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Analysis of the Mechanism of Weeding with Rotary Weeding Wheel in Paddy using Dynamic Software

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ABSTRACT

Mechanical weeding in paddy is getting popularized only after dry sowing method i.e., where line sowing is done by tractor drawn seed drill/planter at desired row to row and hill to hill spacing. In the actual operation process in the field, weeding device needed to perform not only efficient weeding but also its effect on quality of tillering in puddled soil to increase the porosity of soil and effectively promote nutrient absorption from the soil. To simulate the soil tillering condition of optimized weeding wheels, the explicit dynamics software LS-DYNA was used to establish the fluid–solid coupling model of weeding wheels and water soil. Based on the working state of the optimized weeding wheel and the agronomic requirements for weeding, the forward speed of 0.58 m/s, the rotating speed of 150 revolution/min and the weeding depth of 50 mm were selected. The density of soil increases significantly after the disturbance of the weeding wheel, which is due to the effect of the tillering the soil layer in the water layer. From the analysis, it was observed that, the weeding wheels greatly disturbed the soil and could bury weeds and churn the soil. In addition, when the weeding wheels moved in the simulated paddy field environment, the mud mixture move freely and the overall coupling stress is low, which indicated that the resistance of the weeding parts was small and the energy consumption of the weeding wheels was low.

Keywords: Weeding, Puddled soil, Simulate, Density, Coupling stress

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INTRODUCTION

Rice (Oryza *sativa* L.) is India's prominent crop, and is the staple food for most of the Indians. India has the world's largest area under rice cultivation and is one of the largest producers of white rice, accounting for 20% of global production. Even though many improved technologies have been introduced in paddy cultivation, still management of weed is a major concern in paddy cultivation which competes for sunlight, space and nutrients with the main crop and directly responsible for reduction in crop yields due to 10 to 25% weeds and 35 to 45% in direct sowing paddy (Yaduraju, 2012). The common type of weeds which affects yield is *Cyperus difformis*, *Marselia quadrifoli, Echinochloa crusgalli etc.,* (Yaduraju, 2012). Line sowing method of paddy cultivation with tractor drawn seed-cum-ferti drills or transplanting of raised paddy nursery in rows is becoming a common practice The major problem in direct sowing of paddy is weed infestation like in dryland crops, where huge labour force of about 900 to 1200 man hours/hectare are required. (Yaduraju, 2012). Mechanical weeding is getting popularised only after dry sowing method i.e., where line sowing is done by tractor drawn seed drill/planter at desired row to row and hill to hill spacing. Different manufactures, industries and scientists have developed different types of weeders for both dry and wet land paddy conditions. Now a days farmers are using improved equipment like hand hoe, finger and cono weeders, animal, power tiller and self-propelled weeders for weeding in paddy fields. The major problems during weeding operation in paddy fields with above machines are:

1. Chocking of mud in between the teeth/blades & wheels of the equipment
2. No built-in adjustability in working width as crop advances
3. High risk of maneuverability due to sticky soil condition in mostly puddle soils
4. Tedious to operate for longer periods in puddle soil conditions
5. High cost of operation

Keeping in view the above factors and identified research gap, an investigation was taken up for the analysis of mechanism of weeding using burying with rotary weeding wheel. The weeding device with driving serrated teeeth for burying weeding working mode was designed, and the structural parameters and working parameters were optimized to improve the comprehensive operation performance. In the actual operation process in the field, weeding device needed to perform not only efficient weeding but also its effect on quality of tillering in puddled soil to increase the porosity of soil and effectively promote nutrient absorption from the soil.

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Due to the complex working environment of paddy fields, the interaction mechanism between mechanical components, water and soil is very complex and cannot be completely determined through theoretical analysis. With the development of computer technology, virtual simulation provides a good technical method for this aspect of study. Many scholars have performed relevant simulation research on this topic. Bentaher *et al*. (2013) simulated the interaction between plows and soil through the finite element method and explored the best plow angle. Zhang *et al*. (2015) established a soil model by using discrete element simulation software and explored the best parameter combination of the trencher of a direct seeding machine for rape. Kotrocz *et al.* (2016) used the discrete element method to simulate the infiltration of soil through the cone penetrometer and effectively evaluated the mechanical properties of the soil. Most of the above studies focus on dry land with single soil characteristics and obvious particle properties, which is not suitable for complex paddy field environments. The weeding wheel blends the water and soil. However, the paddy field environment cannot be directly observed and analyzed through actual operation.

MATERIALS AND METHODS

To simulate the soil tillering condition of optimized weeding wheels, the explicit dynamics software LS-DYNA was used to establish the fluid–solid coupling model of weeding wheels and water soil. The weeding wheels were placed in a paddy field to analyze the soil disturbance and coupling stress. The model of the weeding wheels was simplified to reduce the simulation time and to reasonably and effectively perform simulations and calculations (Liu *et al*., 2020). All materials are defined as rigid bodies, and irrelevant parts are removed. The model of the weeding wheels was meshed by hexahedral grid cells, and the K-files were generated and imported into LS-Prepost of LS-DYNA. The material of the weeding wheels uses the MAT_RIGID keyword, and the parameters of the area were as follows: the density was 0.0013 g/mm^3, the elastic modulus was 0.82MPa, and the Poisson's ratio was 0.245 (Choi *et al*., 2015).

The water layer model and soil model were established by LS-Prepost of LS-DYNA. The water model is directly built on the soil model. The node coincidence command is used to overlap the nodes of the two cuboid models to form the coupling model of water and soil. According to the agronomic requirements, the size of the model of the water layer was set at 650 X 300 X 30 mm, and the size of the soil model was set at 650 X 300 X 60 mm. MAT_NULL in LS-DYNA was selected as the water layer material. The density and cutoff pressure were selected as 0.004 g/mm^3, and 1x 10^{-5} MPa (shinoto *et al*., 2020). The EOS equation of state was defined to determine the material parameters of soil and air. The main parameters were as follows: the soil density was 0.00161 g/mm^3, soil particle density was 0.00273 g/mm^3, bulk modulus was 5.6 MPa, shear modulus was 1.9 MPa, cohesion was 0.0155 MPa, internal friction angle was 15°, and water content was 40%.

The solid grid cell of the multi-material ALE algorithm was used to define the type of water grid and soil grid cell. To simulate the real environment of water and soil, the gravity condition was applied to the water–soil coupling model. The water-soil composite model is shown in Fig.1.

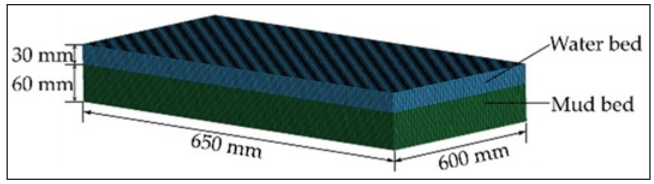

Fig. 1: Water soil composite model

RESULTS AND DISCUSSION

Based on the working state of the optimized weeding wheel and the agronomic requirements for weeding, the forward speed was 0.58 m/s, the rotating speed of the weeding wheels was 150 revolution/min, and the weeding depth was 50 mm. The ALE element (water-soil model) was defined as MASTER, the Lagrange element (weeding wheels model) was defined as SLAVE, and the penalty coupling algorithm was set to simulate fluid–solid coupling. The simulation process is shown in Fig. 2.

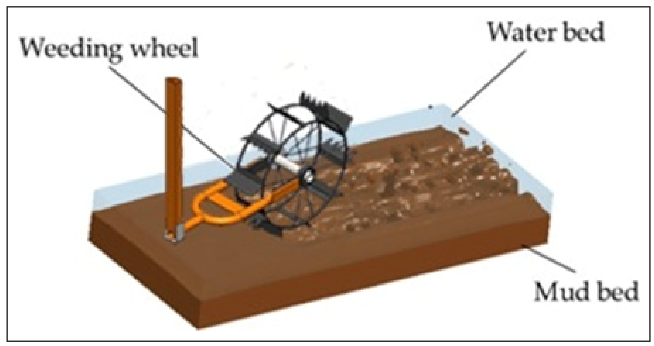

Fig. 2: Fluid–solid coupling simulation of the weeding wheels and water soil

LS-Prepost can be used to analyze the density distribution at different times, and the density distribution is shown in Fig. 3.

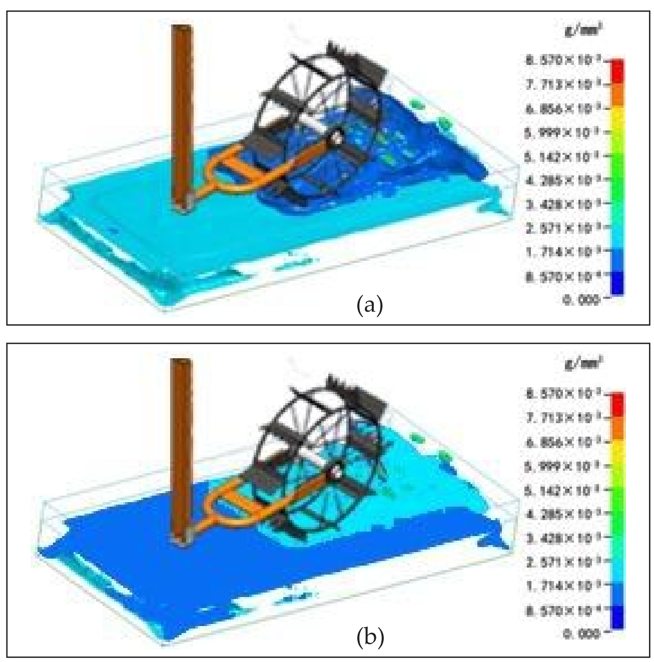

Fig. 3: Density distribution map: (a–b) represent density distribution map

It is evident from Fig. 3 that the pressure generated by the contact between the weeding wheel teeth and the topsoil destroys the topsoil, and the weeding wheels greatly disturb the mud layer after entering the soil. As the simulation time increases, the weeding wheels continue to roll in the soil model. The path density increases significantly after the disturbance of the weeding wheel, which is due to the effect of the weeding wheel tillering the soil layer in the water layer. The results show that the weeding wheels greatly disturbed the soil and could bury weeds and churn the soil.

The coupling stress is the average value of the coupling stress generated on the coupling surface during the interaction between the weeding components and the water– soil model. The smaller the coupling stress is, the smaller the resistance of the component and the smaller the operation energy consumption. The stress distribution at different times was measured by LS-Prepost. The stress distribution is shown in Fig. 4.

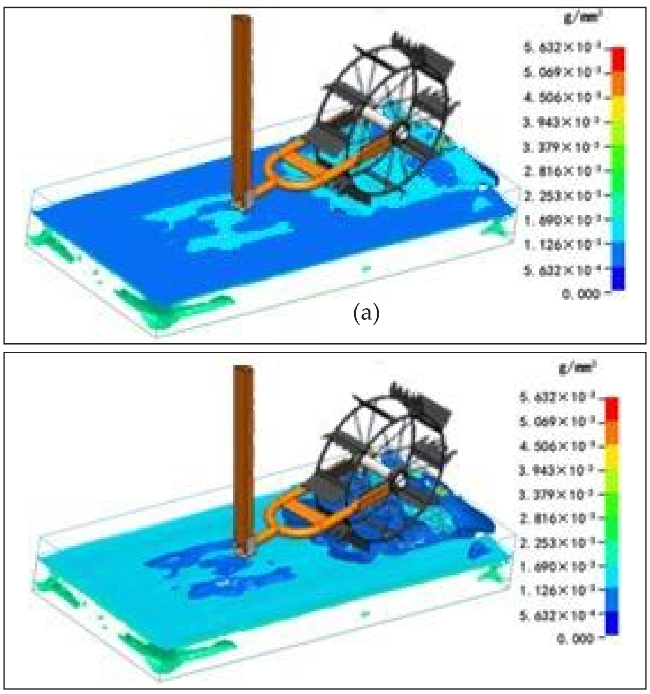

Fig. 4: Stress distribution diagram: (a–b) represent stress distribution diagram

It is evident from Fig. 4 that after the serrated teeth of the weeding wheels were embedded in the soil, the back of the serrated teeth compressed the soil in the direction of rotation while the weeding wheels rotated, so the stress on the soil on the backside of the weeding wheels with serrated teeth was positive. The soil on the front of the serrated teeth was subject to negative tensile stress as the serrated teeth tillering backward and disturbed the soil. As the serrated teeth e distributed soil in a uniform distribution, the coupling stress of the weeding wheels and water–soil composite model was in a pulse state with the serrated teeth entering the soil successively. In addition, when the weeding wheels moved in the simulated paddy field environment, the mud mixture did move, and the overall coupling stress was small, which indicated that the resistance of the weeding parts was small and the energy consumption of the weeding wheels was low.

CONCLUSIONS

To simulate the soil tillering condition of optimized weeding wheels, the explicit dynamics software LS-DYNA was used to establish the fluid–solid coupling model of weeding wheels and water soil. The weeding wheels were placed in a paddy field to analyze the soil disturbance and coupling stress. All materials are defined as rigid bodies, and irrelevant parts are removed. The model of the weeding wheels was meshed by hexahedral grid cells, and the K-files were generated and imported into LS-Prepost of LS-DYNA. The density and cutoff pressure were selected as 0.004 g/mm^3, and 1x 10^{-5}MPa. Based on the working state of the optimized weeding wheel and the agronomic requirements for weeding, the forward speed was 0.58 m/s, the rotating speed of the weeding wheels was 150 revolution/min and the weeding depth was 50 mm. The path density increases significantly after the disturbance of the weeding wheel, which is due to the effect of the weeding wheel tillering the soil layer in the water layer. The results show that the weeding wheels greatly disturbed the soil and could bury weeds and churn the soil. In addition, when the weeding wheels moved in the simulated paddy field environment, the mud mixture did move, and the overall coupling stress was small, which indicated that the resistance of the weeding parts was small and the energy consumption of the weeding wheels was low.

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