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Field investigation of a trash-board, tillage depth and low speed effect on the displacement and burial of straw

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ABSTRACT

A minimum amount of straw is still needed to protect soil from wind and water erosion. To better understand the soil protection effect of straw, the relation of wheat straw displacement and its burial status with plowing speed, tillage depth and the attachment of trash-board was studied. Three controlling factors were evaluated in a field tillage testing, i.e., two types of plow (with and without trash-board), three lengths of straw (100 mm, 150 mm, and 250 mm), and various straw conditions. Straw pieces with specific lengths were prepared before the experiment and used as point tracers to measure the soil and straw displacement. The results indicated that the soil and straw displacements were significantly different but that the two were interrelated. As the length of straw increased, the soil displacement decreased due to the forward and lateral displacements; the straw displacement was always significantly larger than soil displacement, independent of the straw mixtures. Attachment of a trash-board reduced the soil displacement, but had no apparent effect on the straw displacement. Longer straws were less effective to be incorporated into the soil than the shorter ones, and the presence of a trash-board led to higher straw burial performance. The results also indicated that low tillage speed resulted in larger soil fragments and straw displacement with more straw buried. Moreover, longer straw was less effectively buried than shorter straw at the same speed. However, straws neighboring the shear were more extensively displaced than those nearby the share bottom.

1. Introduction

Crop residue cover protects soil from erosion and retains soil moisture from evaporation. Increasing residue cover, even by small amount, decreases the soil erosion potential (Lal et al., 2007). Evaluating the crop residue cover fraction and its spatial distribution is important to scientists involved in the modeling of soil erosion and surface runoff as well as to researchers trying to assess soil conservation management measures adopted by farmers (Arsenault and Bonn, 2005). However, when the residue is overabundant, excessive crop residue must be removed by bailing or be incorporated into soil with tillage tools, e.g., a moldboard plow. Due to the important impacts of tillage operation on crop residue cover, cover residue management has been integrated into tillage operations (Liu et al., 2010). However, the rate and degree of organic matter accumulation associated with surface residues vary widely due to differences in climate, soil type, and residue (Schomberg et al., 1994).

Raper (2002) studied the effects of operational factors on residue cover using a disk, a chisel, and a knife-type fertilize opener. He reported that a shallower tillage depth and a slower speed could reduce the residue burial performance, indicating that tillage depth is a critical operational parameter affecting the residue burial. Other researchers found that the residue distribution and incorporation were affected by the forwarding speed of the tool, the tillage depth, the type of implement, the soil conditions, the type of crop residues, and the height of stubble (Sommer et al., 2011). However, little research has been performed on how interactions between tillage tools and the length of residue affect the soil displacement and the residue burial performance and distribution. It is well known that flat residue and standing stubble have different impacts on many aspects of soil, such as soil moisture and the performance of the seeding operation (Doan et al., 2005a, b). However, information on how the soil and straw movement is affected by standing stubble and plant roots and the nature of the interaction between standing stubble and the length of flat straw was not found in previous studies (Liu et al., 2007). Different soil-engaging tools have different effects on residue burial (Hanna et al., 1995).

Agricultural straw is a widely used mulch for erosion mitigation (Foltz, 2012). The incorporation of crop residue into soil can be beneficial if the carbon–nitrogen ratio remains at an adequate level in the soil. However, only when quantitative relationships among tillage tools, soil, and residue conditions are known where we are able to control the amount of residue cover, either via incorporation or simply by leaving the residue on the soil surface for particular tillage systems. In other cases, when agricultural residues are used as feed stocks, the amount of crop residue that is retained in the field or that can be

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removed from the field must also be determined in a sustainable manner (Graham et al., 2007). Previous plant residues can significantly influence the next plant germination and growth, especially when they are unevenly placed on the field surface (Kumhála et al., 2005). According to La1 1995 in the United States, annual crop residue produced by 19 principal crops is estimated at 400 million tons year^{-1}, compared with 2962 million tons year^{-1} produced worldwide (Kumar and Goh, 1999; Kumar et al., 2001). Unfortunately, data are lacking regarding interpretation of the physical processes of interactions between soil, tillage tool, and crop residue. In addition, more detailed studies of soil and straw movement, as well as soil and straw interaction during tillage, are required. By manipulating the conditions of the soil and crop residue, and by manipulating the tillage operations, it is possible to enhance the sustainability of tillage and crop production. The effect of soil movement on crop residue displacement and burial was not considered in the previous studies. In addition, insufficient data are available for a thorough understanding of the interactions among soil, tillage tools, and crop residues upon using a moldboard plow with or without a trash-board. Therefore, a detailed study on tillage tool–soil–crop residue interaction under controlled conditions is required. Based on these findings, field experiments were designed to illustrate the interactions among straw cover, straw length, and tillage speed. The goal of this study is to better understand the process of the tillage tool–soil–residue interaction. The specific objectives include: (1) soil and straw displacement mediated by tillage under a field condition with and without a trash-board; (2) differences of straw burial related to a moldboard plow with and without a trash-board; and (3) effects of tool interactions with soil and straw displacements.

2. Materials and methods

The experiments were conducted at Jiangpu experimental farm in Nanjing Agricultural University, Nanjing, China. The farm is located in a suburb of Nanjing (32° 3′ 4.96″ N, and longitude of 118° 36′ 38.78″ W). This area is characterized by cold and arid conditions in the winter and heavy rainfall and high temperatures in the summer. The soil physical and mechanical properties are listed in Table 1.

The collected soil samples were oven dried at 103 °C for 24 h to determine the moisture contents. The soil bulk density and the soil moisture contents were measured at three locations and at 3 depths (5, 10 and 15 cm soil depths). The measured soil parameters were used (Table 2 and Fig. 1) to describe the shapes of the trash-board and the moldboard plow.

2.1. Straw preparation

Prior to the experiments, observations were made on straw lengths in threshed windrows. The straw length was found to range from 50 to 250 mm, with most straw in the size range from 100 to 250 mm. Only the stem portion of the straw was used. The straw was cut into the desired lengths using a scissor and was then numbered, colored and labeled on each side. Straw of different lengths was stored separately. These straw pieces were used as the flat straw applied to the plots used in the field experiments. Each length of straw was applied to a particular plot to form a treatment. Tracer methods for measuring soil movement were developed in the study of tillage erosion (Liu et al., 2007). Point tracers are individually colored, numbered and labeled objects of various shapes and materials, which have the distinctive advantage of the ability to characterize soil and straw movement in three dimensions.

Determining an appropriate chopping length for a certain straw cover was another purpose of this study. Straw mixtures of different lengths were used to represent the actual field straw state. A total of three straw mixtures were used to examine the interaction between the straw pieces of different lengths and to evaluate whether a straw mixture is compatible with those composed of single lengths. Straw pieces were manually applied and laid flat onto the soil surface; this straw condition is referred to as flat straw hereafter. There were no detectable crop residues in the field test before applying the flat straw. The amount of the flat straw was 6 g m^{-2} for both the straw mixture and the single-sized straw, equivalent to a straw yield of 6 ton/ha. The amount of straw used was to simulate the field situation after harvesting and straw bailing (Kato et al., 2007) (Fig. 2).

Table 1
Soil properties/bulk density, soil penetration resistance, cohesion and internal friction angle.

Depth (mm)	Bulk density (g/cm^3)		Penetration resistance (kpa)	Cohesion kPa	Frictional angle Φ/(°)
	Dry density	Wet density			
0–50	0.98	1.45	537.5	31.167	3.49
50–100	1.18	1.7	784	51.39	8.55
100–150	1.29	1.82	1200.5	73.39	15.21
150–200	1.45	1.93	1784.5	77.01	9.64

Table 2
Characteristics of a trash-board under investigation.

A trash-board parameter	A trash-board number and identity
Trash length (TL) (mm)	270
Trash blade length (TBL) (mm)	130
Trash blade height (TBH) (mm)	30
Trash height (TH) (mm)	100
Trash mass (g)	200
Trash board angle (°)	25

2.2. Experimental design

Three experiments were conducted:

Experiment 1 was designed to study the effect of a trash-board on straw burial, soil movement and straw displacement using the three straw lengths. The experiment was conducted using one-pass tillage of a single tool at the speed of 0.1 m s^{-1}.
Experiment 2 was designed to examine the experimental methods, such as comparing the straw displacement using the straw position as a mixture and the flat straw of uniform size. The treatments examined were 25 pieces of flat straw, three straw mixtures and three single lengths of straw.
For Experiment 3, in each experiment, the length of the platform was divided into two sections. Three treatments having the same tillage speed were randomly assigned. The tillage operation involved three parallel passes at the speed of 0.1 m s^{-1}. All of the trials were replicated three times at 3 tillage depths.

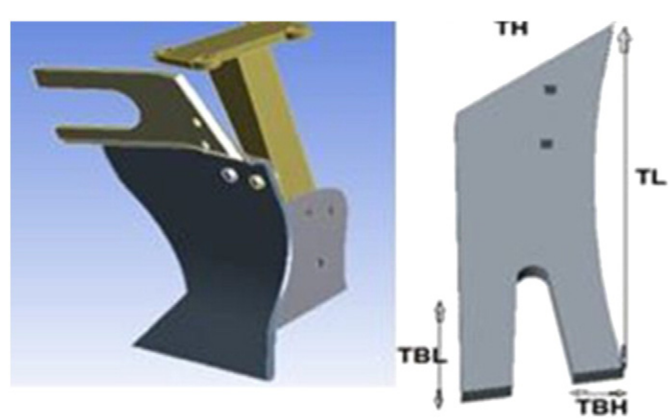

Fig. 1. Schematic views of 3D solid model of moldboard plow with a trash-boar (TL; trash length, TBL; trash blade length, TBH; trash blade height, and TBH; trash blade height.