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A fixed-amount and variable-rate fertilizer applicator based on pulse width modulation

Chang Chen, Peixiang He, Jianjun Zhang*, Xiaoxian Li, Zhenyu Ren, Jin Zhao, Jiacheng He, Yang Wang, Hongbo Liu, Jie Kang

College of Engineering and Technology, Southwest University, Chongqing, PR China

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ABSTRACT

Fertilizer plays a significant role in increasing crops quality. When fertilizer users use inappropriate fertilization practices in fields, it brings nutrient waste, large investment and residue in soil. The purpose of the present paper is to develop a fixed-amount and variable-rate fertilizer applicator with a vertical spiral conveyor to minimize this risk. As for row replacement, high accurate and uniform application patterns from a reliable fertilizer applicator for precision farming are required. This applicator includes a speed measure unit and a fixed-amount and variable-rate Pulse Width Modulation control system. In order to evaluate our fertilizer applicator, its performance was tested in both laboratory and field. The findings of this study suggest that the applicator with a vertical spiral conveyor and a variable-rate pulse width modulation control system makes fewer errors during application. To guarantee the degree of accuracy of this applicator, the linearity between travel speed and amount of fertilizer is essential. Both of the applicator tests revealed that using the applicator was a positive experience because it can preset expected consumption by operator and always keep amount of fertilizer uniform and accurate while traveling, and it will be widely used in Southwest China.

1. Introduction

Fertilization is one of the most important and effective methods for soil amendment to meet planting requirements and increase yield and production (Mueller et al., 2012; Wang et al., 2012). As reported, the consumptions of fertilizer in agricultural production in China rose year by year with the average speed of 3–5%, reaching an average of 480 kg hm^{-2}, which was nearly 4 times of the global level (Fischer et al., 2010). However, the use ratio was less than 50% and most fertilizer nutrients not absorbed by plants went into the atmosphere and water by the way of leaching, volatilization and so on (Xin et al., 2012). So the application of sufficient quantities of plant nutrients is an urgent need.

Spatial information on soil properties and crop conditions has been used in precision farming sector to reduce consumption of fertilizers. Batte and VanBuren Fred (2007) reported that 54.2% of commercial farmers in Ohio, USA, have adopted at least one precision farming component as of 2007. Yield monitors and precision guidance systems were the most frequently adopted precision farming components, with about 32% of all commercial farmers adopting these systems to date. However, due to the limitation of land and technical conditions, only a few areas where the land is wide and flat use commercially available applicators. Manual application is still favored in some area because mechanical applicators, lacking a speed feedback mechanism to adjust fertilizer application rate, are believed to waste fertilizer. However, manual fertilizer application is often kept constant over time or large areas, rather than tailed to meet crop nutrient requirements (X. Xu et al., 2017). This brings about unbalanced, inefficient fertilization and poor economic returns (Pampolino et al., 2007), as part of the reason for fertilizer overuse, which runs in the opposite direction of environmentally friendly agriculture. Furthermore, excessive and unbalanced fertilization also leads to low nutrient use efficiency (Qin et al., 2013), which is associated with negative impacts on the environment such as greenhouse gas emissions (Feng et al., 2013), land degradation, and freshwater pollution (Guo et al., 2010; Reidsma et al., 2012).

Better fertilizer applicator is one of the keys to resolve the contradiction. Centrifugal disc fertilizer spreaders are widely used in both Europe and America. The power output shaft turns the fertilizer disc around and spills the fertilizer out with the centrifugal force (Liu et al., 2017; Guoqiang et al., 2016). Although a large scale test equipment was established and the Discrete Element Method (DEM) was used to simulate the distribution, they were not done outdoors or in field. Przywara (2015) took tests on a centrifugal disc fertilizer spreader with

* Corresponding author at: College of Engineering and Technology, Southwest University, 400715 Beibei, Chongqing, PR China.
E-mail address: zhjj61@163.com (J. Zhang).

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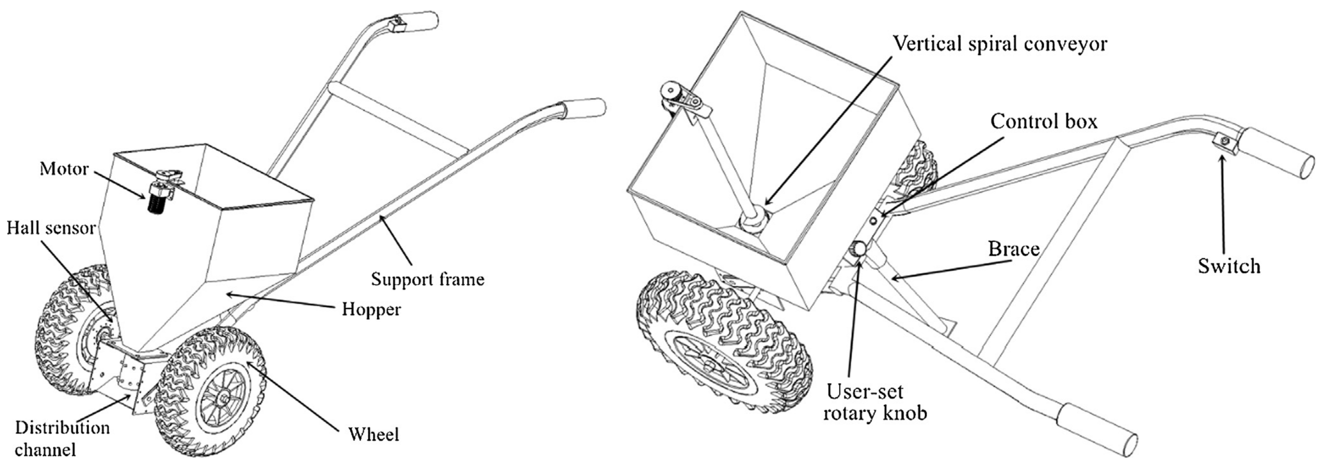

Fig. 1. Drawing of the fixed-amount and variable-rate fertilizer applicator.

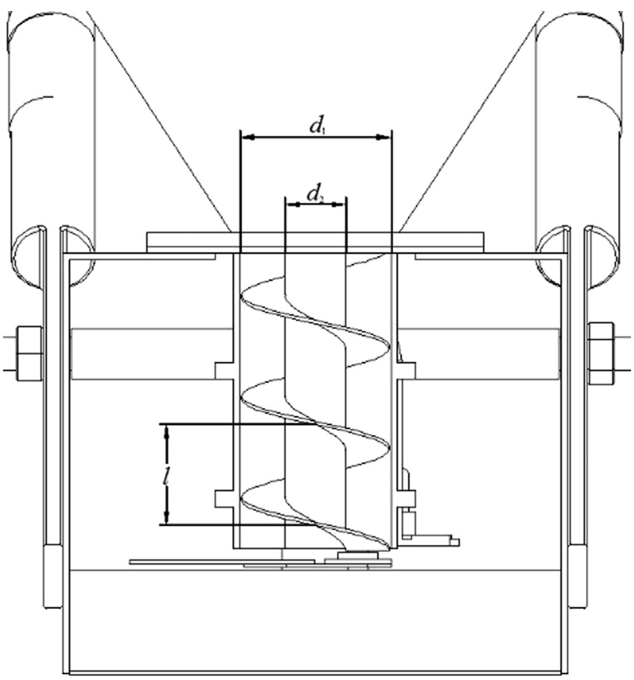

Fig. 2. The parameter of vertical spiral conveyor.

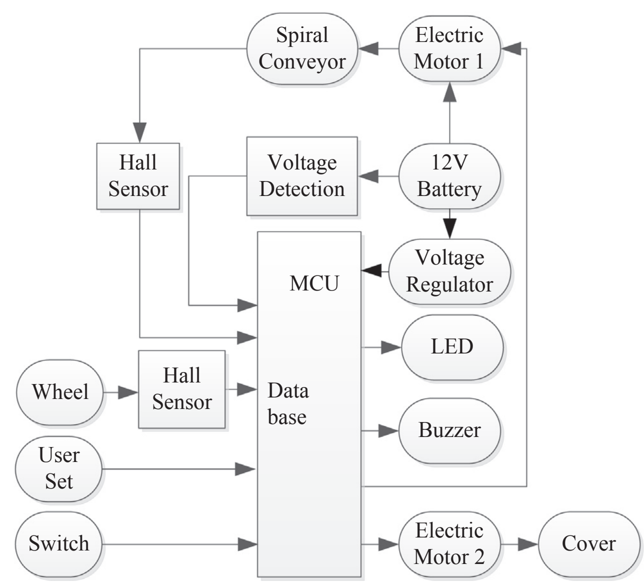

Fig. 3. Schematic diagram of the instrumentation of the fixed-amount and variable-rate fertilizer applicator.

different disc rotation speeds, fertilizer feed position and the vanes angle on the disc to specify the impact of structural and operational parameters of the centrifugal disc spreader. The tests revealed that the fertilizer type and the disc rotation speed had great influence on the average radius of the stationary spread, but these tests were conducted in a close hall, which ignored the effect of wind and the direction and did not proved the practicality. Fulton et al. (2005) characterized distribution patterns at varying rates for different granular applicators: two spinner-disc spreaders and two pneumatic applicators. Three applicators showed an increase of coefficient of variation (CV) with application rate increased. A overlap analysis was conducted on a spinner-disc spreader and a pneumatic applicator, both performed well at the two lower rates (CVs < 19%) but not at the highest rate (CV = 27%). To evaluate application uniformity, they used a CV of 20% as an acceptable level of uniformity. According to these results, there were potential application errors with VRT and thus, the need for proper calibration to maintain acceptable performance.

For past few years, an increasing number of researches on variable-rate technology (VRT) can be seen. Kim et al. (2008) developed a new type of variable-rate pneumatic granular applicator with a 10 m boom span. Field tests revealed that the application uniformity (CV) in both the transverse and traveling direction were in the range of 11.2–13.1% and 2.9–15.3%, respectively. The application accuracy ranged from 81.9% to 97.4% as its working speed ranged. The response time was no more than 3.0 s, which was sufficient compared to previous studies. However, with a large engine supplying power for work and a long span, it has high energy consumption and large volume. Zhang et al. (2011) developed a variable-rate fertilizer system to control amount of fertilizer by optical sensor measured NDVI of crop, which includes optical sensor, PWM valve and hydraulic motor. It changes the hydraulic motor rotation to achieve the variable work, making the errors less than 5.17%, and CVs range from 0.35% to 2.67%.

Considering that both fertilizer recommendation based on soil testing and large-scale machines (Chen et al., 2015) are not suitable in most areas of China, especially in Southwestern regions, a fixed-amount and variable-rate fertilizer applicator was proposed to meet the requirement. The applicator adopted row replacement method and the fertilizer conveyor outlet is close to soil surface in order to reduce the influence of wind on the distribution of fertilization. This kind of applicator is light, easy to operate and driven by small motors, which make it much more accessible in Southwestern fields. It fills the gap of precision agricultural machinery in most of hilly areas of China.