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Motion analysis and system response of fertilizer feed apparatus for paddy Variable-Rate fertilizer spreader

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ABSTRACT

Precision agriculture and variable-rate technology have gained increasing public interest. To improve the rapid response ability of the control system of a variable-rate fertilization and reduce the errors corresponding to the feed fertilizer system in a centrifugal variable-rate spreader, three devices that could adjust the application rate using different actuators were developed; these involved the gear and rack structure A, electric handspike structure B, and screw slider structure C. Mechanism motion analysis models were established based on vector equations, the response analysis of system delay was performed according to the model of lag fertilization, and subsequently, performance tests were executed to calibrate the lag distance of falling fertilizer, as well as the response time of actuators and the error of feed fertilization flow. The test results indicated that for actuators A, B, and C, the average lag distance of falling fertilization was in the order $L_A > L_C > L_B$, with the respective values being 3.56, 2.72, and 1.85 m; the corresponding lag correction times were 1.99, 1.74, and 1.48 s, respectively. A positive proportional relation was noted between the application increment and response time of apparatus execution, and $T_{Bi} > T_{Ci} > T_{Ai}$ (i denotes the corresponding feed fertilization flow). Furthermore, the error of fertilization flow first decreased and then increased with the increasing application rate; the extremum appeared between 250g/s and 380g/s, and $\gamma_{Bi} > \gamma_{Ai} > \gamma_{Ci}$. The feed fertilizer with structure C was optimized and integrated field validation tests, and incorporating the corresponding correction time of lagging response $T_{lag} = 1.74$ s into the control system, the mean error of variable-rate fertilization system was determined as 9.67%, and the average lag distance of fertilization was 0.37 m. This indicated that the control system of variable-rate fertilization with correction response time alleviated the problem of lag falling fertilizing, improved the response speed of variable-rate fertilization for rice, and helped achieved better fertilization accuracy.

1. Introduction

The rational application of fertilizers and pesticides is indispensable for increasing the yield of rice and the high efficiency of rice crop harvesting. To this end, the variable-rate technology (VRT) has emerged as an effective means for distributing fertilizer nutrients; this technique can not only satisfy the necessary growth demand of the crops, but also improve the agroecological environment, and therefore, become an important link in the implementation of precision agriculture (Liu, 2012; Zhang et al., 2012; Wang et al., 2015). Variable-rate fertilization for rice crops mainly includes information collection and communication, machine design, implementation of control system, and other key aspects (Su et al., 2015a; Su et al., 2015b); furthermore, the control system is a core part of the VRT, and ensuring accurate information collection and quick response by this system is key to achieve the desired results of variable-rate fertilization (Cai et al., 2016).

In recent years, researchers globally have focused on the development and improvement of control systems in variable-rate fertilizer applicators, and have achieved certain results pertaining to variable system responses (Wang et al., 2017; Zhang et al., 2017; Ban et al., 2013; Esquivel et al., 2015; Liu et al., 2015; Barros et al., 2016; Yu and Jiang, 2012; Zhang et al., 2015; Zhang, 2013). MALEKI studied the response delay of the control system in a developed variable-rate fertilizer applicator on the basis of the soil nutrient information; the time delay from information acquisition to fertilizer regulation was analyzed

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through static and dynamic experiments, and then, the correct position of the installed sensor and the correction time of system delay were determined (Maleki et al., 2008; Chattha et al., 2014). Meng Zhijun et al. designed a set of control system for variable-rate fertilization on the basis of the rate prescription map (Meng et al., 2011; Lang et al., 2013); in this work, the fertilizer position lag model of the variable system was translated into the system delay time, and using field tests, the correction delay time of variable fertilization was measured to be 1.84 s. Qiu Bai-jing et al. developed a new control system software for a variable spray device; the response ability and step characteristics of the control system were monitored in real-time using test methods, and the effect of the system response delay on the operation properties of variable spray was analyzed (Qiu et al., 2010; Qiu et al., 2007). Although, the existing theoretical analysis and experimental research regarding the response ability of variable control systems have played a key role in improving the operation performance of variable-rate fertilization systems, however, only a few in-depth analyses have been reported on the control technique for variable and even fertilization in centrifugal fertilizer spreaders based on spectral sensors for paddy fields.

This study, based on the existing studies on variable-rate fertilizer operation carried out by our research team (Chen et al., 2015; Shi et al., 2015; Shi et al., 2017), aims to investigate the control system of the developed centrifugal surface variable-rate fertilizer spreader, on the basis of real-time growth information of rice. The subsequent sections describe the establishment of motion models of three different actuators for application rate adjustment through the structural analysis of the designed adjustment device. Further, the analysis of lag model of fertilization and delay response of control system is reported. The comparative optimization of the fertilizer distributing actuator through performance tests is explained, and the lag correction method of the control system response is proposed. These findings are expected to improve the response speed of variable-rate fertilization for rice crops, and the accuracy of distributing fertilizer, which can thereby improve the spreading performance of the centrifugal surface variable-rate fertilizer spreader for paddy fields.

2. Machine structure and working principle of the variable fertilizer spreader

2.1. Spreader structure

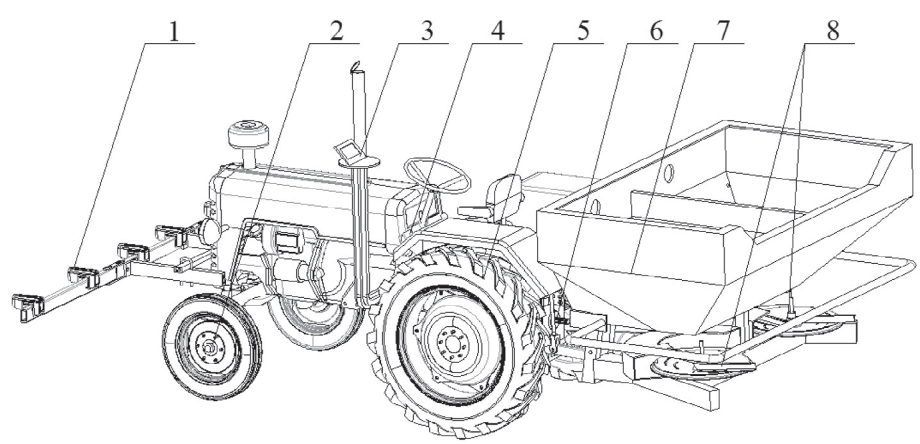
Fig. 1 shows the overall structure of the developed real-time variable-rate spreader for paddy fields, which is based on spectrum technology and involves double centrifugal discs. The spreader comprises a spectral sensor system, wireless communication system, vehicle-mounted control terminal, spreader device, and control system, along with other minor parts.

2.2. Working principle

The developed variable-rate fertilizer spreader for rice crops has suspension traction and exhibits a high degree of automation and uniform spreading distribution. The spreading discs are driven reversely by tractor power take-off (PTO), and the effective spreading swath width of a single pass was more than 24 m. The disc rotation speed and the opening of the fertilizer distributing feed gate are adjusted through the closed-loop feedback system. These factors improve the fertilizer utilization rate and hence the production efficiency, making the fertilizer spreader suitable for large-scale modernized agriculture of the rice and wheat rotation area. During the fertilization process, the normalized difference vegetation index (NDVI) values of the rice canopy are acquired in real time using the Green Seeker™ spectrum detection system. These values are then transmitted to the vehicle-mounted control terminal through a wireless serial interface module. A variable-rate fertilization expert decision system preset into the CPU is run based on the optimization of the Raun model to generate the target fertilizer rate in real time. The feedback information concerning the current walking speed, rotational speed of the disc, and opening feed gate of fertilizer box is integrated into the control system. A core controller (STM32 microcontroller) is guided through a decision-making system to drive a stepper motor for adjusting the opening feed gate of the fertilizer can. In this manner, an online real-time adjustment of crop fertilizer application rate is achieved, and the relative precision variable-rate fertilization for rice is obtained.

3. Structural design and motion analysis of the fertilizer distributing device

The device that adjusts the application rate is a critical component of the variable fertilizer spreader, and its feeder distributing performance directly influences the fertilizer accuracy. On the basis of the working principle and distributor characteristics of the variable-rate fertilizer spreader for rice, three adjustment devices with different actuators based on the control of stepper motor, and which satisfied the work requirements, were developed. These included the gear and rack structure A, electric handspike structure B, and screw slider structure C.



1. Spectral sensor; 2. Speed sensor; 3. On-board CPU; 4. Control system; 5. Driving system; 6. Transmission system; 7. Fertilizer box; 8.Spreader disc

Fig. 1. Structural diagram of centrifugal variable-rate fertilizer spreader.