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Simulation of Pressing Effect of Press Wheel with Different Rims by Discrete Element Method

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Abstract. Pressing is an important part of precision seeding operation, which has an important effect on crushing soil. In order to enhancing the effect of soil crushing, some press wheels with flange rim are used. But further research is needed to evaluate whether the use of these press wheels affect the actual seeding depth that will affect precision seeding quality. Three kinds of press wheels, with the smooth rim, circular flange rim and rib rim respectively were designed, and the PFC3D discrete element method (DEM) software was used to simulate the pressing processes of these press wheels, and the contact force between the rim and soil, soil displacement and porosity were analyzed. It was concluded that the press wheel with the smooth rim is better than others in precision seeding operation.

Introduction

Precision seeding is defined as the placing of desired numbers of seeds at a precise depth and spacing. It has many advantages such as saving seeds, reducing time and labor consumption in the process of thinning out seedlings and improving the production and quality of crops [1]. Precision seeding is an advanced modern method for planting crops and an inexorable trend of agricultural development, and is an important measure to increase agricultural production and reduce grain production costs

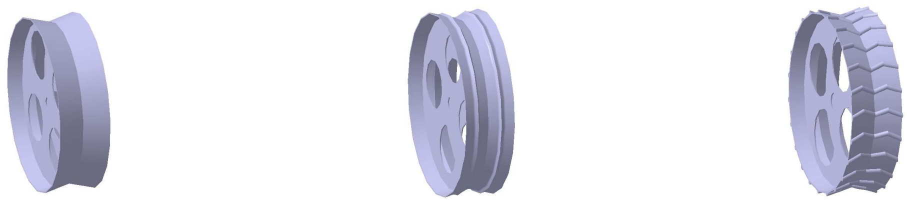
Pressing can reduce the large soil pores and moisture evaporation, conserve soil moisture and improve soil capillary action to create favorable conditions for seed germination and growth [2]. Another role of pressing is to crush soil, compact soil, make moisture from the lower soil layer rise to surface and seeds closely contact the soil, which is favorable for seed emergence and seedling growth [3]. Three kinds of press wheels with different rim structure were studied to evaluate the effect of the press wheel on the actual seeding depth, seed germination and seedling growth. The study evaluated the effect of three kinds of press wheels on the actual seeding depth and seed germination and growth.

The DEM simplifies discrete particles to form a certain shape and mass of particle set. The numerical model is built based on the characteristics of discrete particles and to give the discrete particles themselves, between particles and between particles and the outer boundary a contact mechanics model and the model parameters used to consider the different mechanical and physical characteristic of them [4,5,6]. In the field of mechanics, the DEM is mainly used in rock mechanics, mechanics of granular media and soil mechanics and in engineering, it is mainly used in agricultural engineering, food engineering and chemical engineering.

The mechanical models of the press wheel and land surface system were established by using DEM to evaluate changes in soil morphology produced by the interaction between the press wheel and soil and to compare the performance of the three kinds of press wheels[7,8].

Simulation Experimental

Parameters Selection. In consideration of the applicability of the model, this article adopts the experimental data from 2BH-3 inter-row precision seeding-machine for corn stalk mulch farming developed by Jilin University. The width of the press wheel was b=132mm, the radius is r = 225mm, and the pressure acting on the press wheel was F= 637N. The forward speed of the press wheel was 0.05m/s and rotational speed was 0.05rad/s. Three kinds of the press wheels are shown in Fig. 1. The Discrete element parameters of soil in soil bin are given in Table 1.



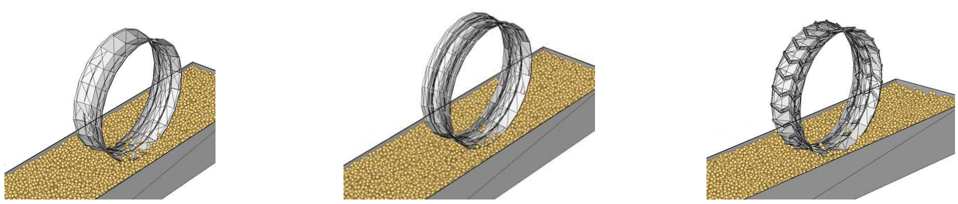
(a) with smooth rim (b) with circular flange rim (c) with rib rim

Fig. 1 Press wheels

Table 1 Discrete element parameters of soil in soil bin

Friction coefficient	0.5
normal contact stiffness	$2.42\text{x}10^5$
contact stiffness ratio	2.34
normal critical damping ratio	0.84
tangential critical damping ratio	0.62
parallel constraint radius amplification coefficient	1.0
parallel constraint normal stiffness(pa/m)	$1.66\text{x}10^5$
parallel constraint stiffness ratio	2.51
parallel constraint strength(pa)	$4.23\text{x}10^4$
parallel constraint deviation	0.18

Models Description. First, the soil bin model was established under loose soil conditions and then the press wheel mode required was introduced. Simulation of the pressing process was conducted based on the weight, forward speed rotation speed and other parameters of the press wheel.; the pressing effects of three kinds of press wheels were analyzed and compared in contact force, displacement and porosity of the soil. Simulation process of pressing is shown in Fig.2.

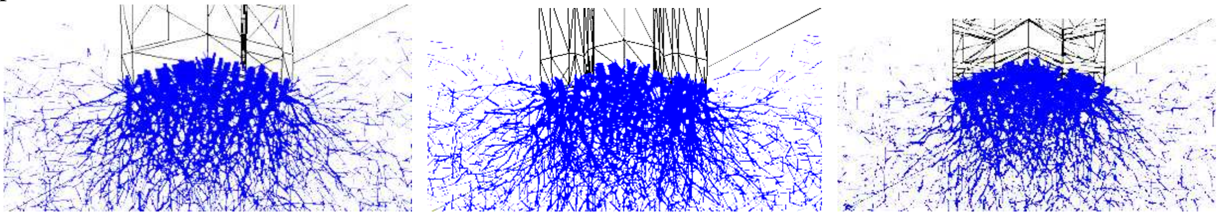


press wheel (a) press wheel (b) press wheel (c)

Fig. 2 Simulation models of the press wheels

Results and Discussions

Contact force field. Figure 3 shows the contact forces between the press wheel and soil particles.

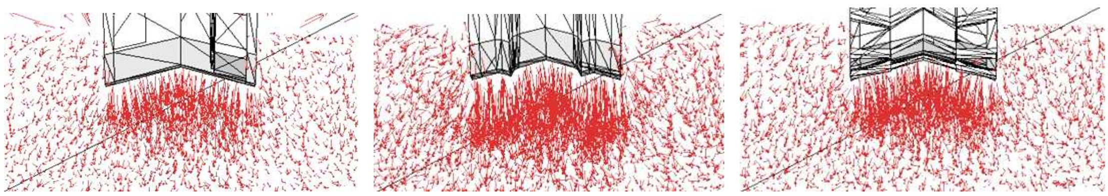


Press wheel (a) Press wheel (b) Press wheel (c)

Fig. 3 Contact force fields

Contact forces included the contact pressure and contact tension. As shown in Fig.3, the wider the line, the greater the contact forces. It can be seen from the contact force fields that as the depth increases, the contact forces between the press wheels with different rims and soil particles increased, and the distribution range of the contact force was enlarged and the contact force decreased.The contact forces between press wheel (a) or (b) and soil particles were relatively large, which slowly reduced with the depth increased. The contact force between press wheel (c) and soil particles mainly concentrated in the particle surface layer and the contact force decreased faster as the depth increased.

Displacement Field. The change in the displacement field of the representative particles of three kinds of press wheels is shown in Fig. 4



Press wheel (a) Press wheel (b) Press wheel (c)

Fig. 4 Displacement fields

The length of the line and the direction of the arrows represent the quantity and direction of displacement. The changes in the flow regime of soil can clearly be seen. The schematic diagram of displacement field shows that the soil particles have larger displacement flow in central part of the seed row or above the seed and have smaller displacement flow on both sides of the seed row The effect of press wheels (b) and (c) on displacement of soil particles were significantly higher than press wheel, (a) and press wheel (b) produced a maximum soil disturbance above the seed.

Porosity. According to the change in the contact force field and displacement field, the porosity in the interval of Y = 0 mm, Z = 20.5 mm, X = 22-42 mm was calculated. In the selected location, a circle with a radius of 5 mm was drawn and the porosity in unit volume of the soil was calculated. The soil porosity curves in the interval for three kinds of press wheels are shown in Fig.5.

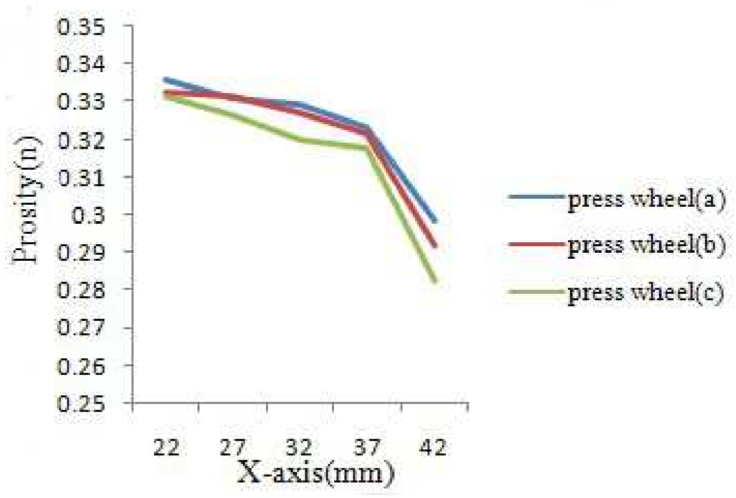


Fig. 5 Soil porosity curves

It can be seen from Fig.5 that the soil porosity in the same area pressed by three kinds of press wheels is significantly different. The porosity for press wheel (a) is larger than that for press wheel (b) which is larger than press wheel (c). It can also be seen that in a given interval the three curves decline because the soil particles themselves have a rebound effect after the soil pressed by the press wheels.

Discussions. Under the same conditions, the change in the contact forces produced by the press wheels with the smooth rim and with circular flange rim is relatively uniform. The press wheel with the rib rim produces a great contact force, which may cause excessive soil compaction in the upper soil layer, affecting seed germination.

Under the same conditions, the press wheel with smooth rim produces soil disturbance much less than the press wheels with the circular flange rim and with the rib rim and the press wheel with the circular flange causes a maximum displacement field. The press wheels with the rib rim and with the circular flange rim have a strong effect on the vertical distribution of seed.

Under the same conditions, the press wheel with the smooth rim produces the largest soil porosity above the seed, and the press wheels with the rib rim and with the circular flange rim next.,

Conclusions

The press wheel with smooth rim causes more uniform soil compaction, less soil disturbance and higher soil porosity, which can hold the seeding accuracy, and higher soil porosity, which can hold more air and moisture, strengthen the microbial activity and accelerate the transformation of nutrients. Therefore, the press wheel is suitable to the precision seeding machine.

The press wheels with the circular flange rim and with the rib rim and the press wheel with the circular flange causes a larger displacement and excessive soil compaction in the upper soil layer, affecting the seeding accuracy and seed germination. The pressure of the press wheels should be properly adjusted if they are used.

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