-2005, the discharging and coefficient of variation are employed as the evaluation index

$$\begin{cases} q = \dfrac{\sum_{i=1}^{j} q_i}{j} \\ CV = \dfrac{\sqrt{\dfrac{1}{j-1}\sum \left(q_i - q\right)^2}}{q} \times 100\% \end{cases} \tag{7}$$

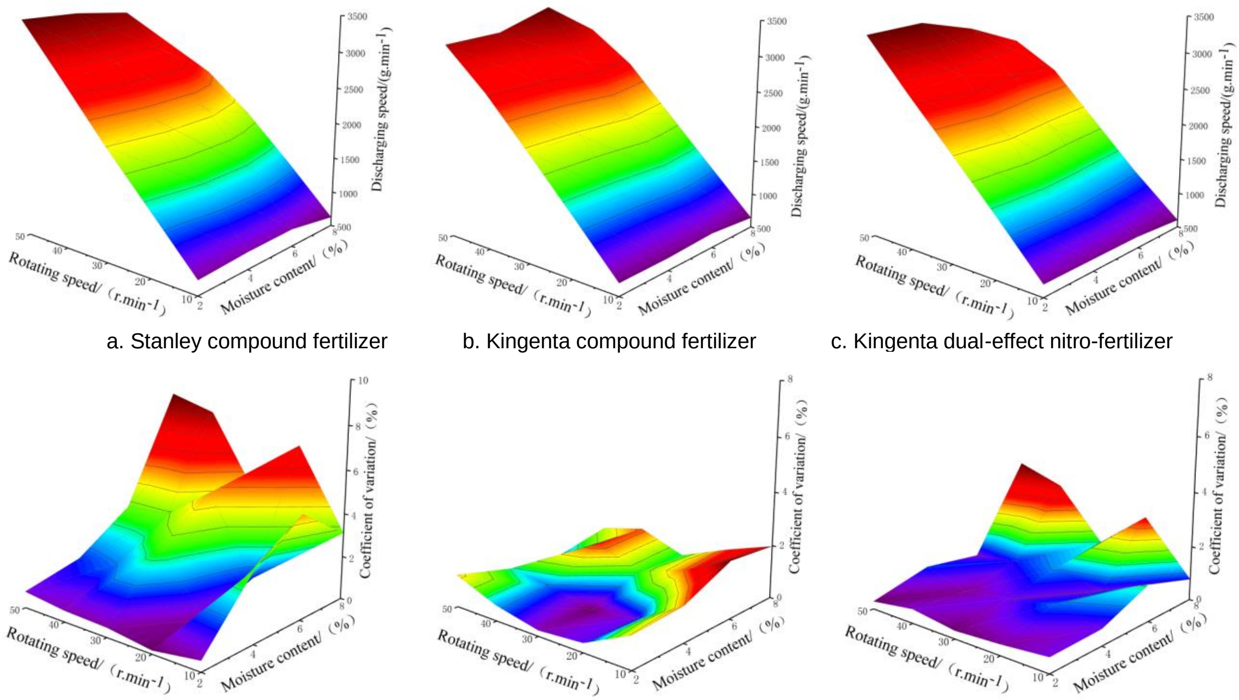
where q is the discharging, *g*; q_i is the amount in 1 minute of i times, *g*; j is the repetitions, and CV is the coefficient of variation of fertilizers, %.

RESULTS

Effect of the Discharging and Coefficient of Variation

The result showed that the fertilizer apparatus could discharge three different fertilizers with 2-8% moisture content, and the discharging increased with the increase of rotating speed from 10 r/min to 50 r/min. The range of discharging per minute is 602.64-3494.50 (Figure 8a~c), which can meet the agronomic requirement of discharging 30-60 kg per 667 m^2 in the field. When the rotating speed was lower than 40 r/min, the discharging was stable. However, when the rotating speed reached 50 r/min, only the discharging of Kingenta dual-effect nitro-fertilizer still had the same trend, while the others decreased. It indicates that greater rotating speed and higher moisture contents could increase the discharging, and the uniformity is worse. The reason is that the diameters and bulk density of moist fertilizers change, and the fertilizers are damaged into powder and adhered in the wheel.

In addition, the coefficient of variation of discharging increases with the increase of moisture content (Figure 8d~f), only the coefficient of variation of discharging Kingenta compound fertilizer is fluent in 10-50 r/min rotating speed, and the others change greatly. Especially in the case of 8% moisture content and 50 r/min rotating speed, the trend of coefficient of variation is the same as the discharging. For discharging Stanley compound fertilizer, Kingenta compound fertilizer and Kingenta dual-effect nitro-fertilizer under this apparatus, the minimum values of coefficient of variation are 0.16%, 0.12% and 0.28%, respectively, and the maximum values are 8.21%, 2.14% and 3.75% respectively. The results are better than the outer-flute fertilization wheel fertilizer apparatus. Consequently, the cam-linkage self-cleaning fertilizer apparatus could discharge no more than 8% moisture content of compound fertilizers with 10-50 r/min rotating speeds.



a. Stanley compound fertilizer b. Kingenta compound fertilizer c. Kingenta dual-effect nitro-fertilizer

d. Stanley compound fertilizer e. Kingenta compound fertilizer f. Kingenta dual-effect nitro-fertilizer

Fig. 8 - The performance of fertilizer apparatus in different moisture contents and rotational speeds

The variance analysis shows that the fertilizer types, the moisture content, the rotating speed, the interaction between the fertilizer types and the moisture content, the interaction between the moisture content and the rotating speed, all have a significant influence on discharging, as shown in Table 5. The sequence of influencing factors is as follows: the rotating speed, the moisture content, the types, the interaction between the types and the moisture content, the interaction between the moisture content and the rotating speed.

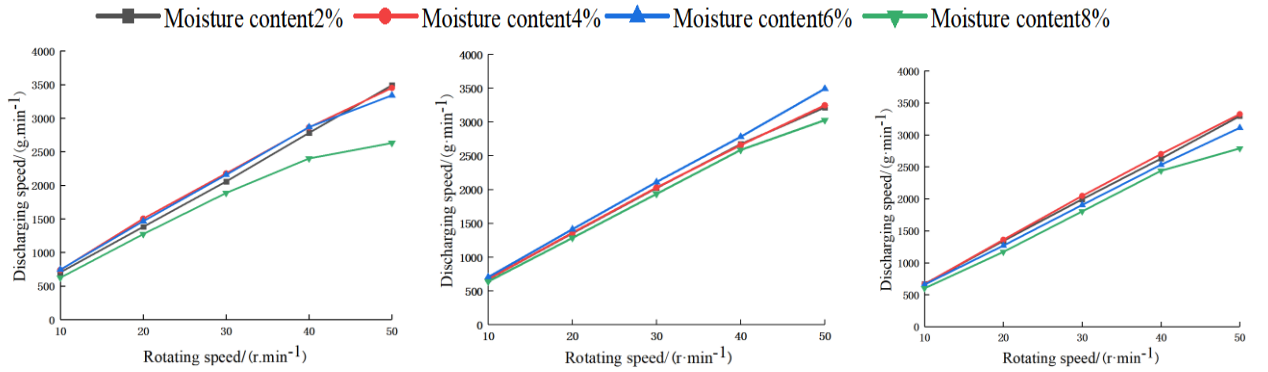
Table 5

Analysis

Error source	Square sum	df	Mean square	F	Sig.
Model	4.987E+007	35	1.425E+006	298.42	<0.0001**
Kinds	1.302E+005	2	65075.62	13.63	0.0001**
Moisture content	6.064E+005	3	2.021E+005	42.33	<0.0001**
Rotating speed	4.867E+007	4	1.217E+007	2548.36	<0.0001**
Interaction between types and moisture content	1.761E+005	6	29352.23	6.15	0.0005**
Interaction between types and rotating speed	18781.62	8	2347.70	0.49	0.8500
Interaction between moisture content and rotating speed	2.684E+005	12	22363.21	4.68	0.0006**
Interaction between types, moisture content and rotating speed	1.146E+005	24	4774.99		
Total	2.852E+008	60			
Correct total	4.999E+007	59			

Mathematical Model of Discharging

To figure out the effect between the rotating speeds and the discharging with 2-8% moisture content fertilizers on this fertilizer apparatus, the linear equations are fitted (Figure 9) and the determination coefficients R^2 are more than 0.974 (Table 6). The results show that the rotating speed controls the discharging of moist fertilizers, and the moisture content reaches 8%. The discharging decreases as the damage and bonding increase and the fitting curve is still parallel. This indicates that the discharging with three kinds of compound fertilizers has a linear relationship in 10-50 r/min rotating speed and 2-8% moisture content. This fertilizer apparatus can adapt different fertilizers, and is easy to adjust the rotating speeds to control the discharging in applications. This conclusion is the same as the experimental results.



a. Stanley compound fertilizer b. Kingenta compound fertilizer c. Kingenta dual-effect nitro-fertilizer

Fig. 9 - Relationship between the discharging speed and the rotating speed

Table 6

Linear relationship of discharging different fertilizers between discharging and rotating speeds

Moisture content / %	Stanley compound fertilizer		Kingenta compound fertilizer		Kingenta dual-effect nitro-fertilizer	
	Equations	Determination coefficient/R^2	Equations	Determination coefficient / R^2	Equations	Determination coefficient/R^2
2.00	$y=69.72x-7.8$	0.999	$y=64.02x+68.68$	0.998	$y=65.37x+26.1$	0.999

Table 6

(continuation)

Moisture content / %	Stanley compound fertilizer		Kingenta compound fertilizer		Kingenta dual-effect nitro-fertilizer	
	Equations	Determination coefficient/R^2	Equations	Determination coefficient / R^2	Equations	Determination coefficient/R^2
4.00	$y=67.82x+112.72$	0.998	$y=64.44x+62.56$	0.999	$y=66.58x+24.12$	0.999
6.00	$y=65.94x+137.34$	0.995	$y=69.44x+19.38$	0.999	$y=61.69x+46.22$	0.999
8.00	$y=51.38x+222.16$	0.974	$y=60.75x+74.1$	0.995	$y=56.44x+68.56$	0.991

CONCLUSIONS

(1) A new cam-linkage self-cleaning fertilizer apparatus is designed for discharging the moist fertilizer in southern rice region, aiming to solve the bonding and blockage problem of traditional fertilizer apparatus. The polar coordination equations of the cam-linkage mechanism are built to determine the parameters of the flute cam. The mathematical model of discharging is analyzed to obtain the wheel diameter and groove number, and the self-cleaning device is designed for scraping the residual fertilizers.

(2) The results show that the fertilizer apparatus can discharge less than 8% moisture content compound fertilizers, and the sequence of influencing discharging speed are: the rotating speed, the moisture content, the fertilizer types, the interaction between the fertilizer types and the moisture contents, the interaction between the moisture contents and the rotating speeds.

(3) The experimental results show that the fertilizer apparatus can discharge 2-8% moisture content under different compound fertilizers (Stanley compound fertilizer, Kingenta compound fertilizer and Kingenta dual-effect nitro-fertilizer) in 10-50 r/min rotating speeds. The coefficient of variation of discharging increases with the increase of moisture content, and the range changes from 0.12% to 8.21%. Furthermore, the discharging has a linear relationship with the rotating speed, and the determination coefficient R^2 is more than 0.974.

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