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FIELD INVESTIGATION OF THE PERFORMANCE OF ROTAVATOR UNDER HEAVY STRAW CONDITION

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Abstract

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The incorporation of straw into the soil increases soil organic carbon storage and reduces soil erosion. Straw is rich in organic material and soil nutrients, thus it is increasingly considered as an important natural organic fertilizer. The present study investigated the physio-mechanical properties of soil, displacement and burial of straw under heavy straw conditions at three rotational speeds (180, 230 and 280 rpm). Soil and straw displacement were measured using tracer technology, soil shear properties were determined by direct shear box, penetration resistance was measured with a hand-held penetrometer (OK-JS1, Zhengzhou Oukeqi Instrument Manufacturing Co., Ltd). Results revealed that the lateral and forward displacements of both straw and soil increased with the rotational speeds. Forward displacement of both soil and straw was significantly larger than that of lateral displacement. The addition of straw increased the cohesion and internal friction angle of soil, thus strengthened the soil. The penetration resistance of soil decreased with the increasing rotational speeds. The mean clod diameter was smaller at higher rotational speeds, while the rate of soil breakage increased with increasing rotational speeds. The rate of straw burial increased with the increasing rotational speeds. It is concluded that the fields should be cultivated at the rotational speed of 280 rpm to achieve the better soil conditions, displacement and burial of straw.

Key words: C-type rotary blade, soil and straw displacement and burial, physio-mechanical properties, soil breakage, mean clod diameter

Introduction

Rice and wheat are the two main cereal crops; their production accounts for 80% of the total grain production in China (Yang et al., 2000). After harvesting of these crops, the residues (straw) are incorporated into soil to increase soil organic carbon storage (Zhang et al., 2014) and to reduce soil erosion (Foltz et al., 2012). Straw is rich in organic material and soil nutrients, thus it is increasingly considered as an important natural organic fertilizer (Tan et al., 2007). Incorporation of straw into soil either directly or indirectly promotes the soil environment or maintains the physicochemical condition of the soil (Li et al., 2002).

The degree of straw incorporation into the soil depends on the tillage (Lal, 1997) and the implement types (Hanna et al., 1995). Mari et al. (2014) used single disc tool in a soil bin under controlled conditions, while Farid Eltom et al. (2015) used moldboard plow in a field. Liu et al. (2007, 2010) used sweep tool in both soil bin and in a field. Munir et al. (2012) used furrow opener in untilled field condition. In contrast rotary tiller is widely used in Jiangsu province of China, which accounts for 75.8% of all tilling land ma-

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chines (China machinery industry yearbook, 2013). Chen et al. (2015) found a gentle soil surface and better straw burial with mini-powered rotary tiller. Sirisak et al. (2008) concluded that the rate of straw burial increased with the increase in the rotational speed of rotary tiller. Tillage with rotary tiller can obtain better mechanical stability and favorable environment for plants (Horn, 1986). Moreover Ji et al. (2012) pointed out that the working quality of rotary tiller could meet the requirements of national standard of China. Many studies have explored straw displacement and burial with stubble only and with different amounts of straw, but a little information is currently available on the straw displacement and burial under heavy straw condition after harvesting of a crop.

Thus, the present study was designed to investigate the straw displacement and burial, shear properties of soil, penetration resistance, mean clod diameter and soil breakage at different rotational speeds under heavy straw condition.

Materials and Methods

Experiments were conducted at Jiangpu Experimental Farm of Nanjing Agricultural University, Jiangsu Province of China during 2015. It is located at 32°01′-32°03′N latitudes and 118°36′-118°38′E longitudes. The average precipitation is 1000 mm, average humidity is 76%. Prior to the experiments both straw and stubbles were cut by smashed machine (4J-180B, Henan Haofeng Machinery Manufacturing Co., Ltd), and the total amount of residues on soil surface after smashing was 6.3 t per hectare. The soil was composed of 39.4% sand, 32.7% silt, and 27.9% clay and was classified as clay loam and the organic matter content was 4.2%. The average dry bulk density of soil was 1.57 g cm^{-3} and cone index was 1106, 1758, 3286 kPa at 5, 10, 15 cm depth, respectively.

Fig. 1. Field condition

Rotary tiller (1GQN-200H, Henan Hao feng machinery manufacturing Co., Ltd) with 2 m working width was used in the experiments. The C-type rotary blade (58 IT245), with 245 mm radius and 50 mm tilling width were installed in double helix on the rotor shaft. The blade was operated at three different rotational speeds corresponding to 180, 230, and 280 rpm, while the tractor speed (0.5 m s^{-1}) and working depth (100 mm) were kept constant during tests. Figure 1 depicts the field conditions.

Physical and mechanical properties of soil

Moisture content

The undisturbed soil and soil-straw cores (61.8 mm diameter and 20 mm long) were procured from the field, while straw samples were collected in the aluminum boxes (70 mm diameter and 35 mm long). The aluminum boxes, soil and soil-straw cores were labeled, packed and brought to the laboratory. The moisture content of soil and straw mixture was determined by gravimetric method (Blake and Hartge, 1986). The moisture content of straw was 19.6%, the moisture of soil was 24.6%, while the moisture content of soil straw mixture was 23.3%.

Soil and straw displacement

Tracer technology was used for measuring soil and straw displacement in field experiment, similarly as done by Liu et al. (2007, 2010) and Chandio et al. (2013). Seven tin alloy cubes (2 cm) were marked and then inserted into soil perpendicular to the direction of rotary tiller to track the movement of surface soil. Straw pieces used as tracers, were colored, labeled and laid flat on the surface at designated spots laterally and longitudinally. The longitudinal tracers were placed parallel to the travel direction, and the lateral ones were positioned perpendicular to the direction of tool travel (Figure 2). Soil and straw displacements were then calculated by the

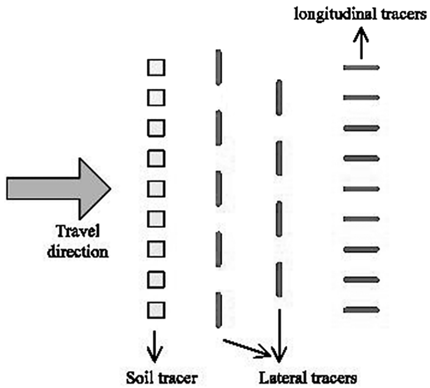

Fig. 2. Schematic view of soil and straw tracer placements in the field

absolute difference between the original positions and final positions.

Straw burial

The rate of straw burial was measured following method adopted by Dursun et al. (1999) using a square frame (500 × 500 mm^2) as shown in Figure 3.

$$B = \frac{(A_1 - A_2)}{A_1},$$

whereas:

B = Burial straw, %

A_1 = Total weight of straw before tillage, g

A_2 = Buried weight of straw after tillage, g

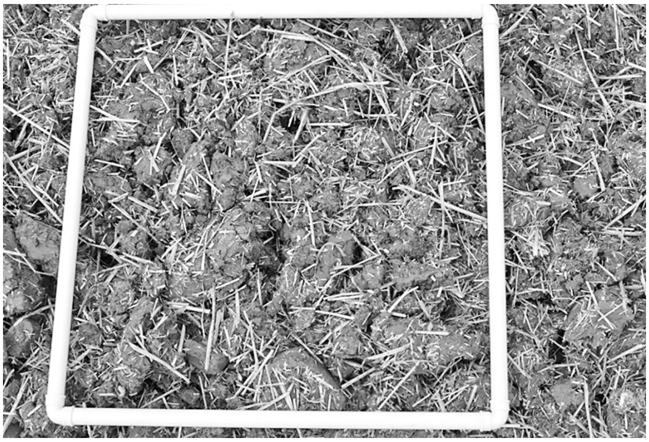

Fig. 3. Measurement of straw burial

Shear properties of soil

Soil samples were taken with no straw burial before the incorporation of straw and with straw burial after the incorporation of straw (Figure 4). Shear properties of soil and soil-straw samples were determined using direct shear box (SDJ-1 strain-controlled, Nanjing Soil Instrument Co., Ltd, Nanjing, China) at Soil Mechanics Laboratory, Department of Agricultural mechanization, College of Engineering, Nanjing Agricultural University, Jiangsu, China.

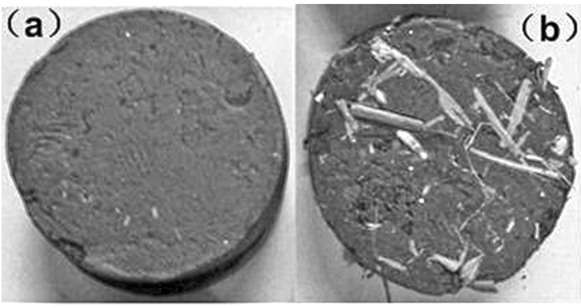

Fig. 4. Soil samples: (*a*) with no straw and (*b*) with straw burial

Penetration resistance

The penetration resistance (cone index) was measured at 5 different locations in each plot at the depths of 0-15 cm with a hand-held penetrometer (OK-JS1, Zhengzhou Oukeqi Instrument Manufacturing Co., Ltd).

Soil breakage

After tillage, the resulting soil clods were sampled from an area of 500×500 mm^2 at the depth of 100 mm, and then rate of soil breakage was determined using following relation (Lee et al., 2003):

$$R_{sb} = \frac{m_1 - m_2}{m_1},$$

whereas:

R_{sb} = The rate of soil breakage, %,

m_1 = The mass of total soil of the area, g,

m_2 = The mass of soil with a diameter of 20 mm or more of the area, g.

Soil clod diameter

The mean clod diameter was determined using following equation (Sirisak et al., 2008):

$$S_{cd} = \frac{5A + 15B + 27.5C + 37.5D + 45E + 55F}{M},$$

whereas&

S_{cd} = The mean soil clod diameter, mm,

M = The mass of total soil, g,

A–F = The weight of soil retained on the next smaller sieve.

Statistical analysis

The experiments were arranged in a randomized complete block design (RCBD) with three replications. One way ANOVA and Duncan's multiple range tests (DRMT) were carried out to assess differences between means at 5% probability level using SPSS software (ver. 20, SPSS, Inc., Chicago, IL, USA).

Results and Discussion

Soil and straw displacement

The lateral displacement of the straw was 87.30, 132.50 and 203.90 mm at 180, 230 and 280 rpm, respectively; while forward displacement of the straw was 273.72, 365.80 and 446.90 mm at 180, 230 and 280 rpm, respectively (Figure

5a). Similarly the lateral displacement of soil was 76.00, 85.56 and 126.67 mm at 180, 230 and 280 rpm, respectively; while the forward displacement of soil was 305.67, 353.39 and 418.17 mm at 180, 230 and 280 rpm respectively (Figure 5b). It was found that the lateral and forward displacements of both straw and soil increased with the rotational speeds. This is consistent with Liu et al. (2010), who concluded that straw displacement increased with the increase in speed. Mari et al. (2014) concluded that with the increase in the speed of disc tool, the lateral and forward displacements of straw increased. Rahman et al. (2001, 2005) found that the slight increase in the forward speed led to larger soil movement. Also Hendrick and Gill (1971) concluded that increasing rotational speed resulted in a greater movement of soil particles.

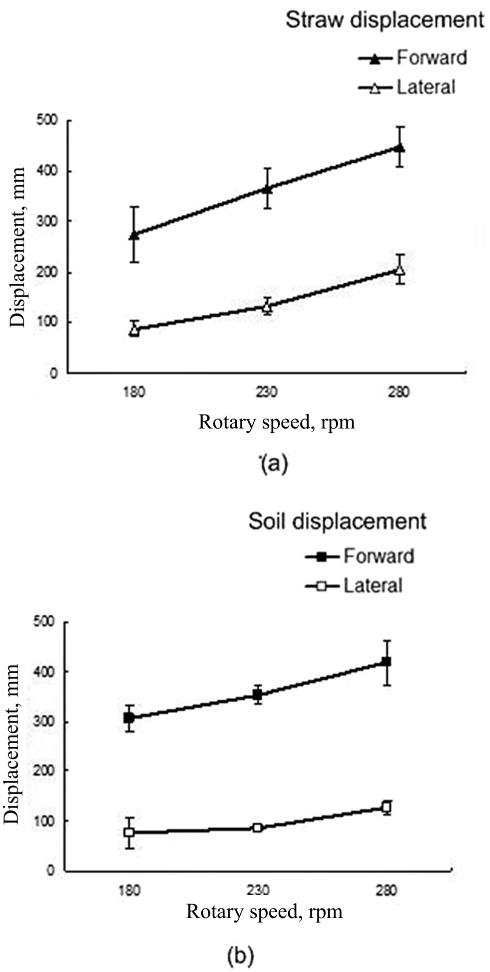

Fig. 5. Lateral and forward displacements at different rotational speeds: (*a*) straw and (*b*) soil

It was also found that the forward displacement of soil and straw was larger than that of lateral displacement. This is consistent with Liu et al. (2010), who concluded that the forward displacement of both soil and straw were larger compared to the lateral displacement. The displacement of straw was larger than that of soil, possibly due to straw dragging (Liu et al., 2010). This is consistent with Eltom et al. (2015) who found that the straw displacement was larger compared to the soil displacement. However the forward displacement of soil was larger than that of straw at 180 rpm.

The statistical analysis of the data (ANOVA) showed significant differences among the lateral displacements of straw at the rotational speeds of 180, 230, 280 rpm. Similarly non-significant differences were found among the forward displacements of straw at the rotational speeds of 230 and 280 rpm, while the significant ($p < 0.05$) differences were observed at the rotational speed of 180 rpm. The non-significant differences were obtained among the lateral displacements of soil at the rotational speeds of 180, 230 and 280 rpm as well as among the forward displacements at 180 and 230 rpm rotational speeds, while significant differences were experienced at the rotational speed of 280 rpm.

Shear properties

The cohesion of soil before tillage was 40.7 kPa, while after tillage operation, the cohesion was 75.64 kPa. Internal friction angle of the soil before tillage was 7.12°, while after tillage operation, the internal friction angle of soil was 13.44°. The cohesion and internal friction angle of soil after tillage operation significantly increased compared to that of the before tillage operation. The results revealed that the addition of straw increased the cohesion and internal friction angle of soil, which strengthens the soil. Thus it will require additional forces to till the soil compared to the soil with no straw (Mckyes, 1985; Subrata et al., 2014). This is consistent with Farid Eltom et al. (2015), who found that the draught

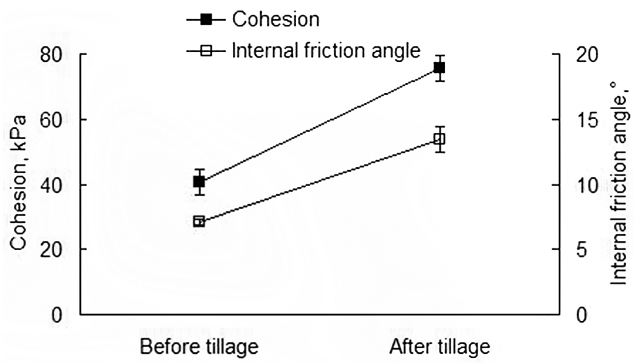

Fig. 6. Cohesion and internal friction angle of soil before and after tillage operation

force of moldboard plough was larger in dense straw cover (Figure 6).

Penetration resistance

The average penetration resistance before tillage operation was 114.16 N, while after tillage operation, it reduced to 63.21, 40.60 and 32.14 N, at the rotational speeds of 180, 230 and 280 rpm, respectively (Figure 7). The penetration resistance significantly decreased ($p < 0.05$) after tillage, but the differences of penetration resistance among different rotational speeds were non-significant ($p > 0.05$). Unger et al. (1998) found lower values of penetration resistance in stubble mulch tillage plots than no-tillage plots due to soil losing by tillage. Osunbitan et al. (2005) found a significant ($p < 0.05$) decrease in penetration resistance with the soil manipulation during tillage. Salokhe and Ramalingam (2001) also concluded that the penetration resistance significantly decreased ($p < 0.05$) after the tillage.

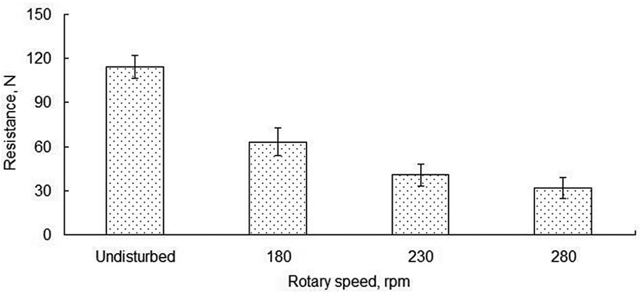

Fig. 7. Penetration resistance at different rotational speeds

Soil breakage and clod diameter

Figure 8 shows the mean clod diameter and rate of soil breakage at different rotational speeds. The mean clod diameter of soil was 37.23, 29.67 and 23.69 mm at the rotational speeds of 180, 230 and 280 rpm, respectively; while the rate of soil breakage was 22.43, 32.53 and 42.98% at the rotational speeds of 180, 230 and 280 rpm, respectively. The results showed that the rotational speeds had significant effects on the mean clod diameter and rate of soil breakage. Higher rotational speed leads to the smaller bite length. This is consistent with Matin et al. (2015), who concluded that at higher rotational speeds, blades cut a smaller soil slices in each bite, which break into smaller clods. Tsuchiya (1965) concluded that at higher rotational speeds the mean clod diameter would be very small. Indeed Sirisak et al. (2008) also found a decrease in mean clod diameter with the increase in rotational speeds. Meanwhile, the soil breakage rate increased with the increase in the rotational speeds. Duncan test showed significant differences ($p < 0.05$) among the values of mean clod diameter at three rotational speeds, while in case of soil breakage rate significant differences ($p < 0.05$) were found at the rotational speeds of 180 and 280 rpm, however non-significant differences ($p > 0.05$) were observed at the rotational speed of 230 rpm.

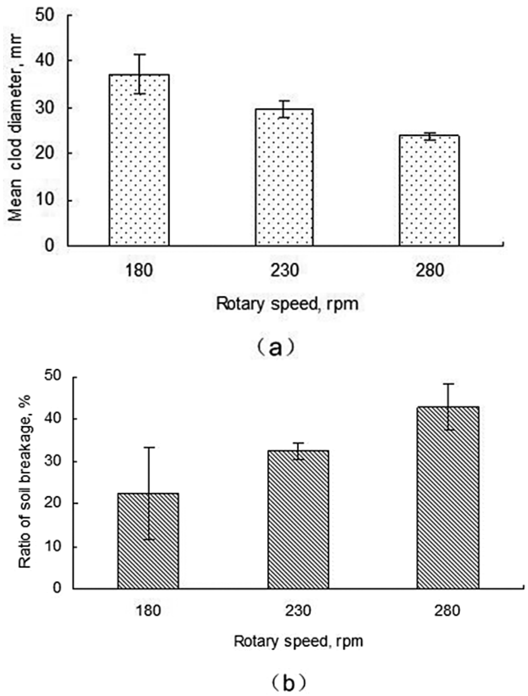

Fig. 8. Mean clod diameter and rate of soil breakage at different rotational speeds

Straw burial

Straw burial rates were 82.09%, 84.13%, and 90.50% at the rotational speeds of 180, 230 and 280 rpm, respectively (Figure 9). It showed that rotational speeds have positive impacts on the straw burial. This is consistent with Mari et al. (2014), who reported the increase in straw burial rate

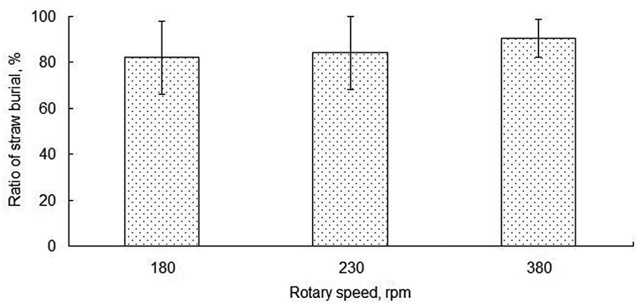

Fig. 9. Straw burial rates at different rotational speeds

with increasing speed. Liu et al. (2010) also obtained more straw burial at higher speeds. Sirisak et al. (2008) concluded greater straw burial with increasing rotational speed of rotary tiller. Duncan test showed significant differences ($p < 0.05$) among straw burial at the rotational speeds of 180 and 280 rpm. However non-significant differences ($p > 0.05$) were found at the rotational speed of 230 rpm.

Conclusions

The study has shown significant effects of rotational speeds on the physio-mechanical properties of soil, displacement and burial of straw under heavy straw conditions after harvesting of a crop.

The lateral and forward displacements of both straw and soil increased with the rotational speeds. Forward displacement of soil and straw was significantly larger than that of lateral displacement. The addition of straw increased the cohesion and internal friction angle of soil, thus strengthened the soil. The penetration resistance decreased significantly ($p<0.05$) after tillage operation with increasing rotational speeds. The mean clod diameter was smaller at higher rotational speeds, while the rate of soil breakage increased with increasing rotational speeds. The study has also shown that the rotational speeds had positive effects on the straw burial. The rate of straw burial increased with the increasing rotational speeds.

Acknowledgments

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