STUDY ON THE STRAW-SOIL DISTURBANCE CHARACTERISTICS OF A LIFT-TYPE WINGED CHISEL PLOW
/
抬土式带翼凿式犁对秸秆-土壤扰动特性的研究

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ABSTRACT
This study developed a lift-type winged chisel plow-straw-soil interaction model, and its validity was confirmed through multiple experimental indicators obtained from both soil bin tests and simulation experiments. The Discrete Element Method (DEM) was employed to analyze soil disturbance behavior and straw incorporation performance. Results showed that the plow tip of the lift-type winged chisel plow effectively sheared, loosened, and fractured the plow pan soil, while the soil-lifting plate pushed and turned the soil, promoting thorough mixing of straw and soil. Compared to traditional designs, the addition of wings increased the working width, and the soil-lifting plate significantly enhanced the frequency of straw–soil disturbance and soil fragmentation - resulting in a mixing rate of 42.98% and a uniformity rate of 92%.

摘要
本研究建立了抬土式带翼凿式犁-秸秆-土壤相互作用模型，通过土槽实验和仿真实验中的多试验指标（秸秆的正向和侧向位移、牵引力、秸-土混埋率）证明了模型的合理性。采用 DEM 研究其对土壤的扰动行为和秸秆的混埋行为。结果表明：抬土式带翼凿式犁的铲尖剪切、松动、破碎犁底层土壤；抬土板推移、翻动、混合秸秆-土壤。相比于传统的凿式犁相比，铲翼提升了作业宽度，同时抬土板增加了其对秸秆-土壤的扰动次数和土壤的破碎程度，混埋率提高到 42.98%，秸-土混合均匀度提高到 92%。

INTRODUCTION
Surface residue cover helps retain soil moisture and enhance soil fertility (*Reicosky & Saxton, 2007; Jacobs et al., 2022*). However, excessive residue density can negatively affect seeding quality and hinder seedling growth, becoming a key limiting factor for crop yield (*Wu & Chen, 2024; Li et al., 2022*). Therefore, evaluating the effectiveness of residue displacement and incorporation is essential for assessing the operational performance of tillage tools (*Hobbs et al., 2008*). Traditional tillage methods, such as rotary tillage for full straw incorporation (*Zhou et al., 2020; Zhu et al., 2023*), bury most of the straw in the soil. While effective in incorporation, these methods disturb the original soil profile, expose moist soil to the surface, and leave minimal residue cover - leading to increased soil erosion and runoff (*Wu & Chen, 2024*). In contrast, the winged chisel plow used for partial straw incorporation has proven effective in both straw incorporation and soil loosening (*Salar et al., 2021*). This implement mixes a portion of the straw residue into the soil to improve soil organic matter content while retaining some surface residue to minimize moisture loss. However, its performance can be limited by uneven soil aggregate fragmentation and inconsistent straw-soil mixing.

The winged chisel plow not only breaks through the limitations of the soil tillage layer system but also incorporates part of the straw into the soil, achieving straw incorporation and surface coverage operations (*Zhang et al., 2022*). *Xia, (2018),* demonstrated that the winged chisel plow could break through the constraints of the tillage layer and plow pan, achieving more uniform soil fragmentation and improving soil permeability. However, this study did not explore the effectiveness of straw incorporation (straw-soil mixing mechanism) in conjunction with its operation.

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Wang, (2018), investigated the effects of the winged chisel plow on soil disturbance behavior, suggesting that soil fragmentation at different depths, real-time displacement, and velocity changes of particles at key positions are important indicators for evaluating its operational performance. *Zeng et al., (2020),* studied the effects of different types of chisel plows on straw-soil disturbance and straw burial rate. However, they did not examine the degree of soil aggregate fragmentation after disturbance, nor did they relate this to the degree of straw-soil mixing. These studies primarily focused on soil fragmentation, soil disturbance, and straw-soil mixing rates, without considering the uniformity of straw-soil mixing after incorporation. In contrast, the straw-soil mixing mechanism during the operation of the winged chisel plow is more complex. Investigating the mechanism of incorporation and mixing is a prerequisite for designing and optimizing high-performance winged chisel plows. Building on the foundation of incorporation and return-to-field technology, this study proposes adding a soil-lifting plate to the rear of the winged chisel plow (*Wang., 2021*). This addition aims to improve soil loosening and fragmentation effects and enhance the uniformity of straw-soil mixing during partial straw incorporation.

This incorporation mechanism involves mixing a portion of the straw into the soil while leaving the rest on the surface to improve soil structure, reduce soil erosion, and lower runoff risks (*Salar et al., 2021*). However, accurately and intuitively representing the operational mechanism of the lift-type winged chisel plow remains a challenge.

The discrete element method (DEM) offers unique advantages in analyzing the interactions between agricultural machinery components, straw, and soil. It provides data on the forces and motions of soil and straw under specific machinery structures and operational conditions from a microscopic perspective (*Barr et al., 2018; Sadek et al., 2021*). By building precise models, DEM overcomes the limitations of two-dimensional measurements. During the simulation of straw-soil operations, it reveals the complex coupled mechanisms of factors such as straw morphology distribution and soil aggregate interactions. Additionally, it enables precise capture and quantification of the dynamic changes in the uniformity of straw-soil mixing (*Liu et al., 2023a&b*), addressing the limitations of single-point practical observations that fail to present the mixing effects. DEM also comprehensively represents the three-dimensional spatial characteristics of the straw-soil mixing process (*Zeng et al., 2020*), providing theoretical support and technical guidance for the study of the lift-type winged chisel plow.

In summary, the objectives of this study are to establish a discrete element model of the interaction among the lift-type winged chisel plow - straw - soil, reveal the mechanisms of straw-soil disturbance and incorporation by the soil-lifting plate from a microscopic perspective during the incorporation operation, and quantify the changes in straw burial rate and the uniformity of straw-soil mixing under the influence of the soil-lifting plate, so as to provide a theoretical basis for the research and evaluation of straw incorporation tools and operational performance.

MATERIALS AND METHODS

Measurement of Straw and Soil Basic Parameters

(1) Measurement of Straw and Soil Properties

Soil samples were taken from a no-tillage seeding experimental field in Xilu Village, Zhangdian District, Zibo City, Shandong Province (36°87′~36°88′ N, 117°98′~119°99′ E). The soil samples were weighed on an electronic balance (model FA2104B), and the average soil sample density was calculated to be 241 kg/m³. The soil moisture content was determined using the drying method according to the "Standard for the Determination of Soil Dry Matter and Moisture by Weight" (Standard No.: HJ 613-2011), yielding a moisture content of 21.37% (on a dry weight basis).

Prior to selecting straw samples, corn plants (Zhongbang 1088 corn, commonly grown in northern China) were screened to ensure they were disease-free. Using a sampling knife, whole corn stalks were cut at a height of 50 mm above the ground. According to the methods outlined in GB/T 14699.1-2005 (Feed Sampling) and GB/T 6435-2014 (Determination of Moisture and Other Volatile Substances in Feed), the straw moisture content and density were measured to be 16.59% and 1450 kg/m³, respectively.

The soil shear strength was measured using the ZJ-type strain-controlled direct shear apparatus from Nanjing Soil Instrument Factory, under a vertical load pressure of 50 kPa. The shear force was obtained by combining the mechanical dial readings with the stress ring correction coefficient (C = 1.531 kPa/0.01 mm). Shear tests were conducted on soil samples from three different depths, and the values collected from each point were averaged. The measured internal friction angle of the test soil was 21.93°, and the Poisson's ratio was calculated as 0.38 using Equation 1.

$$\tau = c + p\tan\varphi \tag{1}$$

where: τ is Stress (N); c is Soil cohesion (N); p is Vertical pressure (N); φ is Internal friction angle of the soil (°).

(2) Measurement of the straw-soil mixture repose angle

The repose angle of the soil and straw mixture was measured physically. Since this study does not involve radial and axial damage to the straw, only the physical parameters related to the straw skin were calibrated. The repose angle of the straw-soil mixture was measured as 38.415° using an intelligent powder characteristics tester (model BT-1001).

(3) Measurement of Material Friction Between Agricultural Machinery Components, Straw, and Soil Using an Inclined Plane Test

The static and dynamic friction coefficients between the straw-soil-steel plate are determined using the inclined plane method. The static and dynamic friction coefficients between the two materials are calculated using Equations 2 and 3, respectively.

$$f_s = \tan\theta \tag{2}$$

where:

f_s is the static friction coefficient; θ is the angle between the wooden board and the horizontal plane (°).

$$f_d = \frac{L_1 \sin\theta + L_2}{L_1 \cos\theta} \tag{3}$$

where:

f_d is the rolling friction coefficient; θ is the angle between the wooden board and the horizontal plane (°); L_1 is the sliding distance along the inclined plane (cm); L_2 is the horizontal sliding distance (cm).

The experiment was repeated 10 times, and the average values were calculated. The static and dynamic friction coefficients were measured for the following material pairs: soil-soil, straw-soil, soil-steel plate, straw-straw, and straw-steel plate.

Establishment of the Straw-Soil Simulation Model

The soil particles were defined as uniform spherical particles with a radius of 5 mm, and the Hertz-Mindlin with Bonding contact model was selected. During the operation of the lift-type winged chisel plow, the effect on the straw was primarily spatial displacement, with negligible deformation of the straw. Therefore, the straw was treated as a rigid body. The corn straw was modelled as an assembly of uniform particles with a radius of 10 mm. The mechanical interaction model between the straw, soil, and the lift-type winged chisel plow was set to the Hertz-Mindlin (no-slip) contact model to facilitate the analysis of the interactions between the implement, straw, and soil.

Establishment and Validation of the Lift-Type Winged Chisel Plow-Straw-Soil Model

The soil and straw model parameters were defined based on the calibrated values. Particle positions were randomly generated, resulting in a total of 234,250 soil particles and 709,181 bonding keys used to simulate cohesive interactions among the soil particles. The soil bin dimensions were set to 2000 × 1000 × 300 mm. Considering the actual working depth of the implement and the variation between the cultivated layer and the plow pan, the soil profile was divided into two layers: a cultivated layer and a plow bottom layer. To simulate field straw coverage, 1,200 straw pieces were randomly distributed on the soil surface, corresponding to a surface coverage density of 0.5 kg/m². The geometric model of the lift-type winged chisel plow was created using SolidWorks 2022, exported in STEP format, and imported into EDEM 2022 for simulation. The material used was 65Mn steel.

Simulation experiment of the motion state measurement of the lift-type winged chisel plow-straw-soil interaction

In the simulation experiments, the motion states of the soil and straw are monitored by tracking the positions of 12 soil tracers and 5 straw tracers. The soil cutting force (traction force, vertical force, and lateral force) is the sum of the contact forces between the soil particles and the machine in the corresponding directions.

In the center direction of the chisel plow operation, starting from the surface, four particles are sequentially marked at intervals of 50 mm downwards, labeled as J12, J22, J32, and J42. Then, 8 additional particles are marked 100 mm to the left and right of these four particles, labeled as J11, J21, J31, J41, J13, J23, J33, and J43, as shown in Figure 1.

At the same time, straw tracer 3 is placed at the center of the chisel plow's working area, with tracers 1, 2, 4, and 5 placed in parallel on either side of straw tracer 3 at a 40 mm interval. The soil displacement in the forward, lateral, and vertical directions is calculated by the changes in the coordinates of the soil tracers, while the forward and lateral shifts of the straw are calculated by the changes in the coordinates of the straw tracers in the forward direction.

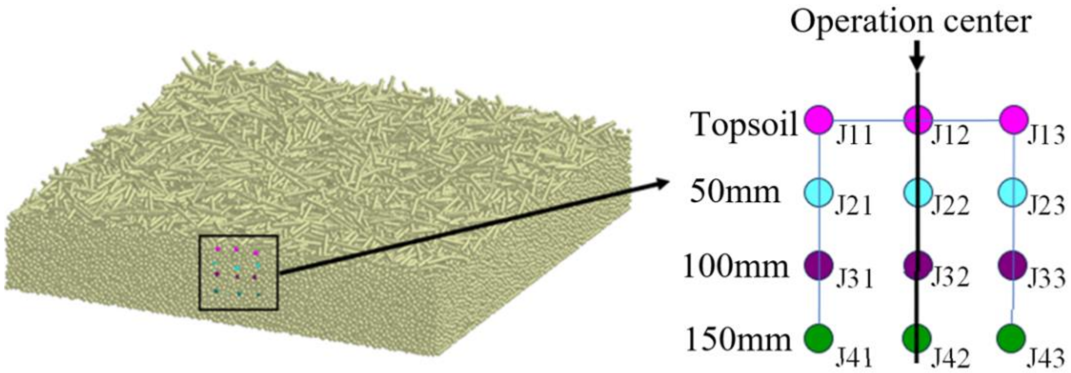


Fig. 1 - Marking the Position of Particles

Comparison of working performance between the lift-type winged chisel plow and the standard chisel plow

The experiment was conducted in the digital soil bin at the Agricultural Machinery Equipment Greenhouse of Shandong University of Technology. The soil in the bin was loam (72% sand, 15% silt, and 13% clay). Before each test, the soil was tilled using a 1 GKN-125 rotary tiller (tillage depth 120-160 mm), and then compacted using the soil bin vehicle. Soil samples were randomly taken from 10 different locations in the soil bin using a ring knife, with sampling depths of 5 mm, 10 mm, and 15 mm. The soil samples were dried in an oven at 105°C for 24 hours to measure soil moisture content. The average moisture content and average bulk density of the soil were measured as 17.6% (dry basis) and 1.36 g/cm³, respectively, according to ASABE Standards (2015).

RESULTS

Contact Model Parameter Results and Validation

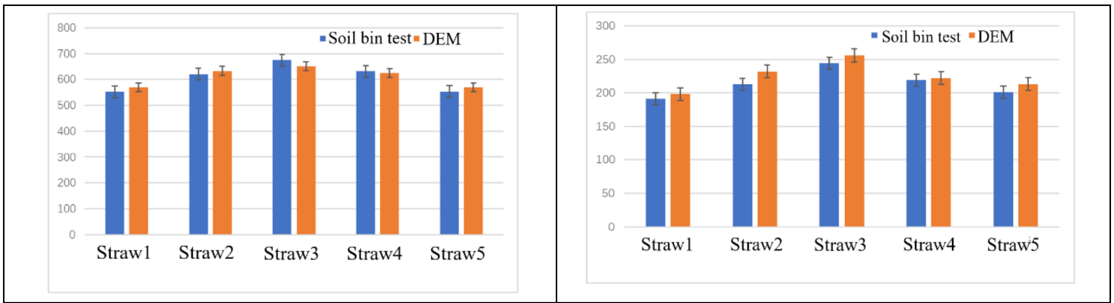
Within the parameter range set for the simulation test, the optimization module in Design Expert 12 software was used to optimize the regression equation for the repose angle, with the measured repose angle of 38.415° from the actual experiment as the target value. Several solutions obtained were validated through discrete element simulations to find the solution that most closely matched the actual repose angle. The optimal solution was chosen based on the simulation results.

The optimized parameters are as follows: soil-soil static friction coefficient of 0.57, soil-soil rolling friction coefficient of 0.18, and straw-soil dynamic friction coefficient of 0.12. The model parameters were set to these optimal values in EDEM 2022 software, while other parameters were taken as the average values measured in the actual experiment. The simulation was repeated five times, with the average measured repose angle being 39.49°, resulting in a relative error of 3.29% when compared to the actual experimental repose angle, thus validating the accuracy of the discrete element model.

Validation Results of the Lift-Type Winged Chisel Plow-Straw-Soil Interaction Model

The forward and lateral displacements of straw, traction force, and straw burial rate from both the soil bin experiment and the simulation experiment were compared, with relative error used to assess consistency.

The forward and lateral displacements of the five marked straw pieces from both the soil bin experiment and the simulation experiment were plotted as bar charts, as shown in Figure 2. From the figure, it can be observed that straw 3, located at the center of the machine's operation, has the largest displacement. The further the straw is from the center position, the smaller its displacement. The overall trend of straw displacement is consistent with the simulation results. The forward displacement error of the straw ranges from 1.67% to 5.45%, and the lateral displacement error ranges from 0.52% to 6.84%.



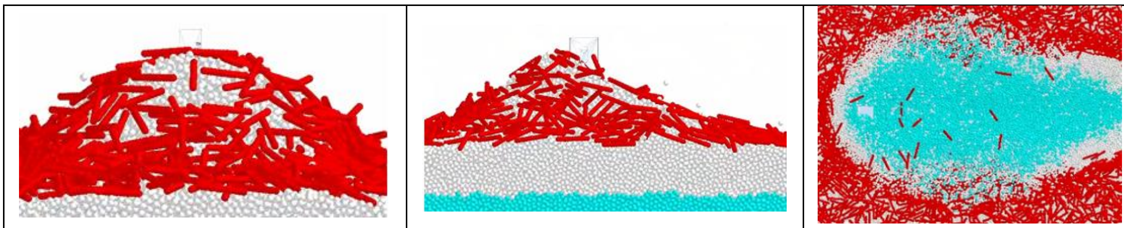
(a) (b)

Fig. 2 - Comparison between simulation and actual experiment. (a) Horizontal displacement (b) Positive displacement

The average straw burial rates in the soil bin experiment and the simulation experiment were 84.37% and 78.3%, respectively, with a straw burial rate error ranging from 2.54% to 6.37%. The average traction force of the machine during stable operation in the soil bin experiment and the simulation experiment were 1603.24 N and 1498.77 N, respectively, with a machine traction resistance error ranging from 5.29% to 12.60%. All indicator errors are within the permissible range of model errors (*Ucgul et al., 2017*), and the variation trends in the experimental data are consistent with the simulation results. The soil bin experiment verified the accuracy of the discrete element simulation and the feasibility of discrete element modeling for field trials.

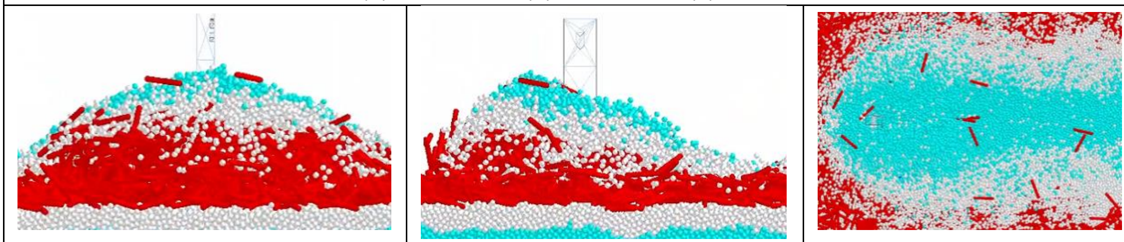
Analysis of the Performance of the Lift-Type Winged Chisel Plow in Simulation Experiments

The lift-type winged chisel plow is equipped with a soil-lifting plate on the winged part of the chisel plow. By comparing the working performance of the two plows, the role of the soil-lifting plate in the operation of the machine can be analyzed more intuitively. Figures 3 and 4 show the disturbance trajectories of soil and straw in the X (horizontal), Y (longitudinal), and Z (vertical) directions at the same moment, with color processing applied to the straw and soil (red for straw, white for tilled soil, green for plow bottom soil), enhancing the contrast. Compared to the Winged Chisel Plow with less burial effect, the lift-type winged chisel plow has a wider working width and less straw residue on the soil surface (Figures 3c and 4c). It also demonstrates better soil turnover (Plow bottom soil eversion, Figure 3b and 4b), surface straw burial, and straw-soil mixing effects. In summary, the soil-lifting plate can increase the working width of the winged chisel plow (51.5%) and improve the efficiency of straw mixing (69.3%).



(a) (b) (C)

Fig. 3 - Analysis of the Winged Chisel Plow Operation Process
(a) X-direction, (b) Y-direction, (c) Z-direction



(a) (b) (C)

Fig. 4 - Analysis of the Lift-Type Winged Chisel Plow Operation Process
(a) X-direction, (b) Y-direction, (c) Z-direction

Analysis of Straw-Soil Micro-Disturbance Process at Different Moments

To understand the disturbance state of soil at different positions below the surface as the lift-type winged chisel plow moves forward, the Clipping function in the post-processing module of EDEM software is used to create a cross-sectional view of the soil model along the longitudinal centerline of the lift-type winged chisel plow. Four moments are selected for the cross-section: when the plow has not yet entered the soil (0.02 s), when it has fully entered the soil (0.22 s), during the deep loosening process (0.42 s), and during the soil ejection process (0.62 s), as shown in Figure 5.

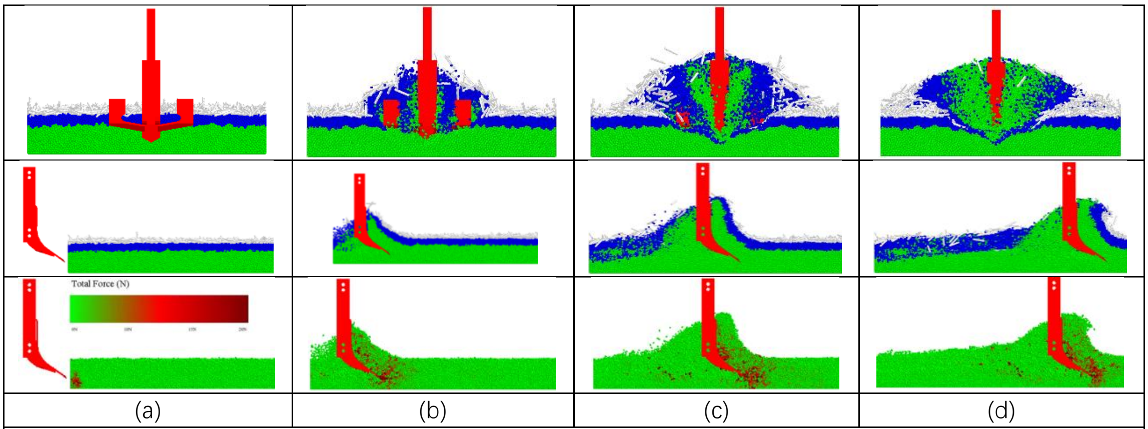


Fig. 5 - Disturbance of soil-lifting plow with wing chisel at different times
(a) 0.02 s (b) 0.22 s (c) 0.42 s (d) 0.62 s

Micro-disturbance Analysis of Straw-Soil at Different Positions

In order to explore the working range of the lift-type winged chisel plow and understand the soil disturbance state at different positions and depths, the role of each component in mixing and burying the straw was clarified. The longitudinal and transverse cross-sections of the soil at intermediate moments during the stable working process of the lift-type winged chisel plow were obtained. Based on the width of the chisel wing and the horizontal distance from the chisel tip to the chisel wing, the distances between the longitudinal and transverse cross-sections were set to 80 mm and 50 mm, respectively. Figure 6 shows the cross-sections in each direction at intermediate moments.

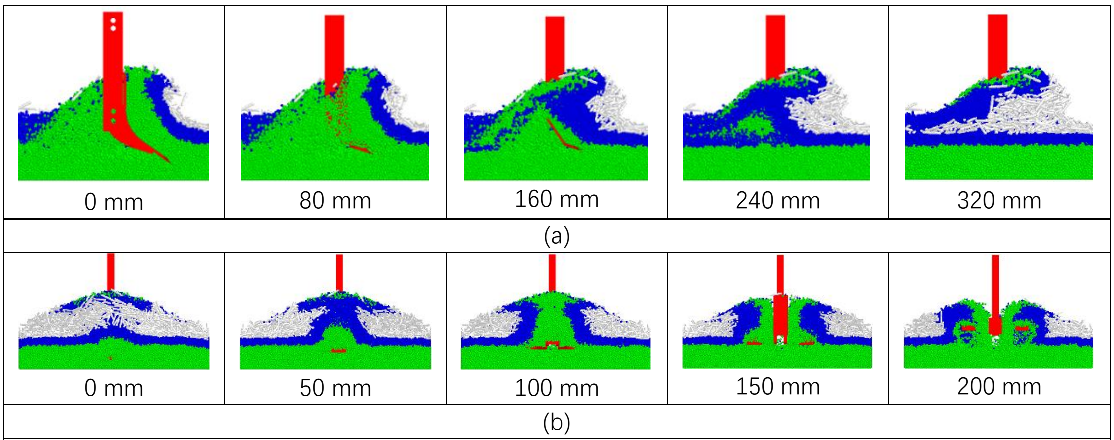


Fig. 6 - Soil disturbance state at different positions. (a) transverse (b) longitudinal

As shown in Figure 6(a), the disturbance of the plow bottom layer by the lift-type winged chisel plow gradually decreases as the horizontal longitudinal distance increases. Comparing the positions at 0 mm and 160 mm, the disturbance of the plow bottom layer by the chisel wing is relatively small. Due to the effect of the lifting plate, the straw-soil mixture in front of the chisel wing undergoes a turning action, and secondary disturbance is caused to the straw-soil mixture overturned by the lifting plate. From the changes in the number of straws before and after the positions at 240 mm and 320 mm in Figure 6(a), it can be seen that the working width on one side of the tool is about 300 mm, with the total working width of the tool being 600 mm. Within the horizontal width range of 300 mm from the center, there is very little straw.

Figure 6(b) illustrates that the lift-type winged chisel plow effectively turns and displaces the soil in the plow bottom layer, loosening the compacted soil by pushing it to both sides. The chisel tip initially cuts through the bottom layer soil, while the lifting plate lifts it through a turning motion. At transverse positions of 150 mm and 200 mm, the chisel wings notably expand the working width of the implement. Additionally, the lifting plate introduces secondary disturbances to both soil and straw particles (Figure 6a & 6b), thereby enhancing soil loosening, increasing fragmentation, and improving the uniformity of the straw-soil mixture following incorporation.

Straw-soil motion state analysis

To analyze the effect of the lift-type winged chisel plow on the overall motion behavior of the straw-soil mixture during operation, longitudinal cross-sections were taken at three key positions: the longitudinal center of the chisel plow (0 mm), the midpoint of the winged blade (160 mm), and the edge of the winged blade (320 mm). Three time points were selected for analysis: the moment the chisel tip enters the soil (0.02 s), the point at which the entire lift-type winged chisel plow is fully engaged in the soil (0.152 s), and the midpoint of the working stroke (0.302 s). A comparative analysis of the straw-soil motion velocity and distribution patterns at different times and cross-sectional positions was conducted, as shown in Figure 7.

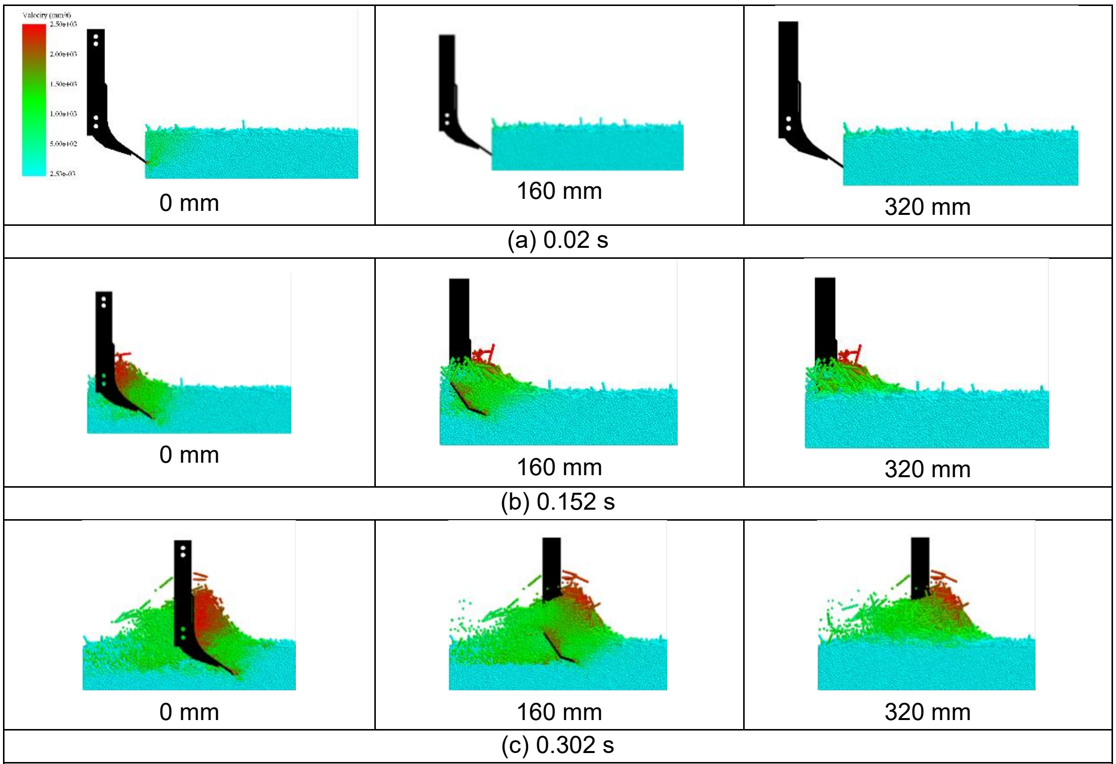


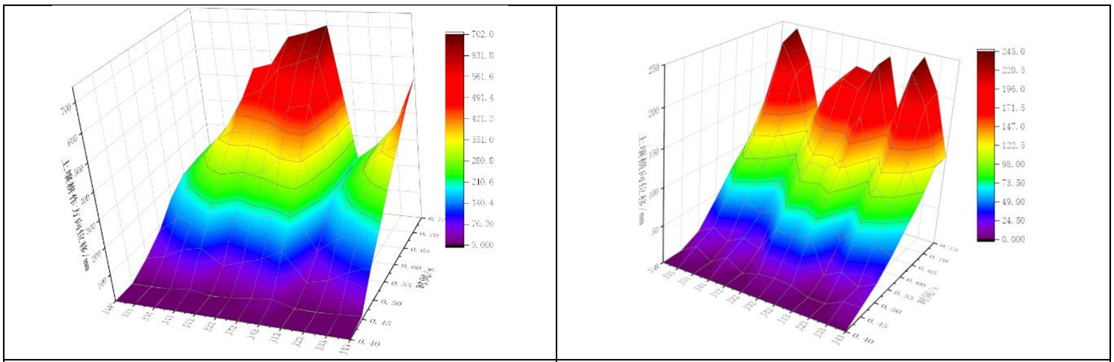
Fig. 7 - Analysis of particle velocity distribution at different positions

After the chisel tip enters the soil (Figure 7a), the subsoil begins to move upward due to the extrusion effect generated by the chisel tip. Simultaneously, the straw on the soil surface above the chisel tip begins to shift. However, because the pushing force of the chisel tip is limited, it produces minimal disturbance in the soil at the wing and wing-edge positions. When the wing enters the soil (Figure 7b), significant surface soil movement is observed at the horizontal center position (0 mm). This is attributed to the combined action of the lifting plate's pushing force and the extrusion pressure from the underlying soil. The highest movement velocities of both straw and soil occur in the region near the lifting plate of the lift-type winged chisel plow.

At the wing position, 160 mm from the horizontal center, the soil adjacent to the wing exhibits higher velocity. The maximum soil velocity curve closely aligns with the contour of the wing's lifting plate, indicating that this region is directly influenced by the wing structure. At this stage, the surface straw located above also begins to move under the combined action of the wing and lifting plate. By 0.302 s, the lifting plate actively flips the straw and soil through its plowing action. The highest movement velocities of both soil and straw are observed in front of the lifting plate. In these regions, particularly around the wing and lifting plate, the surface straw also gains significant velocity due to tool-induced disturbance. Meanwhile, the ridged soil lifted above the surface gradually collapses and backfills into the furrow under the influence of gravity.

Analysis of the velocity distribution across different positions reveals that the region in front of the lifting plate experiences the most intense disturbance. The maximum velocity contours of the soil particles correspond closely with the shape of the lifting plate and wing of the lift-type winged chisel plow. This demonstrates that the wing notably enhances disturbance in the cultivated soil layer and surface straw, contributing to improved mixing and loosening performance.

Microscopic Analysis of Soil Disturbance Displacement



(a) (b)

Fig. 8 - Soil displacement analysis Soil tillage.
(a) vertical displacement; (b) horizontal displacement

In the working direction (Figure 8a), the soil particles located beneath the lift-type winged chisel plow's lifting plate (J12, J22, J32, J42) exhibit relatively larger displacements. Among them, the bottommost soil particle at the center of the tool (J42) shows the greatest displacement in the working direction, while the soil particles near the wing blades and the lifting plate exhibit relatively smaller displacements. The soil particle directly beneath the lifting plate (J41) displays the smallest displacement. In the horizontal direction (Figure 8b), the soil particles directly beneath the lifting plate (J41, J43) exhibit minimal horizontal movement. In comparison, the remaining soil particles show relatively consistent horizontal displacement magnitudes. The soil particles located at the center of the lifting plate and the chisel tip (J21, J42, J23) experience the largest displacements. Considering the combined horizontal and working-direction displacements of soil particles, it can be observed that J41 and J43 are not directly influenced by the tool. Instead, the movement of particles in their vicinity is indirectly caused by the compressive forces among soil particles. At this point, the wing blades are positioned above a soil depth of 150 mm, and the lifting plate exhibits a greater disturbance effect on the cultivated soil layer. For soil particles located at the center of the lifting plate and chisel tip, the displacement increases with depth. This is due to the overturning action of the lifting plate, which flips the bottom-layer soil to a higher position, resulting in a longer forward movement duration. Conversely, the soil particles near the wing blades and the lifting plate are flipped to a lower height due to the height limitations imposed by the lifting plate. As a result, these particles experience a shorter forward movement duration and smaller displacements in the working direction.

In summary, the lift-type winged chisel plow exhibits the greatest disturbance within the cultivated soil layer. The addition of wing blades and the lifting plate effectively expands the disturbance range within this layer, although the direct force exerted by the wing blades on the plow pan is relatively limited. The chisel tip is capable of disturbing deeper soil layers, and a lower installation height of the wing blades increases the effectiveness of disturbance at depth. However, this also results in greater resistance, leading to increased energy consumption and reduced soil-loosening efficiency. The lifting plate of the lift-type winged chisel plow plays a critical role in achieving effective straw-soil mixing. However, its height significantly influences the displacement of the soil in front of it. During tillage operations, an insufficient lifting height may limit the upward movement of the soil above the lifting plate, impairing the burial of surface straw. This can ultimately reduce the effectiveness of straw-soil mixing achieved by the implement.

Performance Comparison of Soil Bin Tests

To investigate the effects of the winged blade and lifting plate on implement performance, soil bin tests were conducted to compare the straw burial rate (R), working width (W), straw burial depth (H), and straw-soil mixing uniformity (E) between the conventional chisel plow and the lift-type winged chisel plow. The lift-type winged chisel plow, with its wing blades and soil-lifting plate, demonstrated superior straw burial performance.

As shown in Table 1, compared to the conventional chisel plow, the lift-type winged chisel plow increased the burial rate to 42.98%, working width to 81.33 cm, and straw-soil mixing uniformity to 92%. The experimental results indicate that the lift-type winged chisel plow meets the quality standards for straw burial treatment as specified in DB21/T 3590-2022: Technical Specifications for Mechanized Operations of Corn Straw Incorporation into Soil. Comparing the actual working performance of the two implements, the lift-type winged chisel plow demonstrated superior loosening and crushing of the soil, as well as better uniformity of straw-soil mixing after incorporation.

Table 1

Soil bin test results

Category	R / %	W / cm	H / cm	E / %
Lift-type winged chisel plow	42.98	81.33	16.1	92
Ordinary chisel plow	13.2	39.47	17.2	61

CONCLUSIONS

This study investigated the motion characteristics of straw and soil during the operation of the lift-type winged chisel plow, as well as its effect on the micro-disturbance of the straw-soil mixture. A discrete element interaction model of the lift-type winged chisel plow, straw, and soil was established to explore the mechanism of straw-soil disturbance caused by the implement. The accuracy of this interaction model was validated through soil bin tests, and the working performance of the conventional chisel plow and the lift-type winged chisel plow was compared. The main conclusions are as follows:

1. The optimal combination of contact parameters for the straw-soil mixture was determined to be: a soil-soil static friction coefficient of 0.57, a soil-soil rolling friction coefficient of 0.18, and a soil-straw dynamic friction coefficient of 0.12. Under this parameter combination, the relative error between the simulated and experimental repose angles was 3.29%.

2. From a micro-scale perspective, the motion states of straw and soil at different time intervals and locations, as well as their influence on straw-soil micro-disturbance, were analyzed. The height of the soil-lifting plate was identified as the primary factor affecting soil fragmentation and straw burial efficiency.

3. The lift-type winged chisel plow shears and loosens the subsoil with its chisel tip, while the soil-lifting plate pushes, overturns, and mixes the straw and soil. Compared to the conventional chisel plow, the wing blades increased the working width, while the soil-lifting plate enhanced the frequency of straw-soil disturbance. The burial rate was improved to 42.98%, and the straw-soil mixing uniformity increased to 92%.

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