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# EFFECT OF RICE STUBBLE ON SOIL COMPACTION PROPERTIES OF A CRAWLER UNDERGOING COMBINE HARVESTER HARVESTING

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**KEYWORDS**

crawler structure, wet and soft soil, rice stubble, trafficability, soil compaction.

**ABSTRACT**

In the process of rice harvesting, the passability of the track combine harvester is often limited by the state of the soil. Meanwhile, wet and soft paddy soil is compacted under the rolling of harvesting machinery, which also affects the soil function and the ecological environment. Therefore, the relationship between the physical and mechanical properties of wet and soft paddy soil was studied in this paper. In addition, compaction from a track combine harvester on field soil with and without rice stubble was studied. The density and gradation of wet and soft paddy soil were positively correlated with cohesion and negatively correlated with the internal friction angle. In paddy soil with a moisture content of 16–36%, the soil moisture content was negatively correlated with cohesion and internal friction angle. Additionally, the plastic deformation of soil with rice stubble under compaction was greater than that without rice stubble, and the plastic deformation of the field with rice stubble mainly occurred in the second rolling stage. Increasing the speed of the track combine harvester effectively reduced the compaction risk of rice stubble soil.

## INTRODUCTION

Rice, one of the three most important food crops in the world, is the staple food of more than 50% of people in the world and the main food crop in China (Tang et al., 2021). Paddy soil is a special kind of soil that is affected by both human activity and natural soil-forming factors. It is of great significance to study its physical and chemical properties to evaluate the passability of combine crawlers in wet and soft paddy fields. The mechanical properties of soil are influenced by many factors, including density, water content and pH (Horn & Fleige, 2003). Many scholars have studied the mechanical properties of soil. For example, Luo et al. (2020) found that the internal friction angle decreased with an increase in natural moisture content in the karst slope cropland of Central Guizhou, while cohesion showed a first increasing and then decreasing trend with an increase in moisture content. Chen et al. (2022) investigated the effect of moisture content on the time-dependent deformation, strength and failure behaviors of undisturbed loess specimens from Nangou in Yan'an city, Shanxi Province, China. Abedi Koupai et al. (2019) studied the influence of pore water pH on the engineering properties of natural clay. For the study of paddy soil, Walsh & McDonnell (2012) studied the influence of organic residues from straw returning to field on soil physicochemical properties. Gu et al. (2022) found that rice straw recycling use for biochar and co-application with different chemical fertilizer doses on paddy soil did not reduce the japonica rice yield, while amending soil properties. Zhang et al. (2023) found that rotation tillage can improve the stability of soil structure in rice–wheat double cropping areas and increase the comprehensive nutrient content of soil. However, the above research mainly focuses on the relationship between the physical properties and mechanical properties of other non-rice soils. Research on rice soil mainly focuses on the effects of organic matter content, fertilization methods and farming methods on the physicochemical properties of rice soil. Therefore, there is a lack of research on the relationship between the physical and mechanical properties of paddy soil in the rice harvest season.

The compaction problem in agricultural soil has always been the focus of scientists and farmers. Soil compaction is a physical form of soil degradation that adversely affects the porosity, bulk density and strength of the soil (Nawaz et al., 2013). Some scholars have found that factors such as vehicle grounding mode, driving speed and

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passing times affect the compaction effect of vehicles on soil, thus affecting the growing environment of the crop. For example, Horn et al. (1989) studied the influence of the speed of wheeled vehicles on the vertical and horizontal stress in different soil depths. Lamandé et al. (2018) tested the vertical stress acting on the soil surface when the same vehicle uses tires and crawlers. In addition, Wang et al. (2022) determined the stress on soil when two tractors (LOVOL M904 (HC) and John Deer 280 (LC)) with different masses passed through field experiments many times and studied the influence of this stress on soil bulk density and corn growth. Khemis et al. (2022) predicted the influence of tractor speed and soil moisture on the soil compaction state through the artificial neural network method. Feitosa et al. (2015) studied the influence of tire internal pressure and driving speed of agricultural tractors on soil physical properties (bulk density, total porosity and cone index). However, the current research mainly focuses on the compaction effect of wheeled vehicles on soil under different driving speeds and passing times. There is still a lack of research on the compaction difference of track combine harvesters in rice stubble fields and no rice stubble fields and the influence of crawler combine harvester driving conditions on the compaction of rice stubble fields.

To determine the potential influence of field soil on the passability of track combine harvesters, the relationship between paddy soil's physical and mechanical properties was studied. In addition, the compaction effect of the track combine harvester on soil with and without rice stubble was evaluated by determining the vertical stress in soil, which can provide a new direction for studying the compaction of the track combine harvester on wet and soft rice fields and a way of thinking about reducing the compaction risk of soil in rice harvesting fields.

## MATERIAL AND METHODS

### Physical and mechanical properties of paddy soil

#### Paddy soil sample acquisition

The mechanical properties of wet and soft paddy soil are mainly affected by soil gradation, straw stubble in soil, moisture content and so on. Rice planting occurs in the Dantu District, Zhenjiang, Jiangsu, China. In this paper, paddy soil from wet and soft fields in Dantu District, Zhenjiang City, Jiangsu Province were collected, with three soil samples: mature paddy field, insect-infested paddy field and rice-planted wasteland. The collection environment is shown in Fig. 1.

(a) Mature paddy field (b) Insect-infested paddy field (c) Rice-planted wasteland

FIGURE 1. Sampling sites of different wet and soft paddy soils.

The three undisturbed soil samples were collected using a cutting ring with the five-point method. Vaseline was coated on the inner wall of the cutting ring, and the cutting ring was vertically pressed into the soil using a rubber hammer combined with a cubic handle. After the cutting ring was filled with soil, the excess soil at both ends of the cutting ring was scraped off and the outside of the cutting ring was cleaned. In addition, to prevent water evaporation from affecting the physical and mechanical properties of the soil, the collected soil samples were sealed with plastic wrap, and the three soil samples (mature paddy field, pest paddy field and rice-planted wasteland) were labeled according to A, B and C, respectively.

### Physical parameter acquisition of paddy soil

#### Density

The dry density of soil samples in the same area exhibits little variation, and the natural density can better reflect the influence of real soil conditions on cohesion and the internal friction angle. Therefore, the density in this paper referred to the natural density of soil, that is, the wet density of soil, which was defined as the mass per unit volume of soil in a natural state. The densities of mature paddy field (soil sample A), insect-infested paddy field (soil sample B) and rice-planted wasteland (soil sample C) soil were measured to provide basic parameters for investigating the influence of soil density on the mechanical properties of wet and soft paddy soil.

#### Gradation

Soil gradation was achieved using the screening method, as shown in Fig. 2. The main testing equipment included the GZS-1 high-frequency vibrating screen machine, DHG series dryer, electronic balance (accuracy 0.1 g), and screens with different apertures (aperture: 20, 10, 5, 2, 1, 0.5, 0.25, 0.1, 0.075 mm). Testing the gradation of mature paddy field (soil sample A), insect-infested paddy field (soil sample B) and rice-planted wasteland (soil sample C) soil provided the basic parameters for studying the influence of soil gradation on the mechanical properties of wet and soft paddy soil.


FIGURE 2. Main instruments and steps for obtaining soil sample gradation.

For evaluating the particle size distribution of three soil samples, the uneven coefficient $C_u$ and the curvature coefficient $C_c$ were utilized to evaluate the gradation of soil samples. The uneven coefficient $C_u$ and the curvature coefficient $C_c$ were calculated using Formulas 1 and 2.

$$C_u = \frac{d_{60}}{d_{10}} \tag{1}$$

$$C_c = \frac{{d_{30}}^2}{d_{10} \cdot d_{60}} \tag{2}$$

where:

$C_u$ - Uneven coefficient;

$C_c$ - Curvature coefficient;

$d_{10}$ - Diameter that can make the particle mass account for 10% of the total when sieving, mm;

$d_{30}$ - Diameter that can make the particle mass account for 30% of the total when sieving, mm;

$d_{60}$ - Diameter that can make the particle mass account for 30% of the total when sieving, mm;

**(3) Moisture content**

To investigate the influence of soil moisture content on soil physical properties, soil samples of the same type were collected in the field and then mixed to obtain different moisture contents. The mature paddy field (soil sample A: saturated moisture is 49.99%) was collected and adjusted to the different moisture contents (16%, 26%, 36%) by drying and adding water. These experimental samples were used to investigate the influence of soil moisture content on soil mechanical properties.

**Experiment on the mechanical properties of paddy soil**

As shown in Fig. 3, to determine the mechanical properties parameters of different soils, the cohesion and internal friction angle of mature paddy soil (soil sample A: plastic limit is 13.8% and liquid limit is 43.7%), insect-infested paddy soil (soil sample B), rice-planted wasteland soil (soil sample C) and mature paddy soil with 16%, 26% and 36% moisture content (A1, A2 and A3 soil samples) in the plastic state were tested using a strain-controlled direct shear apparatus.

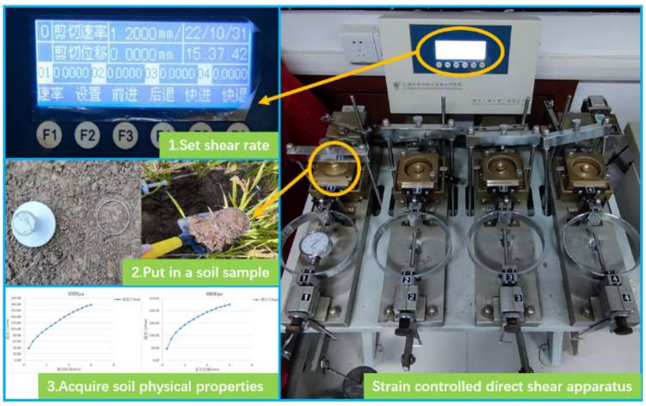



FIGURE 3. Test of soil mechanical properties parameters.

**Structural parameters of rice stubble**

A large amount of rice stubble and broken straw is left in the field after harvesting, using a track combine harvester. To study the effect of a track combine harvester on soil compaction with or without rice stubble, the structural parameters of rice stubble in Dantu District, Zhenjiang, Jiangsu Province, China were measured.


FIGURE 4. Sampling of rice stubble using the five-point method.

As shown in Fig. 4, the stubble height and outer diameter of the stubble field after harvest were tested by the five-point method. The area of each test point was a square of 400cm$^2$. The stubble height and outer diameter of the five straws were randomly selected, and their average value was taken as the final result. The rice stubble height measured by the five-point method ranged from 19.42 to 22.40 mm, and the outer diameter ranged from 5.87 to 6.59 mm.

At the same time, the distribution of rice roots and the diameter of stubble plants will also have a certain impact on soil compaction in stubble fields. Therefore, the length and morphology of the rice roots and the diameter of the stubble plants were also tested. The five-point method was also used to sample the stubble in the field. The collected stubble samples with roots were soaked in clear water for 24 hours, and the roots were cleaned. Then, the stubble samples were measured. The cleaned rice stubble and measurement process are shown in Fig. 5.


FIGURE 5. Measurement process of root length and plant diameter of rice stubble.

Figure 5 shows that the roots of mature rice are mainly white and yellowish brown, and there are basically no black or gray roots. Among them, the yellowish-brown roots were the main part, and there were few white roots. Therefore, there were many old roots in mature rice, and the root absorption capacity was greatly weakened, which agrees with the root characteristics of the mature rice that allow it to grow normally. The root length of mature rice stubble measured by the five-point method ranged from 13.0 to 17.2 cm, and the plant diameter ranged from 11.1 to 14.7 cm.

**Comparison of soil with or without rice stubble using a track combine harvester**

**Test vehicle and location**

The compaction tests were conducted in November 2022 at an experimental field in Dantu District, Zhenjiang City, Jiangsu Province, China (119°37′38″E，32°6′26″N，atmospheric pressure 1019.7 hPa, altitude −53.9 m). The annual average precipitation in this area is 736.6 mm, and the average temperature is 14–22°C. The field soil physical and chemical parameters are shown in Table 1. According to the international standard soil texture classification method, the soil type is clay loam.

TABLE 1. Soil physical and chemical parameters of the experimental field.

| Serial number | Parameter names | Value |
|---|---|---|
| 1 | Clay particle /< 0.002 mm (%) | 20 |
| 2 | Silt particle /0.002–0.02 mm (%) | 38 |
| 5 | Sand particles />0.2 mm (%) | 42 |
| 6 | Density of soil particle (g/cm3) | 1.41 |
| 7 | Organic content (g/kg) | 1.06 |
| 8 | Soil pH | 5.6 |
| 9 | Moisture content (%) | 25.1 |

The vehicle used in the test was a track self-propelled combine harvester, and it is shown in Fig. 6. The traveling mechanism was mainly composed of a rubber track, walking frame, thrust wheel, guide wheel, driving wheel, and support wheel.

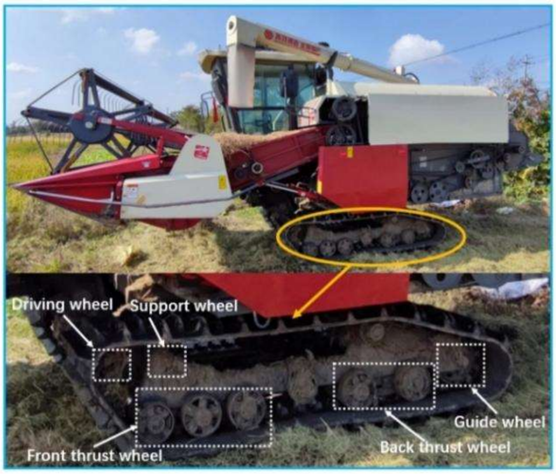



FIGURE 6. Track self-propelled combine harvester and its traveling mechanism.

**Compaction test on wet and soft soil, with or without rice stubble**

The soil compaction test in the field, with or without rice stubble, was carried out by drilling the lateral sections of soil layers at different depths and then embedding two soil pressure sensors at a horizontal interval of 40 cm. The related stress testing process is shown in Fig. 7.

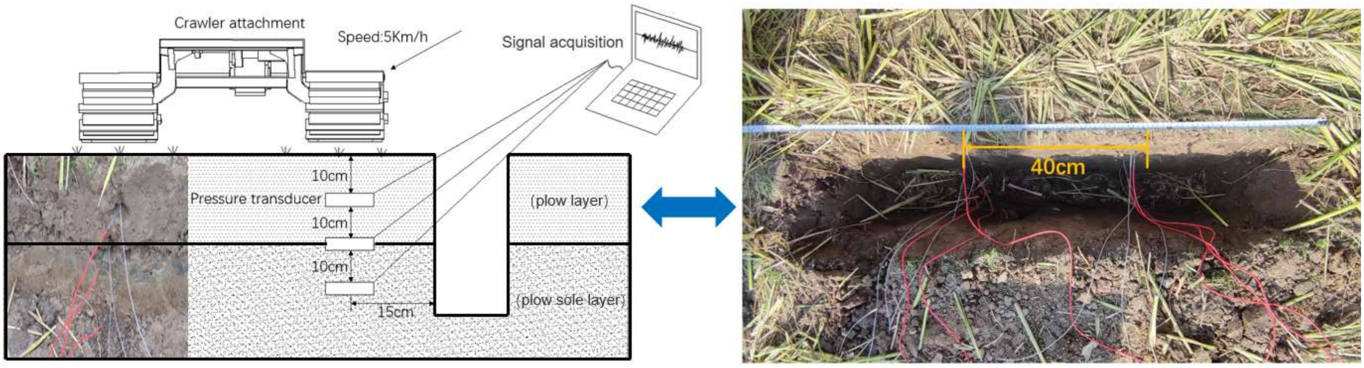



FIGURE. 7 Schematic diagram of the stress testing process.

The experiment was carried out in two kinds of soil with or without rice stubble. First, a pit of 1 m × 0.3 m × 0.5 m was dug at the location where the sensor was buried, and then the earth pressure sensor was horizontally buried in the soil at different depths (10, 20 and 30 cm) from the side section. The distance from the side section to the soil pressure sensor was 15 cm, so that the driver could easily drive the track self-propelled combine harvester to pass above the soil pressure sensor. The track self-propelled combine harvester was driven at a speed of 6 km/h and passed through the paddy soil with and without rice stubble once. In addition, the second and third compaction tests of soil with rice stubble were carried out at the same driving speed of 6 km/h. At the same time, the compaction effects of the track self-propelled combine harvester on soil with rice stubble were compared at different driving speeds (6, 9 and 12 km/h).

## RESULTS AND DISCUSSION

### Effects of the physical properties of paddy soil on soil mechanical properties

This paper conducted direct shear tests on three soil samples: mature paddy soil (soil sample A), insect-infested paddy soil (soil sample B) and rice-planted wasteland soil (soil sample C). The experimental results of the shear stress of the three soil samples varied with shear displacement under different vertical pressures (50, 100, 200, 300, 400 kPa). Due to the high moisture content of soil sample C, there was a high accuracy error in the direct shear experiment under the vertical stress of 50 and 400 kPa. Therefore, these data were excluded. The relationship curve between shear strength and vertical stress of three soil samples A, B and C is shown in Fig. 8.

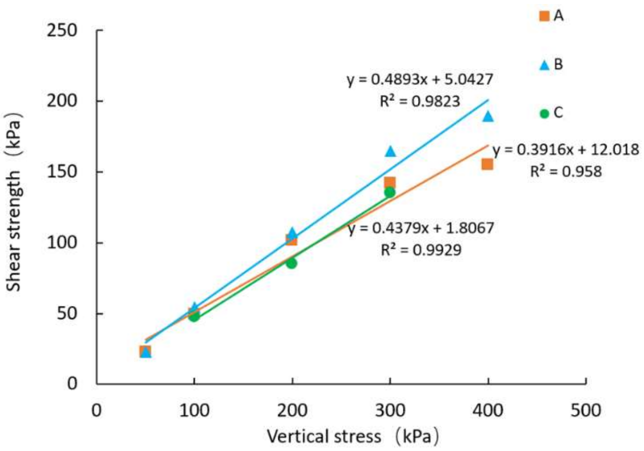



FIGURE 8. Relationship curve between shear strength and vertical stress of three soil samples A, B and C.

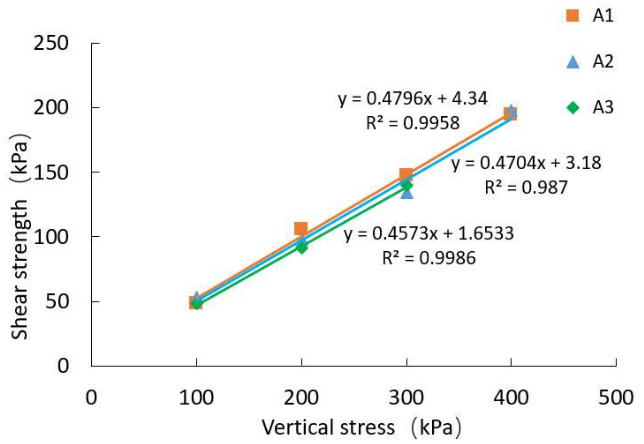



FIGURE 9. Relationship curves between shear strength and vertical stress of soil samples A1, A2 and A3.

Through linear fitting of the curve, the fitting degree of the three soil samples was greater than 0.95, so the direct shear test data were accurate. Therefore, the cohesion of soil sample A was 12.02 kPa, and the internal friction angle was 21.39°. The cohesion of soil sample B was 5.04 kPa, and the internal friction angle was 26.07°. The cohesion of soil sample C was 1.81 kPa, and the internal friction angle was 23.65°.

In addition, through the direct shear experiments of three soil samples (A1, A2 and A3 soil samples) with 16%, 26% and 36% moisture content in mature paddy fields, the experimental results of the changes of shear stress with shear displacement of three soil samples with different vertical pressures (50, 100, 200, 300, 400 kPa) were obtained. Due to the high moisture content of soil sample A3, there was a large accuracy error in the direct shear experiment under a vertical stress of 400 kPa. Therefore, these data were excluded. The relationship curve between shear strength and vertical stress of three soil samples, A1, A2 and A3, is shown in Fig. 9.

Similarly, through a linear fitting of the curve, the fitting degree of the three soil samples was greater than 0.95, so the direct shear test data were accurate. Therefore, the cohesion of soil sample A1 was 4.34 kPa, and the internal friction angle was 25.62°. The cohesion of soil sample A2 was 3.18 kPa, and the internal friction angle was 25.19°. The cohesion of soil sample A3 was 1.65 kPa, and the internal friction angle was 24.57°.

The wet density of three soil samples, namely mature paddy field (soil sample A), insect-infested paddy fields (soil sample B) and rice-planted wasteland (soil sample C) soil, were calculated. The wet density of the three soil samples was 1.77, 1.62 and 1.66g/cm$^3$, respectively. The cohesion and internal friction angle of three soil samples A, B and C were related to their respective average wet density. The influence of wet density on soil cohesion and internal friction angle has been discussed. The corresponding relationship is shown in Fig. 10.

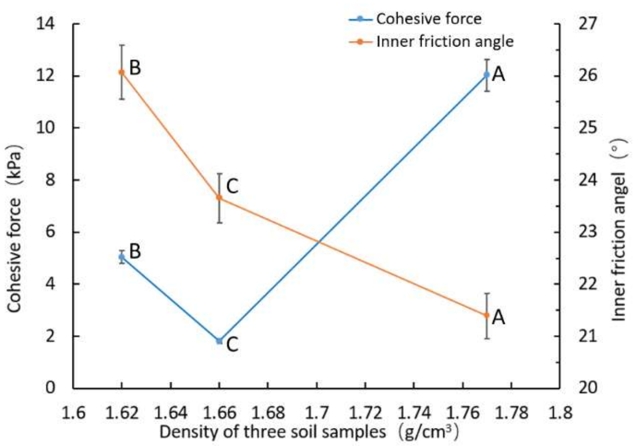



FIGURE. 10 Influence of wet density on soil cohesion and internal friction angle.

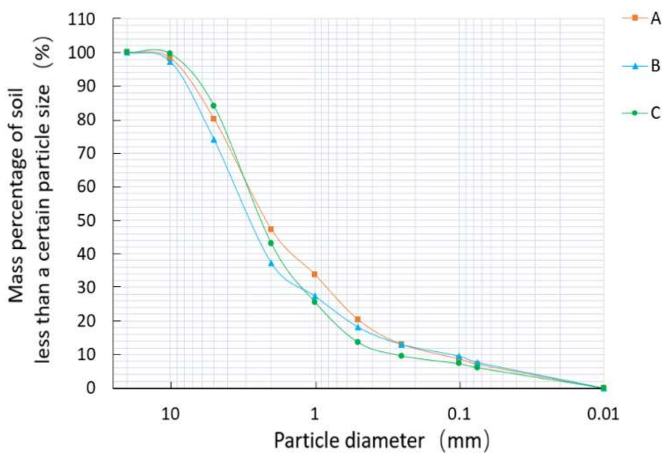



FIGURE. 11 Comparison of particle size distribution of three soil samples.

Based on the influence of wet density and gradation discussed later on soil cohesion and the internal friction angle, the density of soil sample B was smaller than that of soil samples A and C, which was caused by the large uneven coefficient and discontinuous particle size distribution of soil sample B. Therefore, although the wet density of soil sample B was smaller than that of soil sample C, the cohesion of the soil sample B was greater than that of soil sample C. This is similar to the conclusion that the gradation of soil sample B was poor, but the cohesion of soil sample B was greater than that of soil sample C. The influence of wet density on soil cohesion and the internal friction angle was affected by gradation. The wet density of soil with poor gradation was smaller than that of soil with good gradation. For soil with good gradation, however, the better the gradation, the greater the wet density. The wet density of soil was positively correlated with cohesion, while the wet density was negatively correlated with the internal friction angle.

In the vibration screening experiment, a screening method was used to screen the particle size of three soil samples, A, B and C. According to the screening results, the particle size distribution curves of soil samples A, B and C are drawn in Fig. 11.

Figure 11 shows the particle sizes that can make the sieving weight of soil samples A, B and C account for 10%, 30% and 60% of the total mass. The gradation of soil samples A, B and C was evaluated by calculating the $C_u$ and $C_c$. The gradation of the three soil samples is shown in Table 2.

TABLE 2. Gradation of three soil samples.

| Soil sample | $d_{10}$ | $d_{30}$ | $d_{60}$ | $C_u$ | $C_c$ | Gradation |
|---|---|---|---|---|---|---|
| A | 0.14 | 0.83 | 2.86 | 20.43 | 1.72 | Fine |
| B | 0.11 | 1.37 | 3.58 | 32.55 | 4.77 | Poor |
| C | 0.26 | 1.30 | 2.93 | 11.27 | 2.22 | Common |

The cohesion and internal friction angle of soil samples A, B and C were related to their respective gradation. The influence of gradation on soil cohesion and internal friction angle has been discussed. The corresponding relationship is shown in Fig. 12.

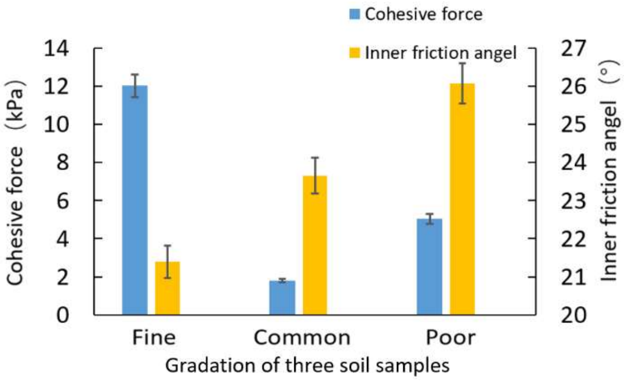



FIGURE. 12 Influence of gradation on soil cohesion and internal friction angle.

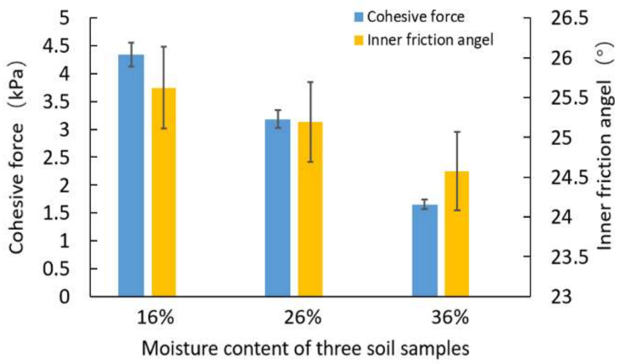



FIGURE. 13 Influence of moisture content on soil cohesion and internal friction angle.

As shown in Fig. 12, the better the gradation of soil samples, the better the uneven distribution of soil particles and the higher the spatial utilization rate among soil particles, which makes the mutual attraction between soil particles stronger and the cohesion force greater. Meanwhile, the smaller the biting force between soil particles due to embedding and interlocking effects, the smaller the internal friction angle, making the soil easier to shear. Although the gradation of soil sample B was poor in this paper, its cohesion was between that of soil samples A (good gradation) and C (common gradation). This occurred because although the curvature coefficient of soil sample B was large and the continuity was poor, the uneven coefficient of soil sample B was large and the particle distribution was very uneven. Furthermore, the influence of particle inhomogeneity on cohesion plays a major role, so the cohesion of soil simple B was between that of soil samples A and C.

The cohesion and internal friction angle of soil samples A1, A2 and A3 were related to their respective moisture content. The influence of moisture content on soil cohesion and internal friction angle has been discussed. The corresponding relationship is shown in Fig. 13.

As shown in Fig. 13, the cohesion and internal friction angle of the same soil sample gradually decreased with the increase in moisture content and the cohesion and internal friction angle decreased more when the moisture content increased by the same amount. This shows that an increase in moisture content reduces the mutual attraction between soil particles, thus making soil particles more dispersed. At the same time, with the gradual increase in moisture content, the aggregation state between soil particles is more easily dissolved. In addition, with an increase in moisture content, the gaps between soil particles are filled with water, which reduces the biting force between particles. Water acts like a lubricant, which makes the soil shear.

### Effect of rice stubble on compaction stress in wet and soft paddy fields

From Table 3, it can be found that the average value of the soil peak stress in the field with rice stubble at three depths was smaller than that in the field without rice stubble at three depths on the whole, after the fields with and without rice stubble were compacted by the track self-propelled combine harvester for the first time. However, the maximum vertical stress of soil in the field with rice stubble at three depths was greater than that in the field without rice stubble at three depths. Moreover, the maximum vertical stress of the soil in the field with and without rice stubble occurred at the place where the back thrust wheel of the traveling mechanism pressed over the soil.

TABLE 3. Comparison of vertical stress data of the first compacted soil from a track self-propelled combine harvester in the rice stubble field and no rice stubble field.

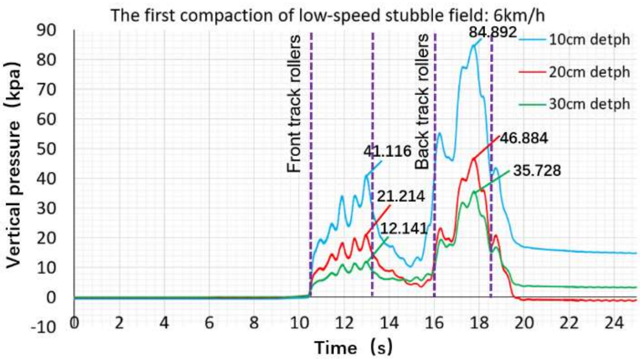
| | Maximum stress at 10 cm (Mpa) | Maximum stress at 20 cm (Mpa) | Maximum stress at 30 cm (Mpa) | Average value of the peak stress at 10 cm (Mpa) | Average value of the peak stress at 20 cm (Mpa) | Average value of peak stress at 30 cm (Mpa) |
|---|---|---|---|---|---|---|
| Field with rice stubble | 84.892 | 46.884 | 35.728 | 63.004 | 34.049 | 23.934 |
| Field without rice stubble | 66.419 | 46.468 | 31.568 | 61.032 | 41.901 | 28.832 |

The vertical stress in the soil was reduced due to the uneven internal stress after plastic deformation of the soil. The average value of peak stress of soil with or without rice stubble showed that the plastic deformation in the field with rice stubble was greater than that in the field without rice stubble during the compaction of the track self-propelled combine harvester. These results were likely caused by the fact that the distribution of rice stubble roots in the fields increased the void ratio of the soil and reduced soil compactness. However, the maximum vertical stress of the field without rice stubble was less than that of the field with rice stubble, which shows that the plastic deformation in the field without rice stubble was greater than that in the field with rice stubble when the back thrust wheel of the traveling mechanism passed through the soil. This may be due to the lack of soil fixation and the flow limitation of the root system in the soil without rice stubble. Additionally, due to the influence of the position arrangement of the front and back thrust wheels of the crawler traveling mechanism, the maximum vertical stress of the soil, with or without rice stubble, occurred at the place where the back thrust wheel of the traveling mechanism pressed over the soil. In summary, compared with the field without rice stubble, the compaction risk in the field with rice stubble was greater. Additionally, it would be very meaningful to study how to reasonably arrange the positions of the front and back thrust wheels of crawler traveling mechanisms to reduce the compaction risk of paddy soil.

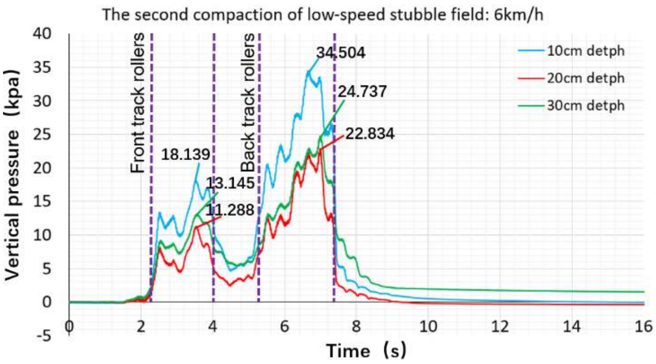
**Effect of compaction times on the compaction stress of rice stubble soil**

The influence of compaction times on the compaction stress of rice stubble soil is shown in Fig. 14(a), (b) and (c). The vertical stress of the soil was the largest when the track self-propelled combine harvester passed through the rice stubble field for the first time at a low speed of 6 km/h, and the vertical stress of soil decreased obviously when it passed through the rice stubble field for the second time. Additionally, the vertical stress of soil in the third compaction had little change from that in the second compaction.

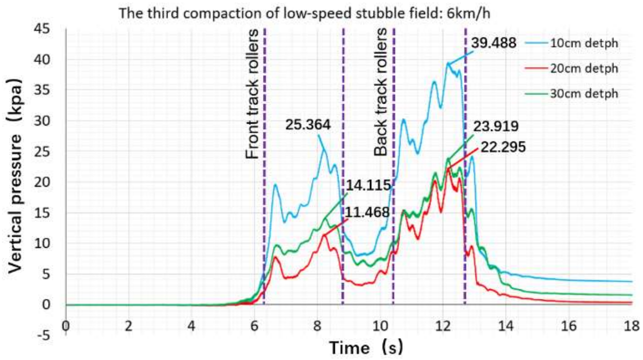
The influence of compaction times of tracked vehicles on the vertical stress of the soil with rice stubble is similar to that of Lamandé et al. (2018) on the influence of compaction times of wheeled vehicles on the vertical stress of soil without rice stubble. However, the influence of compaction times of tracked vehicles on the vertical stress of 40 cm in the swamp in Alakukku et al. (2003) may have been caused by the influence of moisture content and soil type. Based on the experimental results of this paper, the plastic deformation of rice stubble soil was small when it was compacted by a track self-propelled combine harvester for the first time, but it was large when it was compacted for the second time. The plastic deformation of rice stubble soil was basically completed when it was compacted for the third time. Therefore, the track self-propelled combine harvester did not cause a great compaction risk when it was rolled again in the rice stubble fields after rice harvest, but it greatly increased the compaction risk of the soil if it was rolled for a second time.



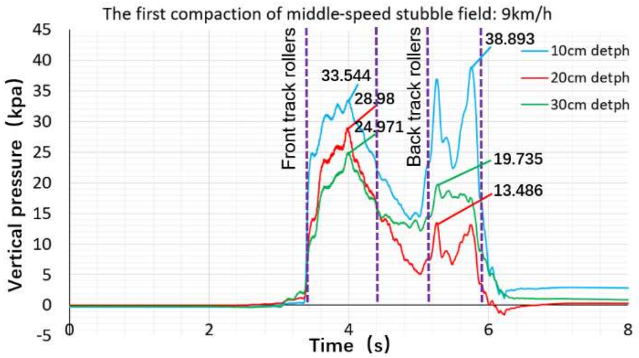

(a) Fist compaction of a low-speed stubble field at 6 km/s.



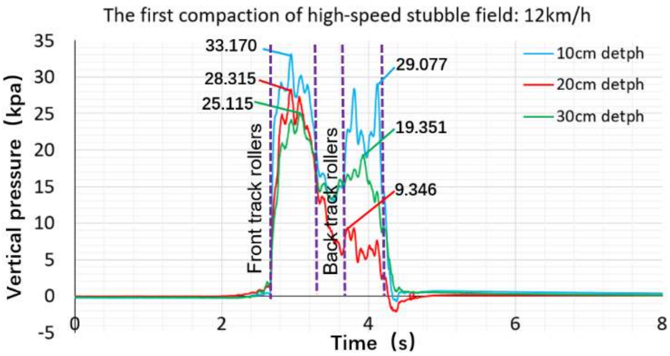

(b) Second compaction of low-speed stubble field at 6 km/s.




(c) Third compaction of low-speed stubble field at 6 km/s.




(d) Fist compaction of middle-speed stubble field at 9 km/s.




(e) First compaction of high-speed stubble field at 12 km/s.

FIGURE 14. Curves of vertical stress in rice stubble field with different compaction times, depths and speeds.

**Influence of driving speed on the compaction stress of rice stubble soil**

As shown in Fig. 14 (a), (d), (e) and Fig. 15, the maximum vertical stress in soil with rice stubble at different depths (10, 20, 30 cm) decreased with the increase in the travel speed of the track self-propelled combine harvester, and the maximum vertical stress also decreased with the increase of soil depth. On the one hand, the influence of depth on the maximum vertical stress of the soil was close to the logarithmic function relationship, as shown by fitting the maximum vertical stress of soil at different depths at the same driving speed. On the other hand, the influence of speed on the maximum vertical stress of soil was close to the power function relationship when fitting the results of the maximum vertical stress of soil at the same depth and at different speeds. In addition, the interaction between speed and depth on the maximum vertical stress of soil was not obvious when analyzing the interaction between two factors (speed and depth) on the maximum vertical stress of soil. However, a simple effect analysis of the difference between the two levels among the six levels showed that the maximum vertical stress of shallow soil decreased more than that of deep soil with increasing driving speed, which showed that different driving speeds had a greater influence on the compaction of shallow soil, especially at the plow layer.

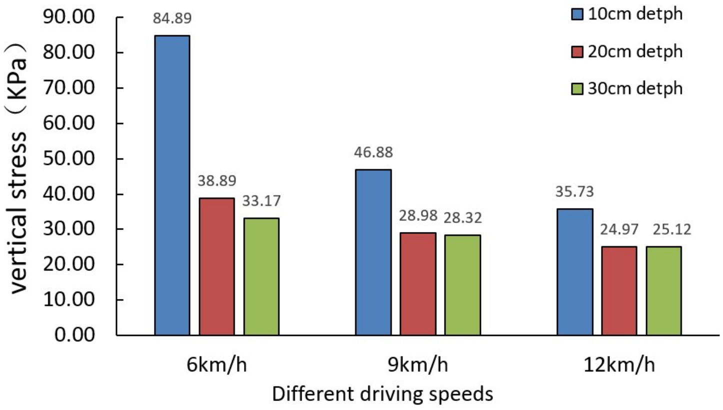



FIGURE. 15 Comparison of vertical stress in rice stubble fields under different driving speeds and depths.

The conclusion obtained in this paper was the same as that of Horn et al. (1989) on the influence of the vehicle speed of wheeled vehicles on the vertical pressure of soil at a depth of 35 cm, but it disagreed with the influence of the vehicle speed of wheeled vehicles at the depth of 15 cm on the vertical pressure of soil. The properties of soil are different, which affected these differences. In Horn et al. (1989), the moisture content of shallow soil was high. At the same time, the increase in vehicle speed increased the deformation speed of the soil, resulting in an increase in water pressure in soil pores. However, the research in this paper used a field with rice stubble that had a relatively low moisture content after harvesting in sunny weather, and the roots of rice stubble limited the deformation speed of the soil. Therefore, the risk of soil compaction was effectively reduced by increasing the driving speed of tracked vehicles in rice stubble fields after harvest.

## CONCLUSIONS

1. The soil density with poor gradation was less than that with fine gradation. For the soil with fine gradation, the density of soil was positively correlated with cohesion and negatively correlated with the internal friction angle. The gradation of soil samples was positively correlated with soil cohesion and negatively correlated with the internal friction angle in most cases. Furthermore, the cohesion and internal friction angle of the soil were negatively correlated with the moisture content (16–36%) in paddy soil.

2. The plastic deformation of soil in rice stubble fields during compaction was greater than that in fields without rice stubble. However, the plastic deformation of the field without rice stubble was greater than that of the field with rice stubble when the back thrust wheel of the traveling mechanism passed through the soil. It will be of great significance to study the influence of the position arrangement of the front and back thrust wheels on soil compaction risk in future research.

3. The plastic deformation of soil with rice stubble mainly occurred in the second compaction, and the plastic deformation of soil with rice stubble was basically completed in the third compaction. As a result, rolling in the rice stubble field after rice harvest did not cause a great compaction risk. In addition, when the travel speed of the track combine harvester was increased, the maximum vertical stress in soil with rice stubble at different depths decreased. Therefore, the risk of soil compaction after rice harvest can be effectively reduced by increasing the speed of tracked vehicles in rice stubble fields.

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