STUDY OF THE KEY COMPONENT PARAMETERS OF THE WINGED CHISEL PLOW ON SOIL-STRAW DISTURBANCE PATTERN
/
混秸带翼凿式犁关键部件扰动规律的研究

Kun CHEN[1], Xianliang WANG[*1], Jiangtao JI[2], Xiangcai ZHANG, Xiupei CHENG[1], Hua ZHOU[1], Zhongcai WEI[1] Lei LIU[1], Mingyue BAI[1], Shang GAO[1],
[1]School of Agricultural Engineering and Food Science, Shandong University of Technology, Zibo (255000), China;
[2])College of Agricultural Equipment Engineering, Henan University of Science and Technology, Luoyang (471000), China
Tel: +86-18560168518; E-mail: 18560168518@163.com
Corresponding author: Xianliang Wang
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ABSTRACT
Understanding the soil-straw disturbance pattern of the key component parameters of the straw mixing winged chisel plow is the key to designing and optimizing the straw mixing winged chisel plow (a chisel plow for mixing and mulching straw). In this study, a straw-soil-winged chisel plow interaction model was established, and the working principle, key components of the winged chisel plow were determined based on soil bin experiment and theoretical analysis. Discrete element method (DEM) was used to study the influence of disturbance pattern of key components of the winged chisel plow on soil-straw displacement, straw mixing rate and draught force. The results show that the main components of the winged chisel plow that affect the operating efficiency of the implement are the soil lifting plate height, the wing mounting height and the wing width. The height of the soil lifting plate affects the efficiency of the winged chisel plow in secondary disturbance of soil-straw and its own performance in turning over soil, with an optimal range of 110 mm-170 mm. The installation height of the wing mounting mainly affects the position of the soil lifting plate in the soil layer. In order to achieve the best operating effect, the position of the soil lifting plate needs to meet the "lower lifting and upper turning" requirement. The optimal installation height of the wing mounting is 95 mm-145 mm. The width of the wing mainly affects the working width of the implement, and its optimal value is 180 mm-220 mm. The width of the wing mainly affects the working width of the implement, and its optimal value is 180 mm-220 mm. The established simulation relative error is within 12.60%, which can better study the disturbance pattern of soil-straw. This study may provide a reference for optimizing and designing wing-type chisel plows and subsoil shovels.

摘要
了解混秸双翼凿式犁关键部件参数对土壤-秸秆的扰动规律，是设计和优化混秸双翼凿式犁（一种覆混秸秆的凿式犁）的关键。本研究建立了秸秆-土壤-混秸双翼凿式犁相互作用模型，以土槽试验为基础，结合理论分析确定了混秸双翼凿式犁的工作原理与关键部件，并采用离散元法（DEM），研究了混秸双翼凿式犁关键部件的参数变化对土壤-秸秆位移、机具混埋效果以及机具牵引力的影响规律。结果表明：混秸双翼凿式犁影响机具作业效果的关键部件为抬土板高度、铲翼的安装高度与铲翼的宽度。抬土板高度影响带翼凿式犁二次扰动土壤-秸秆的效率与其本身翻转土壤的性能，最优取值范围为 110mm-170mm。铲翼安装高度主要影响抬土板在土层之中的位置，为了作业效果达到最佳状态，抬土板的位置需满足"下抬上翻"，铲翼安装高度的最佳取值为 95mm-145mm。铲翼宽度主要影响机具的作业宽度，其最佳取值为 180mm-220mm。建立的仿真相对误差在 12.60%内，能较好的研究土壤-秸秆的扰动规律。该研究可能为优化和设计翼式凿式犁和深松铲提供参考。

INTRODUCTION
In conservation tillage, large amounts of straw cover have been one of the main factors limiting crop yields, so effective straw handling is an important requirement for arable tools. At present, the main methods of straw return to the field in China include mulching return to the field, rotary plow return to the field, deep turning return to the field, and mulching and mixing return to the field *(Chen Q.C. et al., 2015).*

Deep turning and rotary plow for field return, using a moldboard plow and rotary tiller respectively, turn and break up the soil, leaving no residue on the soil surface, and have a high efficiency of straw return *(He J. et al., 2018)*, but long-term use of these two implements can damage soil structure and lead to a decline in soil nutrients, as well as increase the risk of soil erosion and runoff *(Yang L.Q. et al., 2018; Sun N.N. et al., 2018)*. In contrast, the use of chisel plows to cut the soil in mulching and returning to the soil does not completely bury the residual straw on the surface, part of the straw is stored on the surface to prevent wind and water erosion of the soil and the other part of the straw is buried with the soil to increase the organic matter of the soil and at the same time break up the compact soil layer of the soil, effectively improving the soil structure *(Guan W.D. et al., 2023)*. The chisel plow is one of the main supporting implements in mulching and mixing *(Wang H.N. et al., 2017)*. Many studies have been conducted on chisel plows by scholars at home and abroad. *Zhang C. et al., (2022),* took the chisel plow as a research object, used DEM to study the effect of soil disturbance and compared it with the deep pine shovel, and found that the chisel plow could significantly increase the effect of soil disturbance. *Salar R.S. et al., (2021),* studied a new type of winged chisel plow, conducted research on the performance of the wings, and found that the winged chisel plow can effectively improve soil loosening efficiency and retain some residues on the soil surface. *Zeng Z. et al., (2020),* analyzed the effects of chisel, wing, narrow and torque shovels on straw-soil disturbance in soil bin experiment and combined them with simulation experiments to illustrate the effects of different implements on soil-straw. Compared with the ordinary chisel plow, the winged chisel plow can effectively improve the mixing rate, soil loosening rate and working width, and it is a kind of excellent land preparation implement. Understanding the soil-straw disturbance pattern of the key components of the wing chisel plow is crucial for its design and optimization.

In plowing, the soil-straw-equipment interaction affects the surface straw movement while also determining the degree of surface straw mixing *(Zheng K. et al., 2016)*. Due to the difficulty of analyzing soil and straw movement states at the microscopic level in soil bin experiment and actual field tests, DEM has become the mainstream for dealing with particles-equipment interactions *(Guo Y.J et al., 2017)*. Scientists at home and abroad use DEM to establish particles-straw models and simulate their mutual movements, which can effectively and accurately observe the movement status of the particles. *Wang W.W. et al. (2022),* designed a vertical bionic stubble cleaning and anti-blocking device based on the multi-segmented serrated structure of mantis toe, and verified the high straw cleaning rate and seedbed uniformity of the machine through DEM analysis of the straw disturbance displacement and straw cleaning rate under the operation of the machine. *Song C.Y. et al., (2022),* established a soil-trencher model to analyze the microscopic disturbance behavior of soil at different depths and operating speeds. *Fan Z. P. et al., (2023),* explored the conveying mechanism of crushed corn stalks in a screw conveyor, and verified the feasibility of using discrete element simulation to analyze the conveying process of crushed corn stalks. *Ren D. Z. et al., (2022),* used DEM to determine the optimal structural parameters of the soil removal device for straw pickup and pelletizing machines. At present, the particles-machine model established by DEM is relatively perfect, and DEM can be used to analyze the microscopic movement of particles and some regular conclusions, however, most of the scholars rely on DEM to analyze most of the research on the machine, and most of the soil bin experiment carried out are used to validate the accuracy of the model, which is likely to cause the simulation test and the actual working conditions are not consistent with each other, which will lead to the actual results of the machine being not able to reach the best state. In this study, based on the soil trough test and theoretical analysis, the key components and their parameter ranges affecting the straw mulching and mixed effect of the winged chisel plow are obtained, which correspond to the actual working conditions. The winged chisel plow improves the effect of straw mulching on the basis of maintaining the original loosening effect of the chisel plow. Based on this, this paper investigates the perturbation pattern of the key components of the winged chisel plow, which is the key to designing and optimizing an efficient winged chisel plow.

In this study, a winged chisel plow is used to analyze the working principle of the machine based on soil bin experiment and to study the microscopic patterns using DEM. The objectives of this study were: (1) To study the soil and straw disturbance characteristics of the winged chisel plow through soil bin experiment and theoretical analysis, to explain the working principle of the machine, to compare it with the ordinary chisel plow, and to clarify the main working parts and parameter ranges of the machine. (2) The soil-straw-winged chisel plow interaction model was established by DEM, and the microscopic motion pattern of soil and straw, straw mixing rate and draught force during machine operation were investigated. (3) To analyze the pattern of influence of the variation of different key parameters (the soil lifting plate height, the wing mounting height, the wing width) on the disturbance characteristics of the machine. (4) Experimental data such as straw displacement, draught force and straw mixing rate were used to verify the accuracy of the simulation model.

MATERIALS AND METHODS

Winged chisel plow structure and parameters

The structure of the winged chisel plow consists of a shovel handle, shovel tip, tilling board, wings and soil lifting plate. The shovel handle of the chisel shovel is a rounded shovel handle, and the general structure of the implement is shown in Fig. 1. Among these, the outer contour line of the shovel tip is a straight section, and the tilling board is a curved section with a radius of curvature of 320 mm, and the straight section is tangent to the curved section. *Salar M.R. et al., (2013),* studied the mechanical characteristics of the winged chisel plow and found that the degree of soil fragmentation, area of disturbance and its resistance of the forward wing is greater than that of the rearward wing, and the role of the shovel wing is mainly to take up the lifting plate of the shovel wing and to increase the width of the operation, so the choice of the rearward wing reduces the resistance of the implement. *Aluko O.B and Seig D.A., (2000),* showed that the chisel plow produced the least traction at an entry angle of 30°, so the entry angle of the winged chisel plow was chosen to be 30°. The specific structural parameters of the chisel winged plow are shown schematically in Fig. 2.

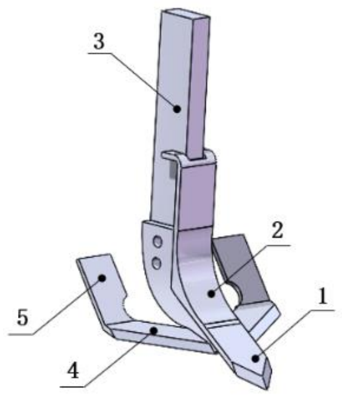


Fig. 1 - Winged chisel plow

1 – shovel tip; 2 – tilling board; 3 – shovel handle; 4 – wing; 5 – soil lifting plate

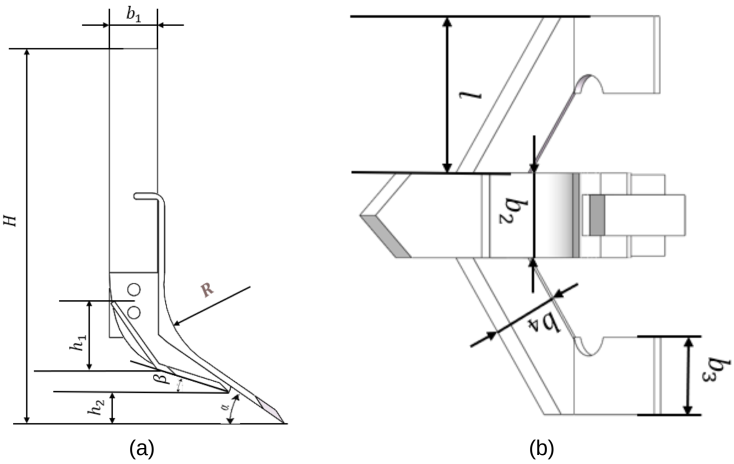


Fig. 2 - Structure parameter diagram

(a) Side view; (b) Top view

Table 1

Winged chisel plow structural parameters

Parameter	Unit	Size
overall height H	mm	850
shovel handle width b_1	mm	90
shovel handle thickness t_1	mm	25
tilling board width b_2	mm	60
the radius of the tilling board R	mm	320
soil lifting plate width b_3	mm	60
Angle of entry of the shovel, α	degrees	30
Angle of entry of the wing, β	degrees	20

Soil bin experiment procedure and data acquisition

The trial was completed in July 2023 in an indoor soil bin at the Innovative Laboratory of Protected Tillage Technology and Intelligent Equipment, Shandong University of Technology. The soil in the soil bin was loam (72% sandy soil, 15% silt, and 13% clay). Using a cutting ring, soil samples were taken from 10 different locations with a sampling depth of 5 mm, 10 mm, and 15 mm. The average moisture content of the soil was measured to be 17.6% (dry basis) using a drying method, and the average bulk density of the soil was 1.51 g/cm^3. In the soil bin simulating the field where corn straw was crushed and returned to the field, the density of straw paving was 0.5 kg/m^2.

Mark five stalks as shown in Fig. 3a. The length of the five stalks is 7.5 cm and the radius is 1 cm. The third stalk is placed at the center of the implement operation, and the remaining stalks are placed horizontally with a horizontal distance of 4 cm. Mark a 500 mm x 100 mm work area A (Fig. 3a) using a marking ruler and chalk powder, and observe and record the position of the straw in area A after the work is completed using the marking ruler. The test machines were a winged chisel plow and a common chisel plow.

The draught force was measured during the test using a six-component force measurement instrument (Fig. 3b) on the frame of the electric inverter four-wheel drive tractor (TCC-2.1 model, Harbin Bona Technology Co., Ltd., Shanghai, China). The implement is installed on the frame of the tractor, which is connected to the frame using a three-point suspension and secured to the frame with U-bolts. The frame is equipped with a draught force load sensor and a data acquisition box to export the draught force during the implement's operation. The winged chisel plow has a penetration depth of 250 mm, allowing the tractor travel at a speed of 8 km/h. Record the movement trajectory of the five straws during work, find the final position of the straws, calculate the forward and horizontal displacement of the straws from the initial and final positions, and derive the traction force value recorded by the traction load sensor from the computer of the tractor.

(a) (b) (c)

Fig. 3 - Preparation for soil bin experiment
(a) Calibrated straw position; (b) Six-component force measurement instrument; (c) Winged chisel plow

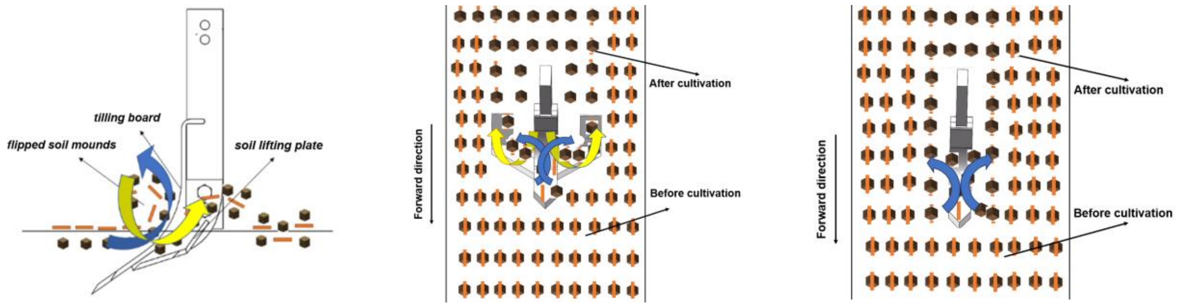
Figure 4b shows the working effect of the winged chisel plow. To calculate the straw mixing rate after the work is completed, the binary method is used in Matlab to process the area A in Figure 3a and Figure 4b, and the result is shown in Figure 4c. The area of straw exposed to the surface is captured, and the percentage of straw on the soil surface is determined as the straw mixing rate *(Zeng Z. and Chen Y., 2018).*

(a) (b) (c)

Fig. 4 - Straw cover
(a) Job effectiveness; (b) Area A after operation; (c) Binary processing.

Operating principle

The working principle of the winged chisel plow and the working process of each component were clarified through soil tank experiments. During the interaction between the winged chisel plow and the soil, it exerts cutting, squeezing, and other effects on the soil, causing soil fragmentation. This not only loosens the soil, but also turns it over, forming strip-shaped soil ridges that are turned over onto the surface (Fig. 5a), allowing the surface straw to be mixed into the soil. During forward operation of the machine, the tilling board pushes the soil-straw mixture to the sides. The more soil disturbance caused by tools, the higher the level of straw incorporation, and the lower the level of coverage remaining on the soil surface. The winged chisel plow is equipped with wings and soil lifting plates. The soil pushed to the sides falls onto the soil lifting plates on both sides, which perform secondary mixing of soil and straw. The ordinary chisel plow has a narrow working width and poor straw mixing effect (Fig. 5c). In contrast, the design of the wings and the soil lifting plates in the winged chisel plow greatly increases the working width of the chisel and the efficiency of straw mixing and burying.



(a) (b) (c)

Fig. 5 - Operating principle

(a) Soil-straw movement; (b) Winged chisel plow tillage effect; (c) Ordinary chisel plow tillage effect.

The design of the wing mounting height h_2

When the wing mounting height is 7 cm, 12 cm, and 17 cm, the position of the soil lifting plate is located in the soil tillage layer, between the soil surface and the tillage layer, and in the soil surface (Fig. 6). The wing mounting height not only affects the penetration performance and disturbance range of the implement, but also determines the mixing effect of the surface straw. When the wing height is 7 cm, the soil lifting plate is completely located in the soil, at which point the soil lifting plate will generate a large amount of resistance, causing the greatest disturbance to the soil. The surface soil will also be greatly disturbed due to the squeezing and pushing force of the wing on the cultivated soil layer. However, the soil lifting plate does not directly affect the surface straw, the actual mixing effect does not reach the ideal state. When the wing mounting height is 17 cm, the wing has a cutting effect on the soil surface layer of 0-5 cm. The soil lifting plate is completely located above the soil surface layer, at this time the disturbance of the wing to the soil is too small, and the loosened soil of the wing is too little to have a mixing effect on the straw above the surface layer. The machine relies solely on the tilling board for mixing, and the mixing effect is not good. When the wing mounting height is 12 cm, the soil lifting plate penetrates the soil surface and is located between the soil tillage layer and the surface layer. Due to its own angle of penetration, the soil lifting plate also has a turning effect on the soil, turning the soil and straw in front of itself. At the same time, the soil lifting plate located on the upper part of the topsoil can also disturb the soil and straw ahead of the tilling board, resulting in a secondary disturbance, which maximizes the soil mixing effect. In addition, the plow wing part has a large disturbance range on the surface soil, which solves the mechanical compaction problem of the surface soil.

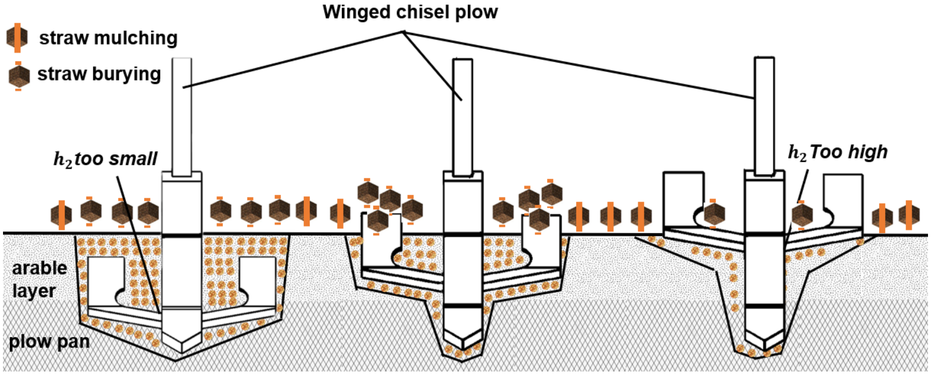


Fig. 6 - The influence of wing mounting height on soil-straw disturbance

The design of the soil lifting plate height h_1

Figure 7 shows the position of the soil lifting plate when it is 8 cm, 14 cm, and 20 cm, respectively. When the height of the soil lifting plate is 8 cm, the top of the soil lifting plate is located at the surface of the ground, and the soil lifting plate is completely located in the soil. Although its effective area can completely disturb the soil, due to the height limit, the disturbance of the surface straw at this time is basically caused by the extrusion and burial of the soil, and the soil lifting plate does not directly affect the surface straw. In actual working conditions, the tilling board turns the soil and straw in front of it by turning the soil, while pushing the soil and straw to the sides (Fig. 8). The soil lifting plate will have a secondary turning effect on it. If the height of the soil lifting plate is not enough, the secondary turning effect of the straw will be weakened, and the turned soil and straw will fall from above the soil lifting plate onto the ground behind it. When the soil lifting plate height is 20 cm, it reaches the maximum height for turning the soil on the tilling board. However, due to the weight of the soil, when the soil moves in the direction of the soil lifting plate, it will inevitably displace downward, and the upper part of the soil lifting plate will not effectively contact the soil, so this part does not have a significant effect.

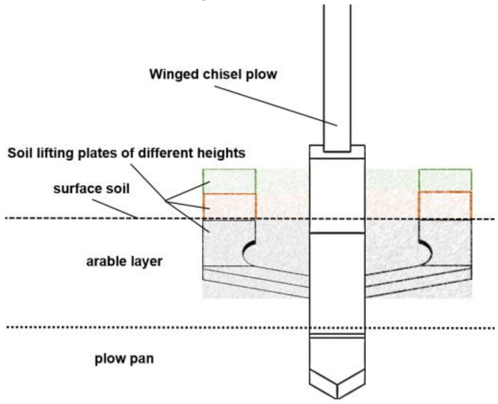


Fig. 7 - Soil lifting plates of different heights

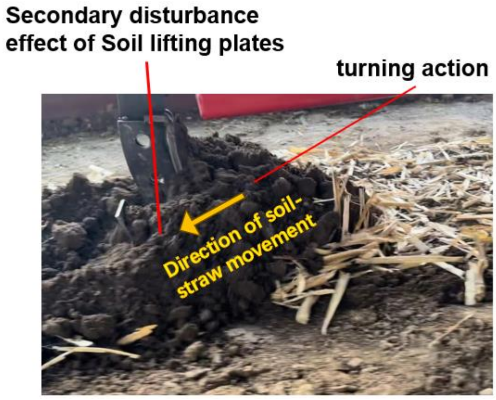


Fig. 8 - Direction of soil-straw movement

The design of the wing width l

The function of the wing is to receive the soil lifting plate and cut the soil during operation. The width of the wing, (see Fig. 2), affects the actual working width and determines the position of the soil lifting plate. If the wing is too wide, the soil lifting plate cannot perform secondary mixing and burying of the soil and straw turned over by the tilling board. At the same time, the horizontal distance between the soil lifting plate and the tilling board is too large, it will also cause less disturbance to the soil and straw in between, and the soil lifted by the soil lifting plate and the tilling board will be squeezed in the middle, resulting in extremely uneven soil surface after the operation of the implement, leaving three soil ditches. If the wing is too narrow, it will directly affect the working width of the implement, and the soil lifting plate and the tilling board will have overlapping soil working areas. At this time, the resistance of the implement will not decrease significantly, but the operation efficiency will decrease.

To explore the optimal value of the width of the wing, it is necessary to understand the effective working width of the tilling board and the horizontal displacement distance of the soil-straw pushed by it. An ordinary chisel plow without wing was used for soil bin experiment, and the experimental process is shown in Figure 9a. The working effect of a common chisel plow is shown in Figure 9b. The overall working width is approximately 394 mm, and the actual measured disturbance widths on the left and right sides of the center of the soil ditch are 196 mm and 198 mm, respectively. Based on this, in order to make the soil lifting plate reach the working width of the tilling board, the soil lifting plate should be placed at a distance of 196-198 mm from the center of the implement. Due to the influence of the width of the soil lifting plate itself, the width of the wing should be between 170 mm and 230 mm. Within this range, the soil lifting plate can provide secondary disturbance to the soil and straw turned over by the tilling board, while achieving the optimal operating width.

(a)

(b)

Fig. 9 - Common chisel plow soil bin experiment
(a) Experiment process of ordinary chisel plow; (b) Working width of ordinary chisel plow.

Establishment of discrete element simulation model

Set up a soil model in EDEM, with soil particles modeled as single particles with a radius of 5 mm, and the mechanical relationship between soil particles modeled as Hertz-Mindlin with Bonding contact model. The Bonding model can reflect the adhesion and elastic-plasticity between particles, and the bond radius of particles in the Bonding model can reflect the moisture content of soil, which can better simulate the breakage and deformation between soil particles. The deformation of straw can be neglected, and the effect of the winged chisel plow on straw is basically a disturbance. Therefore, the straw is set as a rigid model consisting of multiple particles stacked together. The mechanical relationship model between straw and soil and the winged chisel plow is a Hertz-Mindlin (no slip) contact model, which can better simulate the interaction between soil-straw-winged chisel plow. Corn straw was set up as a single pile of particles with a radius of 10 mm, the straw length is 75 mm. To simulate field straw mulching, the straw mulching density was set to 0.5 kg/m^2, resulting in a total of 1200 straws, which were randomly generated. After the generation is complete, five stalks are generated in the implement operation center at the same horizontal position as the soil bin experiment to record the forward and lateral displacement of the stalks. Geometric modelling of the winged chisel plow using SolidWorks 2022, the winged chisel plow is saved in step format and imported into the EDEM model, the material is 65Mn steel. The forward speed of the machine is 8km/h, and the penetration depth is 250 mm. The calibration test of material parameters for soil and straw was conducted, and the test process is shown in Figure 10 *(Wang X.L. et al., 2017; Tao C. et al., 2023; Fu M., 2023; Carlos M.et al.)*. The calibrated soil-straw parameters obtained are shown in Table 2.

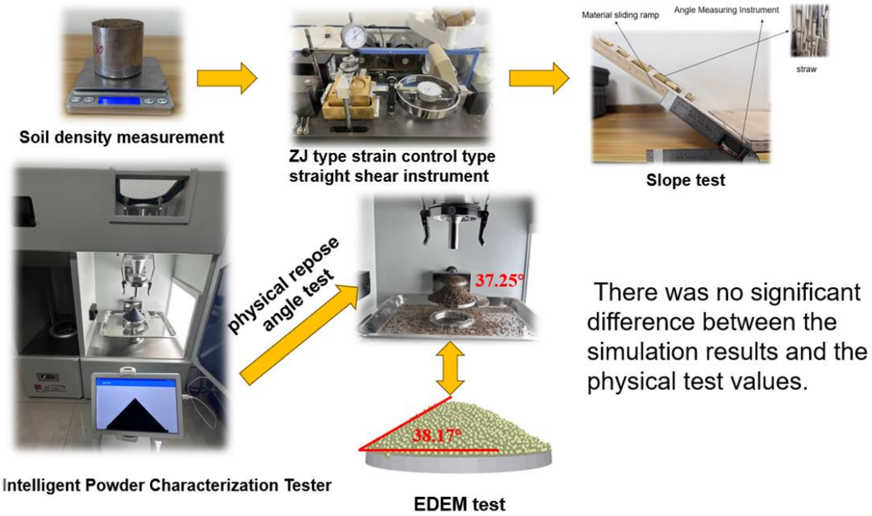


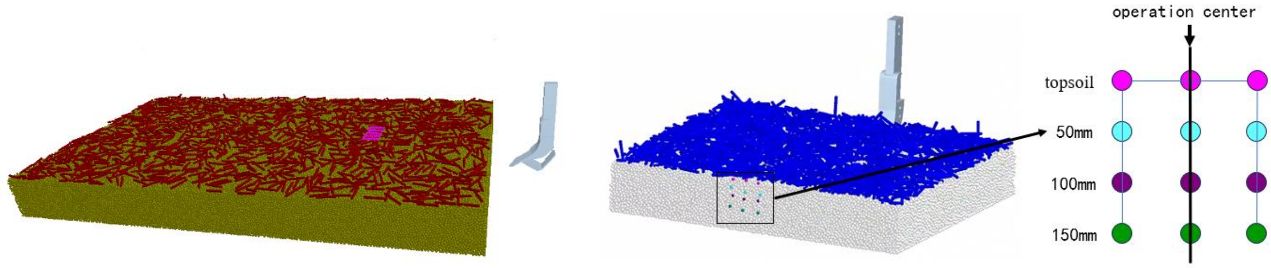
Fig. 10 - Calibration experiment

Table 2

Simulation parameter

Parameters	Value
Soil density/(kg·m^{-3})	1450
Soil Poisson's ratio	0.41
Soil shear modulus /MPa	1.24
Soil-Soil collision recovery coefficient	0.6
Soil-Soil static friction coefficient	0.36
Soil-Soil rolling friction coefficient	0.17
Straw density/(kg·m^{-3})	241
Straw Poisson's ratio	0.4
Straw shear modulus /MPa	1
Straw-Straw collision recovery coefficient	0.485
Straw-Straw static friction coefficient	0.213
Straw-Straw rolling friction coefficient	0.098
Straw-Soil collision recovery coefficient	0.6
Straw-Soil static friction coefficient	0.537
Straw-Soil rolling friction coefficient	0.16

Starting from the surface soil, mark four soil particles with a distance of 50 mm above and below the center of the work, and then mark a total of eight particles with a distance of 100 mm to the left and right (Fig. 11b). The focus is on clarifying the comprehensive disturbance of soil particles at the center of the chisel plow operation, the position of the wing, and the position of the soil particles on the surface under the action of the tilling board, shovel tip, and wing. Through the EDEM post-processing interface, the displacement of selected particles in the real-time longitudinal, horizontal, and vertical directions during the operation of the implement can be statistically analyzed. It is convenient for quantitative analysis of the disturbance of soil particles by winged chisel plow.



(a) (b)

Fig. 11 - Calibration experiment
(a) Calibrated straw position; (b) Calibrated soil position.

Simulation data acquisition

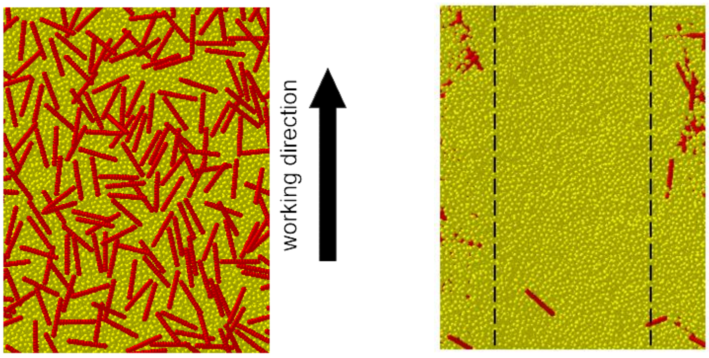
In the simulation experiment, the height of the soil lifting plate h_1, the width of the wing l, and the height of the wing mounting h_2 were used as variables, with four levels for each variable. To ensure the accuracy of the experiment, each group of experiment was repeated five times, and the average value of the obtained results was taken. In post-processing, the displacement changes in the X-axis and Y-axis directions of the marked soil and straw were derived as positive and lateral displacements, respectively, and the draught force of the winged chisel plow was evaluated to estimate the energy consumption generated by the implement.

Table 3

Parameters of key components of winged chisel plow

Variable	h_1/mm	l/mm	h_2/mm
1	80	160	70
2	110	180	95
3	140	200	120
4	170	220	145
5	200	240	170

In the simulation, the overall effect of straw burying is shown in Fig. 12. Fig. 12a shows the initial straw coverage, and Fig.12b shows the straw coverage after the work. The dotted line represents the trajectory of the implement. Generally speaking, the displacement of soil-straw closer to the implement is larger, and the straw mixing effect on the working path of the chisel is better than on both sides. The mixing rate of straw is determined by the ratio of straw area to total area. The mixing rate of straw is a key factor in determining the actual working performance of the implement, and can also be used as an experimental indicator to determine the optimal parameters of the implement.



(a) (b)

Fig. 12 - Calibration experiment
(a) Before the operation; (b) After the operation.

RESULTS

Comparison between ordinary chisel plow and winged chisel plow

The winged chisel plow has an innovative design for the shovel wing, which functions to increase the straw mixing rate and working width of the implement, resulting in a good straw mulching and mixing effect and meeting the requirements for returning straw to the field. To investigate the impact of winged chisel plows on the performance of agricultural machinery, the straw cover R, the working width W, and the draught force F of ordinary chisel plows and winged chisel plows were compared. In comparison to the ordinary chisel plow, although the average draught force of the implement increased by 532.92 N, the average straw mixing rate increased by 42.98%, and the working width increased by 41.86 cm (Table 3). Comparing the images in the figure 4a and figure 9b, it can be seen that the straw burying effect achieved by the tested chisel and wing plow was significantly improved, which was expected.

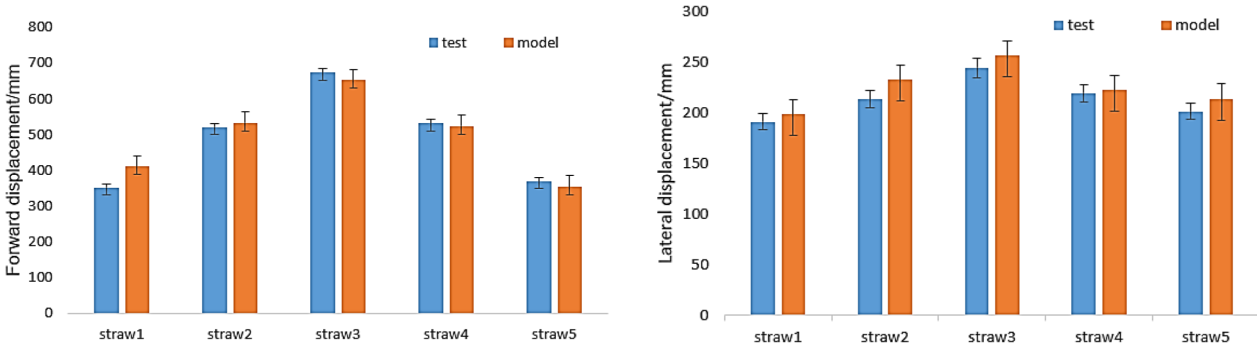
Table 3

Comparison of the two plows

Type	R / %	F / N	W / mm
Winged chisel plow	84.37	1603.24	39.47
Ordinary chisel plow	41.39	1070.26	81.33

Experimental verification

To verify the accuracy of the model, the model results were compared with the measured data from the soil bin experiment, including the positive and lateral displacement of the straw, the draught force, and the straw mixing rate, using relative error to evaluate consistency.



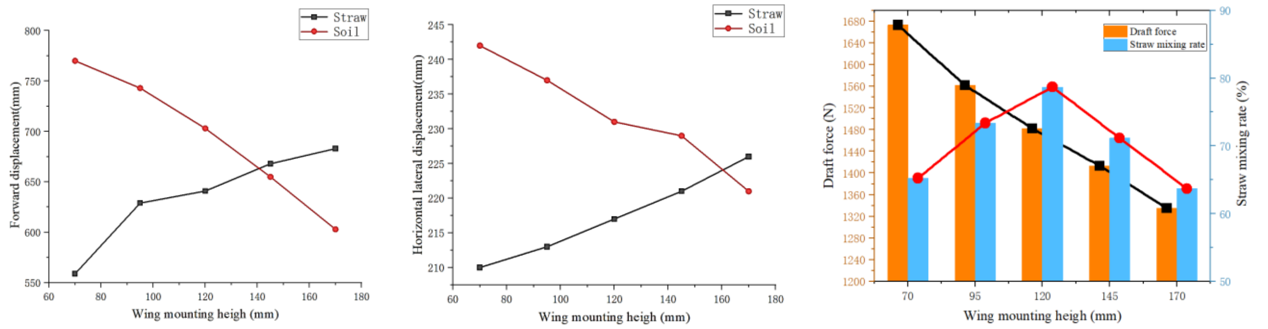
(a) (b)

Fig. 13 –Simulation and practical experiment
(a) Forward displacement; (b) Lateral displacement;

The graphs of positive and lateral displacements of the five calibration straws were drawn and compared with the soil bin experiment results. The analysis of the test results shows that the straw3 located at the center of the implement operation has the greatest impact on the disturbance, and the straw displacement decreases as it moves away from the center. The positive displacement error of straw is between 1.67% and 5.45%; the lateral displacement error of straw is between 0.52% and 6.84%. The average straw mixing rate under simulation was 78.3%, while the average straw mixing rate in actual experiments was 81.9%. The error in straw mixing rate was between 2.54% and 6.37%. The average draught force of the implement when working stably under simulation is 1498.77 N, and the average draught force of the implement measured by a six-point measuring instrument during the soil bin experiment is 1603.24 N. The error of the tractive resistance of the implement is 5.29% to 12.60%, which is relatively small, and the variation trend of the test data is consistent with the simulation test. The soil bin experiment verified the accuracy of the discrete element simulation test and the feasibility of the discrete element simulation field test.

The influence of the wing mounting height

The simulation model was used to predict the impact of different wing mounting height on the displacement of straw and soil, as well as the straw mixing rate and draught (Fig.14). As the wing mounting height increases, the displacement of the wing on the straw gradually increases, and the disturbance on the soil gradually decreases. When the position of the soil lifting plate is closer to the soil surface, the effective disturbance area of the soil decreases, resulting in a decrease in the displacement of the soil, and the draught force also decreases accordingly. The straw mixing rate first increases and then decreases, reaching a maximum of 79.3% at 120 mm. When the wing mounting height is too high, the soil lifted by the soil lifting plate will decrease, and there will not be enough soil to cover the straw, resulting in a decrease in the straw cover. When the height is less than 95 mm, the wing of the shovel cannot produce a turning effect on the soil and straw in front due to its low height.

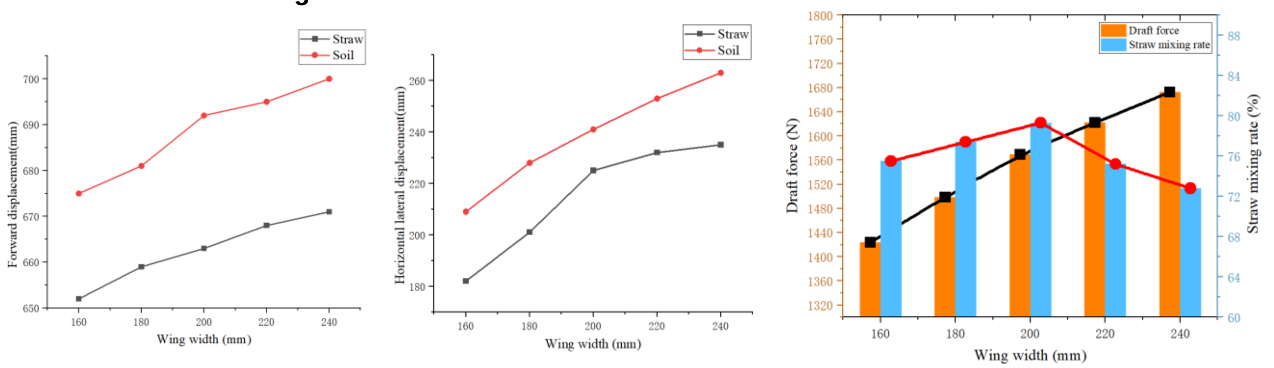


（a） （b） （c）

Fig. 14 – Simulation experiment results of the wing mounting height
(a) Forward displacement; (b) Lateral displacement; (c) Straw mixing rate

The simulation analysis results are consistent with the theoretical analysis results. In order to achieve the best operating effect of the plow, the installation height of the wing should be designed within 95 mm-145 mm.

The influence of the wing width



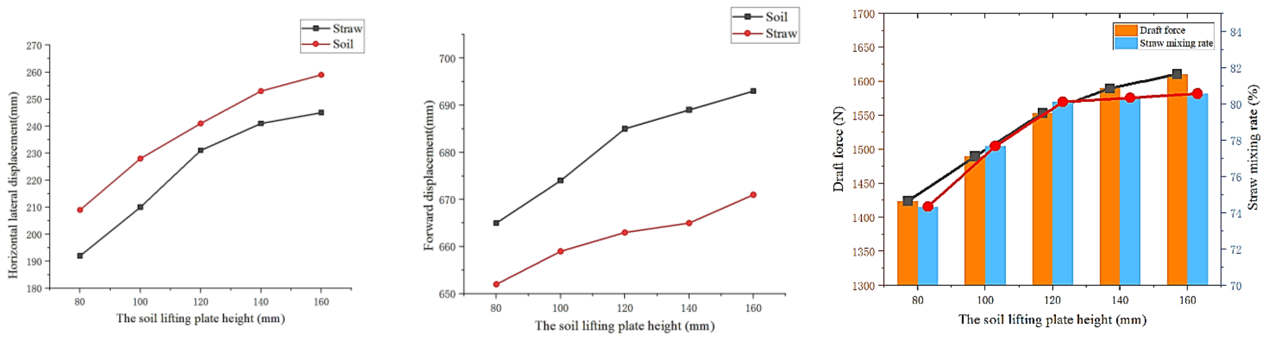
(a) (b) (c)

Fig. 15 – Simulation experiment results of the wing width
(a) Forward displacement; (b) Lateral displacement; (c) Straw mixing rate

The simulation model was used to predict the impact of different wing widths on the displacement of straw and soil, as well as on the straw mixing rate and draught force (Fig.15). The increase in the width of the wing will lead to an increase in the displacement of soil and straw. The increase in the width of the wing means that the width of the soil cut by the wing increases, the disturbance range of the soil is wider, and the draught force also increases. When the wing width is greater than 200 mm, the straw burying rate gradually decreases. The wing width affects the horizontal position of the soil lifting plate in the soil layer. When the wing is too wide, the distance between the soil lifting plate and the center of operation increases, and the effective area of the soil lifting plate for turning the soil and straw on the tilling board decreases, resulting in a reduction in straw mixing efficiency. When the wing is at 170 mm, the disturbance width is insufficient, the amount of soil cut by the wing is small, and the mixing effect cannot reach the optimal state. To sum up, the optimal value range of the wing is 180 mm-220 mm.

The influence of the soil lifting plate height

The simulation model was used to predict the impact of different lifting plate height on the displacement of straw and soil, as well as on the straw mixing rate and draught force (Fig.16). As the height of the soil lifting plate increases, the overall displacement of soil and straw gradually increases, and the traction resistance gradually increases. The soil lifting plate has a small amount of disturbance to the soil in the soil layer, and the impact on soil displacement is mostly due to the secondary turnover effect after the tilting board is turned over.



(a) (b) (c)

Fig. 16 – Simulation experiment results of the soil lifting plate height
(a) Forward displacement; (b) Lateral displacement; (c) Straw mixing rate

The height of the soil lifting plate restricts the maximum height of the mixed straw bale. Before the soil lifting plate reaches the maximum height of turning, the height of the turned soil and straw increases with the increase in the height of the soil lifting plate. When the height increases from 80 mm to 140 mm, the straw mixing rate of straw increases by 5.9%. When the height increases from 140 mm to 200 mm, the straw cover remains basically unchanged. The soil lifting plate reaches its highest value of turning soil and straw at 140 mm-200 mm, so the effective area of the upper part of the soil lifting plate decreases. If the height of the soil lifting plate is not sufficient, the secondary turning effect of the straw will be weakened, and the turned soil and straw will fall from the top of the soil lifting plate onto the rear surface. Therefore, the optimal value range of the soil lifting plate is 110 mm-170 mm.

CONCLUSIONS

Taking the designed winged chisel plow as the research object, through soil bin experiments, theoretical analysis, and simulation tests, the impact of key component parameters of the winged chisel plow on soil-straw disturbance was explored. The conclusions are as follows:

(1) The soil bin experiment found that the winged chisel plow can achieve secondary disturbance of straw-soil interaction, provided that the wing parameters are within the ideal range. Combining theoretical analysis, the key components affecting the secondary disturbance of the winged chisel plow are the wing mounting height, soil lifting plate height, and wing width.

(2) Compared to the conventional chisel plow, the degree of straw coverage achieved with the wing chisel plow, increased by 42.98%, the working width increased by 42.86 cm. The design of the winged chisel plow significantly improved the straw mixing effect.

(3)The wing mounting height determines the depth of the wing and soil lifting plate in the soil layer. When the mounting height is 95 mm-145 mm, the straw cover reaches its highest value. The height of the soil lifting plate determines the effective area of the secondary disturbance of soil-straw. Too low a soil lifting plate reduces secondary disturbance and is not conducive to straw mixing. Too high will cause the upper area to become ineffective. The experiment data shows that after reaching a height of 140 mm, the benefit of straw mixing becomes weak. The width of the wing mainly affects the working width of the winged chisel plow, provided that it is within the range of 160 mm-240 mm. Below this range, the straw mixing efficiency decreases; when it exceeds this range, the land after the operation will become extremely uneven.

(4) The simulation model established using soil-straw parameters obtained from calibration experiment and the experimental data obtained from soil bin experiment were compared. The model was able to predict the disturbance of the soil-straw by the machinery with good accuracy, with relative errors of 6.84%, 12.60%, and 6.37% for straw displacement, draught force, and straw cover, respectively.

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