applied sciences

Review

Research Progress Regarding the Precision of Dosing and Distribution Devices for Fertilizers

Wenzhi Xu [1,2,3,4], Quanchun Yuan [2,3,4,*], Jin Zeng [2,3,4] and Xiaolan Lyu [1,2,3,4,*]

1 College of Mechanical and Electronic Engineering, Nanjing Forestry University, Nanjing 210037, China; xuwenzhi678@163.com
2 Institute of Agricultural Facilities and Equipment, Jiangsu Academy of Agricultural Sciences, Nanjing 210014, China; j-zeng@jaas.ac.cn
3 Key Laboratory of Modern Horticultural Equipment, Ministry of Agriculture and Rural Affairs, Nanjing 210014, China
4 Southern Orchard (Peach, Pear) Fully Mechanized Research Base, Ministry of Agriculture and Rural Affairs, Nanjing 210014, China
* Correspondence: yuanquanchun@jaas.ac.cn (Q.Y.); lxlanny@126.com (X.L.)

Abstract: As a key component of fertilization equipment, the fertilizer discharger has an important impact on the accuracy of the amount of fertilizer applied during the fertilization process. Countries around the world have been advocating for reducing the use of chemical fertilizers and improving fertilizer utilization, and researchers have also conducted in-depth research on precision fertilizer devices. In order to further improve the precision of dosing and distribution devices for fertilizers, in this study, four types of fertilizer dischargers (spiral fertilizer dischargers, groove wheel fertilizer dischargers, disc fertilizer dischargers, and air-feed fertilizer dischargers) which are currently commonly used are thoroughly analyzed. The operating principle and performance characteristics of the fertilizer dischargers are elaborated upon, and the current research status of their structure and working parameter optimization are discussed and summarized. Overall, the research of Chinese researchers is mainly described. The problems existing in research on the precise fertilizer discharge of fertilizer dischargers are pointed out, and the future development trend is predicted, aiming to provide a beneficial reference for improving the technical level of precise fertilizer discharge.

Keywords: fertilizer discharger; precise fertilizer dosing and distribution; research progress; problems; development trend

check for updates

Citation: Xu, W.; Yuan, Q.; Zeng, J.; Lyu, X. Research Progress Regarding the Precision of Dosing and Distribution Devices for Fertilizers. *Appl. Sci.* **2024**, *14*, 3059. https://doi.org/10.3390/app14073059

Received: 28 February 2024
Revised: 23 March 2024
Accepted: 28 March 2024
Published: 5 April 2024

1. Introduction

The growth of agricultural products is inseparable from the nutrients provided by fertilizers. According to statistics from the Food and Agriculture Organization of the United Nations (UNFAO), the rational use of fertilizers can increase crop yields by 40% to 60% [1]. Fertilization is the main means of increasing the production of agricultural products [2], but long-term insufficient fertilization will affect growth, while excessive fertilization will cause serious damage to the soil environment. Therefore, precise fertilization is of great significance. Precision fertilization devices are the key to precise fertilization, and it is necessary to conduct in-depth research on them [3].

As a key component of fertilization devices, the performance of fertilizer dischargers directly affects the uniformity of fertilization and operation stability of the entire machine. The precise dosing and distribution of the fertilizer by fertilizer dischargers are the keys to precise fertilization. In order to achieve precise fertilization, the requirements for the performance of fertilizer dischargers are increasing [4]. In addition to achieving high accuracy, stability, and uniformity of fertilizer distribution, it is also necessary to ensure that they can flexibly and precisely adjust the dosing of the fertilizer so that it can be applied to more crops and will not be affected by external factors such as working conditions and terrain when performing fertilization tasks [5,6].

This review first explains the current research on precision fertilizer dischargers and analyzes the operating principle and performance characteristics of the four types of fertilizer dischargers (spiral fertilizer dischargers, groove wheel fertilizer dischargers, disc fertilizer dischargers, and air-feed dischargers). Then, we discuss and summarize how researchers use precision fertilization-related technologies and optimization methods for fertilizer dischargers' structure and working parameters to achieve precise fertilizer dosing and distribution. On this basis, the problems in the existing research on fertilizer dischargers are pointed out. Finally, the development trend of fertilizer dischargers in the precision fertilizer dosing and distribution is predicted based on previous articles.

2. Current Status of Research on Precision Fertilizer Dischargers

In recent years, there has been continuous research on precision fertilizer dischargers around the world. There are four main types of fertilizer dischargers: spiral fertilizer dischargers, groove wheel fertilizer dischargers, disc fertilizer dischargers, and air-feed fertilizer dischargers. In order to achieve precise fertilizer dosing and distribution, researchers conducted in-depth research.

2.1. Research Status of Spiral Fertilizer Dischargers

The working principle of spiral fertilizer dischargers is as follows: the spiral blades rotate around the axis, and under the pushing of the blades, the fertilizer in the fertilizer box is transported to the fertilizer discharge port and discharged. Its structure is shown in Figure 1 [7]. This fertilizer discharger has low requirements for the physical properties of fertilizers and can be flexibly used for the application of granular fertilizers and powdered fertilizers [8]. It is low in price and has a simple structure. It is suitable for a variety of fertilizers with different physical properties. The amount of fertilizer can be adjusted according to the user's needs. This simple structure is relatively uniform and stable when discharging fertilizer. However, when fertilizing at a low rotation speed, fertilizer quality fluctuates greatly and the fertilizer discharge is uneven.

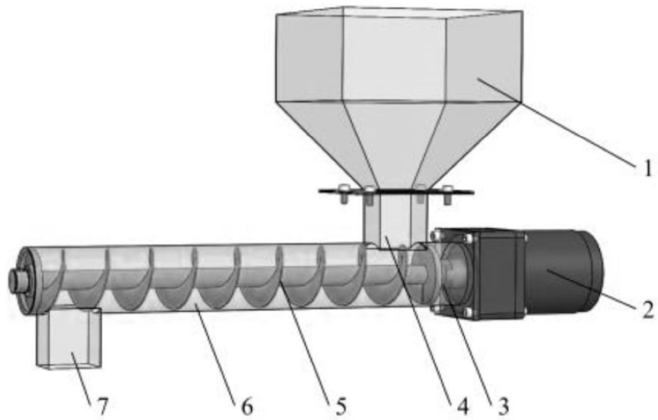


Figure 1. Structural diagram of spiral fertilizer discharger. Note: 1. fertilizer tank; 2. motor; 3. coupling; 4. fertilizer inlet; 5. spiral blade; 6. shell; 7. fertilizer outlet.

The work of international researchers focuses on studying the impact of the spiral blade structure and working parameters on the performance of spiral fertilizer dischargers through discrete element simulation, bench testing, or the development of new designs for spiral fertilizer dischargers and attempts to optimize their conveying effect by adjusting key structural and working parameters to improve the accuracy and stability of fertilizer discharge dosing.

Mondal et al. [9] designed a conveying screw machine for the short-distance transportation of small-particle materials. Its structure is depicted in Figure 2. A bench test study on the filling rate at different screw speeds was conducted, and it was found that when the speed is between 15 and 21 rpm, the filling factor remains within the range of 0.76~0.81, which means the machine has high accuracy when applied to fertilizer transportation.

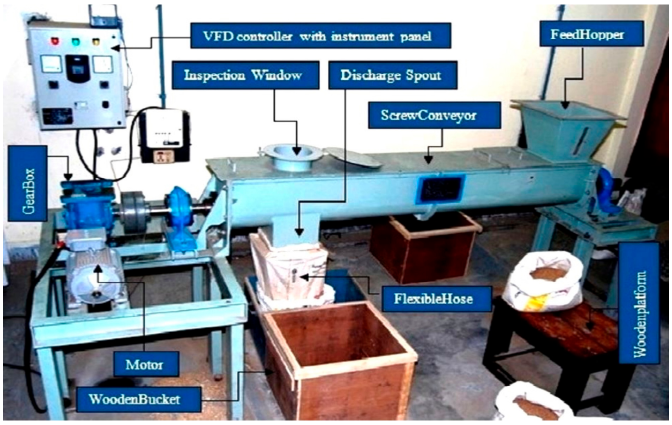


Figure 2. Spiral fertilizer dischargers test diagram.

Lyalin et al. [10] optimized the spiral distributor (SVD) working-body spiral screw (Figure 3) through multi-factor experiments to improve fertilizer discharge accuracy and reduce unevenness. When the fertilizer feed rate is 320 kg per hour, the optimal structural parameters of the spiral screw are a diameter of 49 mm, a pitch of 1.05d (51.45 mm), and a gap of 2.5 mm, and the coefficient of variation in the fertilizer discharge stability does not exceed 0.2%; Meanwhile, when the fertilizer feed rate is 1450 kg per hour, the parameters are a diameter of 90 mm, a pitch 1.25 times the diameter (112.5 mm), and a gap of 7.5 mm. The coefficient of variation in the fertilizer discharge stability does not exceed 0.4%.

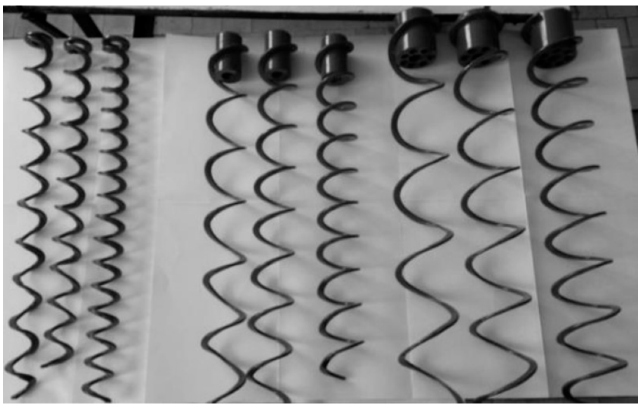


Figure 3. Spiral distributors with different structures.

Zimmermann et al. [11] compared the performance of two nitrogen, phosphorus, and potassium granular fertilizer formulas in a spiral fertilizer discharger at three operating speeds. During the experiment, an automated workbench was built to evaluate the performance of single-spiral and double-spiral fertilizer dischargers, as shown in Figure 4. Two nitrogen, phosphorus, and potassium granular fertilizer formulas (04-14-08 and 04-30-10) were selected for the experiment and tested at different angular velocities. After the test was completed, the flow data were collected for statistics and analysis. It was concluded that as the speed increases, the single-spiral fertilizer discharger shows greater uniformity compared to the double-spiral fertilizer discharger. Although the speeds of 7 and 10 kph increased the flow rate of both granular fertilizers, as expected, the 04-30-10 fertilizer obtained the most even distribution at the lowest speed of 4 kph.

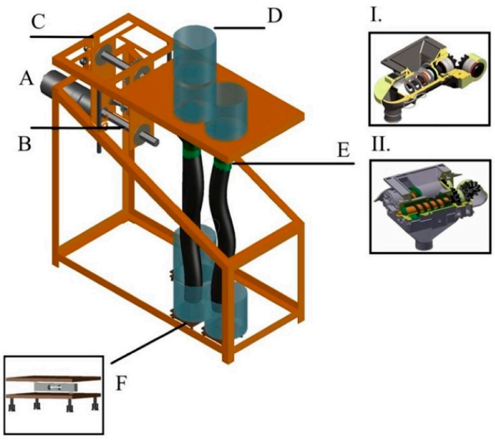


Figure 4. Diagonal projection of the electronic and automated bench. Note: A. electrical control; B. transmission set; C. articulation; D. reservatory; E. spiral fertilizer dischargers; F. data acquisition system. I. single spiral fertilizer dischargers; II. double spiral fertilizer dischargers.

The work of Chinese researchers primarily centers on the design and optimization of the structure and working parameters of spiral blades. Using a method that combines discrete element simulation with bench and field trials, the parameters of the spiral blades are continuously optimized to improve the stability and uniformity of fertilizer discharge dosing.

Zhao Liang et al. [12–14] designed a small-scale spiral quantitative fertilizer discharger, examining the discharge process of three types of fertilizers (urea, compound fertilizer, and organic fertilizer) through discrete element simulation. They established a mathematical model and conducted single-factor and quadratic regression orthogonal rotation combined tests. The order of factors affecting the fertilizer discharge amount is as follows: fertilizer discharge shaft rotating speed, pitch, and spiral blade diameter. Combined with bench testing, optimized parameters were determined to be a diameter of the spiral blade (as shown in Figure 5) of 92 mm, a pitch of 56 mm, and a rotation speed of the fertilizer discharge shaft of 39 rpm. The stability and uniformity of fertilizer discharge were found to be satisfactory, with the measured average coefficient of variation of fertilizer discharge stability at 12.25%. The average relative error between the simulation and experiment was 8.51%. Fertilization in mango orchards meets the requirements well.

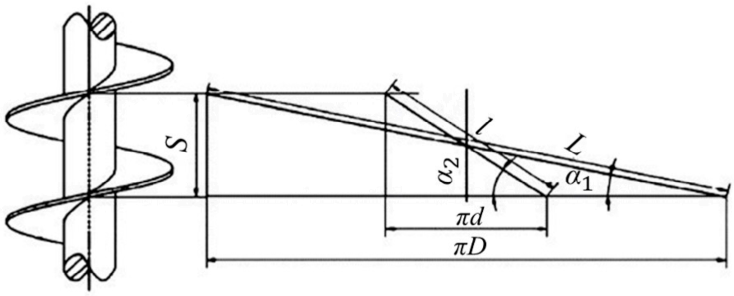


Figure 5. Approximate expansion view of spiral blades. Note: α is the helix angle, S is the thread pitch, D is the diameter of the spiral blade at a certain point.

Wang Jie [15] employed discrete element simulation to investigate the organic fertilizer discharger, with the aim of revealing the movement process of fertilizer particles within it. Additionally, the study aimed to analyze the correlation between the amount of discharged fertilizer and both the rotation speed of the discharge shaft and the number of pitches in the variable diameter and variable pitch section of the shaft's feeding section. The structure of the fertilizer discharge shaft is illustrated in Figure 6. Through two-factor and three-level simulation tests along with field trials, it was concluded that the rotation speed of the fertilizer discharge shaft has a more significant impact on the discharged fertilizer amount compared to the number of pitches in the variable diameter and variable pitch section of the shaft. Notably, when the number of pitches in the feeding section of the fertilizer discharge shaft is set at three, the stability variation coefficient of fertilizer discharge can be reduced to the minimum level, ranging from 6.93% to 7.50%, aligning with relevant industry standards.

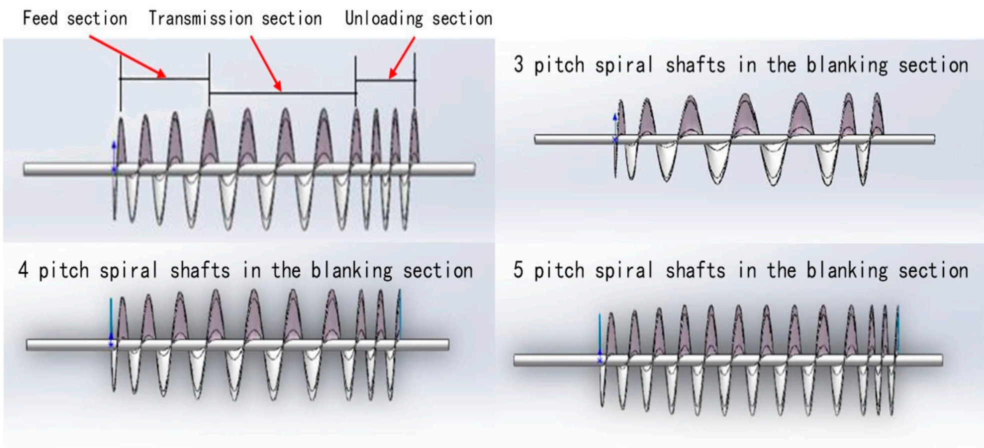


Figure 6. Fertilizer discharge shafts with different pitches in the feeding section.

Xiao Wenli et al. [16,17] devised a four-head, spiral, double-row fertilizer discharger tailored for rapeseed cultivation. The structure of the fertilizer discharge spiral blade is depicted in Figure 7. They executed single-factor discrete element analysis experiments aimed at simulating the movement of compound fertilizer particles within the fertilizer discharger. Through comparative experiments and iterative optimization, it was ascertained that the four-head fertilizer discharge spiral configuration should be adopted, with optimal performance achieved at a pitch of 24 mm. Combining bench and field trials, it was deduced that maintaining a fertilizer discharge spiral blade speed within the range of 40 to 60 rpm ensures that the variation coefficient of the fertilizer discharge uniformity for the three fertilizers remains below 6.8%. Additionally, the stability of the total fertilizer discharge and the consistency coefficient of variation for the double-row fertilizer discharge do not exceed 2.6%. Field trial results indicate a relative error of 2.33% between the actual and target fertilizer application amounts, meeting the requisites for basal fertilizer application quantity and fertilizer uniformity.

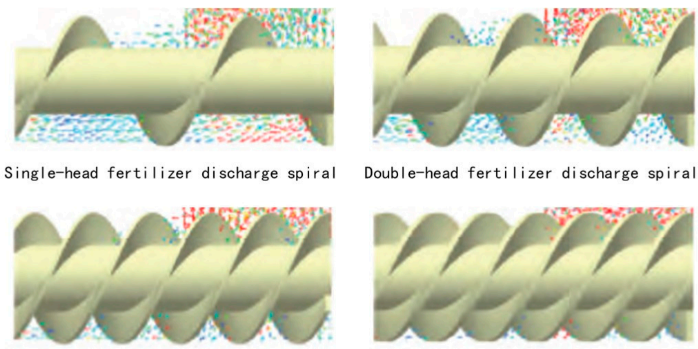


Figure 7. Fertilizing spirals with different numbers of heads.

Liu Wenzheng et al. [18] devised the bidirectional spiral blade for the fertilizer discharge apparatus of the double-side deep fertilization device used in potato cultivation. Through a combination of kinematic analysis and single-factor discrete element simulation testing of polyaspartate boric acid compound fertilizer within the fertilizer discharge apparatus, optimal parameters for the two-side spiral device were determined to be a single-spiral blade length of 120 mm, a spiral outer diameter of 56 mm, and a pitch of 45 mm. Its structural configuration is depicted in Figure 8. Subsequently, the apparatus underwent testing under static working conditions, resulting in a concluded coefficient of variation for fertilizer discharge uniformity of 2.29%. This fertilizer discharger exhibits commendable stability in the fertilizer discharge.

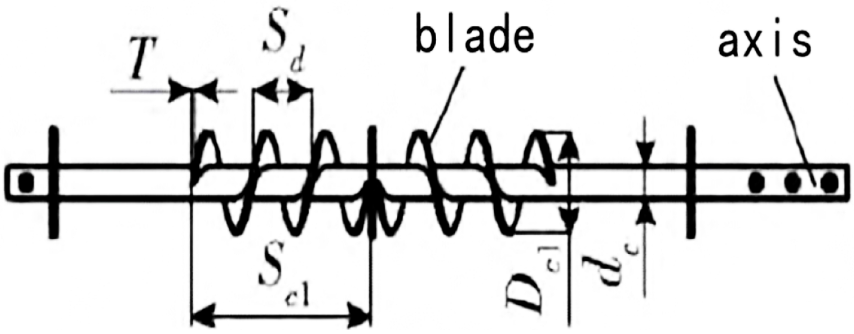
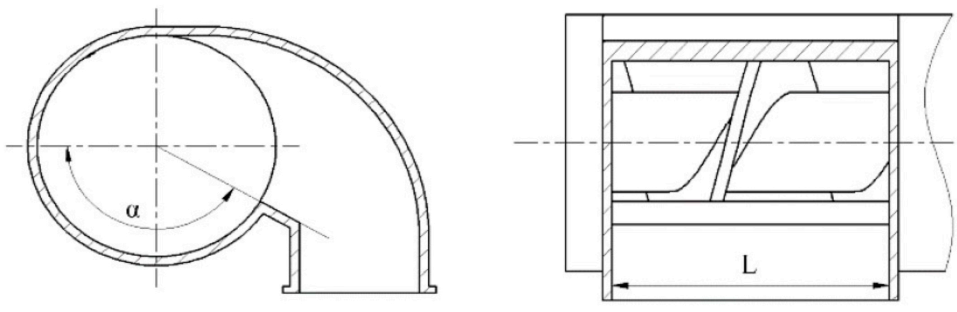


Figure 8. Two-sided spiral device. Note: S_{c1} is the length of the spiral blade, D_{c1} is the spiral outer diameter, S_d is the pitch.

To further enhance the precision of fertilizer discharge dosing from the spiral fertilizer discharger, Chinese researchers studied the structural parameters of the fertilizer discharge port.

Fang Longyu et al. [19,20] investigated the structure of the fertilizer discharge port, analyzing its impact on the performance of the boron sulfate compound fertilizer discharge. Through discrete element orthogonal simulation tests and bench trials, the optimal parameters are determined as follows: an outlet angle of 135 degrees and a length of 40 mm (1.5 times the pitch), as illustrated in Figure 9. Combined with the field trial verifications, it was observed that the optimized fertilizer discharge stability and uniformity of fertilizer discharger were significantly enhanced, with the variation coefficient of fertilizer discharge not exceeding 8.22%. Moreover, the error in the fertilization amount was less than 4%, meeting the precise fertilizer discharge requirements for corn fields per acre.

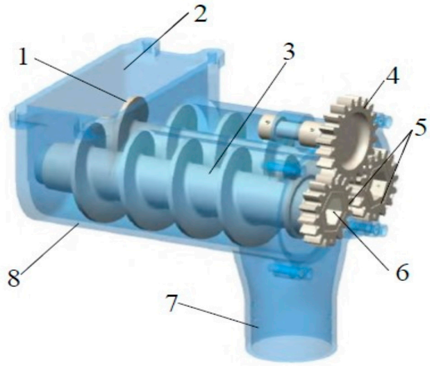


(**a**) (**b**)

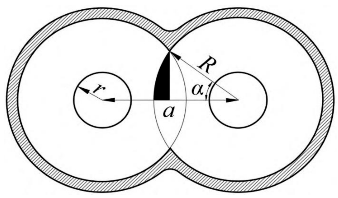
Figure 9. Structural diagram of the fertilizer discharge port: (**a**) schematic diagram of the angle of the fertilizer outlet; (**b**) schematic diagram of the length of the fertilizer outlet. Note: α represents the angle of the fertilizer discharge port; L represents the length of the fertilizer discharge port.

In addition, in order to make breakthroughs in the precise fertilizer discharge dosing from the spiral fertilizer discharger, Chinese researchers are also dedicated to exploring new designs for spiral fertilizer dischargers.

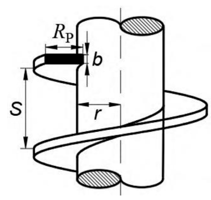
To address the issue of flow fluctuation in the fertilizer discharge from single spiral fertilizer dischargers, Li Xin et al. [21] devised a spiral double-wheel fertilizer discharger, as depicted in Figure 10. The impact of structural parameters on the performance of the Stanley compound fertilizer discharge was theoretically analyzed. Through the establishment of a discrete element mathematical model, a genetic algorithm was employed to optimize the fertilizer discharger's structure. Following optimization, the structural parameters are determined to be a center distance of 49.8 mm, a pitch of 32.5 mm, a blade height of 15.2 mm, a blade thickness of 2.3 mm, and a spiral blade inner diameter of 13.6 mm. The fertilizer discharger is capable of achieving an even fertilizer discharge while increasing the discharge amount. Combined with the bench test verification, the variation coefficient of the fertilizer uniformity can reach a minimum level of 6.78%, enabling precise fertilization control through speed adjustments.



(**a**)



(**b**)



(**c**)

Figure 10. Schematic diagram of the overall and partial structure of the spiral double-wheel fertilizer discharger: (**a**) the overall structure of the spiral double-wheel fertilizer discharger; (**b**) shell cross-section; (**c**) fertilizer wheel chart. Note: a is the center distance, r is the inner diameter of the spiral blade, R_p is the height of the blade, b is the thickness of the spiral blade, S is the pitch. 1. spiral blade; 2. fertilizer inlet; 3. fertilizer discharge wheel; 4. large gear; 5. pinion; 6. inner hexagonal hole; 7. fertilizer discharge port; 8. housing.

The research above primarily focused on parameters such as pitch, number of heads, inner and outer diameters, length, gap, center distance (for double-spiral blade), blade height, blade thickness, rotation speed of the spiral blades, as well as the length and angle of the fertilizer discharge port. These were investigated through discrete element simulation, bench tests, field trials, and other research methodologies. The aim was to enhance the stability and uniformity of fertilizer discharge, meeting the requirements for precise fertilization dosing. This research provides a comprehensive foundation for the design and optimization of spiral fertilizer dischargers and offers valuable technical support for agricultural production.

2.2. Research Status of Groove Wheel Fertilizer Discharger

The working principle of groove wheel fertilizer dischargers is as follows: the groove wheel rotates around the axis, and through the movement of the groove wheel teeth, the granular fertilizer dropped from the fertilizer box is conveyed to the fertilizer discharge port and ultimately discharged onto the soil. Its structure is depicted in Figure 11 [22]. This fertilizer discharger imposes stringent requirements on the physical properties of fertilizers. When handling wet granular fertilizers and powdery fertilizers, fertilizer discharge pulsations are prone to occur [23]. Fertilizers with poor fluidity can easily block the groove wheel, impeding proper operation. With its simple structure and suitability for various types of fertilizers, the groove wheel fertilizer discharger has rapid fertilizer discharge and is widely employed. Nonetheless, it exhibits significant variations in fertilizer discharge effects and may encounter challenges related to poor control accuracy and linearity.

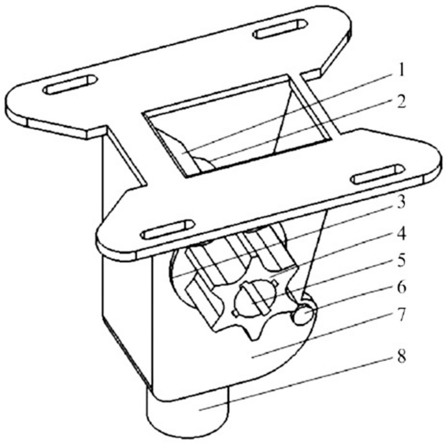


Figure 11. Structural diagram of the groove wheel fertilizer discharger. Note: 1. fertilizer baffle; 2. blocking wheel; 3. backup ring; 4. groove wheel; 5. fertilizer discharge shaft; 6. fertilizer discharge tongue; 7. fertilizer discharge shell; 8. fertilizer discharge port.

The research of international researchers focuses on studying the fertilizer discharge performance through discrete element simulation, conducting comparative bench testing, and developing new designs for groove wheel fertilizer dischargers. They aim to optimize the parameters of key structural components, particularly the groove wheel, in order to enhance the accuracy and uniformity of fertilizer discharge dosing.

Bangura et al. [24] devised a spiral groove wheel fertilizer discharge device to replace the traditional straight groove wheel fertilizer discharge device. The structure of the groove wheel is depicted in Figure 12. The discrete element method was employed to test and simulate the fertilizer discharge performance. Results indicate that, under similar conditions, the spiral groove wheel demonstrates superior fertilizer discharge stability and uniformity compared to the straight groove wheel, with fertilizer particles falling at a faster rate. The relative error between the actual test results and the simulation results is less than 10%. The performance of the developed spiral groove wheel surpasses that of the traditional straight grooved wheel, thereby providing a theoretical foundation for the design of high-performance fertilizer dischargers.

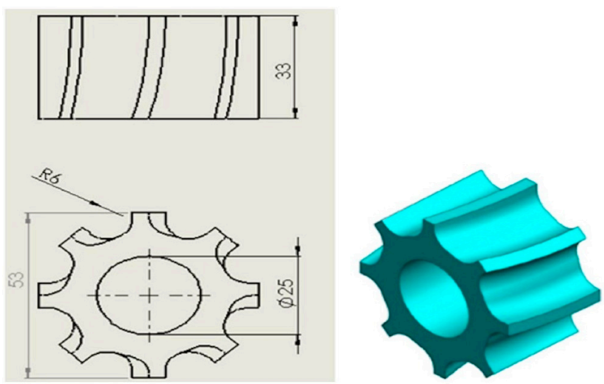


Figure 12. Main structural dimensions and models of the spiral groove wheel.

Sugirbay et al. [25] developed a new design for a pin-roller for variable fertilization, as depicted in Figure 13. The experiment utilized compound fertilizer N-P_2O_5-K_2O and tested three different rotation speeds (20 rpm, 55 rpm, 90 rpm). By optimizing the structural parameters of the pins, improvements were achieved in the uniformity and quantity of fertilizer discharge while effectively preventing fertilizer blockage. The test results indicate that compared to the traditional groove wheel fertilizer discharger, the new fertilizer discharger exhibits a higher coefficient of variation in the fertilizer discharge uniformity when rotating at low speeds, reaching up to 10.36%. However, at higher speeds, the variation coefficient of the fertilizer discharge uniformity between the two fertilizer dischargers is not significantly different, remaining at approximately 5%. Furthermore, the fertilizer discharge quantity of the new fertilizer discharger is notably lower than that of the traditional groove wheel fertilizer discharger, suggesting the need for further enhancements.

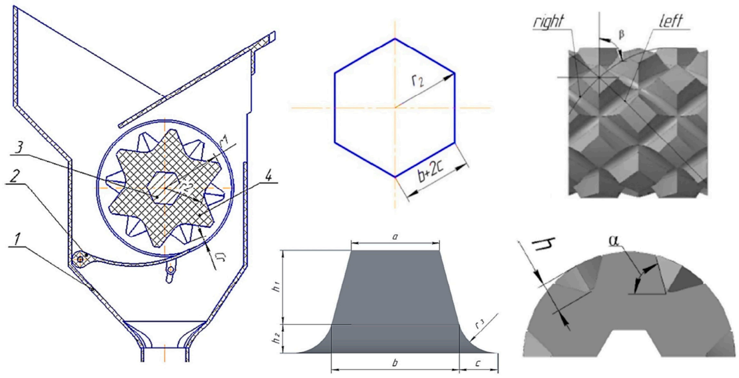


Figure 13. Pin-roller fertilizer discharger. Note: 1. discharge box; 2. flap; 3. shaft; 4. pin-roller. n is the number of right and left entry lines, β is the angle between the vertical axis and the right and left entry lines, h is the height of the roller pin, α is the angle between the hexagonal polygon and the pin inclination.

Lillerand et al. [26] utilized a straight groove wheel fertilizer discharger to achieve precise fertilizer discharge in blueberry planting. The dimensions and cross-sectional area of the grooved wheel are illustrated in Figure 14. The efficacy of precise fertilization using three nitrogen, phosphorus, and potassium solid granular fertilizers was verified. After measuring the fertilizer discharge quality under various conditions, statistical analysis revealed that the coefficient of variation of fertilizer discharge uniformity from the device exceeded 10%, indicating the need for further research and improvement. While this fertilizer discharger demonstrates relative suitability and accuracy when applying one of the three fertilizers, it falls short of meeting the target fertilization rate when applied to the other two fertilizers. Thus, there is a need to enhance its versatility.

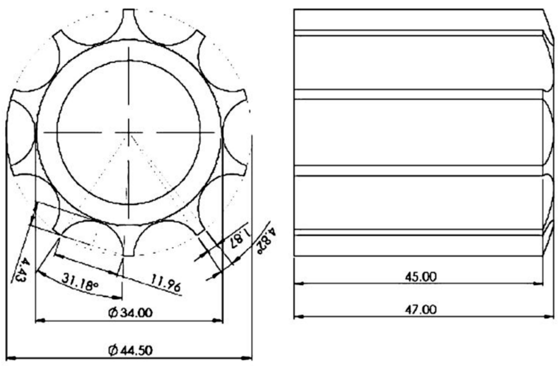


Figure 14. Structure and dimensions of the straight groove wheel.

The work of Chinese researchers primarily centers on the design and optimization of the structure and working parameters of the fertilizer discharge groove wheel. A method combining discrete element simulation with bench and field trials was used to optimize the parameters of the fertilizer discharge groove wheel, resulting in the enhanced stability and uniformity of fertilizer discharge dosing.

To investigate the impact of structural parameters of the groove wheel (as shown in Figure 15) on fertilizer discharge performance, Liang Yuchao et al. [27,28] utilized polyurea as the test fertilizer to construct a model of the fertilizer filling and discharge process of the fertilizer discharger. Employing the discrete element software EDEM 2018, they analyzed fertilizer discharge performance under various groove wheel parameters, conducting single-factor tests on the fertilizer discharge quantity and multi-factor tests on the fertilizer discharge uniformity. The order of factors affecting fertilizer discharge performance is as follows: sheave radius, arc center distance, and number of grooves. The optimal structural parameters are determined as follows: an arc center distance of 25 mm, a sheave radius of 27 mm, and six grooves. Subsequently, bench tests and whole machine tests were carried out, yielding the fertilizer discharge uniformity coefficients ranging from 91% to 95%.

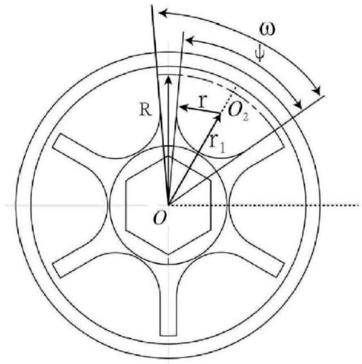
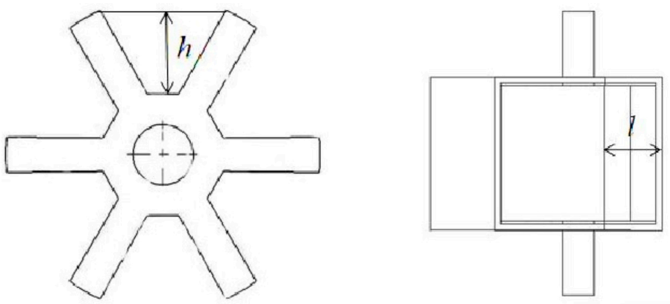


Figure 15. Schematic diagram of groove wheel structure. Note: r_1 is the arc center distance; R is the radius of the groove wheel.

Based on theoretical analysis, Zhou Bin [29] examined the fertilizer discharge process of the groove wheel fertilizer discharger through discrete element simulation. Its structure is depicted in Figure 16. Single-factor and orthogonal experiments were devised to process the acquired data. The optimal parameter combination was a rotation speed of the groove wheel of 34.52 rpm, an effective working length of the groove wheel of 56.01 mm, and a depth of the sheave of 36.287 mm. Subsequently, in conjunction with bench testing, it was determined that the variation coefficient of the potassium fertilizer discharge amount was 8.68%, and the variation coefficient of the compound fertilizer discharge amount was 10.64%. The error between the simulated and actual fertilizer discharge amounts was less than 7%. The optimized fertilizer discharger exhibited superior performance in the jujube orchard.



(**a**) (**b**)

Figure 16. Schematic diagram of partial structure of groove wheel fertilizer discharger: (**a**) groove wheel; (**b**) shell. Note: *h* is the depth of the groove wheel; *l* is the effective working length of the groove wheel.

Yang Liu [30] utilized discrete element software EDEM 4.0.0 to investigate the effects of the working length of the groove wheel, the angle of the lower fertilizer discharge tongue opening, and the rotation speed of the fertilizer discharge shaft on the movement trajectory of fertilizer particles. The structure is depicted in Figure 17. Through single-factor and multi-factor indoor and field trials, it is concluded that the order and optimal parameter combination of factors affecting fertilizer discharge performance are as follows: ① Nitrogen fertilizer: a working length of the groove wheel of 40 mm, a fertilizer discharge shaft speed of 46 rpm, an angle of the lower fertilizer discharge tongue opening of 22.5 degrees, and a coefficient of variation of 3.48%. ② Phosphate fertilizer: a working length of the groove wheel of 42 mm, an angle of the lower fertilizer discharge tongue opening of 22.5 degrees, a rotation speed of the fertilizer discharge shaft of 48 rpm, and a coefficient of variation of 4.274%. ③ Potassium fertilizer: a fertilizer discharge shaft speed of 48 rpm, a working length of the groove wheel of 37 mm, an angle of the lower fertilizer discharge tongue opening of 22.5 degrees, and a coefficient of variation of 5.152%. The results all meet the national precision planting requirements.

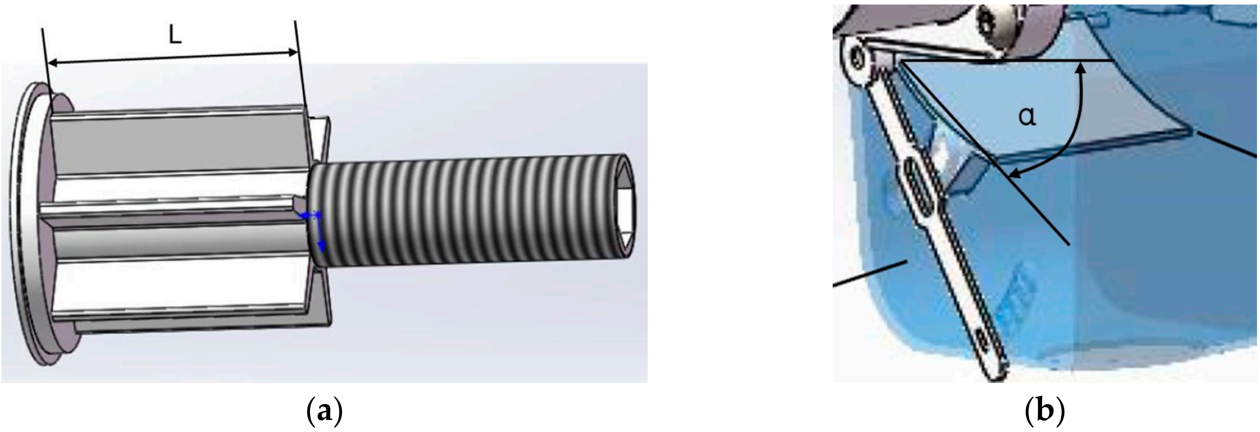


Figure 17. Schematic diagram of partial structure of groove wheel fertilizer discharger: (**a**) groove wheel structure diagram; (**b**) opening diagram of lower row fat tongue. Note: L is the working length of the groove wheel; α is the angle of the lower fertilizer discharge tongue opening.

To further enhance the precision of fertilizer discharge dosing from groove wheel fertilizer dischargers, Chinese researchers improved its structure by incorporating a spiral angle into the design, building upon the traditional right-angle fertilizer discharge groove wheel.

Song Xuefeng et al. [31] devised a spiral groove wheel fertilizer discharger, and the structure of the groove wheel is depicted in Figure 18. Based on the discrete element method, they simulated the movement of urea fertilizer and investigated the impact of parameters such as groove wheel rotating speed, helix angle, and cross-sectional shape (as shown in Figure 19) on the fertilizer discharge performance. Employing a Box–Behnken three-factor and three-level test, the order of affecting factors is determined as follows: groove wheel speed, wheel cross-sectional shape, and spiral angle. Through thorough data analysis, they identified the optimal cross-sectional shape as scoop shape, and the parameter combination was as follows: a groove wheel rotating speed of 21 rpm and a helix angle of 70 degrees. Simulation tests and bench tests demonstrated that the variation coefficient of fertilizer discharge uniformity does not exceed 9.3%, and the error between simulation and measured data was less than 10%, effectively mitigating the fertilizer discharge blockage and enhancing the discharge accuracy.

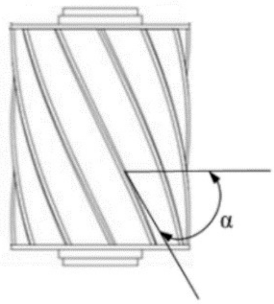


Figure 18. Spiral groove wheel. Note: α is the helix angle.

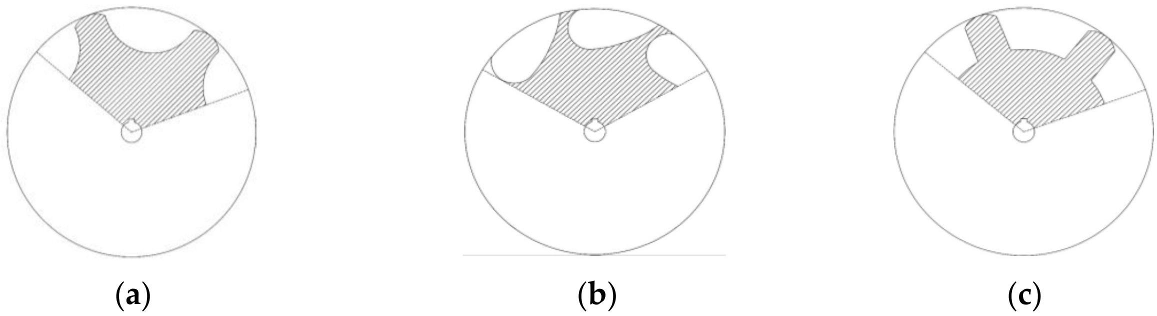


Figure 19. Different cross-sectional shapes of spiral sheaves: (**a**) circular arc, (**b**) spoon shape, (**c**) trapezoid.

Wang Yubing et al. [32,33] conducted a systematical investigation into the impact of fertilizer discharge uniformity, considering factors such as the rotation speed of the opposed, double-spiral groove wheel (as shown in Figure 20), groove section radius, working length of the groove wheel, and spiral angle. Discrete element orthogonal experiments were employed to simulate the movement process of various fertilizers, including urea, compound fertilizer, and organic fertilizer. The optimal parameter combination was determined to be a rotation speed of 30 rpm, a groove section radius of 10 mm, a working length of the groove wheel of 50 mm, and a spiral angle of 45 degrees. Bench testing confirmed the reliability of the simulation with a deviation of only 0.91%. Field trials concluded that the coefficient of variation of fertilization uniformity was 10.13%, meeting the agronomic requirements for deep-side fertilization in tea gardens.

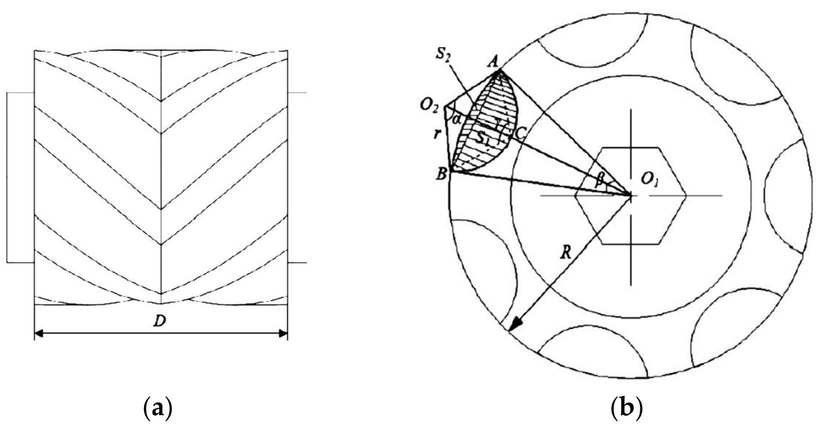


Figure 20. Structural diagram of opposed double-spiral sheave wheels: (**a**) top view; (**b**) left view. Note: D is the diameter of the sheave and the maximum effective working length; r is the radius of the concave section.

In addition, in order to make breakthroughs in the precise fertilizer discharge dosing from the groove wheel fertilizer discharger, Chinese researchers initiated studies on new designs for groove wheel fertilizer dischargers.

Dun Guoqiang et al. [34] enhanced the design of a staggered gear fertilizer discharger based on spur-tooth fertilizer discharge gears, illustrated in Figure 21. Based on theoretical analysis of the fertilizer discharge amount, they utilized the discrete element analysis method to simulate the discharge process of urea granules. Single-factor orthogonal simulation experiments were conducted to analyze the effects of parameters on the uniformity of fertilizer discharge. Results from simulations indicated that the number of staggered gear has a more significant impact on the discharge uniformity than the wheel clearance. Combining integrating simulation tests and bench tests, the best performance was attained by employing three staggered gear plates, with a wheel clearance set at 5 mm and a rotation speed of 60 rpm. This configuration yielded a coefficient of variation for the fertilizer discharge uniformity of no more than 4.8%, closely aligning with theoretical projections. The accuracy deviation of fertilizer amount was measured at 3.1%. The optimized fertilizer discharger exhibits excellent fertilizer uniformity and enables precise control of the fertilizer discharge.

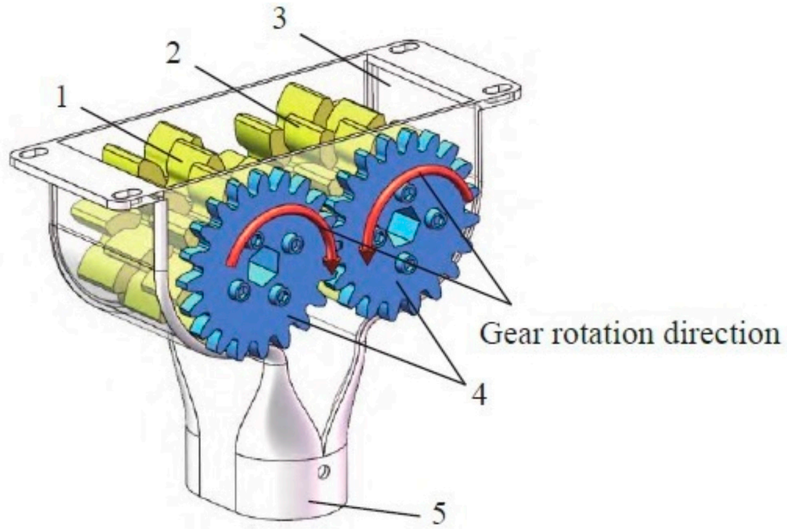
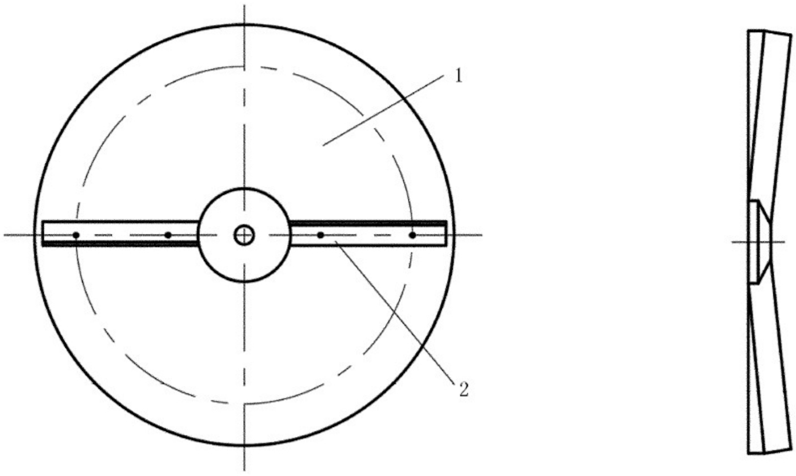


Figure 21. Structural diagram of staggered gear fertilizer discharger. Note: 1. left-hand rotation groove wheel; 2. right-hand rotation groove wheel; 3. shell; 4. transmission gear; 5. fertilizer discharge port.

The research above primarily focused on optimizing parameters such as groove wheel radius, arc center distance, number of grooves, groove cross-section radius, groove depth, effective working length, spiral angle, cross-sectional shape, rotation speed, angle of the lower fertilizer discharge tongue opening, number of staggered gears, and fertilizer wheel clearance through discrete element simulation, bench tests, field trials, and other research methodologies. It offers crucial theoretical and practical backing for achieving precise fertilization with groove wheel fertilizer dischargers and enhancing the stability and uniformity of fertilizer dosing.

2.3. Research Status of Disc Fertilizer Discharger

The working principle of disc fertilizer dischargers is as follows: fertilizer particles drop from the fertilizer box onto the fertilizer spreading disc. The fertilizer blades rotate around the axis, striking the fertilizer as they rotate at a certain speed, pushing the fertilizer toward the edge of the disc. The amount of fertilizer discharged can be adjusted by changing the rotation speed of the turntable and adjusting the height of the door. Finally, under the action of centrifugal force, the fertilizer is thrown out at a consistent speed. The structure of disc fertilizer dischargers includes a fertilizer-spreading disc, along with two or more fertilizer-spreading blades, as depicted in Figure 22. This fertilizer discharger is primarily suitable for granular and powdered fertilizers, offering good looseness and fluidity. It features a simple structure, high operational efficiency, uniform fertilization, and minimal risk of fertilizer accumulation. Although widely utilized, it encounters challenges related to high resistance due to its structure [35].



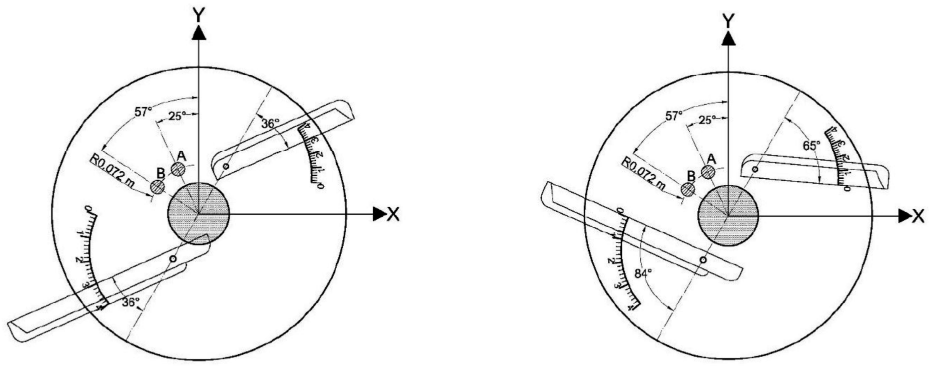
(**a**) (**b**)

Figure 22. Structural diagram of disc fertilizer discharger: (**a**) top view; (**b**) left view. Note: 1. fertilizer spreading disc; 2. fertilizer spreading blade.

The work of international researchers focuses on studying the factors affecting the average spreading radius, the structure and working parameters of the fertilizer spreading disk, and the impact of the fertilizer discharge angle on the fertilizer discharge performance through simulation, bench testing, or developing new designs for disc fertilizer dischargers. They consistently optimize the parameters of fertilizer spreading discs to enhance the precision of fertilizer distribution.

Przywara et al. [36] conducted a bench test employing a four-factor experimental model to investigate the impact of parameter settings on the average radius of the disc fertilizer discharger. They analyzed the movement of three chemical fertilizers (urea, calcium ammonium nitrate, and ammonium sulfate) in discs with two different blade angles (as shown in Figure 23). Model variance analysis revealed that fertilizer type, blade configuration, and disc angular velocity collectively contributed to 91.74% of the variance in the average diffusion radius. Furthermore, linear multiple regression analysis indicated that fertilizer dust fraction and disc angular velocity had an overall impact of 82.72% on the variance of the average diffusion radius. Notably, among the research findings, the negative correlation between fertilizer dust fraction and blade angular velocity was as high as 72.77%, offering valuable insights for future research endeavors.

To enhance the uniformity and efficiency of fertilization, Bulgakov et al. [37] devised a tilt-axis fertilizer discharger, depicted in Figure 24. Field trials revealed that the rotation frequency of the disc exerts the most significant impact on the uneven distribution of fertilizers along the fertilization line in the tilt-axis fertilizer discharger. Adjusting the disc tilt angle and rotation frequency enables effective control of the fertilizer application width. Experimental findings demonstrate that increasing the rotation frequency from 600 to 800 rpm extends the effective fertilization range to 10.5 m while raising the inclination angle to 20 degrees expands the fertilizer spread range to 24 m. The tool exhibits an exponential upward trend in each operational mode, providing a foundation for selecting optimal parameters and operational techniques for fertilizer dischargers.



(a) (b)

Figure 23. Two discs with different blade angles: (**a**) the l3 vane configuration; (**b**) the l0 vane configuration.

Figure 24. Inclined axis centrifugal rotary disk fertilizer applicator.

To address the issue of insufficient fertilizer uniformity during high-speed rotation of centrifugal fertilizer dischargers, Sidneva et al. [38] used a spiral blade working mechanism to replace the straight blade, depicted in Figure 25. Experimental tests indicate that this innovation can enhance fertilizer distribution quality within the speed range of 4 to 16 kph. By adjusting the blade angle ranging from 0 to 20 degrees to optimize fertilizer dispersion, the developed fertilizer discharger can distribute fertilizers at higher speeds and more evenly across the field surface, with relevant parameters showing significant improvements over traditional devices.

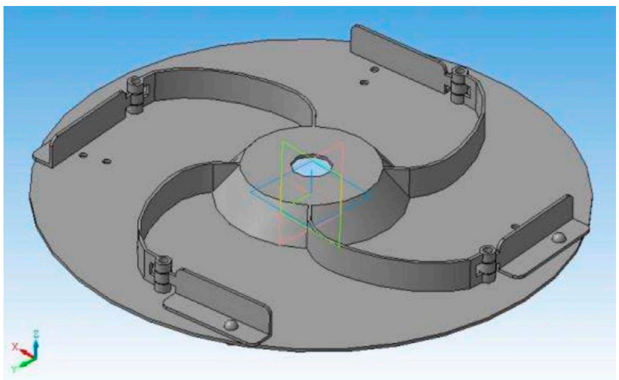


Figure 25. Structural diagram of disc fertilizer discharger.

The work of Chinese researchers primarily centers on the design and optimization of the structure and working parameters of fertilizer spreading discs. They employ a method that combines discrete element simulation with bench and prototype testing to continually optimize the parameters of the fertilizer spreading disk, aiming to improve the stability and uniformity of fertilizer distribution.

Yang Liwei et al. [39] focused on the centrifugal disc fertilizer discharger as their research subject, depicted in Figure 26. They conducted a prototype test to analyze the impact of key parameters on the uniformity of urea fertilizer spreading. Through a multi-factor response surface analysis test, they concluded that the order of factors affecting fertilizer spreading uniformity was as follows: feeding position angle, fertilizer spreading height, and blade position angle. By employing factor interaction response surface analysis, they determined the optimal parameter combination to be a fertilizer spreading height of 68.8 cm, a cutting position angle of 60 degrees, and a blade position angle of 29.63 degrees. With these settings, the coefficient of variation of fertilizer uniformity reached a minimum value of 9.95%, effectively resolving the issue of poor fertilizer discharge uniformity.

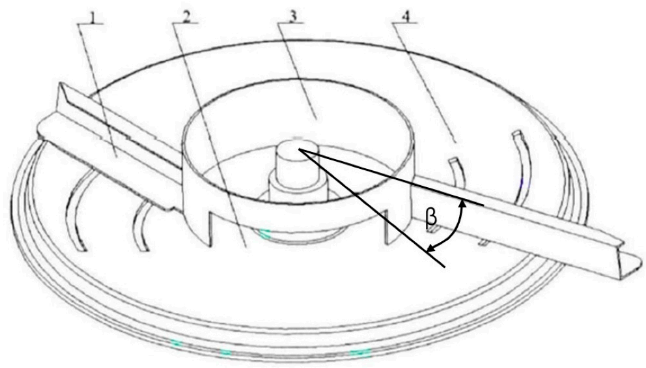


Figure 26. Structural diagram of centrifugal disc fertilizer discharger. Note: 1. blade; 2. evening outlet; 3. evening cover; 4. disc; β is the blade position angle.

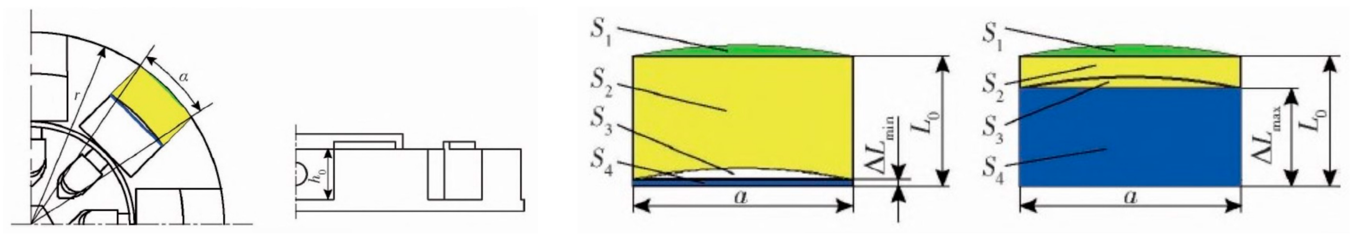
To achieve advancements in the precise distribution of fertilizers by disc fertilizer dischargers, Chinese researchers are dedicated to developing new designs for disc fertilizer dischargers. They utilize fertilizer discharge ejector pins and fertilizer scraping brushes to aid in the fertilizer discharge.

Shang Wenhu et al. [40,41] developed a disc ejection side-deep fertilizing device. The cross-section of the fertilizer trough is illustrated in Figure 27. A kinematic model of the fertilizer discharge process was established and determined through discrete element simulation tests. The optimal working speed of the fertilizer discharge disc ranges from 10 to 60 rpm. Choosing the effective working length of the fertilizer trough as the test factor, results indicate that adjusting the effective working length of the fertilizer trough between 5 to 20 mm leads to a variation coefficient of fertilizer discharge uniformity ranging from 5.96% to 12.77%. Four special compound fertilizers with varying densities for side-deep fertilization of paddy fields were selected for testing. The device demonstrates good adaptability and meets national operating standards.

To further enhance the precision of fertilizer distribution from disc fertilizer dischargers, Chinese researchers additionally devised a fertilizer spreading disc featuring a conical blade shape and examined its structure and working parameters.

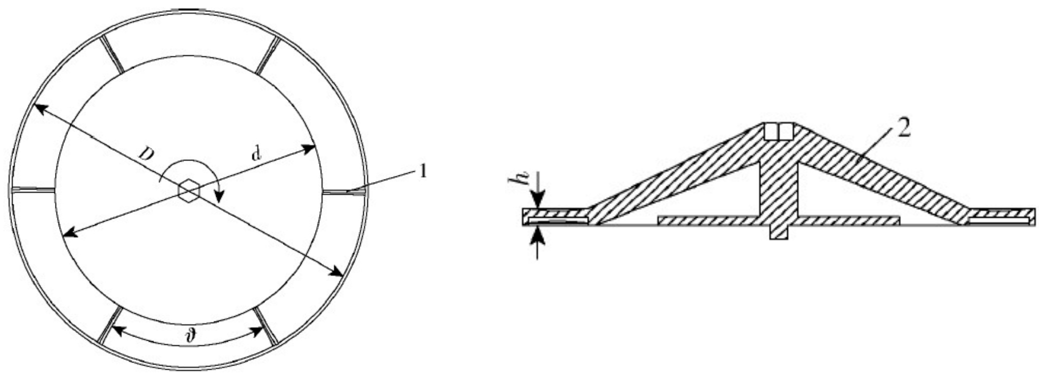
Fu Zuodong et al. [42] devised a conical disc push plate double-row fertilizer discharger. The structure of the conical disc is depicted in Figure 28. The impact of the number of push plates on fertilizer filling and discharge performance was analyzed through discrete element simulation. Findings reveal that with eight push plates, the fertilizer discharger exhibits optimal performance. Utilizing a full-factor bench test, it is observed that the fertilizer discharge amount has a strong linear correlation with both the conical turntable speed (ranging from 15 to 45 rpm) and the fertilizer discharge opening (ranging from 5 to 25 mm). The coefficients of variation for consistency of double-row fertilizer discharge, stability of total fertilizer discharge, and uniformity of fertilizer discharge vary from 1.01%

to 3.88%, 1.05% to 3.81%, and 6.64% to 15.79%, respectively. When the device is tilted at 3 degrees, the maximum coefficient of variation for the consistency of fertilizer discharge in two rows is 6.17%. These test results align with the performance standards required for side-deep fertilization in paddy fields.



(**a**) (**b**)

Figure 27. Schematic diagram of the cross-sectional area of the fertilizer tank: (**a**) schematic diagram of filling a single fertilizer tank; (**b**) maximum and minimum cross-section of a single fertilizer tank. Note: L_0 is the maximum effective working length of the fertilizer tank; ΔL is the change in the effective working length of the fertilizer tank.



(**a**) (**b**)

Figure 28. Schematic diagram of the structural parameters of the conical disc: (**a**) top view; (**b**) sectional view. Note: 1. push plate; 2. conical disc.

Liu Xiaodong et al. [43–45] investigated the fertilizer discharge performance of the spiral cone centrifugal fertilizer discharger (depicted in Figure 29) through discrete element simulation. The quadratic regression orthogonal rotation combination tests were employed to determine the optimal structural parameters: a horizontal inclination angle of 30.4 degrees, a push plate radial deflection angle of 3.2 degrees, and a cone disk speed of 130 rpm. Combined with bench and field trials, it was found that the stability variation coefficient of fertilizer discharge does not exceed 4.57%, thus meeting the standards for compound fertilizer fertilization in rapeseed fields.

In addition, in order to make breakthroughs in the precise fertilizer distribution from disc fertilizer dischargers, researchers initiated research on fertilizer dischargers that integrate a spiral fertilizer conveying device with a disc fertilizer discharger.

Song Shuaishuai et al. [46] combined a vertical spiral fertilizer discharger to develop a disc variable fertilizer discharger tailored for banana orchard fertilization, as depicted in Figure 30. They conducted discrete element simulation tests to determine the optimal fertilizer discharger parameters: a forward speed of 0.25 mps, a rotation period of 10 s, a central angle of 90 degrees, and a curved groove opening size of 20 mm. Field trials yielded an average fertilizer discharge qualification rate of 95.33%. The model and test errors, as well as the simulation and test errors of fertilizer discharge amount, are 11.15% and 6.68%, respectively. The fertilizer discharger demonstrates commendable operational performance.

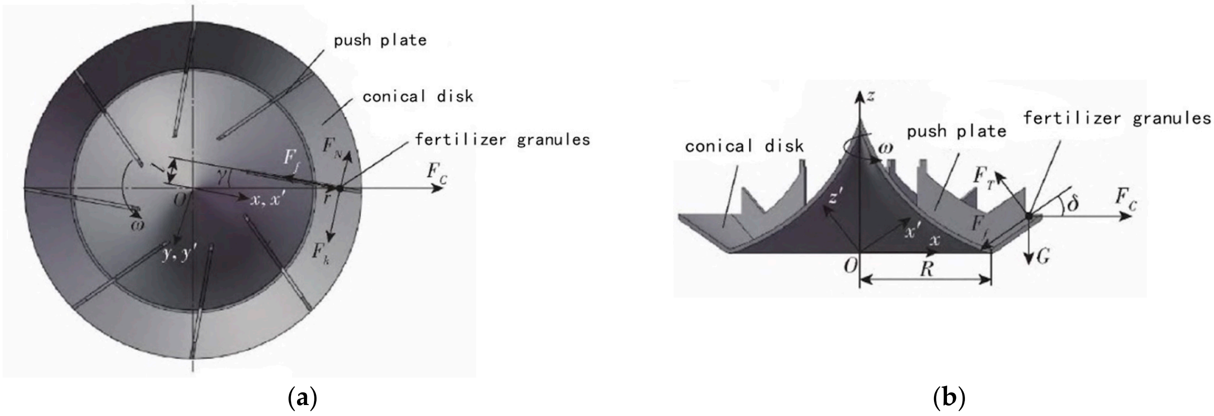


Figure 29. Schematic diagram of the force of granular fertilizer on the conical disc: (**a**) top view; (**b**) xOz face view. Note: δ is the horizontal inclination angle of the conical disk delivery section; γ is the radial deflection angle of the push plate.

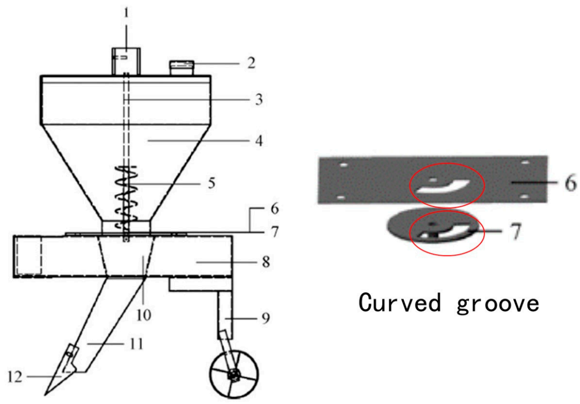


Figure 30. Structural diagram of the turntable variable fertilizer discharger. Note: 1. stepper motor; 2. fertilizer injection port; 3. rotating shaft; 4. fertilizer box; 5. vertical screw conveyor; 6. fixed square plate; 7. rotating disc; 8. frame; 9. soil covering suppression mechanism; 10. conical fertilizer bucket; 11. fertilizer discharge pipe; 12. arrow shovel trencher.

Cao Xin et al. [47,48] conducted a three-factor and two-level general rotation combination discrete element simulation test on a clustered, bidirectional spiral, fertilizer feeding, centrifugal conical disc fertilizer device, as illustrated in Figure 31, to simulate the process of compound fertilizer discharge. The results indicate that the order of significance of factors affecting the variation coefficient of fertilizer uniformity is as follows: bidirectional spiral speed, conical disc speed, and traveling speed. The optimal parameter combination is determined to be a bidirectional spiral speed of 5.27 rpm, a conical disc speed of 243.7 rpm, and a device travel speed of 0.66 mps. Following optimization, the average coefficient of variation of fertilizer uniformity is 17.16%. The optimization and verification test results are highly consistent.

The above research primarily focused on optimizing parameters such as the angle of the fertilizer disc blades, the effective working length of the fertilizer groove, the size of the curved trough opening, rotation speed (angular velocity, frequency, period), fertilizer discharge opening, fertilizer spreading height, cutting position angle, disc inclination angle, and forward speed through discrete element simulation, bench, and field trials. These methods effectively enhanced the stability and uniformity of fertilizer distribution, offering a foundation and valuable references for further investigations into disc fertilizer dischargers.

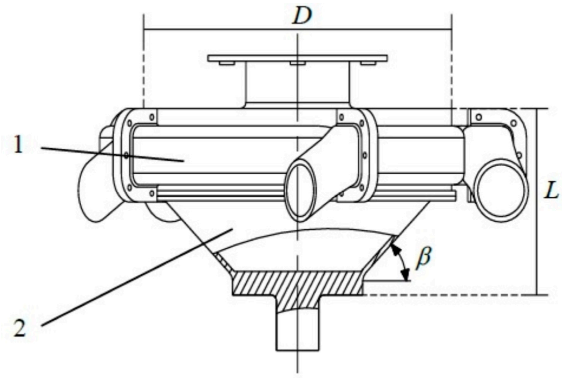


Figure 31. Structural diagram of centrifugal, conical disc fertilizer discharger. Note: 1. centrifugal conical disc cover; 2. centrifugal conical disc.

2.4. Research Status of Air-Feed Fertilizer Discharger

The working principle of air-feed fertilizer dischargers is as follows: the fertilizer discharger utilizes a mechanical device for fertilizer supply, followed by fertilizer transportation through high-speed airflow. The gas–fertilizer mixture is thoroughly mixed in the mixing area via the high-speed airflow, and then the evenly mixed gas–fertilizer mixture is transported to the fertilizer discharge pipe. The structure is illustrated in Figure 32. This method of fertilizer discharge enables a better flow of fertilizer, improved mixing performance, more stable fertilizer discharge, a simple overall structure, and enhanced efficiency in fertilization operations [49].

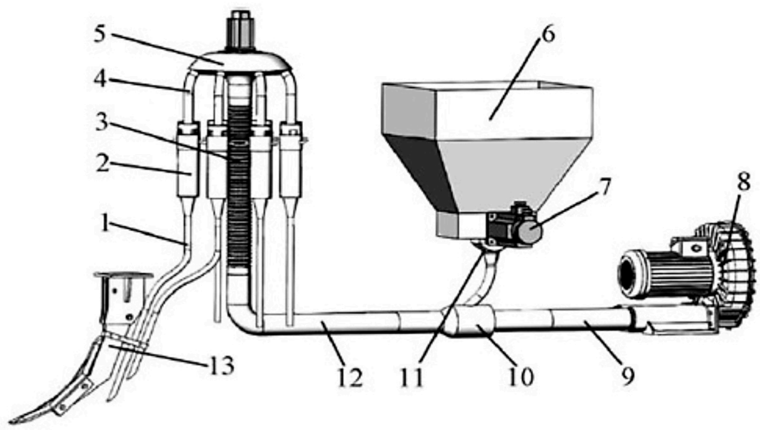


Figure 32. Structural diagram of air-feed fertilizer discharger. Note: 1. fertilizer discharge pipe; 2. air and fertilizer separation device; 3. corrugated pipe; 4. distribution outlet; 5. distribution device; 6. fertilizer box; 7. motor; 8. fan; 9. airflow conveying pipe; 10. air–fertilizer mixing device; 11. mechanical fertilizer discharge device; 12. air–fertilizer delivery pipe; 13. layered deep fertilization shovel.

The work of international researchers focuses on using fluid dynamics modeling and simulation and calculation methods in the fields of pneumatic seeders and agricultural fertilizer dischargers to examine whether fertilizer discharge meets the standards of precise fertilizer distribution.

Konovalov et al. [50] established a linear calculation mathematical model of the pneumatic seeder system using MathCAD 8.0, as illustrated in Figure 33. The system and design plan were detailed. Employing continuum mechanics, a parameter calculation method was proposed to validate the design decisions. By applying linear calculation to the series-parallel arrangement part, the linear calculation and structural indicators were redefined. The results indicate that the standard deviation of the air velocity within the section does not exceed 14%, and the standard deviation of the pressure on the section does not surpass 0.5%. The analytical model exhibited high accuracy, with a mass flow error of only 1.152×10^{-14}%.

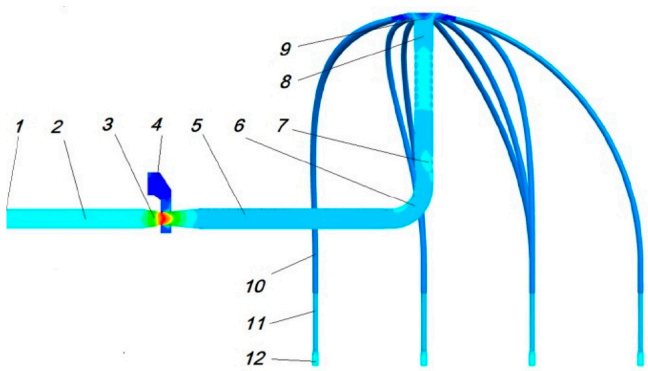


Figure 33. Installation diagram of pneumatic conveying system of pneumatic seeder. Note: 1. fan installation position; 2. air duct; 3. nozzle; 4. seed metering device; 5. horizontal pipe section; 6. bend pipe; 7. vertical pipe section; 8. guide; 9. distributor; 10. delivery pipe (hose); 11. coulter; 12. coulter nozzle.

Marcelo et al. [51] utilized numerical simulation calculations and experimental comparisons, as depicted in Figure 34, to validate the performance of two different types of radial fans in agricultural fertilizer dischargers at a rotation speed of 4000 rpm. Following the determination and validation of the mathematical model, the operational process of the fertilizer discharger was simulated, and the airflow distribution of the fertilizer discharger nozzle was assessed. Through experiments, it was observed that the numerical simulation yielded relatively accurate results, with an average error of 4.3%.

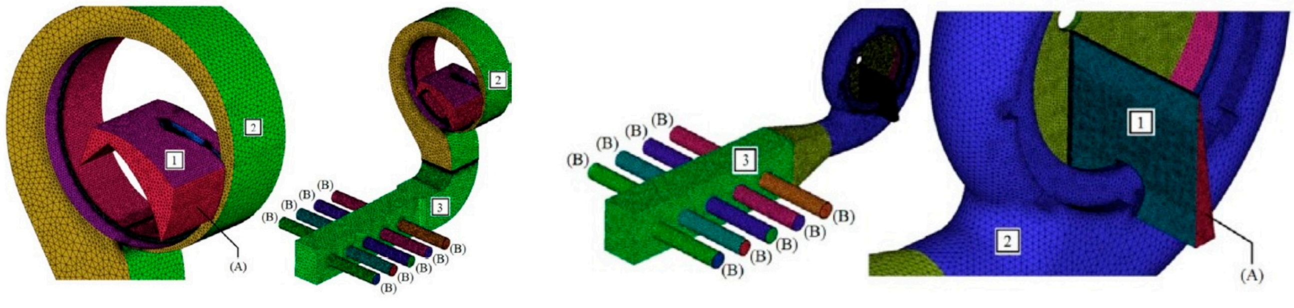


Figure 34. Two different types of radial fans: (**a**) A1 radial fan; (**b**) B1 radial fan. Note: A is the entrance; B is the exit. 1. fan; 2. volute; 3. air distribution box.

The work of international researchers centers on designing and optimizing the structure and working parameters of fertilizer distribution devices and air distribution devices of air-feed fertilizer dischargers. The Hertz theory, CFD fluid simulation, and CFD-DEM air-solid coupling analysis methods were employed to optimize the parameters of the fertilizer distribution device and air separation device, demonstrating improved stability in fertilizer distribution.

Wang Lei et al. [52] investigated the air-feed fertilizer discharger system of an oil–wheat seeder. Based on the Hertz theory, they established an elastic collision model for fertilizer particles and distribution devices. Employing CFD and DEM air-solid coupling methods, they separately analyzed the movement of fertilizer particles and their impact on the fertilizer discharge performance across four types of distribution devices. The structure of the distribution device is depicted in Figure 35. The findings reveal that the dome distribution device exhibits a superior fertilizer discharge performance, with the coefficient of variation of fertilizer discharge consistency in each row fluctuating between 6.35% and 7.52%.

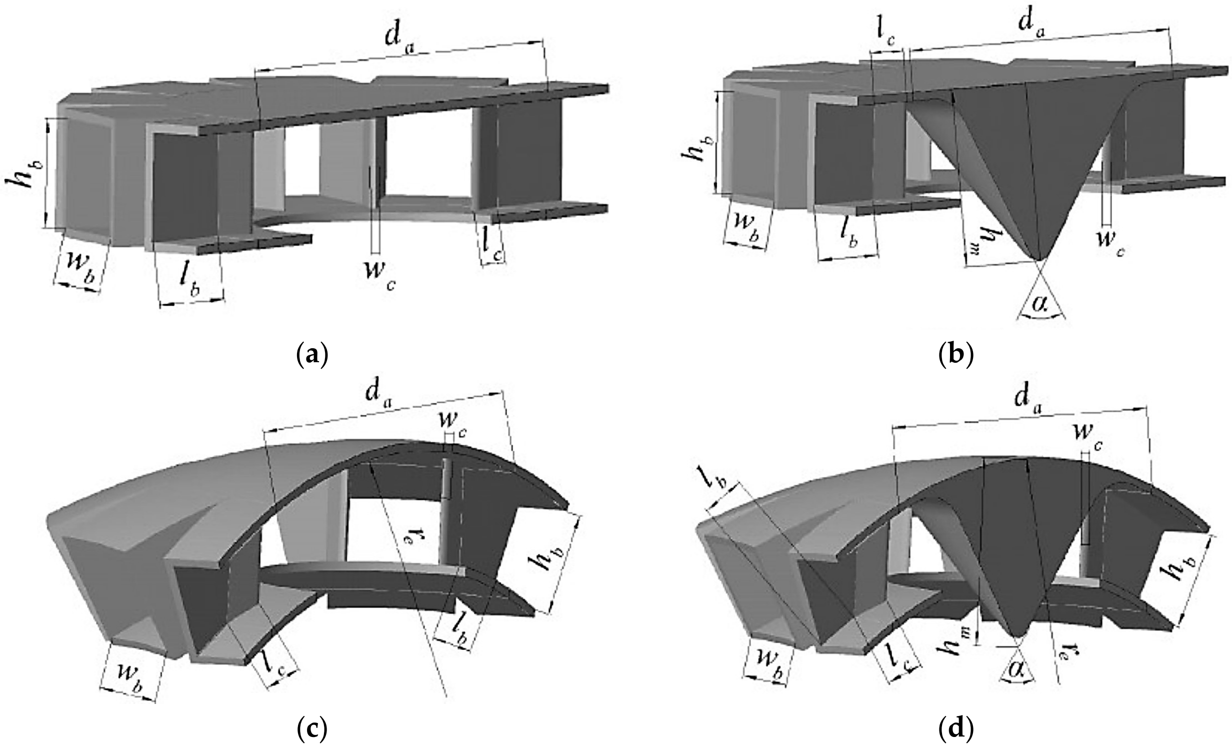


Figure 35. Schematic diagram of the longitudinal section of the main body of different distribution devices: (**a**) flat-top type; (**b**) flat-top inverted cone type; (**c**) dome type; (**d**) dome inverted cone type.

Jia Honglei et al. [53] investigated a pneumatic centralized discharge precision mixing fertilization device for corn, integrating the research of CFD and DEM air-solid coupling methods. They utilized nitrogen, phosphorus, and potassium fertilizers as the test fertilizers and conducted a three-factor and two-level regression orthogonal combination design test. The optimized structural parameters are a fertilizer outlet inclination angle of 45 degrees, a conveying air speed of 35 mps, and a bellows length of 568 mm. The structure is depicted in Figures 36 and 37. Subsequently, field trials were carried out, managing to control the error of fertilizer application within 2%, with a stability coefficient of variation of approximately 2%, meeting national standards.

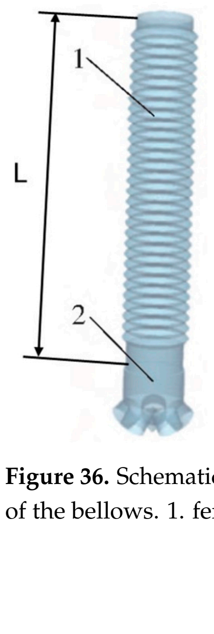


Figure 36. Schematic diagram of the overall structure of the fertilizer distributor. Note: L is the length of the bellows. 1. fertilizer pipe; 2. fertilizer distributor.

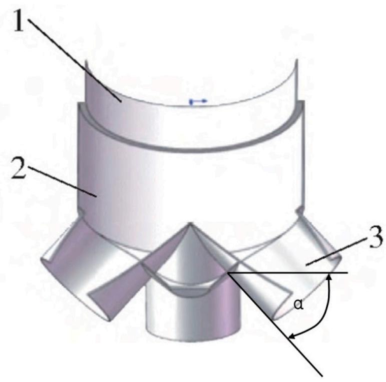


Figure 37. Schematic diagram of the partial structure of the fertilizer distributor. Note: α is the inclination angle of the fertilizer discharge port. 1. distributor inlet; 2. distributor housing; 3. fertilizer discharge port.

Xu Zheng et al. [54,55] utilized CFD fluid simulation to enhance the performance of the air distribution device within the pneumatic fertilizer conveying system in rice fields. Its structure is depicted in Figure 38. It is concluded that the opening angle of the baffle significantly affects the air separation performance, and at an opening angle of 48 degrees, the flow rate consistency of the exhaust port is optimal, with a fertilizer distribution variation coefficient of 5.65%. Concurrently, the connection method of the air–fertilizer mixing device was refined, with the feed pipe being connected and extended into the trachea at an inclined angle, thereby increasing the flow rate. Through the CFD-DEM air-solid coupling simulation test, it was observed that the optimized air–fertilizer mixing device increased the speed of urea particles by 93.6%.

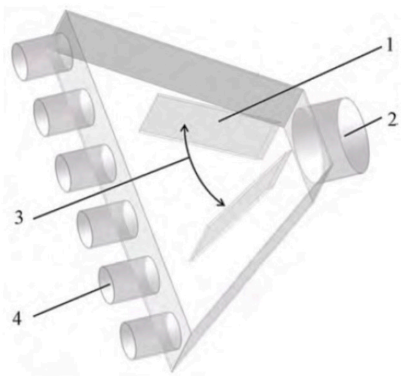


Figure 38. Structural diagram of the air distribution device. Note: 1. deflector; 2. air inlet; 3. deflector opening angle; 4. exhaust port.

The above research uses the Hertz theory, CFD fluid simulation, and CFD-DEM air-solid coupling analysis methods to compare and analyze various types of fertilizer distribution devices of air-fed fertilizer dischargers. The parameters such as the discharge outlet inclination angle, conveying air speed, bellows length, and opening angle of the air distribution device were optimized, effectively enhancing the precision of fertilizer distribution and reducing unevenness and breakage rates during fertilizer discharge, which has a reference value for future studies.

3. Problems

There are numerous key issues in the current research on the precise fertilizer dosing and distribution by fertilizer dischargers, which need to be addressed thoroughly to enhance the accuracy, stability, and applicability of the fertilizer discharge system. The existing problems are outlined as follows:

First, when measuring the physical and mechanical properties of particles, idealized algorithms are often utilized, resulting in certain errors in the obtained results. To ensure more accurate measurement outcomes, a deeper exploration of precise measurement methods is required, which may involve improving algorithms and using more advanced measurement equipment to enhance the accuracy and reliability of measurements.

Secondly, when establishing a mechanical model of fertilizer particles, mechanical and kinematic analyses typically focus solely on individual particles, with the movement among particle groups often ignored and not thoroughly explored. In order to have a more comprehensive understanding of the fertilizer discharge performance, it is necessary to conduct in-depth research on the movement between particle groups to enhance the simulation accuracy of the actual situation.

Thirdly, in simulation, field, and other trials, only a single or few indicators are commonly selected to evaluate the fertilizer discharge performance. To ensure a more comprehensive assessment of the performance of fertilizer dischargers, additional evaluation indicators should be considered, taking into account external factors such as working conditions and terrain. This approach will aid in optimizing the design of fertilizer dischargers and provide more sufficient data support.

Fourthly, the majority of fertilizer dischargers employ flexible materials in the construction of fertilizer delivery devices, such as spiral blades or grooved wheels, to minimize particle breakage and reduce torque fluctuations. However, due to limitations in manufacturing materials and processes, further research is required on flexible fertilizer dischargers. The exploration of new flexible materials or improved processes may be necessary to enhance their stability and longevity.

Finally, in view of the situation that there are many varieties of fertilizers with different physical properties, it is necessary to conduct adaptability research on more varieties of fertilizers. The design of fertilizer dischargers should account for the characteristics of different fertilizers to ensure wider applicability in practical applications. This may require more extensive testing and data collection to optimize the design of fertilizer dischargers.

4. Development Trend

The future development trend of fertilizer dischargers in the precision fertilizer dosing and distribution research can be summarized into the following three aspects.

First of all, in view of the errors caused by the current idealized calculations and simplified models, future research can be devoted to establishing more accurate measurement methods and mechanical models. In the measurement of particle physical and mechanical properties, more modern measurement tools and technologies, such as advanced sensors and high-precision imaging equipment, can be utilized to improve the accuracy of particle physical and mechanical properties. Simultaneously, for in-depth research on the movement of fertilizer particle groups, complex system modeling and simulation technology can be used to consider more affecting factors, improving the fidelity of mechanical models.

In addition, considering the numerous varieties of fertilizers with different physical properties, future research should further expand the study of the adaptability of fertilizer dischargers for different varieties of fertilizers. Meanwhile, more in-depth research on the materials and processes of fertilizer dischargers, especially for flexible blades of spiral fertilizer dischargers, can enhance their performance and stability through the exploration of new materials and manufacturing processes.

Finally, future research on fertilizer dischargers can utilize more advanced control systems and real-time monitoring devices with the help of intelligent technology. Using advanced CNC processing technology for manufacturing fertilizer dischargers, combined with an intelligent control system, can improve accuracy and stability. In simulations and field trials, by considering factors such as working conditions and terrain and employing more accurate evaluation indicators and real-time monitoring systems, further data on the fertilizer discharge performance can be obtained. These data will facilitate the optimal design of fertilizer discharge devices, providing more reliable support for future research.

5. Conclusions

The research status of the structure and working parameters optimization of four types of fertilizer dischargers (spiral fertilizer dischargers, groove wheel fertilizer dischargers, disc fertilizer dischargers, and air-feed fertilizer dischargers) that are currently commonly used is summarized. The problems existing in the research on precise fertilizer dosing and the distribution of fertilizer dischargers are put forward, and their future development trends are predicted. Within the background of the Agriculture 4.0 revolution, this research above will facilitate more accurate and efficient fertilization operations by fertilizer dischargers in future practical applications, thereby enhancing agricultural production's precision and intelligence. Furthermore, this integration of intelligent agricultural machinery and equipment with agricultural production aims to continually enhance production efficiency, lower costs, improve production quality, safeguard environmental resources, and foster sustainable agricultural development.

Author Contributions: Conceptualization, W.X. and Q.Y.; methodology, W.X. and Q.Y.; validation, Q.Y. and X.L.; formal analysis, X.L. and J.Z.; investigation, W.X. and J.Z.; data curation, W.X.; writing—original draft preparation, W.X.; writing—review and editing, W.X.; project administration, X.L.; Funding acquisition, X.L. and Q.Y. All authors have read and agreed to the published version of the manuscript.

Funding: The research was funded by The National Key Technology Research and Development Program of China, grant number [2022YFD2001400]; China Agriculture Research System of MOF and MARA, grant number [CARS-28-21]; National Science and Technology Development Program of China, grant number [NK2022160104]; and Jiangsu Agricultural Science and Technology Innovation Fund, grant number [CX(23)3037].

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The original contributions presented in the study are included in the article; further inquiries can be directed to the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Hu, X.W.; Mao, W. Research status and development trends of fertilization machinery. *Mod. Agric. Equip.* **2023**, *44*, 25–29+50.
2. Yang, L.F. Promote soil testing and formulated fertilization technology to promote sustainable agricultural development. *Heilongjiang Grain* **2023**, 110–112. [CrossRef]
3. Gong, S.; Hao, W.Y. Research on the development status of precision fertilization technology. *Mod. Agric. Res.* **2022**, *28*, 136–138.
4. Li, Z.P.; Liang, C.Y.; Li, P.; Wang, P.Y.; Zou, L.W.; Zhang, R.D. Research status and prospects of precision fertilization technology. *Trop. Agric. Eng.* **2022**, *46*, 47–50.
5. Zhang, H.T.; Xie, H.Y.; Jia, C.Y. Research status and development trends of organic fertilizer spreader fertilizer dischargers. *Agric. Mech. Res.* **2022**, *44*, 262–268.
6. Wang, Q.; Wang, Y.L.; Er, S.Z. Current Situation and Development Ideas of Orchard Machinery and Equipment in China. *Farm Mach.* **2019**, 109–111. [CrossRef]
7. Zhang, M.Q.; Tang, Y.R.; Zhang, H.; Lan, H.P.; Niu, H. Parameter Optimization of Spiral Fertilizer Applicator Based on Artificial Neural Network. *Sustainability* **2023**, *15*, 1744. [CrossRef]
8. Wu, Y.T.; Yang, Y.Z.; Yin, Z.H.; Li, Q. Research status and prospects of fertilizer discharge devices for orchard fertilization equipmen. *Agric. Technol. Equip.* **2023**, 47–48. [CrossRef]
9. Mondal, D.; Nabendu, G. Study on filling factor of short length screw conveyor with flood-feeding condition. *Mater. Today Proc.* **2018**, *5*, 1286–1291. [CrossRef]
10. Lyalin, E.A.; Trutnev, M.A.; Trutnev, N.V. Parameters of the spiral-screw device for dosing mineral fertilizers with different consumption characteristics. *Perm Agrar. J.* **2022**, *4*, 14–22. [CrossRef]
11. Zimmermann, G.G.; Jasper, S.P.; Savi, D.; Moreno, F.G. Distribution of granulated fertilizers in dispensers mounted with single and double helicoidal. *Ciência Rural.* **2024**, *54*, e20220358. [CrossRef]
12. Zhao, L. Simulation and Experiment of Mango Fertilizer Spreader Spiral Fertilizer Discharger Based on Discrete Elements. Master's Thesis, Kunming University of Science and Technology, Kunming, China, 2020.
13. Xue, Z.; Zhao, L.; Wang, F.H.; Wang, S.; Song, G.; Wang, G. Research on fertilizer discharge performance of spiral fertilizer discharger based on EDEM. *Agric. Mech. Res.* **2020**, *42*, 87–95.

14. Xue, Z.; Zhao, L.; Wang, F.H.; Wang, S.; Wang, G.; Pan, R. Performance simulation test of spiral fertilizer discharger based on discrete element method. *J. Hunan Agric. Univ. (Nat. Sci. Ed.)* **2019**, *45*, 548–553.
15. Wang, J. Design and Experimental Study of Subsoiling Fertilizer Spreader in Yunnan Mountains. Master's Thesis, Kunming University of Science and Technology, Kunming, China, 2020.
16. Xiao, W.L. Design and Experiment of Rapeseed Mechanical Direct Seeding Precision Deep Fertilization System. Ph.D. Thesis, Huazhong Agricultural University, Wuhan, China, 2023.
17. Xiao, W.L.; Liao, Y.T.; Shan, Y.Y.; Li, M.L.; Wang, L.; Liao, Q.X. Design and test of four-head spiral double-row fertilizer distributor for rapeseed direct seeding machine. *J. Agric. Mach.* **2021**, *52*, 68–77.
18. Liu, W.Z.; He, J.; Li, H.W.; Wei, Z.C.; Zhang, Z.G.; Li, X.Q. Design and test of double-side deep fertilization device for potato mini seed potato planting machine. *J. Agric. Mach.* **2020**, *51*, 56–65.
19. Fang, L.Y. Design and Test of Electric-Driven Spiral Fertilizer Discharge Device. Master's Thesis, South China Agricultural University, Guangzhou, China, 2020.
20. Yang, W.W.; Fang, L.Y.; Luo, X.W.; Li, H.; Ye, Y.Q.; Liang, Z.H. Experimental study on the influence of spiral fertilizer discharge outlet parameters on fertilizer discharge performance. *Chin. J. Agric. Eng.* **2020**, *36*, 1–8.
21. Li, X.; Jiang, X.B.; Ji, X.X.; Dun, G.Q.; Zhao, Y.; Du, J.X. Optimal design and experiment of spiral double-wheel fertilizer distributor based on genetic algorithm. *J. Henan Agric. Univ.* **2023**, *57*, 1026–1034.
22. Yang, H.K.; Zhang, L.X.; Dong, W.C.; Fang, Y.; Hu, D.B.; Yang, D.J. Analysis and test of the fertilizer discharge device of the dual-variable fertilizer spreader based on the discrete element method. *Mech. Des. Res.* **2019**, *35*, 179–183.
23. Wang, B.T. Working Process Simulation and Parameter Optimization of External Groove Wheel Fertilizer Discharger Based on Discrete Element Method. Master's Thesis, Northwest A&F University, Xianyang, Chian, 2017.
24. Bangura, K.; Gong, H.; Deng, R.; Tao, M.; Liu, C.; Cai, Y.; Liao, K.; Liu, J.; Qi, L. Simulation analysis of fertilizer discharge process using the Discrete Element Method (DEM). *PLoS ONE* **2020**, *15*, e0235872. [CrossRef]
25. Sugirbay, A.M.; Zhao, J.; Nukeshev, S.O.; Chen, J. Determination of pin-roller parameters and evaluation of the uniformity of granular fertilizer application metering devices in precision farming. *Comput. Electron. Agric.* **2020**, *179*, 105835. [CrossRef]
26. Lillerand, T.; Reinvee, M.; Virro, I.; Olt, J. Feasibility analysis of fluted roller dispenser application for precision fertilization. *Acta Tech. Corviniensis-Bull. Eng.* **2023**, *16*, 71–76.
27. Liang, Y.C.; Tang, Z.H.; Ji, C.; Zheng, X.; Liu, J.B.; Li, Q.C.; Zhang, L.Y. Optimization and experiment of structural parameters of outer groove wheel fertilizer discharger. *Agric. Mech. Res.* **2023**, *45*, 7–14.
28. Liang, Y.C. Design and Research on Electric Fertilizer Discharge and Monitoring System of Layered Fertilizer Spreader. Master's Thesis, Shihezi University, Shihezi, China, 2022.
29. Zhou, B. Research on Optimization of Key Components of Zaoyuan Ditching and Fertilization Equipment. Master's Thesis, Tarim University, Alaer, China, 2022.
30. Yang, L. Design and Experiment of Electric Driven Nitrogen, Phosphorus and Potassium Fertilizer Application Device. Master's Thesis, Heilongjiang Bayi Agricultural University, Daqing, China, 2019.
31. Song, X.F.; Dai, F.; Zhang, X.K.; Gao, W.J.; Li, X.Z.; Zhang, F.W.; Zhao, W.Y. Simulation and Experiment of Fertilizer Discharge Characteristics of Spiral Grooved Wheel with Different Working Parameters. *Sustainability* **2023**, *15*, 11309. [CrossRef]
32. Wang, Y.B. Design and Experiment of Deep Lateral Fertilizer Spreader in Tea Gardens. Master's Thesis, Huazhong Agricultural University, Wuhan, China, 2022.
33. Wang, Y.B.; Liang, F.; Xu, F.; Deng, W.H.; Yu, Y.Z. Discrete element simulation and experiment of opposed double helix outer sheave fertilizer discharger. *Inmateh-Agric. Eng.* **2022**, *68*, 617–628. [CrossRef]
34. Dun, G.Q.; Sheng, Q.B.; Ji, X.X.; Jiang, X.B.; Zhao, Y.; Zhou, C. Optimization and test of staggered gear fertilizer discharger. *Chin. J. Agric. Eng.* **2023**, *39*, 20–27.
35. Zhao, X.T.; Li, F.; Li, H.G.; Yuan, H.Y.; Zhao, W.G. Research on air-blown collector-discharge fertilizer distributor. *Agric. Technol.* **2021**, *41*, 61–63.
36. Przywara, A.; Santoro, F.; Kraszkiewicz, A.; Pecyna, A.; Pascuzzi, S. Experimental study of disc fertilizer spreader performance. *Agriculture* **2020**, *10*, 467. [CrossRef]
37. Bulgakov, V.; Adamchuk, O.; Pascuzzi, S.; Santoro, F.; Olt, J. Experimental research into uniformity in spreading mineral fertilizers with fertilizer spreader disc with tilted axis. *Agron. Res.* **2021**, *19*, 28–41.
38. Sidneva, I.; Kurdjumov, V. The results of research for improving the working tool of the mineral fertilizer spreader. *Редакция Журнала «НАУКА В ЦЕНТРАЛЬНОЙ РОССИИ»* **2022**, *10*, 42. [CrossRef]
39. Yang, L.W.; Chen, L.S.; Zhang, J.Y.; Sun, H.; Liu, H.J.; Li, M.Z. Fertilizer spreading uniformity test of centrifugal disc fertilizer spreader. *J. Agric. Mach.* **2019**, *50*, 108–114.
40. Wang, J.F.; Shang, W.H.; Weng, W.X.; Wang, J.W.; Wang, Q.; Chen, X.S. Design and experiment of disc ejection type deep side fertilization device for paddy fields. *J. Agric. Mach.* **2021**, *52*, 62–72.
41. Shang, W.H. Design and Experimental Study of disc Ejection Type Deep Side Fertilization Device for Paddy Fields. Master's Thesis, Northeast Agricultural University, Haerbin, China, 2021.
42. Wang, J.F.; Fu, Z.D.; Weng, W.X.; Wang, Z.T.; Wang, J.W.; Yang, D.Z. Design and experiment of double-row fertilizer distributor for deep side fertilization of paddy fields with conical disk push plate. *J. Agric. Mach.* **2023**, *54*, 53–62+106.

43. Liu, X.D.; Ding, Y.C.; Shu, C.X.; Wang, K.Y.; Liu, W.P.; Wang, X.P. Analysis and test of disturbance and anti-blocking mechanism of spiral cone centrifugal fertilizer discharger. *J. Agric. Mach.* **2020**, *51*, 44–54.
44. Liu, X.D. Design and Test of Precision Fertilization System for Rapeseed Direct Seeding Machine. Ph.D. Thesis, Huazhong Agricultural University, Wuhan, China, 2022.
45. Liu, X.D.; Hu, R.; Wang, D.H.; Lu, B.; Wang, W.C.; Ding, Y.C. Optimization and experiment of fertilizer discharger based on granular fertilizer movement model. *J. Agric. Mach.* **2021**, *52*, 85–95.
46. Song, S.S.; Duan, J.L.; Zou, X.J.; Yang, Z.; Ou, Z.W.; Wang, B. Optimization and experiment of variable fertilizer discharger parameters based on banana root distribution morphology. *J. Agric. Eng.* **2020**, *36*, 11–18.
47. Cao, X.; Xie, F.P.; Wang, X.S.; Liu, D.W.; Wu, B. Design and experiment of bidirectional spiral fertilizer feeding centrifugal cone-disc fertilizer discharge device. *J. Hunan Agric. Univ. (Nat. Sci. Ed.)* **2021**, *47*, 338–343.
48. Cao, X. Design and Experimental Research on Centrifugal Cone-Disc Fertilizer Discharge Device. Master's Thesis, Hunan Agricultural University, Changsha, China, 2021.
49. Liu, H.N. Design and Test of Air-Delivered Centralized Fertilizer Discharger for Granular Fertilizers. Master's Thesis, Sichuan Agricultural University, Yaan, China, 2021.
50. Konovalov, V.; Kravtsov, A.; Zaitsev, V.; Petrov, A.; Petrova, S. Pneumatic system of a seeder with pneumatic sowing. *IOP Conf. Ser. Earth Environ. Sci.* **2019**, *403*, 012131.
51. Fogal, M.L.D.F.; Micheli, G.B.; Scalon, V.L.; Padilha, A. Numerical-experimental comparison of radial fans applied in pneumatic transport of agricultural fertilizer spreaders. *Revista Brasileira De Engenharia Agrícola E Ambiental* **2020**, *25*, 58–64. [CrossRef]
52. Wang, L.; Liao, Q.X.; Liao, Y.T.; Gao, L.P.; Xiao, W.L.; Chen, H. Effect of the structural type of the distribution device of the air-feed fertilizer discharge system on the fertilizer discharge performance. *Chin. J. Agric. Eng.* **2021**, *37*, 24–34+315.
53. Jia, H.L.; Tan, H.W.; Wen, X.Y.; Wang, G.; Yuan, H.F.; Huang, D.Y. Design and test of pneumatic centralized and precise mixing fertilization device. *J. Agric. Mach.* **2022**, *53* (Suppl. S2), 109–119+203.
54. Xu, Z. Design and Experiment of Ratoon Rice Bud Promotion and Top Dressing Machine. Master's Thesis, Huazhong Agricultural University, Wuhan, China, 2022.
55. Xu, H.M.; Xu, Z.; Yang, H.; Wang, Q.C.; Zhang, G.Z. Development of germination-promoting top dressing machine for regenerated rice. *J. Agric. Eng.* **2022**, *38*, 12–20.