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Research paper

Effect of straw length and rotavator kinematic parameter on soil and straw movement by a rotary blade

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ABSTRACT

Plenty of straw is left in field after harvesting, so soil-tillage tool interaction has changed into straw-soil-tillage tool interaction. To obtain the detailed movement of soil and straw and identify interaction between straw, soil and tillage tool, soil bin experiments were conducted by tillage with a rotary blade. Lengths of wheat straw were 130–230 mm with increments of 20 mm. One IT225 rotary blade was operated at rotary speed of 77r/min and forward speed of 0.222 m/s, and three rotavator kinematic parameters (6.8, 8.8 and 10.8) with working depth of 100 mm. Tin alloy cubes (2 cm^3) and colored straw were used for measuring soil and straw movement. Moreover straw forward movement was observed greater than soil movement. The unburied percent of 150 mm straw decreased from 98% to 91% when rotavator kinematic parameters increased from 6.8 to 10.8. Further results indicated that straw mixtures might not fit for studying soil displacement, especially for lateral soil displacement; higher rotavator kinematic parameter resulted in soil and straw being spread in a larger area and more straw being buried. The average displacement of lateral and longitudinal straw tracers is recommended for forward straw displacement, and longitudinal straw tracer is used for side one.

1. Introduction

Tillage redistributes straw/crop residue and mixes them with soil. It accounts for about half of the energy consumed in crop production, which needs to be properly managed in order to reduce the overall costs (Kushwaha and Zhang, 1998; Shmulevich et al., 2007). Proper management of energy consumption could be achieved by developing a better understanding of soil-implement interaction, which becomes a very complex process due to spatial variability of soil, the dynamic effects of tool, soil movement and mixing (Shmulevich et al., 2007), or becomes even more complex in the presence of straw.

The effect of tillage on straw/residue depends on types of implement, speed and working depth of tillage tool (Chen et al., 2004). A study for assessing the working parameters of disc, chisel and fertilizer applicator on residue cover conducted by Hanna et al. (Hanna et al., 1995) revealed that more residues were buried at higher speed and deeper depth. Rahman et al. (Rahman and Chen, 2001; Rahman et al., 2005) measured soil disturbance under the action of two sweep types and two disc types of tillage tools in a controlled soil bin and investigated soil displacement in longitudinal, vertical and horizontal directions using point tracers. They concluded that increase of tillage depth and forward speed led to larger soil disturbance and soil movement, but straw was not considered. Liu et al. (Liu et al., 2007) used tracer methods to study the interaction of crop residue, soil and sweep under different forward speeds and concluded that straw displacement was lager than that of soil and forward speed also impact straw displacement and burial. Mari et al. (Mari et al., 2014) studied straw burial and soil disturbance using a disc and concluded more straw burial and soil disturbance were found in larger working speed and depth.

Rice and wheat are the two major cereal crops in China; their

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production accounts for 70% of total grain production (Wang, 2005). The plenty of straw left on the field surface after harvesting is incorporated into soil (Zhang et al., 2014). Straw returning was popularized by government in China since the end of last century (Du, 2009). Thus it is imperative to thoroughly understand the straw-soil-tillage tool interaction.

Soil bin is used for studying straw-soil-tool interaction since it would be too hard to control parameters and clearly explain straw-soil-tool interaction in field conditions. Furthermore, rotary tiller is widely used in Jiangsu province of China, which accounts for 75.8% of all tilling land machines (China machinery industry yearbook editor committee, 2013), however, a little information currently available on the straw-soil-rotary blade interaction. So it's suitable to conduct indoor research for the study of straw and soil movement within the controlled conditions and up to now, there is no such work been done on it with interaction of rotary blade.

The study was conducted to develop better understanding regarding soil movement and straw movement under controlled conditions. The specific objectives were to detect the way of measuring soil and straw movement under tillage of rotary blade using straw mixture and study impacts of straw length and rotavator kinematic parameter on soil and straw displacement.

2. Materials and methods

Tracer technology was used for measuring straw and soil movement in this study. Same researches were done with a sweep (Liu et al., 2007; Mari et al., 2014; Liu, 2005; Liu et al., 2010). Different lengths of straw laid on soil surface were used to simulate field situation. Many peasants in China use combine harvester to reap the crop and the cutting length is adjustable.

2.1. Description of soil bin and tillage tool

The experiments were conducted in soil bin at Soil Mechanics Laboratory of Nanjing Agricultural University, Jiangsu, China. The dimensions of the soil bin are 6 m × 2.5 m × 0.5 m (length × width × depth) filled with enough soil that can facilitate testing of equipment without side effects and variability. The experimental soil was obtained from Yongning county of Nanjing, Jiangsu, China, and classified as silt clay soil (47% silt, 42% clay and 11% sand). It was dried, sieved and filled into the soil bin and then compacted to a density of 1.25 g/cm^3 to mimic the density in the field (Chen et al., 2014). The average soil moisture content was kept constant at 16% during the experiments and the cone index was 1106 Pa. The soil cohesion and internal friction is 13.12 kPa and 2.17°.

A 225-mm-rotary radius blade (IT225, shown in Fig. 1a) was selected due to its universal application in Jiangsu Province of China. IT225 rotary blade is a kind of C-type blade and is made of 65Mn. The tool carriage (powered by a 7.5 kW advanced variable speed motor) supported by two rails was mounted on soil bin and then a rotary blade was attached with tool carriage. To provide rotary motion of blades, an 11 kW motor was installed on tool carriage. Soil bin device and rotary blade used are shown in Fig. 1b.

2.2. Description of the straw

Wheat is one of the major crops in China, so wheat straw was used to represent crop residue in this study. It showed that length of wheat straw ranged from 80 to 260 mm with the majority between 130 and 230 mm after harvesting. Thus, straw lengths from 130 to 230 mm with increments of 20 mm were selected for the experiments.

Two kinds of straw mixture (I and II) were adopted to evaluate the interaction between different lengths of straw and check if straw mixture can represent straw of single length in studying soil and straw movement. Straw mixture I was composed of 130 mm, 170 mm and 210 mm straw and mixture II consisted of 150 mm, 190 mm and 230 mm straw. Each mixture contained 198 pieces with 66 pieces of each length. Plots with single length straw were also conducted in experiments. The amount of the single-sized straw was 200 pieces representing the straw density of 200 g/m^2 as actual field.

2.3. Experimental design

2.3.1. Plot and tracers

Straw applied on the soil surface form a plot and all plots has same area of 0.52 m in width and 3 m in length. Nine tin alloy cubes of 2 cm^3 were marked with numbers and then inserted into soil to track the movement of surface soil, and they were placed in three lines perpendicular to the direction of blade forward speed. Straw of specific lengths laid on soil surface with different colors and numbers were used as straw tracers. The lateral tracers with red color were placed perpendicular to the direction of blade forward speed, and the longitudinal ones with yellow color were placed parallel to the forward direction. All tracers were placed in the way shown in Fig. 2a.

2.3.2. Measurement

A) Positions of soil and straw tracers

Straw and soil displacements were calculated by the absolute difference between the original position and final position. A device (Fig. 2b), which has two fixed line with number labeled, along with measuring tools, were used to arrange and record the tracer positions before (original position) and after (final position) tillage.

B) Straw burial

The burial of straw includes the percent of completely buried, partially buried and unburied straw. Burial rate of straw was calculated by following equation proposed by Dursun et al. (Dursun et al., 1999).

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

whereas,

B = Burial straw, %
A_1 = Total weight of straw before tillage, grams
A_2 = Buried weight of straw after tillage, grams

2.3.3. Treatments design

Two experiments were conducted in the present research for studying the behavior of soil and straw movement under the controlled tillage of rotary blade. Experiment 1 was designed for evaluating experimental methods, such as studying whether straw orientation will affect straw displacement and whether different straw length has effect on each other and if the straw mixtures can represent single-sized one when studying soil and straw displacement. The treatments were 8 straw conditions: two straw mixtures and six single-sized straws. One rotary blade was operated at rotary speed of 77r/min and forward speed of 0.222 m/s in working depth of 100 mm.

Experiment 2 was to study the rotavator kinematic parameter, λ,

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